ABSTRACT

ATKINS, JUSTIN TAYLOR. The Interaction between Lighting Power and Other Sensible Load Reductions with HVAC in Cooled Only Industrial Buildings With and Without Air Side Economizers. (Under the direction of Dr. Stephen D. Terry).

This study explores the relationship between cooling loads and lighting power reduction in industrial facilities that are cooled only. It is clear that in buildings that are cooled only there is a significant cooling load, electrical and monetary savings that is often ignored when considering upgrading light fixtures to more efficient ones. This means that by not including cooling load savings, lighting upgrade projects are under reporting the potential savings they offer. This is critical in industrial facilities where paybacks over two years often do not make the cut. The result is a correction factor that can be used to estimate the associated cooling savings for a lighting upgrade project. This correction factor is designed to be easy to use with minimal background knowledge required.

Many users will calculate lighting energy (kWh) and demand (kW) savings along with maintenance savings associated with a lighting upgrade project. However, by reducing the lighting energy there will be an HVAC interaction. In cooled only buildings this results in significant energy savings with no heating penalty. These users are likely to be familiar with these types of calculations but lack to the expertise to properly create a building energy model.

The data shows once a building has a high enough load that it is cooled only, the correction factor is constant. This is expected because once the building is cooled year around, the shell and ventilation loads are constant so the only way to remove heat is mechanically or with economizers. This means that users will not need to calculate their internal load in order to use this correction factor. If the user knows that their building in cooled only then they can use the correction factor in the table. Results were calculated for buildings both with and without

economizers. Since only loads were considered in the study, it is independent of the air side system type and efficiency of heat removal system.

Also, during the course of this study data was collected in various cities for buildings both with and without economizers. This data was analyzed to help make back of the envelope and other feasibility estimates for how much energy can be saved by adding economizers to buildings that are cooled only. In addition, they can be used as checks for when a building is being modeled with and without economizers.

Looking at the available literature there are correction factors available that consider high internal load buildings but not economizers. In addition, there is a method that considers the effect of economizers but ignores high internal load cooled only buildings. This combination of high internal load cooled only buildings and economizers examined in this study was not available before this research.

The Interaction between Lighting Power and Other Sensible Load Reductions with HVAC in Cooled Only Industrial Buildings With and Without Air Side Economizers

by
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DEDICATION

I dedicate this thesis to my girlfriend Mercedes Richards and my parents Dave and Elise Atkins for all their support in the long road to my master's degree.

BIOGRAPHY

After spending a few years without a college degree Taylor realized that opportunities for advancement were few and far between and he would need a college degree to be successful. He had always worked hard and been interested in how things worked. After driving crappy cars for many years and fixing them constantly, he became interested in mechanical engineering.

Taylor graduated from North Carolina State University with a BS in mechanical engineering and was accepted into the accelerated bachelors and master's program. This allowed him to get his master's degree in just one year.

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1.1 Project Objective

This project will look at developing a relationship between a reduction in lighting energy and its interaction on HVAC loads for industrial buildings. A correction factor will be used that can be applied easily to buildings types that fit the constraints.

These changes can be implemented in energy conservation studies for a wide variety of users such as the Industrial Assessment Center at North Carolina State University. This will be targeted to users that are doing savings calculations based on energy, demand and maintenance savings already. Many users know that there will be interactions with the HVAC system but do not have the time or expertise to do a full building model to determine precise savings or penalties from the interaction of HVAC and lighting power reduction. For these users, it would be extremely useful to have a quick correction factor to apply to their results. In addition, for users that are creating a building model, these correction factors will serve as useful checks in the building modeling process.

Most plant personnel will not have access to energy modeling software and without extensive experience will have difficulty making an accurate model of the building to estimate net HVAC savings from a lighting upgrade. However, these users typically have access to electricity bills and maintenance costs.

Energy services companies that deal with large energy projects will make a model of the building during their process already. These users will already have extensive experience with energy modeling, but the results of this study will allow these users the opportunity to perform

a basic check of their model. Users without modeling software or the time to devote to modeling can use these results in place of an assumption or simply ignoring the effects.

1.2 Background

1.2.1 Current Practices for Savings Calculations

Currently, energy savings calculations can be done in many different ways by various groups and users. The most basic calculations consider purely energy savings with units of kWh. These calculations typically will take the entire energy bill and divide by total energy for the year to find a blended rate for demand and energy in terms of $/kWh. Next, the operational hours are multiplied by lighting kW reduction to find the total savings.

More detailed calculations will look closer at both demand and energy savings. Energy is paid for in terms of the energy used (kWh) and the peak demand (kW) for the month. Lighting retrofitting projects result in a consistent energy and demand reduction so it is excellent practice to break down cost savings for both energy and demand. Using average cost in $/kWh is sometimes inaccurate such as in the case of night lighting where off peak energy may cost less and demand peaks are likely set during the day.

An additional consideration for lighting upgrades in maintenance savings. This is especially important with new LED fixtures that have lifetimes that can be as much as four times longer than other traditional lighting sources.

The above three considerations (energy, demand and maintenance) in lighting retrofit savings are considered traditional methods. These calculations are likely to very accurately reflect the true savings that a project will incur. A final consideration for these projects is how the upgrade

will interact with the overall building system. Lights dissipate nearly all of their energy into heat that will either need to be removed by a cooling system, or supplement the building's heating system. At this time the Industrial Assessment Center at North Carolina State University is using traditional methods to present energy conservation measures for clients.

Next, some groups will consider the HVAC effects the lighting project will include. This is done in a couple different ways. The simplest uses a set of tables to look up values based on building type and then use a correction factor. Some tables include a correction factor for both energy and demand but, more commonly the correction factor is only for energy. Another way that his can be handled is to create a model of the building before and after the lighting project to quantify HVAC interactions from the lighting upgrade. If a good model is made for the building this can be a very accurate way to estimate energy savings.

1.2.2 HVAC Practices

There are three major types of heating and cooling operations. These include buildings that are both heated and cooled, heated only or exclusively cooled. Typically most retail, residential and commercial buildings are both heated and cooled in most climates. Many warehouse facilities will only heat. Finally, many heavy industrial facilities and hospitals provide so much internal load from process that they only require cooling throughout the year in many climates.

Cooled only buildings are a unique case when considering lighting upgrades. With the other two conditioning practices (heated and cooled, heated only) a reduction in lighting energy comes with a heating penalty. Most of the energy from lighting is eventually dissipated into the space in the form of heat. In buildings that require heating during the winter, this heat must be made up in some way. During the cooling season, the load drops and there will be savings

associated it with it. In buildings that are both cooled and heated, it is interesting to look at the net savings. However, it is important to consider the source for the heating and cooling. Cooling is typically done by a vapor compression cycle that will yield a coefficient of performance and result in electrical cost. Heating fuel source include natural gas, propane and electricity. Typically, heating from natural gas is about a third of the cost of electricity when used to provide heat. These considerations are critical to get an accurate understanding of potential savings in a lighting upgrade project. Some facilities use steam or hot water to provide heating to the air side, steam can be produced from a variety of fuels with a varying economic cost associated with them. Electrically is the most expensive fuel, although it typically has the lowest first cost associated with it.

For buildings that require cooling the entire year there are no net considerations only additional savings. Many industrial facilities have a high internal load generation and require cooing all of the year. This type of facility has the greatest potential to have HVAC savings on lighting upgrades make a significant impact. This could be the difference between a lighting upgrade project being done or not, especially in industrial facilities where long paybacks are not tolerated.

1.3 Lighting Power Measurement Tools

There are many different types of equipment used to measure the power used by lighting. The first thing that is considered for this purpose is the power requirements of the lights. This can be measured either by manufacturer specifications sheets or by direct power measurement on the wiring.

Figure 1 Clamp Power Meter

Next, the quantity of light can be measured. This is typically done a waist level where what people will be looking at is located. This measurement is done in foot candles or lux.

Figure 2 Illuminance Meter

ASHRAE has developed standards for illuminance based on different areas and their needs. A parking lot does not require nearly as much light as a quality inspection point on a manufacturing line. An example of these standards is shown in the table below. It is important to consider both the quality of the light in addition to the quantity of the light.

Table 1 Recommend Illumimance and Lighing Power Density by Space Type [1]

IESNA Recommended Horizontal Illuminances and ASHRAE/IESNA 90.1 LPD Recommendations		
Space Type	**Illuminance (fc)**	**LPD (W/ft²)**
Open Offices	30 to 50 (5 to 10 with task lighting)	1.1
Private Offices	50	1.1
Conference Rooms	30	1.3
Corridors	5	0.5
Restrooms	10	0.9
Lobby	10	1.3
Copy Rooms	10	
Classrooms	30	1.4
Gymnasiums	100	1.1
Dining Areas	10	0.9
Kitchen	50	1.2
Labs	50	1.4
Libraries	30	1.2 (reading area), 1.7 (stacks)
VDT Areas	3	
Museums (display areas)	30	1
General Warehousing/Storage	10	0.8
Inactive Storage	5	0.3
General Manufacturing	30	1.2 (low bay), 1.7 (high bay)
Residences (General)	5	
Parking Areas (uncovered)	0.2	0.15

While the amount of light provided by a fixture is very important to user experience, the quality of light also plays an important role. For example sodium lights provide very low quality and color rendering, so it is very difficult to differentiate between colors in a parking lot. If that

parking lot used LED lights, the quantity of light could be the same but, the area will appear to be better lit because the quality of light allows better color differentiation. Often times the ability to distinguish colors under different lights is quantified by Color Rendering Index (CRI).

Table 2 CRI By Lamp Type

Lamp Type	CRI
Incandescent	100
Tungsten	100
Halogen	100
Sunlight	100
Fluorescent	90
LED	70-90
Mercury Vapor	49
High Pressure Sodium	26

All of these measurements must be considered when looking at upgrading the lights in an industrial facility. The critical thing to consider is to measure not only the amount of light required for a specific task or space, but also the quality of the light provided. When upgrading from sodium to fluorescent or LED's the color rendering index improvement will be very large, potentially allowing for less illuminance quantity.

1.4 Industrial Facility Lighting Practices

Currently industrial facilities use a variety of different lighting techniques depending on the needs. Most facilities have at least some portion of space that is devoted to offices that use typical lighting for offices. On the plant floor there can be a mixture of fixture types even within on facility. Most facilities use T12, T8 or T5 fluorescents, metal halide, low or high

pressure sodium, mercury vapor, incandescent and more recently LED lights. Sometimes many different types of lighting can be mixed together even in one space. It is more common to see occupancy sensors installed on new light fixtures in storage areas to allow to the lights to turn off when an area is not in use.

1.5 Literature Review

The topic of HVAC impact on lighting changes has been studied before in detail especially pertaining to commercial and office buildings. Several studies where done in the 1990's that provide correction factors for different types of buildings.

1.5.1 Analysis of energy use in building services of the industrial sector in California: two case studies (1992)

In 1992 Sezgen et. al published a paper on a case study of two buildings in California. This preliminary work laid down the road map to analysis of buildings energy use. The conclusion of this analysis was that in these two particular cases the lighting and HVAC use in these light industrial facilities is comparable to an office buildings. The study concludes that more than half of the electricity and natural gas used for building can be saved using simple and cost effective measures [2].

First, the building design was analyzed. One building was designed to be leased to general office or light manufacturing users. The other building was designed with input from the tenant to make services for their specific needs. It is interesting to note that the stake holders did not believe that there were any existing energy savings measure that would result in effective cost savings. This is likely because sometimes the equipment owners are different from the space users that are paying the utility bills. One group is responsible for capital and maintenance of

equipment and a different group is responsible for paying the energy bills from that equipment. The authors considered the occupancy, lighting, HVAC and process schedules to build an effective model of the operation. In addition, the building envelope was considered including walls, interior walls, roof, ceilings, floor and windows.

The result of this analysis showed that there were opportunities for savings in many places. The most effective opportunities were in the HVAC system. The HVAC opportunities included purchasing new units with a high COP, economizers, fan scheduling, variable speed drives for fans, proper sizing of equipment and a centralized water cooled chiller system. The most notable savings comes from the fans, using a schedule and drives. The next area of savings was in the lighting, the authors recommend using T8 lamps with electronic ballasts. Finally, more energy savings are possible by upgrading the building envelope to a higher R value of insulations on the walls to reduce heat transfer from shell loads. Also, the color of the walls and roof were considered. Due to the mild climate the study was conducted in, building envelope improvements did not result in significant improvement to the energy use.

While this may be accurate in the case study, overall industrial facilities are highly variable in their lighting and HVAC needs. It is very interesting to note that the authors were able to find many opportunities for cost effective energy measures even though the owners and occupants did not expect to find many opportunities. In fact, it is likely that most light industrial buildings are similar but there are some exceptions, especially in cooled only buildings. Many light industrial manufacturing plants are likely similar to office buildings in the internal loads. However, there are many heavy manufacturing facilities that have very high internal load

generation that requires cooling year around and therefore do not behave in a similar way to office buildings.

1.5.2 Evaluation of interactions between lighting and HVAC systems in a large commercial building (1994)

Lighting measures have been found to be one of the most cost effective strategies to reduce energy use especially in commercial buildings [3]. However, reductions in lighting loads will increase the need for heat during the winter but reduce the energy required for cooling during the summer in typical commercial buildings. Sezgen et. al developed a series of tables using the concept of a coincidence factor for various building types and climates. Modeling was done using the U.S. Department of Energy's free energy modeling software DOE 2.x. These look up tables are very useful for users who do not have time or expertise to complete full energy models for commercial buildings.

Coincidence factors are used for annual cooling and heating corrections for both demand and energy. These correction factors are the HVAC savings or penalty divided by the annual lighting savings. This is an excellent method for users that already have calculated the lighting electrical savings because it is only one quick step away from calculating the savings. The demand coincidence factors are calculated in a similar manner.

Next, energy use was modeled in nine locations to represent the various climate types in the United States. Each location has ten different types of commercial buildings with both older and newer buildings considered. To model the reduction in lighting, the energy requirement for lighting was reduced to 2/3 of the original lighting level. The majority of the building types operate only during the day time which means that the cooling correction is higher because

lights are likely to be on during peak cooling time. Also, the heating correction tends to be lower because the lights are typically not on at night when more heating is required. This is in contrast to heavy manufacturing because many of them operate 20 to 24 hours per day.

The commercial buildings that were modeled include fast food restaurants, hospitals, large hotels, large offices, medium offices, large retail, small hotels, sit down restaurants, supermarkets and secondary schools. This represents a significant amount of the building stock.

This research incorporates the use of DOE software to model buildings in various climates. This study will use the most up to date software program, eQUEST version 3.65, to complete the study. In addition, the use of coincidence factor is an excellent way to account for HVAC corrections for lighting upgrades. The generation of tables is a great way to present the findings so that users can look up the applicable coincidence factor for the type of building and climate being considered.

However, in high internally loaded buildings such as some heavy industrial facilities, there are cooling requirements year around so there is only savings and no penalty. The closest building type to cooled year around industrial facilities is hospitals in this study. Hospitals typically have a lot of high load equipment meaning that cooling is done nearly year around. It is important to note that none of these models incorporate economizers, which most cooled only buildings would have. The use of economizers will make a dramatic difference in cooled only buildings because even air side economizers will be used a significant portion of the year to reduce mechanical cooling load requirements. Another consideration is demand and energy reduction correction factors. Industrial facilities typically have undersized systems so there is

not likely to be significant demand savings. This study will only consider energy (kWh) savings resulting in conservative estimates. Another critical consideration for energy use is whether cooling is provided by water cooled or air cooled chillers.

1.5.3 Interactions Between Lighting and Space Conditioning Energy Use in U.S. Commercial Buildings (1998)

Sezgen et. al conclude that over a wide geographic area the energy savings and penalties will cancel each other out in the United States. Warm climates will increase savings and cold climates will increase penalties [4]. This study was conducted in a similar manner to the one done in 1994 in many ways [3]. Using modeling software to simulate commercial building in difference climates correction factors were introduced.

To take this study even further the authors went from considering loads to deriving the energy use. From there the monetary calculations were made to give a simple combined total HVAC coincidence factor. These results are highly dependent of the current fuel costs and heating fuel used. In addition, there could be significant variance in the COP of the system to provide cooling. It is interesting to note, that once again hospitals have the highest correction factor and this is because of near year around cooling provides almost no heating penalty. However, looking at the monetary consideration most building types end up with almost no change.

A major limitation of this study is that once again economizers were not considered. This is a serious concern for buildings that are cooled only because they are likely to be using economizers and they will make a significant difference in the energy usage of cooled only buildings. It is clear that there is an appropriate amount of research to make correction factors

for many types of buildings except for high internal load industrial facilities. However, it important to consider how cooling and heating loads are converted to energy use and cost.

2 Investigation of Lighting Upgrades Interaction with HVAC loads in Industrial Facilities in Central North Carolina, Four Case Studies

The following paper is based on Alexander Viola's 2015 thesis and this paper was co-authored by Taylor Atkins. This paper helps to set the groundwork for the current study by doing an initial assessment of energy impacts on the interaction between lighting and HVAC. However, it is separate from the current study but is included because both Atkins and Viola contributed to its creation. The paper below looks at four industrial buildings and concludes that there is an interaction and that cooled only buildings are the most interesting. This paper is targeted to be published in a peer reviewed journal in 2016 and is presented in full below.

2.1 Abstract

In 2010, the United States used 52 billion kWh of electricity to illuminate manufacturing facilities, equivalent to 1.3% of the total country's electrical consumption [5]. New technologies such as florescent and LED fixtures are making lighting upgrades financially viable. Conventionally, lighting and HVAC are treated as separate entities with regard to energy savings and their interaction is often ignored. Traditional methods include energy, demand, and maintenance savings to justify lighting upgrades. While some groups in the past have explored this relationship, it has been almost exclusively for commercial buildings such as offices, and few have focused on manufacturing buildings. A correction factor (CF) has been developed to account for HVAC interaction with lighting upgrades that can be applied easily to feasibility studies.

This correction factor is multiplied by the demand reduction from lighting and then multiplied by the operational hours to find the change in kWh's.

2.2 Introduction

The effect of upgrading lighting systems on HVAC loads has been analyzed to discover trends between variables which include heating and cooling practices, internal heat generation, and lighting density.

Using the building modeling software eQuest, four buildings representing the three common climate control methods (cooled only, cooled and heated, and heated only) were examined. This was done by simulating different lighting power densities to represent the upgrading of light fixtures to more efficient types. Commercial buildings are typically cooled and heated while industrial facilities are often cooled only because of a high internal generation. Also, manufacturing facilities are often heated only. A second established method was enlisted to compare and contrast the results of this method.

As the internal load increased, the magnitude of change in HVAC loads increased nearly linearly. This indicates that buildings which have processes that produce greater amounts of heat per square foot of building area, have a greater potential for both HVAC savings and penalties. This however, depends on the heating and cooling practices of the facility. By normalizing the data in terms of energy, rather than cost, the regression analysis gives an energy correction factor that can be used to include HVAC interactions in lighting upgrades.

2.3 Previous Studies

Published in April 1998, a study done by Sezgen and Koomey examined the effect of lighting density changes on various commercial buildings throughout the United States [4]. The results showed that in general, across all commercial building types and geographic locations, there

is no significant HVAC related savings or additional costs when the lighting power density is decreased [4]. This study focused on buildings with a low internal heat load generation.

Zmeureanu and Peragine used a slightly different approach [6]. Focusing on commercial office buildings, their method was to create a model which would be evaluated using the program DOE-2.1D. Its accuracy would be determined by comparing the utility bills generated by the simulation to the actual utility bills. The results of this study showed that for their model, heating penalties were greater than the cooling savings. After including this additional cost, this translates to a net loss of 30% of electrical lighting savings. The first reason is that the building in question is located in a cold environment, Montreal, which has a higher heating load than cooling by default. The second is the type of building itself. As an office building, the internal heat generation is much lower than those seen in manufacturing facilities. The hours of operation are also generally much different in manufacturing facilities. Additionally, the light fixtures are different in manufacturing buildings, and they often use higher power fixtures rather than the lower power fixtures in office buildings [6].

Lam, Tsang, and Yang examined how lighting density impacted heating and cooling loads in different climates in China [7]. They conducted energy simulations for five different cities with lighting densities using the program DOE 2.1E. The analysis involved how lighting affected heating and cooling loads. The model used for this study was a generic office building which served as a baseline reference for comparative energy studies. With respect to how lighting impacted heating and cooling loads, it was determined that lighting comprised a small part of the total heating loads but a large part of the cooling loads. Comparing heating and cooling loads, the total cooling loads were determined to always be bigger than the total heating load.

Rundquist, Johnson, and Aumann, explored the interactions between lighting and HVAC [8]. The study resulted in a method that assigns a fractional coefficient which accounts for the amount of cooling and the amount of heating done in a building based on its geographic location and loads. Building area to perimeter ratio is included for building heating. The system seasonal marginal coefficient of performance for cooling equipment and seasonal efficiencies for heating equipment are also considered.

The limitation of this method is that it was designed for use in commercial buildings such as offices. There are significant differences between manufacturing facilities and offices, with the largest being internal heat generation. In addition, heating, cooling and ventilation requirements in manufacturing often has more to do with the process than occupant comfort.

The takeaway from these previous studies is that modeling of different building types using a generic model to represent multiple, individual buildings is an acceptable way to examine the trends seen in the relationship between lighting and HVAC. This same approach is taken in this study. This study limits this geographic variable substantially to include only central North Carolina and apply it to buildings located in southern mid Atlantic, part of the humid subtropical climate zone [6]. In addition, lighting density changes is an acceptable way to model upgrading to more efficient light fixtures. Finally, matching actual energy usage based on historical bills for a building is critical to producing a reliable building model.

2.4 Methodology

The goal in modeling buildings is to develop simple tools to observe the trends in HVAC energy consumption. Rather than model one building with a high degree of accuracy, using eQuest, a generic building type is used for all of the facilities. Major differences such as square

footage, heating and cooling systems, set points, location, hours of operation, lighting power density, and process heating density are changed for each simulation. In addition, the models' projected energy use is matched with historical energy bills to ensure an accurate model is used of the building and its internal loads. Determining heating from process equipment (machinery, ovens etc) is accomplished by using the month of December as the baseline for peak demand, as that is typically a month with little to no cooling loads, and peak heating demand occurs later in the winter.

Variables such as building construction materials are kept constant for each facility in order to remove variables which may cause discrepancies between the different buildings not related to the lighting upgrade effect. In some cases, the building is a good candidate for a lighting upgrade because of the current fixtures. For these buildings, a proposed lighting list is created with fixtures that would be ideal replacements for those currently installed. In others, the building already has most if not all of the recommended fixture types installed. In these cases, a list of hypothetical less efficient fixtures is created which would normally be replaced with the lights currently installed. All of this is in an effort to observe the effect of reducing the lighting power on cooling and heating loads throughout the year. Although specific fixture changes are modeled, the lighting density changes can be applied to many different types of fixture changes.

2.5 Models

Four individual facilities in central North Carolina were considered. First, is a paperboard packaging facility that is cooled year round and does not need to supply any heating because of high internal load generation. The plant operates 24 hours a day, 7 days a week for a total

of 8,400 hrs/yr. and is 173,000 ft^2. Currently, the facility uses a combination of T12 fluorescent and metal halide fixtures. The model will consider an upgrade to T8 fluorescent fixtures.

The analysis of the simulation before and after the lighting upgrade will examine three major components: change in cooling energy consumption, change in heating energy consumption, and change in HVAC fans energy consumption. The cost will be based on each facility's utility rates and compared to the savings calculations of traditional methods: energy, demand and maintenance savings calculation.

Table 3 Simulation Results (MWh)

	Before	After	Savings
Space Cooling	2,687	2,493	194
HVAC Fans	707.1	638.7	68.4
Lighting	1,531	876	655

Throughout the course of the year, the HVAC system (cooling and fans) will see a net savings of 263 MWh. In total, there is a net decrease in HVAC costs of $10,504/yr. Calculations done using traditional methods show the savings directly from the lighting upgrade are $44,944/yr. with a payback of 44 months Therefore, the HVAC savings are an additional 23.4% of lighting savings and the simple payback is reduced to 36 months.

The second facility considered is an assembly manufacturing facility, which is heated and cooled year-round and is 33,000 ft^2. This facility operates 2 shifts for a total of 4,000 hrs/yr. The facility is currently lit by T5, T8 and T12 fluorescent fixtures and the model will assume historical T12 and metal halide fixtures.

Table 4 Simulation Results (MWh)

	Before	After	Savings
Space Cooling	64.64	57.00	7.64
Space Heating	26.11	35.7	-9.59
HVAC Fans	24.18	23.73	0.45
Lighting	223	173	50

The space cooling and fans will see a decrease of 7.19 MWh of electricity and an increase of 9.59 MWh of heating load annually.

In total, there is a net decrease in HVAC costs of $186/yr. because heating fuel is much less expensive than electricity. According to the calculations done using traditional methods including energy, demand and maintenance, the savings are $5,312/yr with a 109 month payback. HVAC savings are an additional 3.5% of lighting savings resulting in a 105 month payback.

Third, is a plastic injection molding facility that runs 24 hours a day, 6 days a week schedule. This 44,000 ft^2 facility cools year-round and does not have heating. Currently, the facility is using a combination of metal halide and T12 fluorescent fixtures. These lights will be upgraded to T8 fixtures.

Table 5 Simulation Results (MWh)

	Before	After	Savings
Space Cooling	785.4	711.4	74.0

HVAC Fans	151.6	139.8	11.8
Lighting	570	537	33

Throughout the course of the year, the HVAC system will see a decrease of 85.8 MWh. In total, there is a net decrease in HVAC costs of $3,612/yr. According to the calculations done using traditional methods the savings directly from the lighting upgrade is $15,932/yr. with a payback of 39 months Therefore, the HVAC savings are an additional 22.7% of lighting savings with reducing the payback to 32 months.

Finally, a 535,000 ft^2 large equipment manufacturing plant will be considered. This facility operates 5,400 hrs/yr. and was heated during the winter but not cooled during the summer.

Table 6 Simulation Results (MWh)

	Before	After	Savings
Space Heating	7,635	7,984	-349
HVAC Fans	1,452.9	1,467.6	-14.7
Lighting	2,072	1,241	831

Throughout the course of the year, the HVAC system will see an increase of 14.7 MWh for fans and an increase of 349 MWh in heating fuel. In total, there is a net increase in HVAC costs of $9,323/yr. According to the calculations done using traditional methods the savings directly from the lighting upgrade are $100,413/yr with a payback of 21 months. Therefore, the HVAC cost increase is 9.3% of lighting savings giving a yielding of 23 months.

2.6 Analysis

A comparison of all of the buildings' HVAC monetary savings or penalties is shown below.

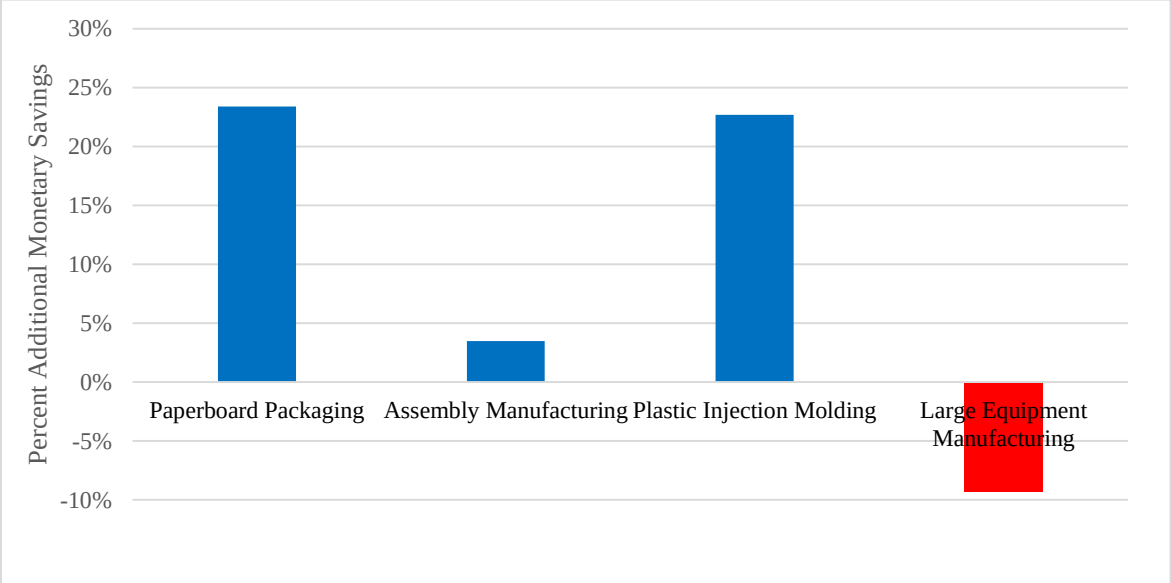

Figure 3 Comparison of HVAC Savings and Penalties for the Buildings Studied

It is clear based on the results, the heating and cooling strategies of the building decide if a lighting upgrade results in savings or penalties. Both the paperboard packaging and the plastic injection molding facilities were only cooled and both buildings showed the highest HVAC savings as a percentage of lighting savings. The vehicle manufacturing building, which was only heated, experienced an HVAC penalty. The assembly manufacturing building showed almost zero HVAC savings, because the gains in cooling were offset by increased heating.

These results will be compared to a previously established model. Comparing and contrasting the results highlights the significance of this projects' findings. From the November 1993

ASHRAE Journal, Rundquist etal. developed an easy to use to method to estimate the lighting effect for commercial buildings HVAC [8]

In an attempt to quantify the difference between commercial office buildings and manufacturing buildings, internal heat generation was examined to see if there was a correlation between its magnitude and the difference between Rundquist's estimation and that produced using the eQuest building modeling technique. Dividing the change in HVAC by the total utility cost allows for normalization of the results. This is done to compensate for the fact that the various facilities have very different energy consumptions. Additionally, magnitude of the change is analyzed rather than the actual change because a building which is heated only has a penalty instead of savings. Comparing this to the internal heat generation rate per square foot shows that as the heating density increases, the change in HVAC due to lighting upgrades changes as well, with a nearly linear relationship for the eQuest data. Therefore, for buildings which mostly cool, a higher internal heat generation results in a higher potential for cooling savings this can be seen in the next figure.

The figure below compares the eQuest and Rundquist methods, it can be seen that Rundquist's method consistently underestimated the magnitude of the HVAC cost change. This occurred when the building was not both heated and cooled rather than one or the other. When a building is either heated or cooled, the Rundquist estimate was between 42% and 75% lower than the eQuest results. When a building is both heated and cooled, the Rundquist estimate was 98% too high. The large percentage difference between the HVAC cost changes in the assembly manufacturing facility can be misleading because the Rundquist estimate is nearly double the eQuest, the actual difference is only $182 where the differences between the other buildings is

thousands of dollars. This implies that the problem with the Rundquist model is not exclusively dependent on the internal heat generation value, but also on the heating and cooling practices. This is reasonable because the Rundquist model was developed to be used for spaces which require both heating and cooling. When a space only requires one or the other, it is no longer a valid candidate. This is because of internal heat generation and HVAC practices of the building.

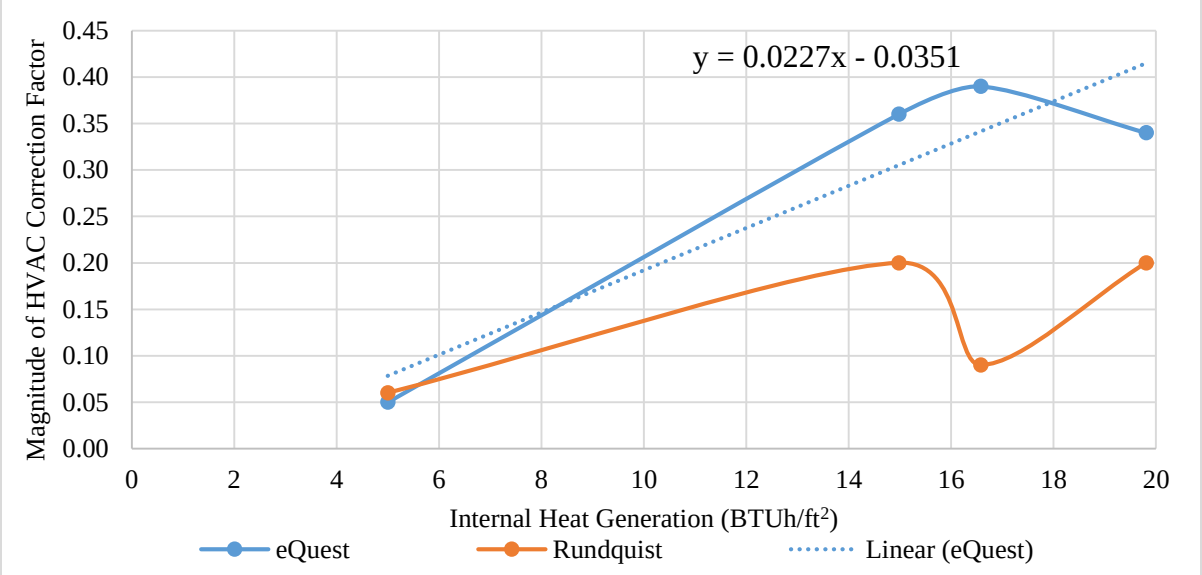

Figure 4 Internal Heat Generation compared to Magnitude of HVAC Correction Factor

In order to apply these results to other facilities the data is normalized on a kW basis. The kW corrections must be multiplied by hours of operation to get kWh corrections in order to account for varying operational hours in different facilities. On average, buildings which cool exclusively, saw an average HVAC power reduction of 0.35 kW per 1 kW of lighting power reduced. This is multiplied by hours of operation to find kWh correction. For buildings which

cooled and heated, average cooling power consumption was decreased by 0.16 kW per 1 kW of lighting power reduction while heating increased 0.26 kW per 1 kW for a net of 0.1 kW average HVAC power consumption per 1 kW of lighting power reduction. For buildings which exclusively heated, an average HVAC increase of 0.39 kW per 1 kW of lighting power reduction was seen. For various internal loads the linear regression suggests that the correction factor (CF) can be found by using the following equation for heated only, cooled only and heated and cooled buildings.

$$CF=0.0227 \times IG -0.0351 \quad (1)$$

IG-Internal heat generation (btu/ft^2)

This correction factor is multiplied by energy savings (kWh) to give the HVAC energy adjustment. This adjustment can be added or subtracted from the calculated energy savings depending on if the facility is cooled only or heated only. There not likely to be HVAC demand (kW) savings associated with lighting upgrades. This is because typical manufacturing facilities have undersized cooing equipment and therefore will fully load the equipment at some point during the month to set a peak demand.

The ratios between HVAC power reductions and lighting power reduction are correction factors which can be applied to future lighting savings calculations. To be more conservative, this correction factor can be reduced, but regardless of its magnitude, there is a significant savings or penalty which should not be ignored as it can change the payback length substantially.

For buildings which are both heated and cooled, more data needs to be collected and analyzed before a correction factor can be confidently applied. It appears that there are small savings available but that it depends very heavily on the individual building with a potential net heating penalty possible. Additionally, it is possible that more data would show a near zero net affect overall confirming Sezgen and Koomy. Until then, it would be more conservative not to apply a correction factor in this case especially because its effect would be much smaller than the buildings with only heating or cooling.

2.7 Conclusion and Future Work

The goal of this project was to develop a method to understand and quantify the interaction between lighting and HVAC. This project has shown that current conventional methods for estimating lighting and HVAC interactions are not suitable for use in manufacturing buildings.

A result of this project shows there is a relationship between the internal load of a building and the changes in HVAC cost. As the heating density increases, expected changes in the magnitude of HVAC expenditures also increases. Therefore, buildings which have a large amount of internal heating per square foot of building area have the largest potential for both cooling savings and heating penalties depending on heating and cooling practices. A linear fit was applied which resulted in an equation which can be used to estimate potential HVAC cost changes based on heating density values. This is an important consideration when determining candidates for this analysis.

Future work in this area would involve increasing the sample size in order to increase the accuracy of the findings of this project, especially buildings that are cooled only. These results could also be applied to different climates to determine and appropriate correction factor for

other locations. Then these results can be confirmed by logging various HVAC equipment before and after the upgrade. This will allow the actual interaction between the HVAC and lighting systems to be determined and used to validate these findings.

3 eQUEST Modeling

After considering the preliminary work shown in the paper above, the current study will look deeper at cooled only buildings. This section shows the steps undertaken to create an appropriate building model for an industrial building that is cooled only. Cooled only buildings were chosen because they will not have any heating penalty and an HVAC correction factor could significantly reduce payback periods in lighting projects. In addition, the current literature does not provide appropriate correction factors for high internal load industrial buildings or account for economizers.

3.1 Baseline Model

The eQUEST baseline model will be constructed first to simulate a generic facility that is cooled only. There are many variables that will affect the results of the model and they are discussed further below.

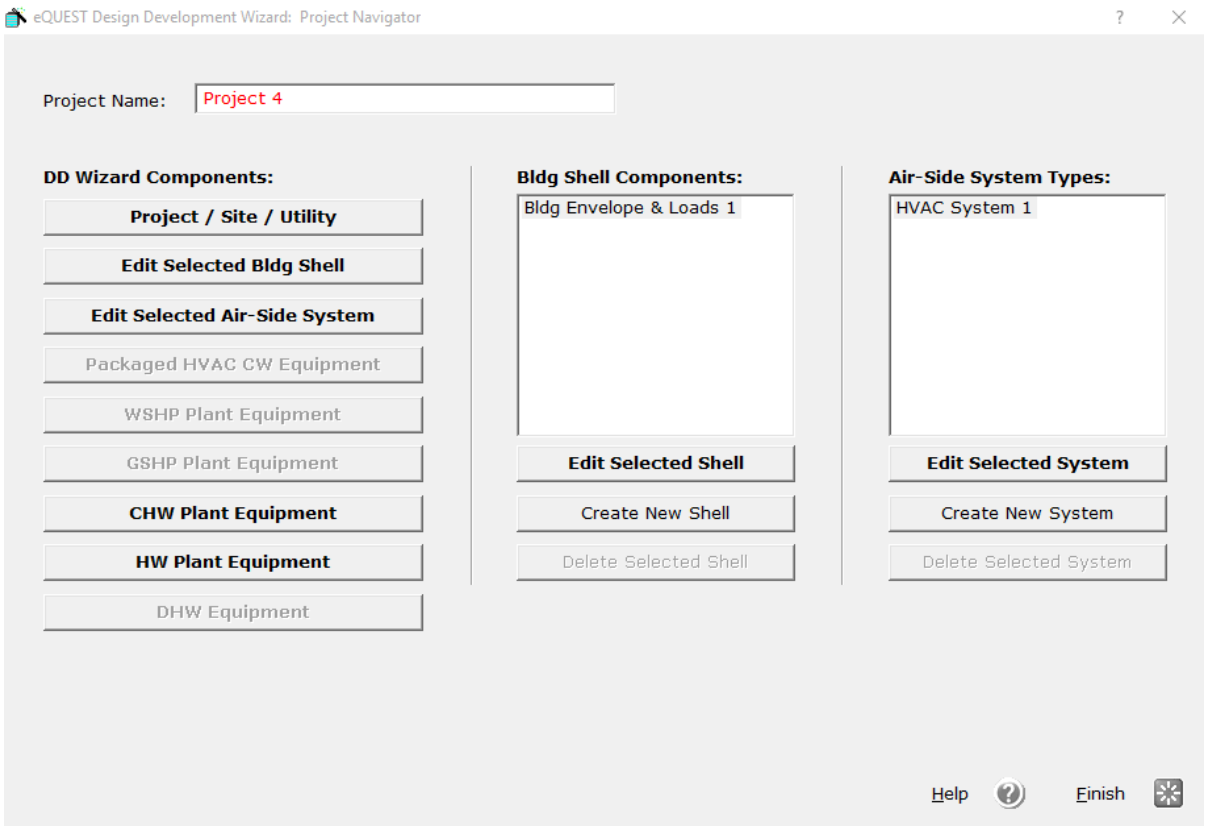

Figure 5 Project Naviagator

This is the screen that puts all of the various components of the model together and organizes them visually. It allows for different air side systems and building shell types to represent different zones and building types.

3.1.1 Project / Site/ Utility

For the first iteration of the model the location of Raleigh, NC is used. This location is an excellent candidate because it has a mild climate without summer or winter extremes. Traditionally, HVAC effects have been ignored in this region because it is believed they essentially cancel out (cooling savings offset heating increases). This study will either confirm

or refute this assumption. Other locations with varying climates will be considered later in this study.

Utility rates for electricity and natural gas will not be specifically considered. When considering cost, there are significant variation over time, industry, geography and rate schedule types. This project is designed for users that can calculate their cost of electricity using energy (kWh) and demand (kW). Therefore, the user can apply their own costs and will be accurate for their facility. Energy costs can even vary widely depending on the rate schedule used to pay for it.

Next, use profiles are created. Typically manufacturing is done year around and is not seasonal. In addition, most plants operate at a similar level throughout the day other than short breaks. Production is either up and running or down for the day.

3.1.2 Building Shell

The building type was set for general manufacturing. This facility is modeled as a single floor, slab on grade, this is by far the most common configuration for industrial facilities. The building is modeled as a 250,000 ft^2 space. However, the exact size of the building is not critical because calculations will be normalized on a per square foot basis. For the interior of the building, lighting controls will not be generally considered. While occupancy sensors are often used in bathrooms and storage areas they are not often used in heavy manufacturing areas for safety reasons. Typically in industrial facilities, safety considerations will take precedence of any energy upgrade or savings.

Since the data will be normalized on a per square foot basis the perimeter to area ratio of the building is important for this model. Manufacturing facilities tend to be rectangular and are added to over time sometimes giving strange shapes. To account for the fact that buildings are not typically square we will assume one side will be twice the length of the other. This is typical for the small and medium sized facilities the author has assessed. This is important because the quantity of heat transfer from shell loads is a function of the area of the wall, more wall space means increased shell loads. Finally, a typical height of 35 feet is used as a default value. This again influences the amount of wall space that can contribute to shell loads. The model will assume the building is oriented to the north this will not likely have a great effect because the model will not include any windows as discussed later. In addition, the buildings will be modeled as a perimeter and core with each zone behaving in a different way.

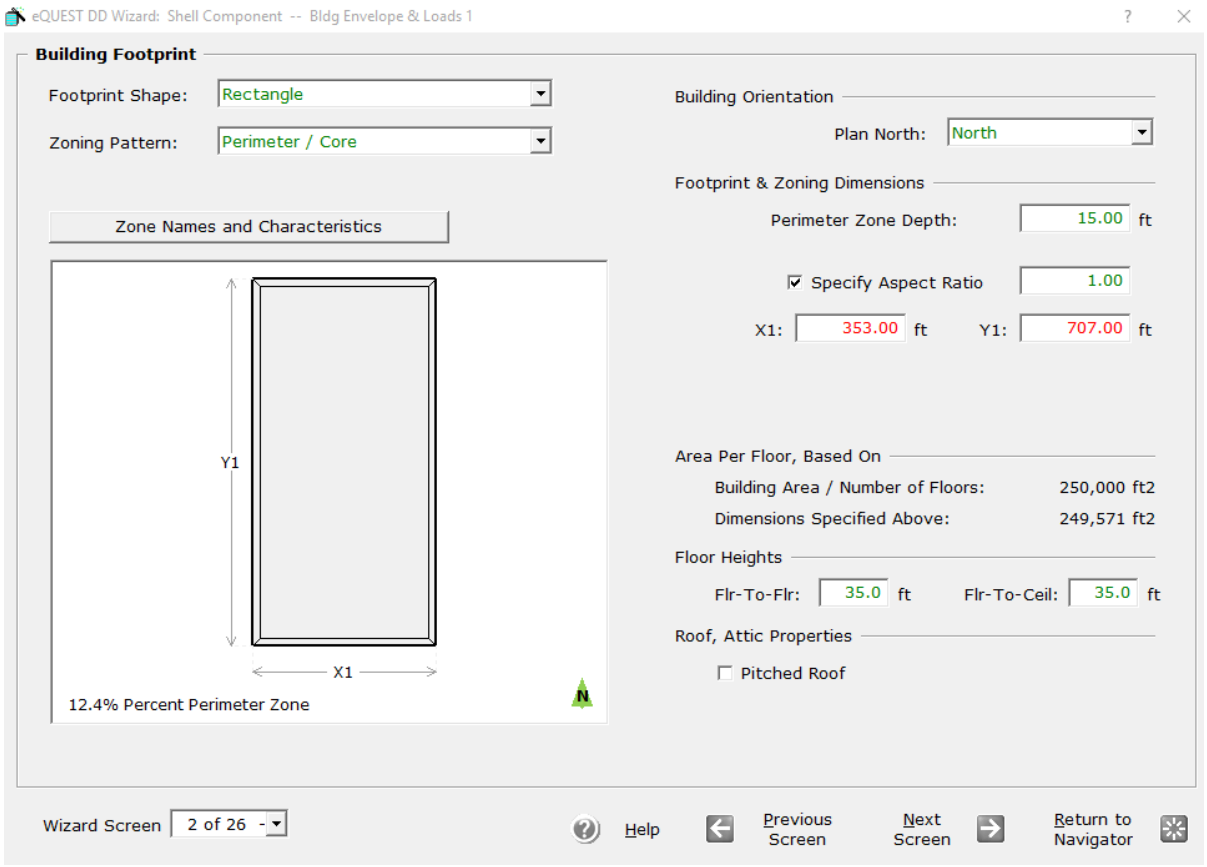

Figure 6 Building Layout

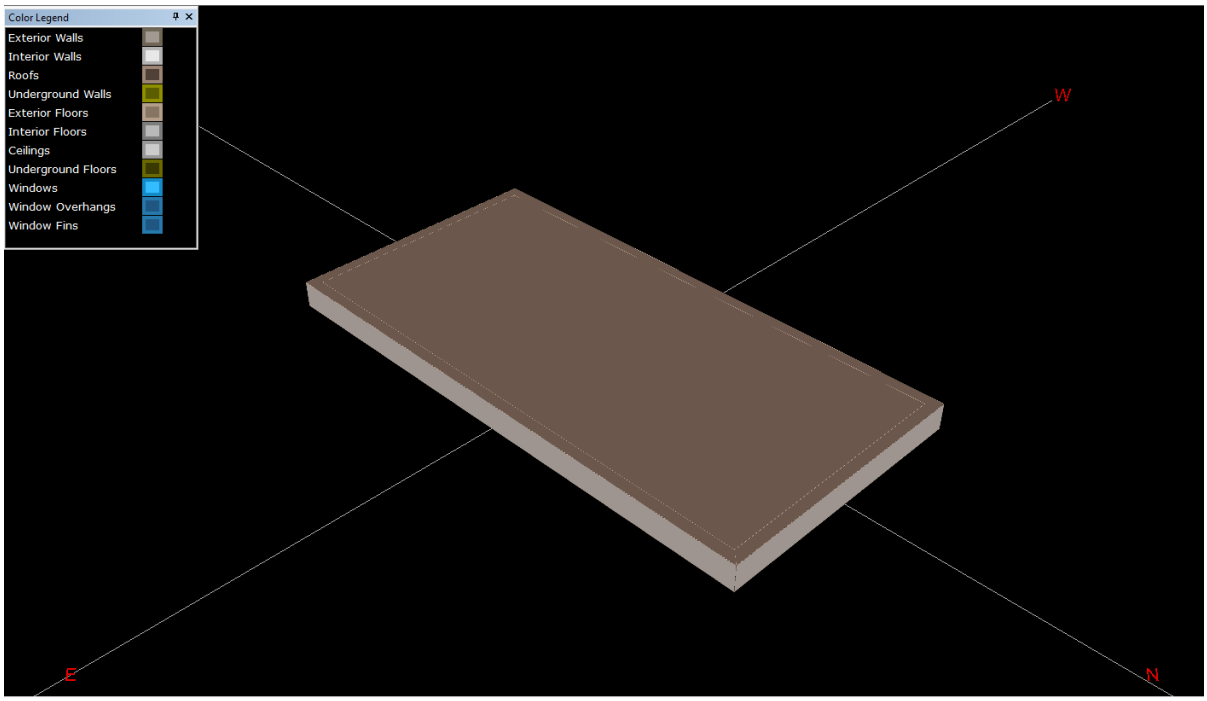

Figure 7 Building Geometry

This general layout uses the outside edges as perimeter areas and one big core area in the middle. Although many manufacturing floors will have some partitions they are often spread out in large rooms.

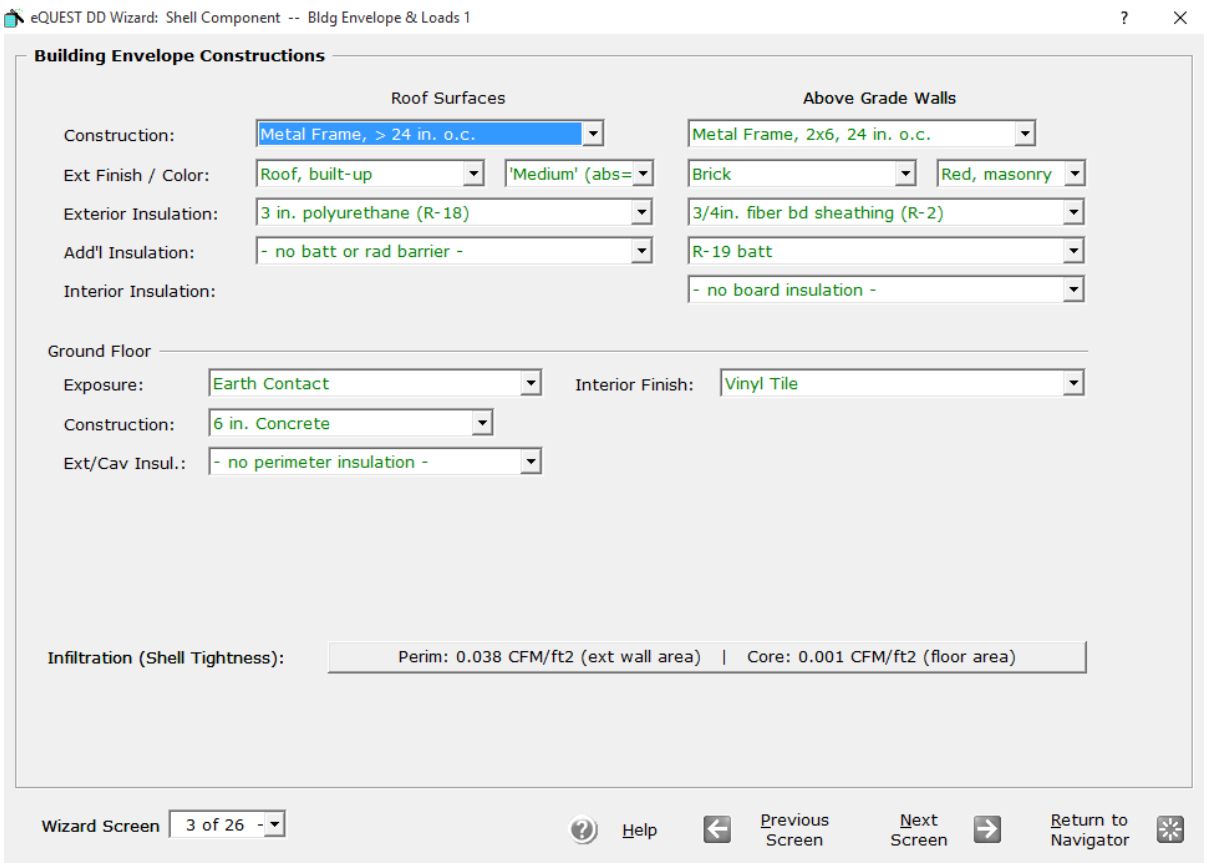

Figure 8 Construction Envelope

The default values for building construction based on a manufacturing facility are shown in green above. These are representative of industrial buildings and are were kept for modeling purposes.

eQUEST allows for the inclusion of windows and doors, in addition their location on the building can be specified. Typically industrial facilities are designed with controlled entrances and exits and very few windows on the factory floor. This is helps to protect the privacy of the process and in addition helps to minimize construction costs. Since there are likely few windows they will not be considered in this model along with window shading.

It will be assumed that the building operates on a 24 hours a day 6 days a week schedule. Facilities that require cooling even during the winter are often operating at night because of the equipment inside. In addition, this equipment is often very expensive and must be operated a high number of hours to maintain profitability. Based on data collected about operations of other cooled only facilities most of them operate either 24/5, 24/6, or 24/7 some even continue operating on holidays.

A critical consideration for this model is ventilation design. For general manufacturing ASHRAE standard 62.1-2010 calls for 0.25 cfm/ft^2. However, each facility will be different and operators may not know or directly control how much ventilation is used. Often times this will be reflected as the percentage of outside air used in the facility. Modifications to this number result in significant changes to the model. Often times exhaust requirements of the facility are even higher than the ventilation requirements so the facility will behave as if the ventilation is even higher. For simplicity of the model, the entire building was assigned to be in two zones, either the core or perimeter.

The next consideration is for the interior end uses that contribute to the space loads. Although there are many different types of space loads, they will be split into either interior lighting loads or process loads. The values of watts per square foot of both process loads and lighting loads will be changed in different iterations of the model. For the baseline model 1 W/ft^2 is used for lighting and 5 W/ft^2 for process loads (all other loads) for a total of 6 W/ft^2. These loads will be modeled as 100% sensible. For this example, a 250,000 ft^2 building would have a 1,250 kW process load and a 250 kW lighting load for a combined load of 1,500 kW. This process load only represents energy that is generated inside the building. This likely would not

include chillers, or air compressors along with any other equipment that rejects heat outside the building.

3.1.3 Air Side System

In this section the air side system will be specified in regards to the heating, cooling and ventilation system. A simple hot water loop will be chosen for this study because the primary focus will be cooled only buildings, which will use little to no heating. Chilled water coils are by far the most common in large facilities that require significant cooling, these systems allow for a centralized chiller plant area. Some industrial facilities will use air washers and even DX coils but they are less prevalent in large cooled only buildings, these do not make a difference in the heating or cooling loads of the space, but rather on how to convert these loads to actual electrical use through the cooling system. It is important to note that since this study examines loads, it is independent of air side system.

The set points used in the model are 74°F in cooling mode and 70°F in heating mode with no setbacks or scheduling because most systems are under sized and would have difficulty in recovering from a setback mode. While some plants may use setbacks in the office areas they are not likely to be used on the manufacturing floor and would not constitute a large percentage of the area of the building.

In addition, humidity controls in the space must be considered. Some facilities may not be measuring or controlling humidity because it does not interfere with the process or effect the product. Other facilities, such as textiles, will be primarily concerned with humidity levels because it can dramatically affect production speeds and quality. ASHRAE standard 62.1-2013 specifies that the maximum recommended humidity is 65% in order to prevent bacterial and

other microbial growth [9]. A minimum humidity requirement of 20% will be used in order to maintain some comfort to occupants. Too low of a humidity can cause drying and discomfort for the occupants. This can have an important influence on the use of economizers because the amount of water in the air is low when it is cold leading to very low relative humidity when it is heated sensibly.

One air handler is used for the model with the default manufacturing values selected. This allowed the supply and return fans to be auto sized according to ventilation requirements specified in the model. In addition, cycling fans at night is not used because the facility already operates around the clock except on Sunday when the fans will be allowed to cycle. However, the results are independent of air side system so even if the target facility has a different system, the results are still applicable.

This model incorporates the ability for the system to use air side economizers. The high limit was set to 28 BTU/lb with a low dew point of 25°F based on ASHRAE 90.1-2013 [9]. This high limit method is approved for all zones in the United States. In addition, there are other region specific options that do not consider enthalpy using only dry bulb. When looking at the United States as a whole, air side economizers are not very common because most facilities are unable to use them for very many months of the year so they are not economical. However, cooled year around facilities will have a high number of hours per year that they can use are side economizers in many climates. This is a critical component to the model because previous studies ignored economizers. Some facilities will use water side economizers but they are less common but can save more energy.

Figure 9 Economizer Inputs

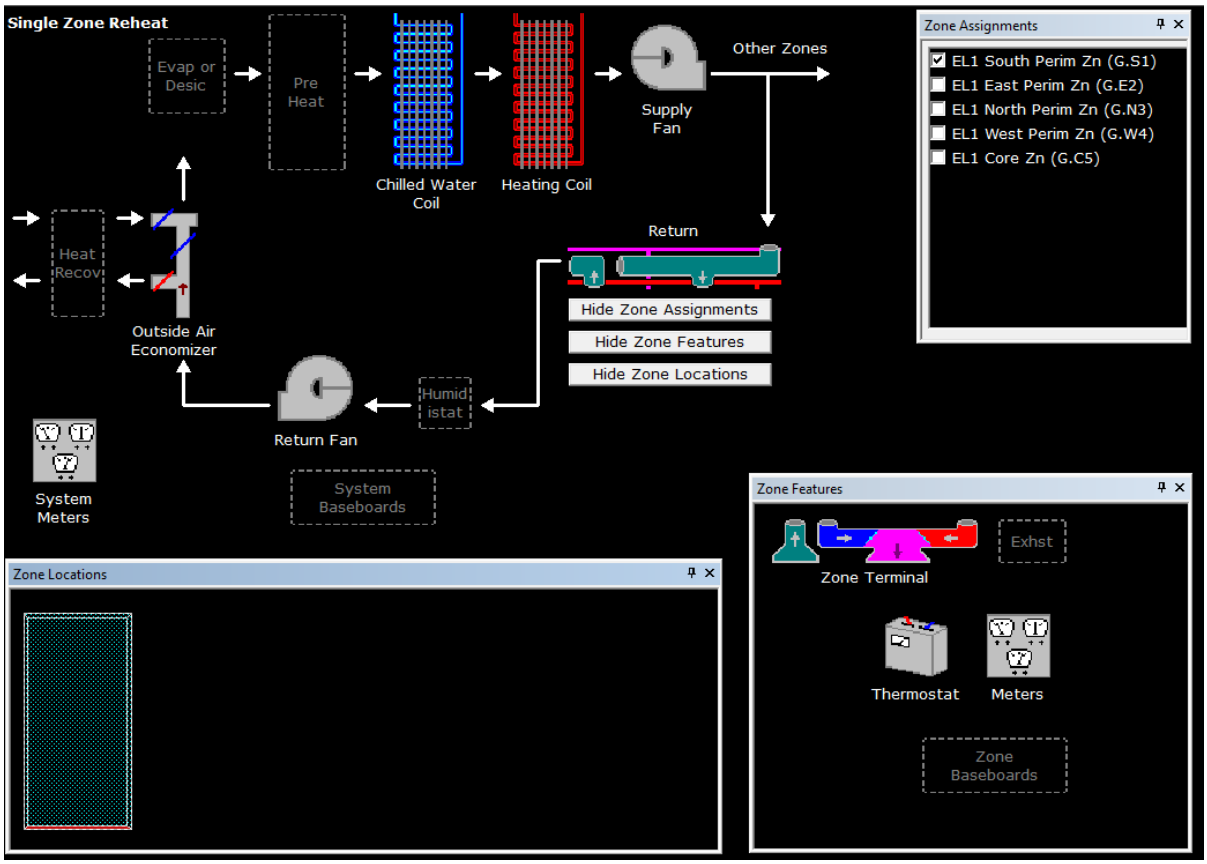

Figure 10 Air Side System Layout

3.1.4 Chilled Water Plant Equipment

Some of the critical input parameters are shown below.

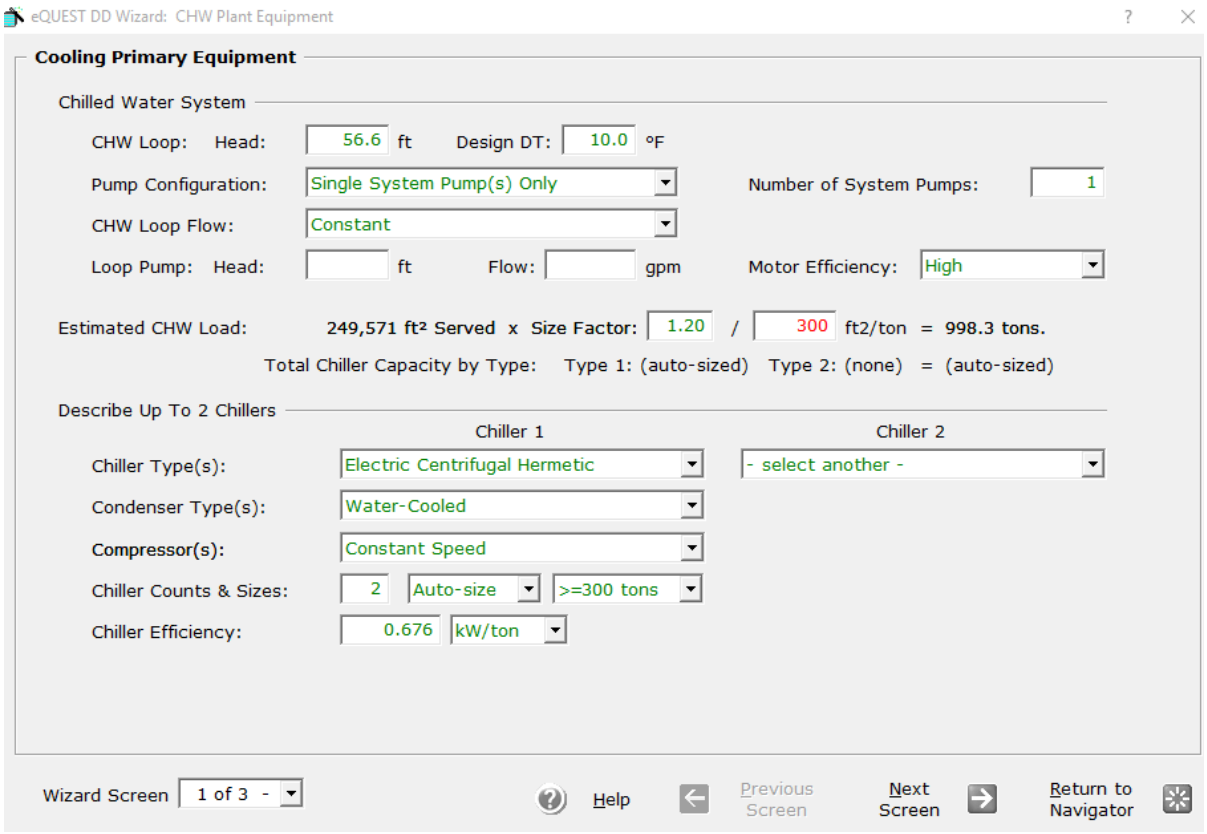

Figure 11 Chilled Water System

Another critical consideration for energy use is the assumption of water cooled chillers. Water cooled chillers are much more efficient than air cooled chillers and are nearly always used for large systems that a cooled only building would require. In addition, these chillers are going to be large with high efficiency motors. However, because this study considers loads the results are applicable to any cooling system type.

The cooling tower is in an open configuration with centrifugal type fans. In addition, these fans will be on variable speed drives because these cooling towers are likely to be big enough that it will be cost effective to include drives. Waterside economizers are not used in this model because they are much less common and require extra control systems and equipment.

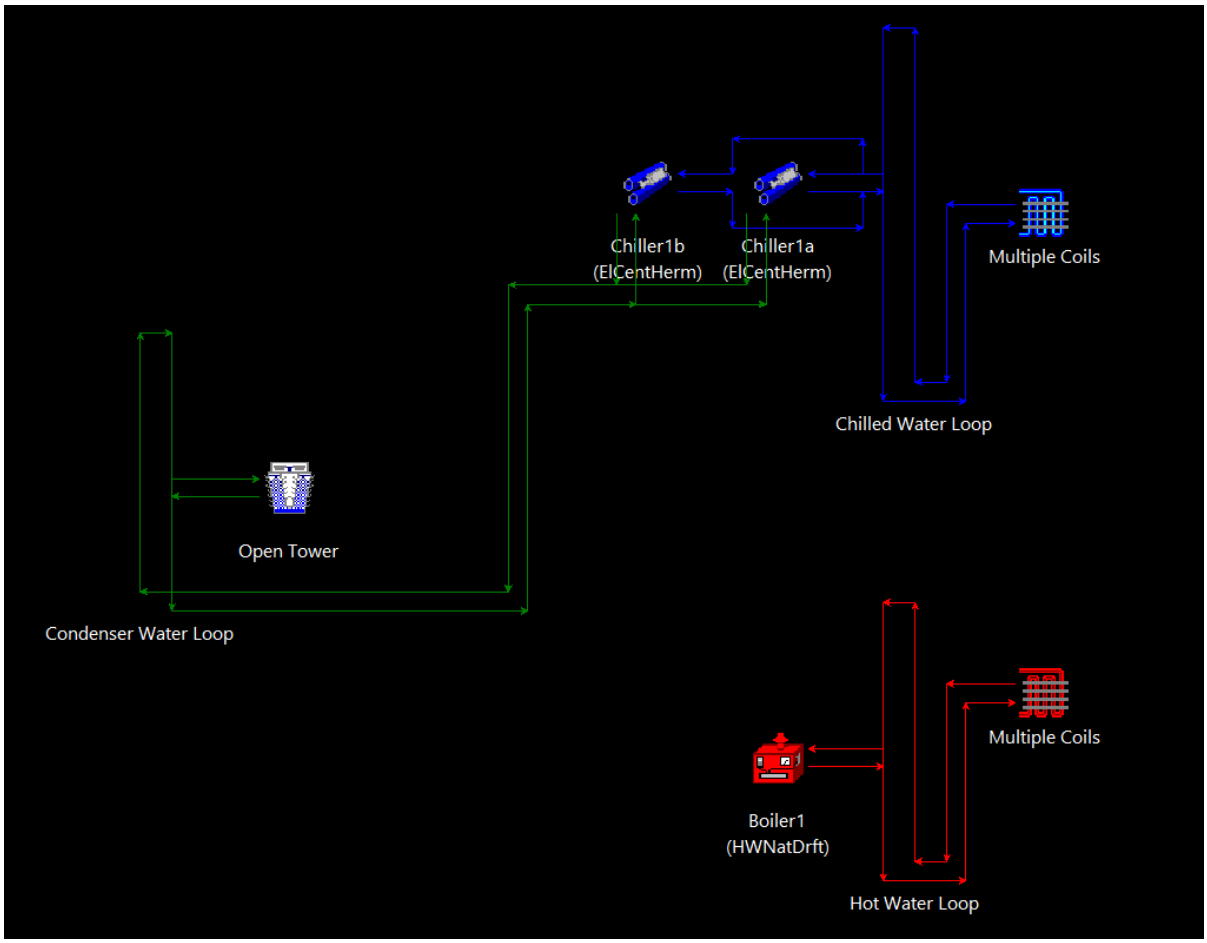

Figure 12 Waterside System Configuration

3.1.5 Hot Water Plant Equipment

The heating system is not of critical importance in this simulation but will still be included. The system is modeled as one large boiler with an efficiency of 80%. Although the loads might imply a smaller boiler, most industrial facilities will have some steam requirements for process loads.

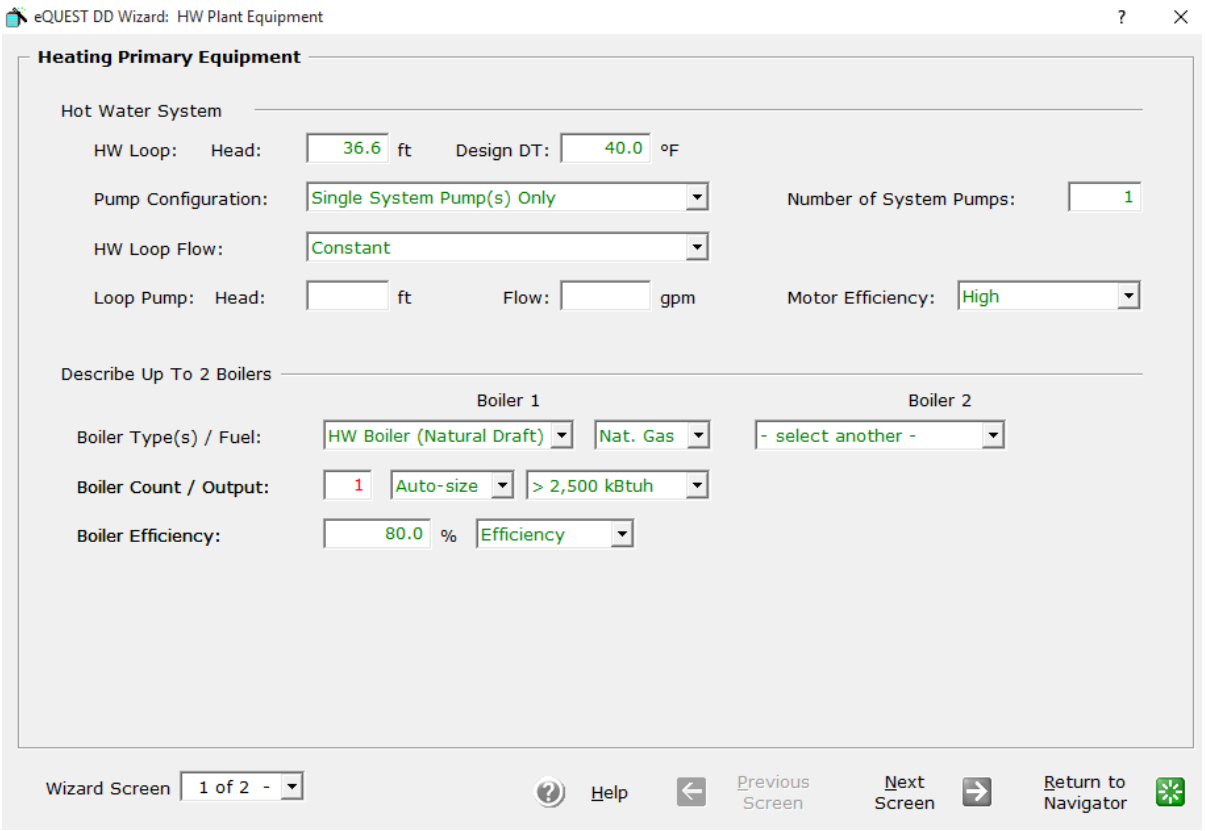

Figure 13 Heating Equipment Specification

3.1.6 Important Considerations

In order to provide a generalized model for a cooled only industrial building some assumptions must be made. Some of them only make a small difference and therefore will not need to be addressed for each induvial situation, others can make big difference and should be considered by the end user.

The biggest influence on the amount of electrical energy required to cool a building is whether the chiller system uses an air cooled chiller or a water cooled chiller. The efficiency of the system is a function the temperature at which heat is rejected. With a water cooled system heat is reject at close to the wet bulb temperature outside, usually around 85 °F. In a water cooled

system heat can be rejected at whatever the outside air temperature is and can be compounded by a heat island effect. The higher the temperature that heat is being rejected at the higher the pressure the refrigerant must be compressed to which in turn causes the chiller to use more energy to move the same quantity of heat.

A good estimate of the efficiency of a water cooled chiller is 0.7 kW/ton which includes cooling tower, fans and pumps. A good estimate of the efficiency for an air cooled chiller is 1.1 kW/ton. This is a huge difference in energy requirements but, it requires a higher capital expenditure up front to purchase, install and maintain. However, the results of this study are independent of cooling system.

Nearly all plants that are cooled year around will have large systems where it is economical to install water cooled chillers and this is why the model uses water cooled chillers. However, there are some exceptions to this rule, and it should be considered if the target facility uses air cooled chillers or roof top units. For a cooled only building this will make the HVAC savings greater so using the methods presented here will be conservative.

Another big influence is the ventilation required for the facility. For this model the ASHRAE standard for ventilation is used. However, many facilities ventilation requirements will be determined by the amount of exhaust air required for certain processes. For example, if a plating or other chemical process is being done the outside air requirements will likely be driven by this exhaust air. The ASHRAE standard is likely a minimum but ventilation rates could be considerably higher, however for cooled only buildings this result will be conservative.

A final consideration is economizers. The existing literature ignores economizers but, nearly all buildings that are cooling year around will use some type of economizing. This study will consider air side economizers. Water side economizers have the potential to save even more energy but are much less common due to more complex controls, piping and initial capital expenditures.

3.2 Lighting Reduction Model

Once the baseline model is complete, the lighting upgrade can be input into the model. Each lighting upgrade project will have different goals and done in a different way. However, most will result in saving energy.

Table 7 Lighting Upgrades

Original			Replacement			Difference			
Fixture	Watts	Lumens	Fixture	Watts	Lumens	Watts	Energy Reduction	Lumens	Lumen Reduction
250W-MH	293	13,500	6xF32-T8	220	19,350	73	25%	5,850	43%
			LED	90	11,200	203	69%	-2,300	-17%
400W-MH	458	24,000	6xF54-T5	360	28,000	98	21%	4,000	17%
			LED	150	14,000	308	67%	-10,000	-42%
1000W-MH	1,080	81,000	6xF54-T5 (double)	720	56,000	360	33%	-25,000	-31%
			LED	300	38,292	780	72%	-42,708	-53%
2xF96-T12	173	11,354	4xF32-T8	110	9,900	63	36%	-1,454	-13%
			LED	65	7,600	108	62%	-3,754	-33%
4xF34-T12	164	8,770	4xF32-T8	110	9,900	54	33%	1,130	13%
			LED	65	7,600	99	60%	-1,170	-13%
Average							48%		-13%

Currently, most upgrades done in industrial facilities involve switching to fluorescents. However, as the capital cost of LED's goes down, lighting upgrades will begin to include LED's instead of fluorescents.

Looking at Table 7 there is a very distinct difference between upgrades that use fluorescents as opposed to upgrades using LED's. The reduction in wattage is much higher in LED's although their initial capital expenditure is much higher.

Table 8 Wattage Reduction LED vs. Flourescents

LED	66%
Fluorescent	30%

It is clear that there is a major difference in energy reduction between LED and fluorescent upgrades. Based on the average, the model will use a lighting reduction of 50%. Varying this number will not make a noticeable difference in the model because the correction factor will normalized by energy reduction.

In eQuest, there is an energy efficiency measure wizard that can be modified to run iterations. Here, the user can specify what type of energy efficiency measure to use. Each type of energy efficiency measure must be specified and then applied to a particular run. In addition, different iterations can be run with different life cycle costs.

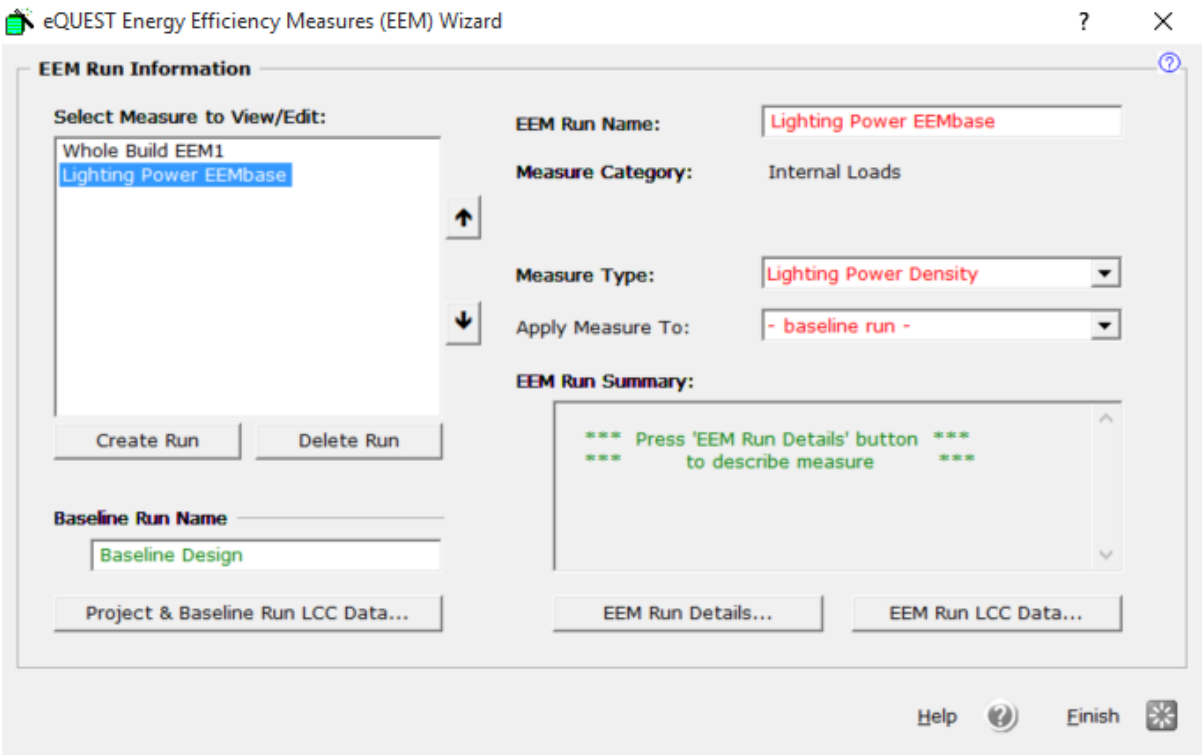

Figure 14 Energy Effeciency Wizard

For lighting measures, there is a built in function which specifies the current lighting density in W/ft^2 and then allows the user to input another value to reflect a lighting upgrade that reduces the amount of energy used to maintain lighting.

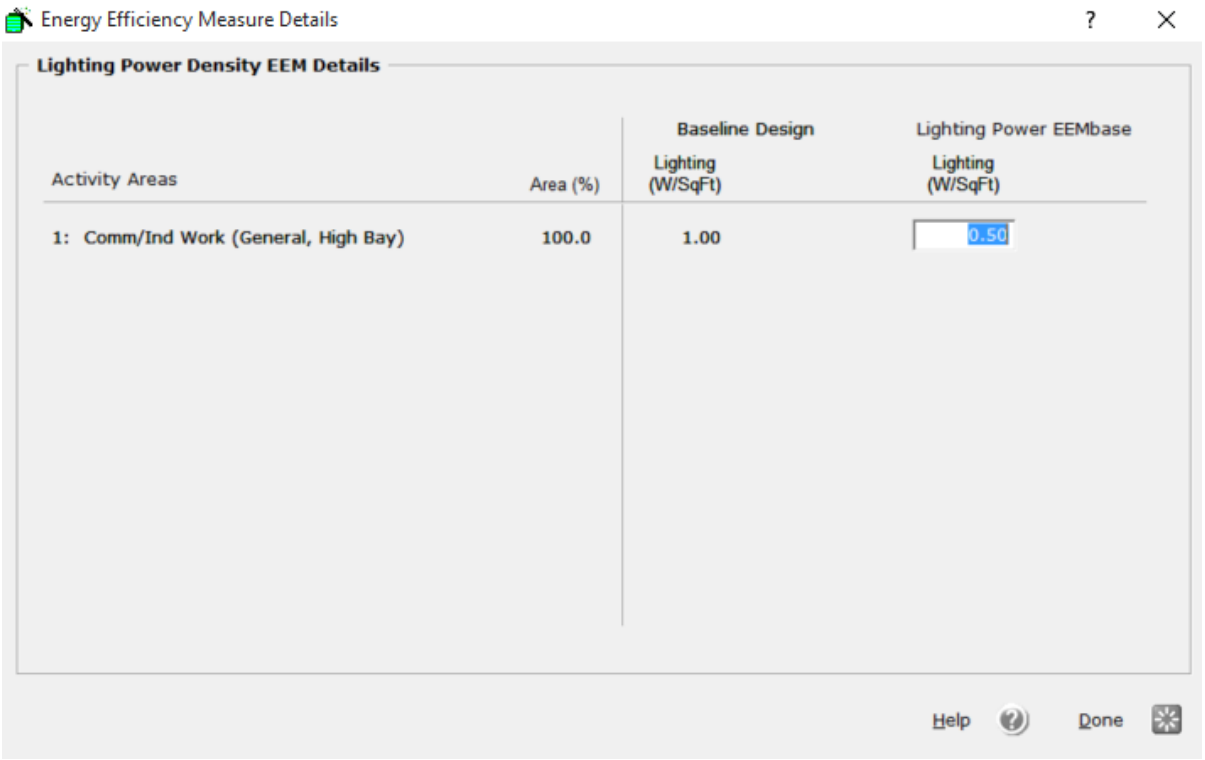

Figure 15 Lighting Details

Since this model uses only one space of a single type, there is only one activity area. For a detailed model based on an existing building the lighting level changes could be specified by space.

3.3 Process Load Iteration Model

One of the things that this study is trying to identify is how the correction factor will vary depending on how much internal load is generated in the building. All internal loads other than lighting have been simplified as process loads. The model will run iterations at various loads and these results will be used to looks for a correlation. Once again energy efficiency wizard will be used.

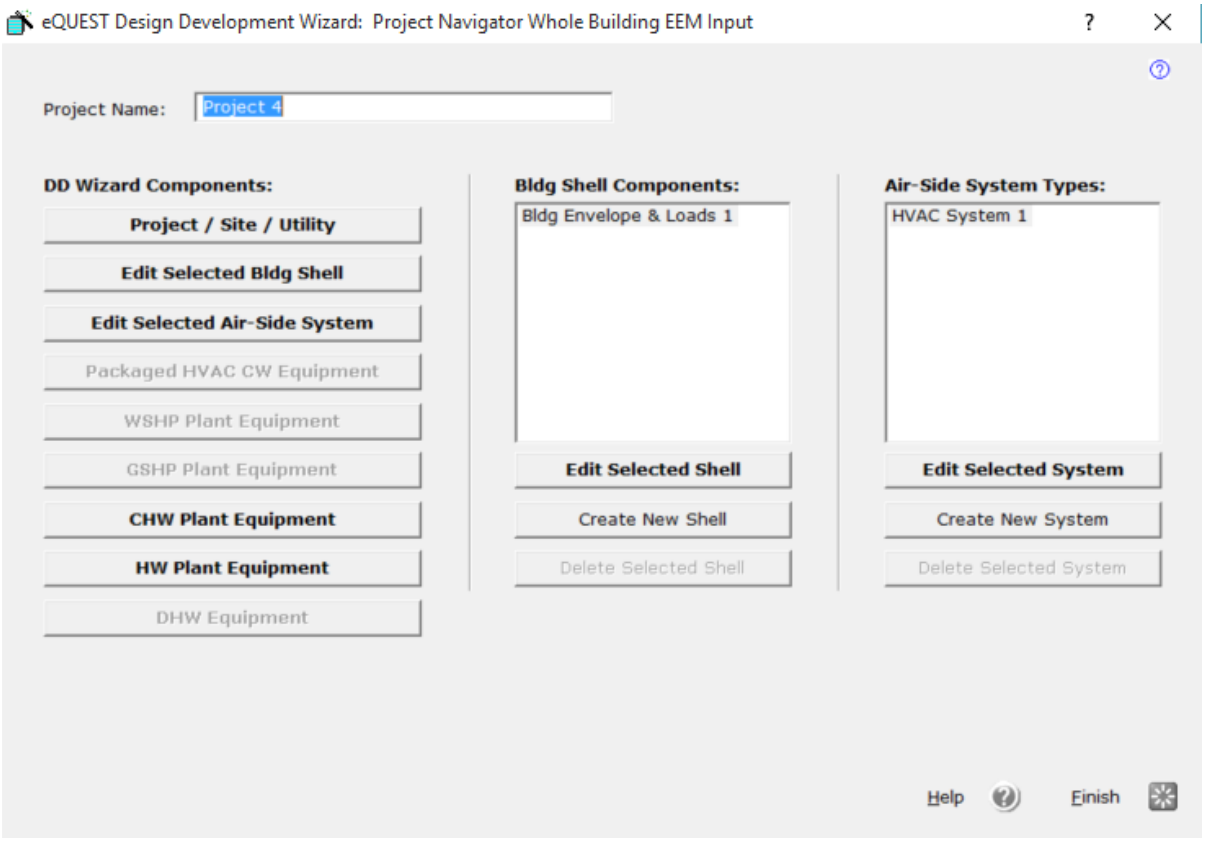

Figure 16. Process Load Details

eQUEST does not have a built in function to allow internal load generation variations. However, this can still be done using the whole building measure. This allows the user to change any detail in the building allowing for a wide variety of efficiency measures to be modeled.

Using the Energy Efficiency Measure (ECM) tool process loads of 0 to 9 W/ft^2 simulations are run. Each process load simulation has a lighting ECM applied to it giving a total of 20 simulations with economizers and 20 simulation without economizers per city.

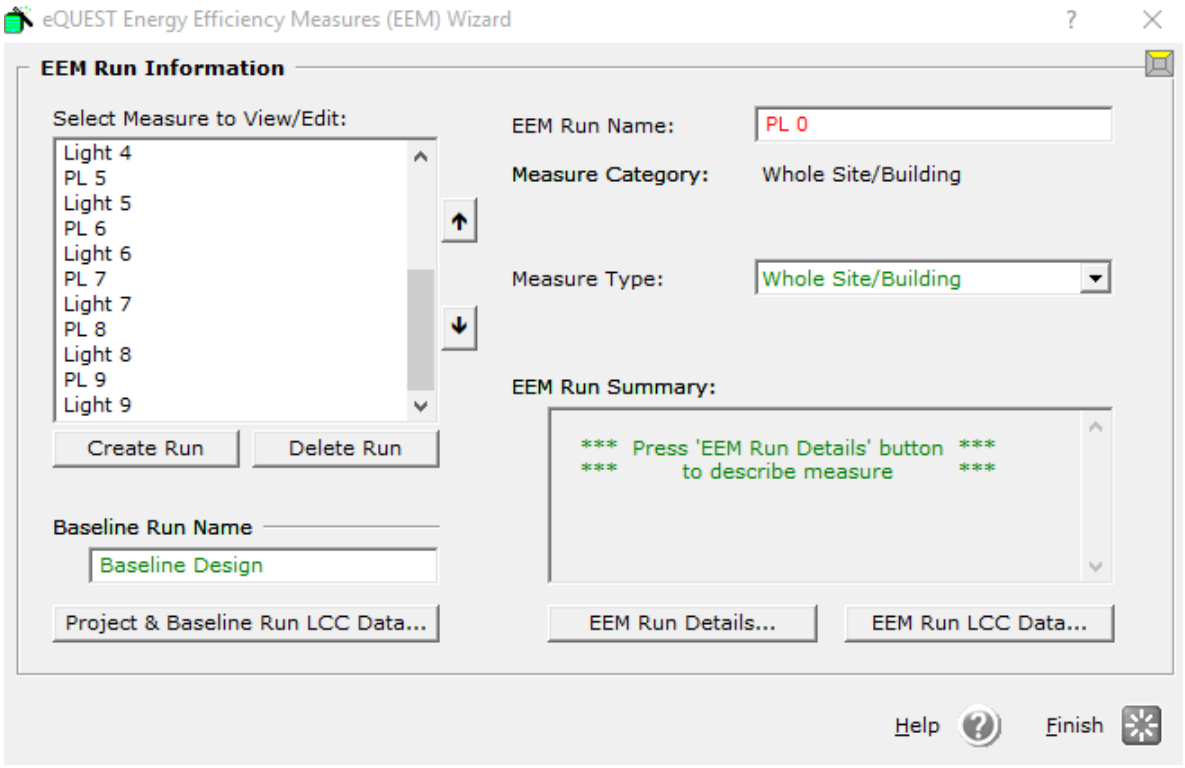

Figure 17 Energy Conservation Measures (ECM)

3.4 Model Output

The results of the model from eQUEST includes a wide variety of information. Some of it is presented in easy to read graphs, more detailed information is available in the simulation text file. These results will show the output from the baseline model at with an internal generation of 5 W/ft^{2}-and 1 W/ft^{2} of lighting, this is called the baseline model.

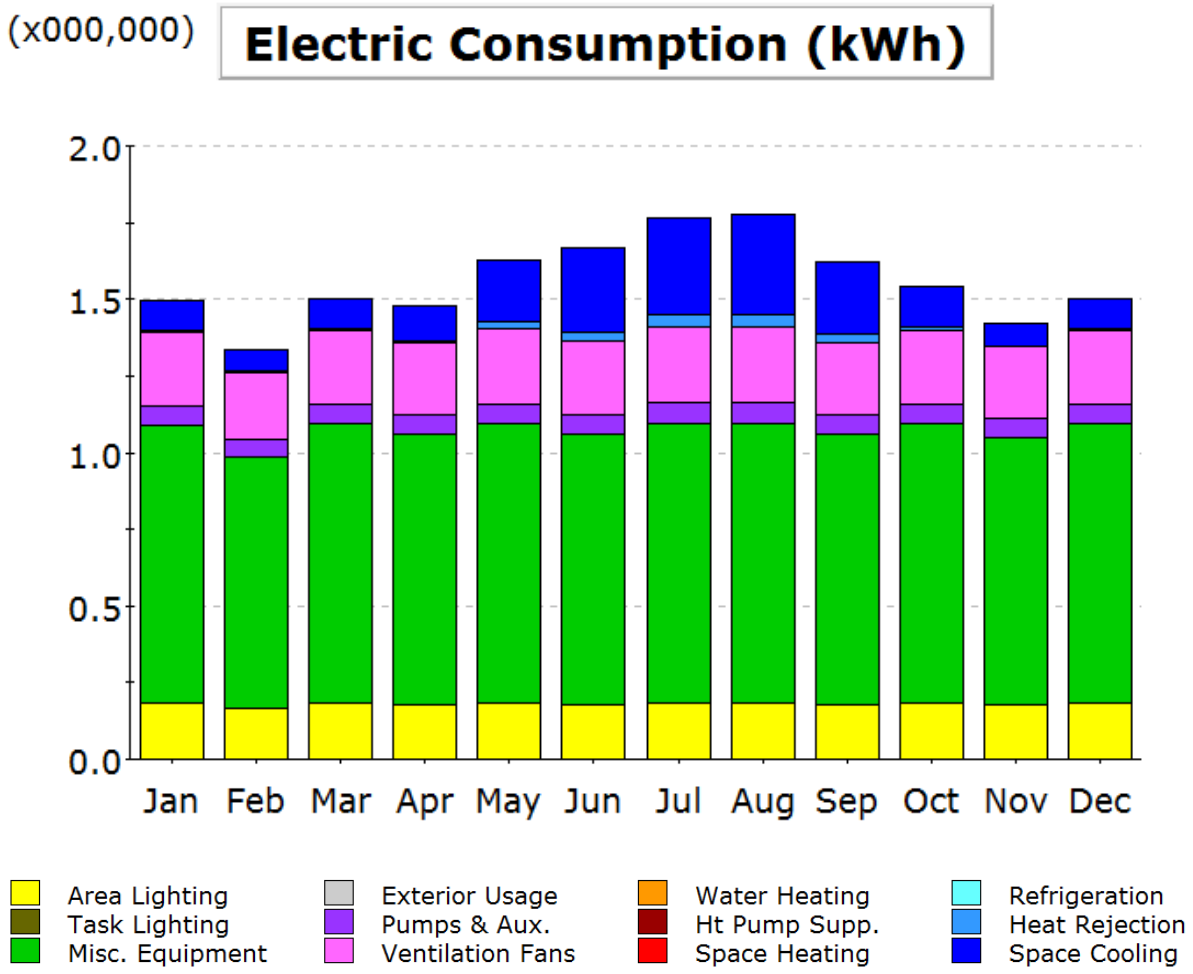

Figure 18 Baseline Model Electric Energy Usage

Table 9 Electric Consumption Table

Electric Consumption (kWh x000,000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	0.09	0.07	0.10	0.11	0.20	0.27	0.32	0.33	0.24	0.13	0.07	0.10	2.03
Heat Reject.	0.01	0.00	0.01	0.01	0.02	0.03	0.04	0.04	0.03	0.01	0.00	0.01	0.20
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	0.24	0.22	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	2.87
Pumps & Aux.	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.77
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	0.91	0.82	0.91	0.88	0.91	0.88	0.91	0.91	0.88	0.91	0.87	0.91	10.69
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	0.18	0.17	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	2.16
Total	1.49	1.34	1.50	1.48	1.62	1.67	1.77	1.78	1.62	1.54	1.42	1.50	18.74

Next, information from the simulation file is extracted regarding cooling load, heating load and fan load during cooling hours.

Table 10 Baseline Simulation Loads

Internal Load ($W/ft^{2)}$	Before Lighting Upgrade		
	Cooling Load (MMBTU)	Heating Load (MMBTU)	Fan Load During Cooling Hours (kWh)
5	28,557	0	1,871,310

The next simulation that will be shown is the same baseline design except with a 0.5 W/ft^2 lighting load.

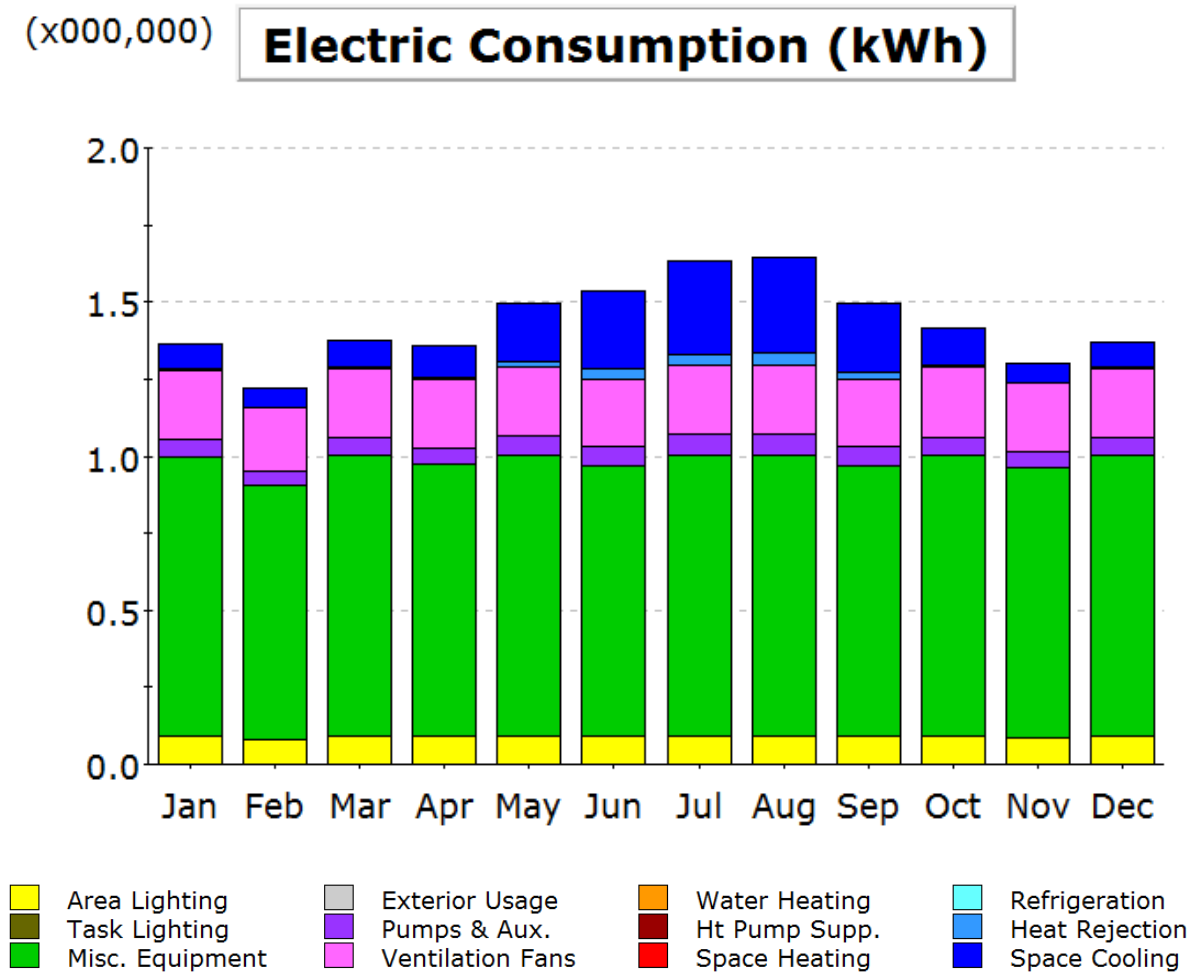

Figure 19 Lighting Reduction Model Electric Energy Usage

Table 11 Electric Consumption Table

Electric Consumption (kWh x000,000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	0.08	0.06	0.08	0.10	0.19	0.26	0.30	0.31	0.22	0.12	0.06	0.08	1.87
Heat Reject.	0.00	0.00	0.01	0.01	0.02	0.03	0.04	0.04	0.02	0.01	0.00	0.00	0.19
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	0.23	0.20	0.23	0.22	0.23	0.22	0.23	0.23	0.22	0.23	0.22	0.23	2.66
Pumps & Aux.	0.06	0.05	0.06	0.06	0.06	0.06	0.07	0.07	0.06	0.06	0.06	0.06	0.72
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	0.91	0.82	0.91	0.88	0.91	0.88	0.91	0.91	0.88	0.91	0.87	0.91	10.69
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	0.09	0.08	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	1.08
Total	1.36	1.22	1.38	1.36	1.50	1.54	1.63	1.64	1.49	1.42	1.30	1.37	17.21

Table 12 After Lighting Simulation Loads

Internal Load ($W/ft^{2)}$	After Lighting Upgrade		
	Cooling Load (MMBTU)	Heating Load (MMBTU)	Cooling Hours Fan Load (kWh)
5	25,596	7	1,684,481

One of the reasons that these conditions were chosen for the base line model is that this near the cut off of where a building is cooled only. The model results shown above for both the baseline and after the lighting upgrade have no heating required.

First, the savings from the lighting upgrade can be calculated based on a demand reduction of 125 kW or 50%, directly as a result of using more efficient light fixtures. Next, the direct electrical savings from using more efficient lighting is 1,082,925 kWh or 50%. Most users are easily able to calculate these savings directly and are very reliable and straight forward. Finally, the cooling saving can be calculated using the correction factor demonstrated in the analysis and results section. Using an efficiency of 0.7 kW/ton with economizers, the correction factor is 0.13, this is calculated using the method shown in the following section. By multiplying the correction factor by the kWh of electrical savings due to lighting there will be an additional savings of 140,870 kWh of cooling energy saved this gives an additional 13% savings.

4 Analysis and Results

4.1 Correction Factor

It is important to consider how the results of this study will be displayed and implemented by the target user group. This can be done using a correction factor (CF). This essentially is represented by the change in cooling energy divided by the change in lighting energy after the lighting upgrade is implemented. The equation that is used to find the correction factor in this study is shown below.

$$CF = \frac{Cooling\ Energy\ Savings\ (kWh)}{Lighting\ Energy\ Savings\ (kWh)} \quad (2)$$

This correction factor is an excellent tool that can be easily implemented by the user. This is designed to be used by groups that have already calculated the lighting energy savings and need to add a correction for cooling loads. Rearranging the equation above will allow users to solve for cooling energy savings.

$$Lighting\ Energy\ Savings\ (kWh) x CF = Cooling\ Energy\ Savings\ (kWh) \quad (3)$$

By using this equation a cost can be calculated and then included to justify a lighting upgrade project at a facility. This method will make for an easy to use metric than can be implemented for any appropriate building or project.

For practical purposes a load correction factor (LCF) will be calculated and then multiplied by the efficiency of the system.

$$CF = LCF \ x\ 3412 \frac{btu}{kWh} x \frac{1}{12{,}000 \frac{btu}{hr\ ton}} \ x\ eff[\frac{kw}{ton}] \tag{4}$$

$$CF = LCF \ x\ 0.284\ [ton/kW]\ x\ eff[\frac{kw}{ton}]$$

$$CF = \frac{LCF}{eff[Coeffecient\ of\ Performance]} \tag{5}$$

It is recommended to use 1.1 kW/ton for air cooled chillers and 0.7 kW/ton for water cooled chillers. This can vary by the overall size of the chillers and what the supply temperature the chiller is producing. In addition, the temperature that heat is rejected is important to consider. If the user knows the COP of their system they can input into the formula to get a more accurate correction factor.

4.2 Load Correction Factor

Since different systems will have a different efficiency associated with what type of cooling is done, this study will focus on loads. This will allow the results to be independent of air side system or cooling equipment type.

One issue that needs to be considered is that this study is only focusing on direct cooling load savings. However, when the internal load of a building is decreased such as in a lighting upgrade, fans will operate less or at a lower speed. This saves energy directly because of reduced electrical requirements to power the fans but, it also reduces the load on the chiller because less heat from fans needs to be removed.

The amount of fan power required can vary significantly based on how the air side system is configured. Fan energy savings will not be considered in this study because of the wide variety of systems in place at this time. In addition to shell loads, infiltration, ventilation, process loads and lighting loads, fans contribute to loads. The output of eQUEST shows cooling loads, which includes the load of removing heat from the fans. In order to control for the wide variety of air side systems the amount of fan energy saved by reducing the lighting load will not be considered. For these reasons the cooling load to be considered will the cooling load output by eQUEST minus the fan power during cooling hours. This will eliminate the variable fan requirements from different systems. In addition, this will make the correction factor even more conservative because many systems may experience some cooling savings in addition to electrical saving because of reduced fan power requirements in the air side system.

The overall effect of this assumption will likely make the resulting correction factor more conservative. This will not necessarily be the case since some systems may not be able to reduce the fan load with an internal load decrease. In order to get cooling loads not including the fan power load the below equation is used.

$$LCF = \frac{Cooling\ Load\ Savings\ (kWh) - Fan\ \ During\ Cooling\ Hours\ (kWh)}{Lighting\ Energy\ Savings\ (kWh)} \quad (6)$$

The values in the above equation are pulled from the simulation file produced by eQUEST on each iteration.

4.3 City Selection

This study will look at the United States and focus on using cities in each climate zone. ASHRAE has developed climate maps that show the different climate types in the United States. An area is given a number 1 through 8 with the lower number being hotter. Then a letter is assigned A is moist, B is Dry and C is marine.

Cities were selected because of large populations and to include a variety of climate zones. Most users will able to find a similar location to use. Users can choose areas geographically close or in the same climate zone.

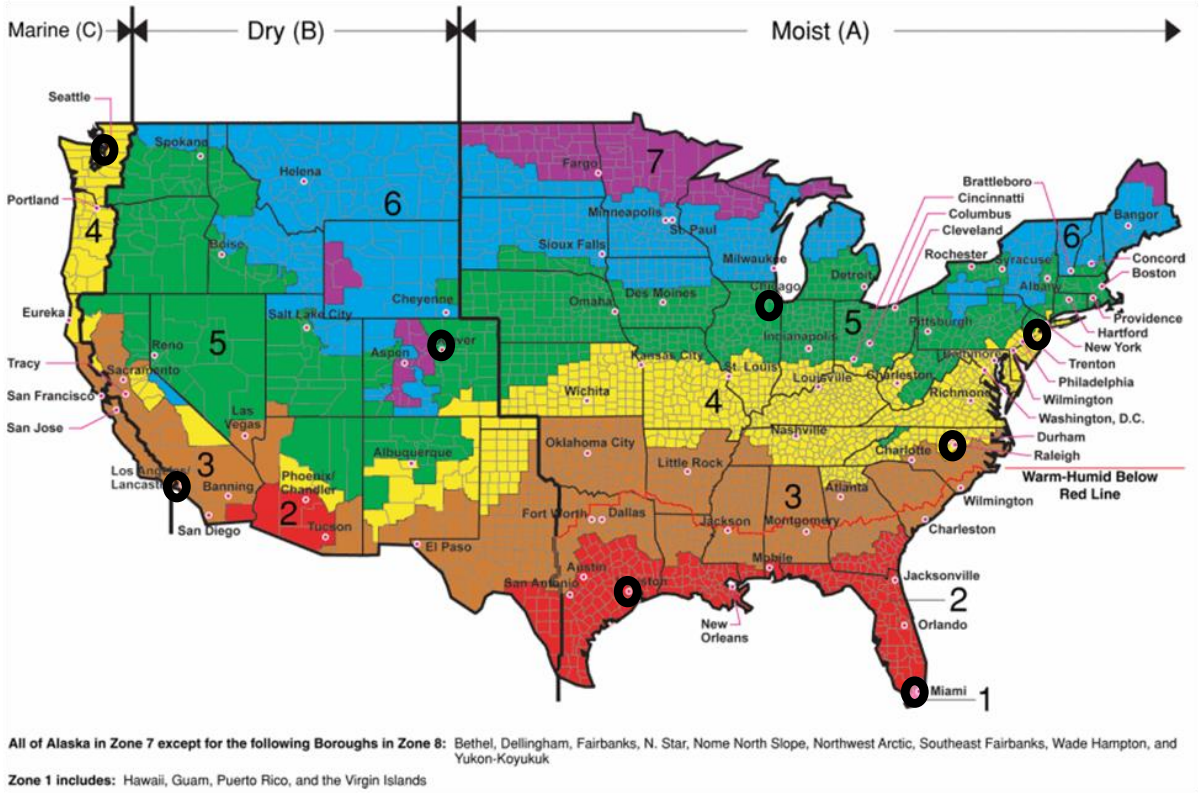

Figure 20 Climate Zones ASHRAE 90.1-2004 [1]

Fairbanks is not shown on the map above however, it is included in the study.

Table 13 Selected Cities

City	Climate Zone
Raleigh, NC	4A
New York, NY	4A
Los Angeles, CA	3B
Miami, FL	1A
Denver	5B
Chicago	5A
Houston, TX	2A
Fairbanks, AK	8
Seattle, WA	4C

4.4 Raleigh, NC Results

This section shows the results of the model and it's iterations for Raleigh, NC. Each city has results calculated in the same way but they were omitted for brevity.

4.4.1 With Economizers

The baseline model presented in the eQUEST modeling section of the report is used to make iterations. As outlined in the process load and lighting load reduction 10 data points were collected. Each data point has a simulation of process load from 0-9 W/ft^2 along with a lighting energy efficiency measure that simulates the effect of a lighting upgrade. The internal load is calculated by adding the process load and 1 W/ft^2 for the lighting power. Then using report SS-D, Building HVAC Load Summary, the yearly cooling and heating load was extracted from the simulation file.

First, the data from the simulations in Raleigh, NC can be analyzed. The raw data is shown in the table below.

Table 14 HVAC Load Data Raleigh, NC With Economizers

Internal Load (W/ft^2)	Before Lighting Upgrade		After Lighting Upgrade		Lighting Energy Reduction (kWh)
	Cooling Load (kWh)	Heating Load (kWh)	Cooling Load (kWh)	Heating Load (kWh)	
1	1,860,085	868,876	1,450,516	1,419,651	1,082,295
2	2,952,571	365,611	2,396,117	563,217	1,082,295
3	4,054,690	107,103	3,536,802	212,051	1,082,295
4	5,164,696	10,180	4,577,745	37,204	1,082,295
5	6,504,470	98	5,822,809	1,994	1,082,295
6	7,904,551	9	7,211,474	31	1,082,295
7	9,313,678	0	8,618,602	0	1,082,295
8	10,733,312	0	10,029,987	0	1,082,295
9	12,157,639	0	11,452,937	0	1,082,295
10	13,583,179	0	12,877,985	0	1,082,295

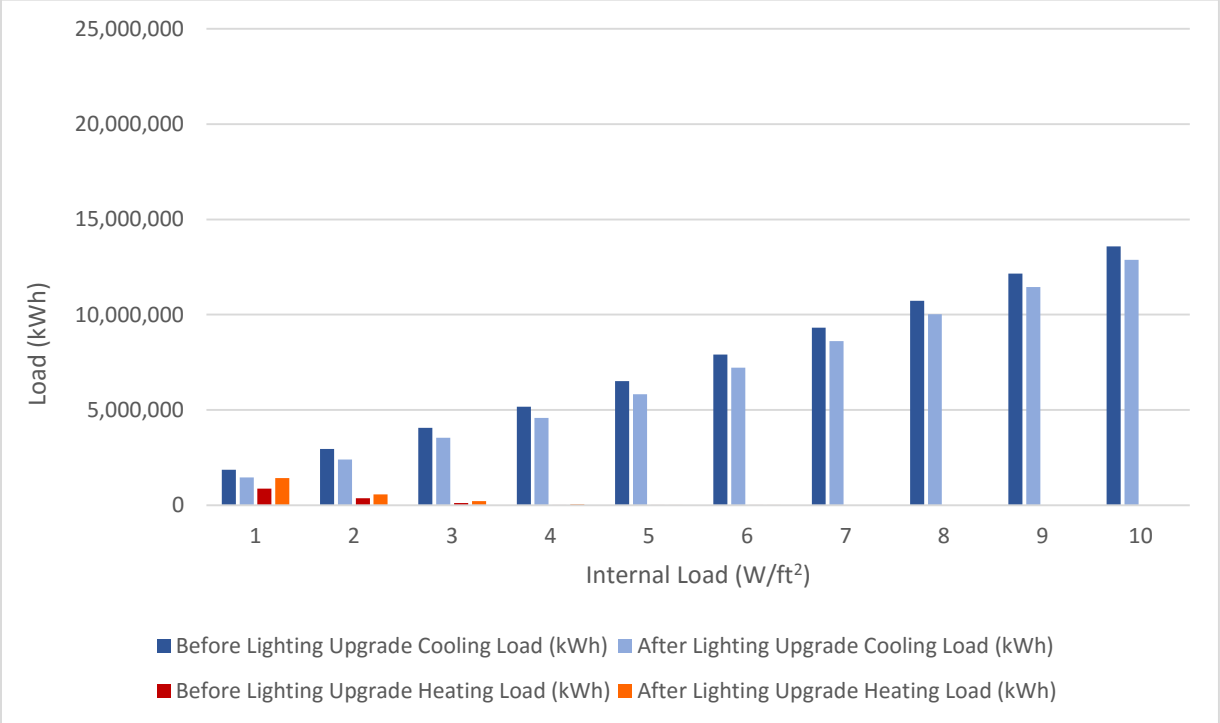

Figure 21 Raleigh Load Results With Economizers

The internal load represents the sum of the process load and the lighting load at each iteration. These loads then are used to compute a Load Correction Factor (LCF) which is the difference in cooling load divided by the difference in lighting energy. These LCF's are shown in the table below at varying internal loads.

Table 15 Load Correction Factor Raleigh, NC With Economizers

Internal Load (W/ft^2)	Cooling Load Correction Factor	Heating Load Correction Factor	Combined Load Correction Factor
1	0.38	-0.51	-0.13
2	0.51	-0.18	0.33
3	0.48	-0.10	0.38
4	0.54	-0.02	0.52
5	0.63	0.00	0.63
6	0.64	0.00	0.64
7	0.64	0.00	0.64
8	0.65	0.00	0.65
9	0.65	0.00	0.65
10	0.65	0.00	0.65

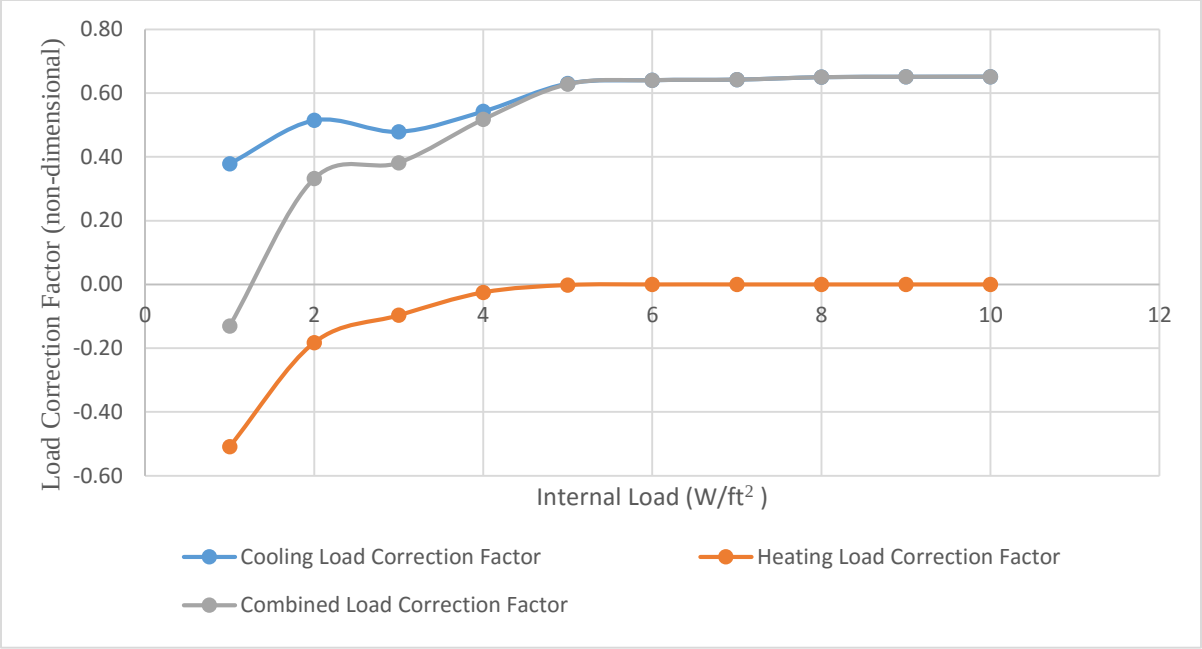

Figure 22 LCF vs. Internal Load Raleigh, NC With Economizers

It can be seen that the load correction factor is smaller at lower internal loads. This is because at this point the building requires heating at some point in the year. At higher internal loads, the LCF begins to level off.

From the load correction factor, a correction factor (CF) for energy can be calculated.

$$CF = LCF \ x\ 0.284\ x\ eff[\frac{kw}{ton}] \quad (7)$$

A good number for efficiency of water cooled chillers is 0.7 kW/ton. The CF at varying internal loads is shown below. However, some users will have access to an estimate of the chiller efficiency of their system.

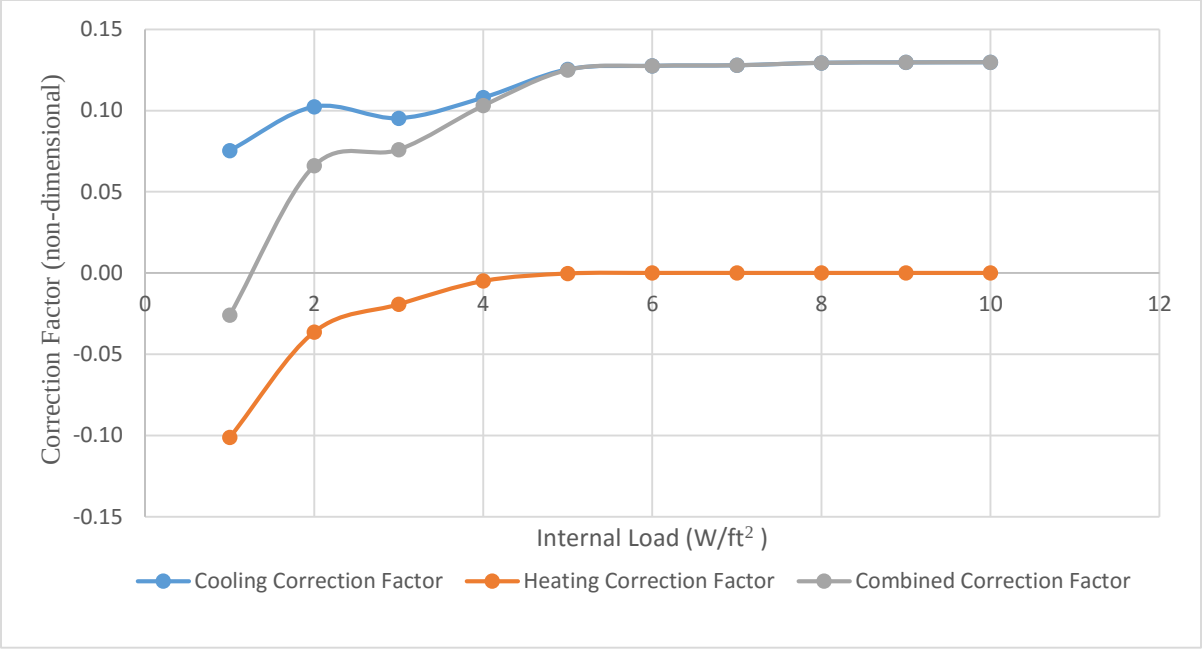

Figure 23 Water Cooled Chillier (0.7 kW/ton) Correction Factor Raleigh, NC With Economizer

A good number for efficiency of air cooled chillers is 1.1 kW/ton. The CF at varying internal loads is shown below.

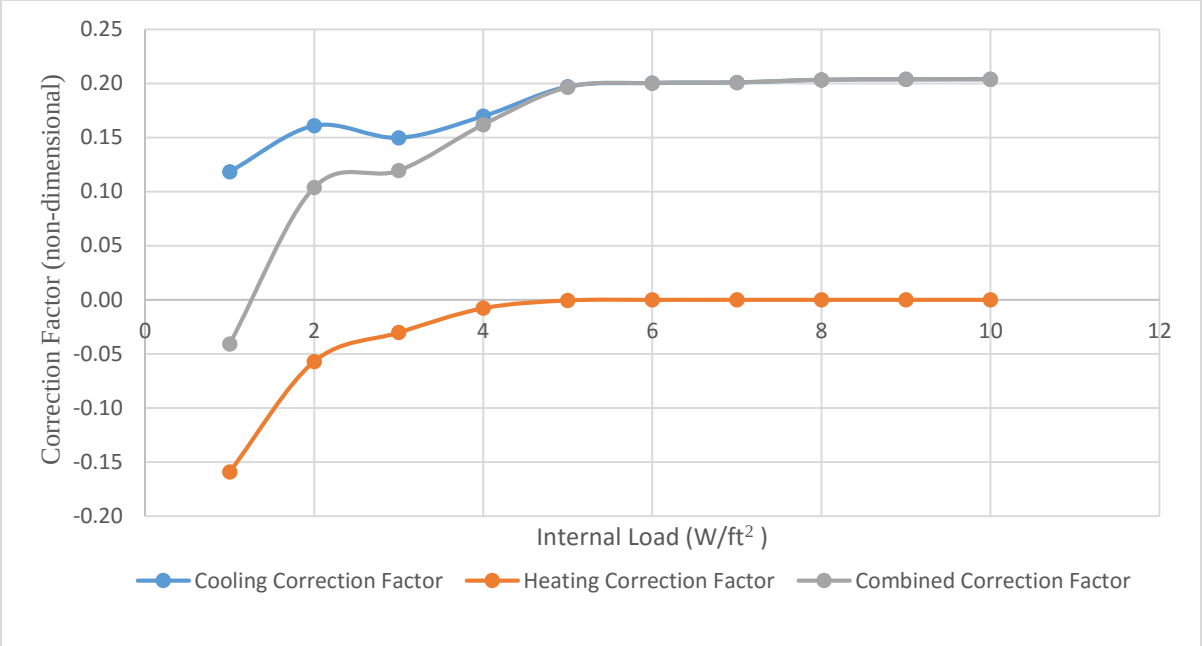

Figure 24 Air Cooled Chillier (1.1 kW/ton) Correction Factor Raleigh, NC With Economizer

4.4.2 Without Economizers

Next, data was collected in the same manner but, without economizers.

Table 16 HVAC Load Data Raleigh, NC Without Economizers

Internal Load (W/ft^2)	Before Lighting Upgrade		After Lighting Upgrade		Lighting Energy Reduction (kWh)
	Cooling Load (kWh)	Heating Load (kWh)	Cooling Load (kWh)	Heating Load (kWh)	
1	1,892,561	867,934	1,441,643	1,426,019	1,082,295
2	3,308,085	364,816	2,567,820	562,096	1,082,295
3	4,957,281	106,707	4,135,037	211,573	1,082,295
4	6,777,422	10,084	5,847,757	36,932	1,082,295
5	8,799,142	94	7,784,027	1,972	1,082,295
6	10,889,914	9	9,856,834	31	1,082,295
7	12,994,412	0	11,956,508	0	1,082,295
8	15,098,889	0	14,061,936	0	1,082,295
9	17,205,361	0	16,165,882	0	1,082,295
10	19,308,742	0	18,270,362	0	1,082,295

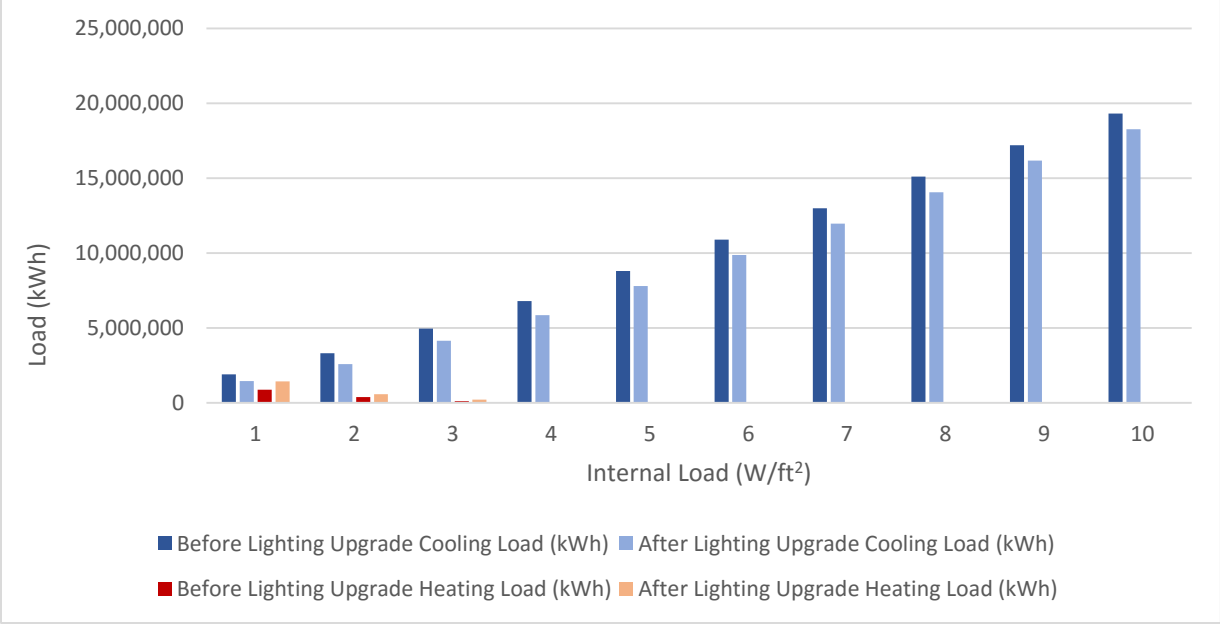

Figure 25 Raleigh Load Data Without Economizers

Table 17 Load Correction Factor Raleigh, NC Without Economizers

Internal Load (W/ft^2)	Cooling Load Correction Factor	Heating Load Correction Factor	Combined Load Correction Factor
1	0.42	-0.52	-0.10
2	0.68	-0.18	0.50
3	0.76	-0.10	0.66
4	0.86	-0.02	0.83
5	0.94	0.00	0.94
6	0.95	0.00	0.95
7	0.96	0.00	0.96
8	0.96	0.00	0.96
9	0.96	0.00	0.96
10	0.96	0.00	0.96

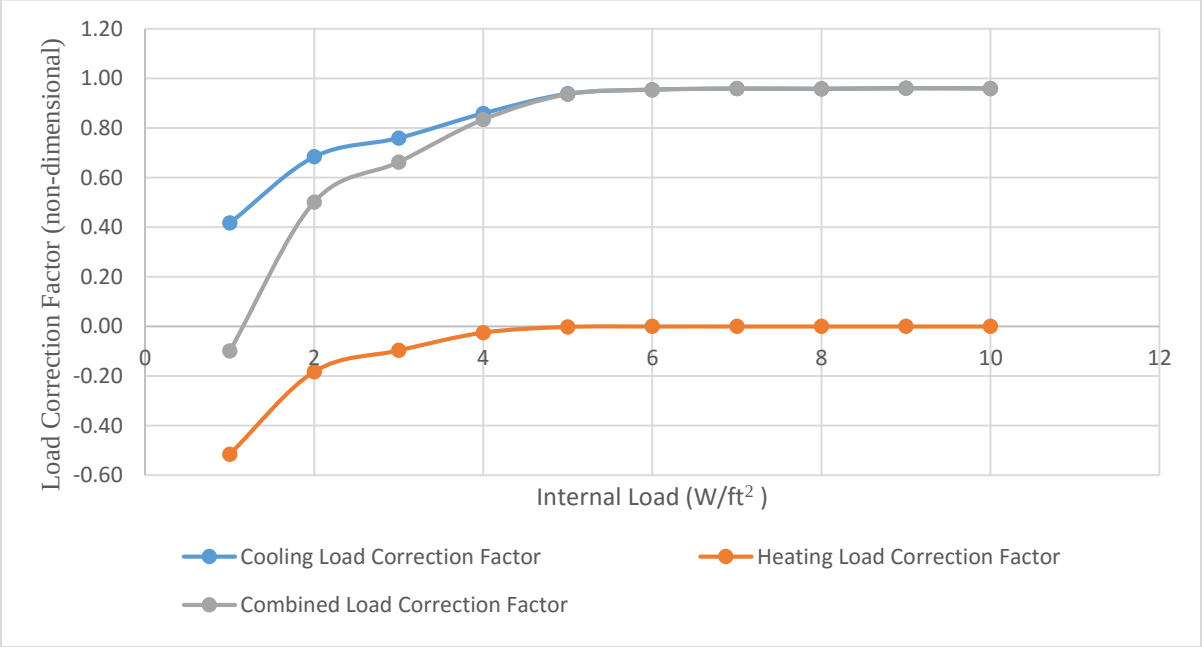

Figure 26 LCF vs. Internal Load Raleigh, NC Without Economizers

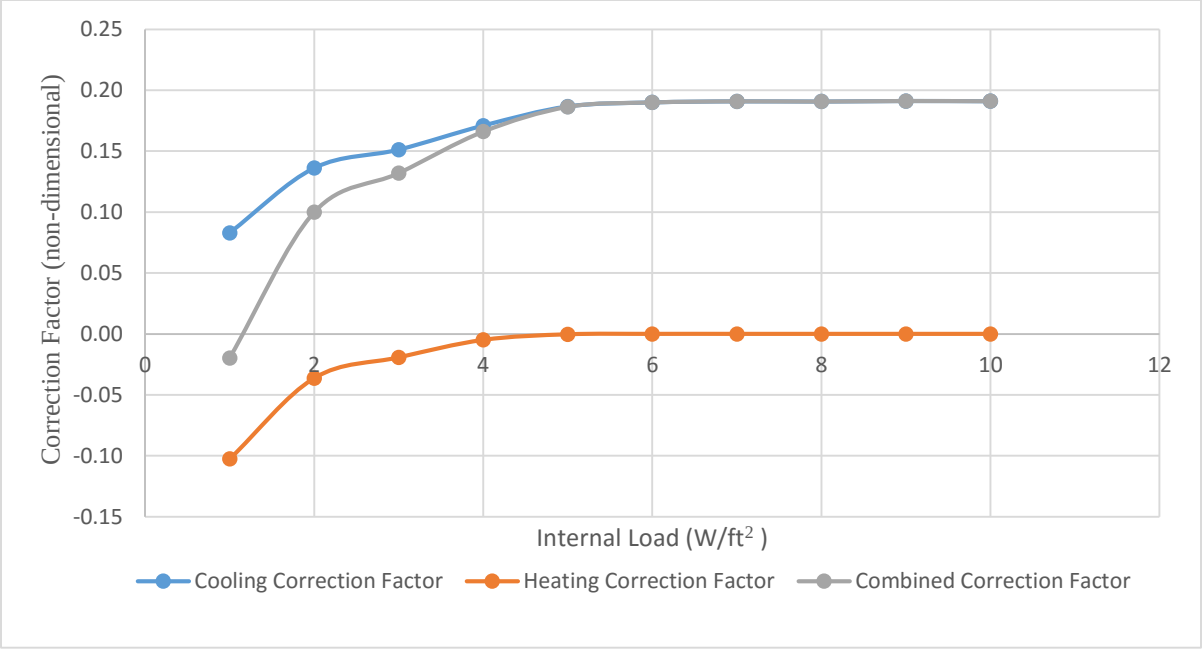

Figure 27 Water Cooled Chillier (0.7 kW/ton) Correction Factor Raleigh, NC No Economizer

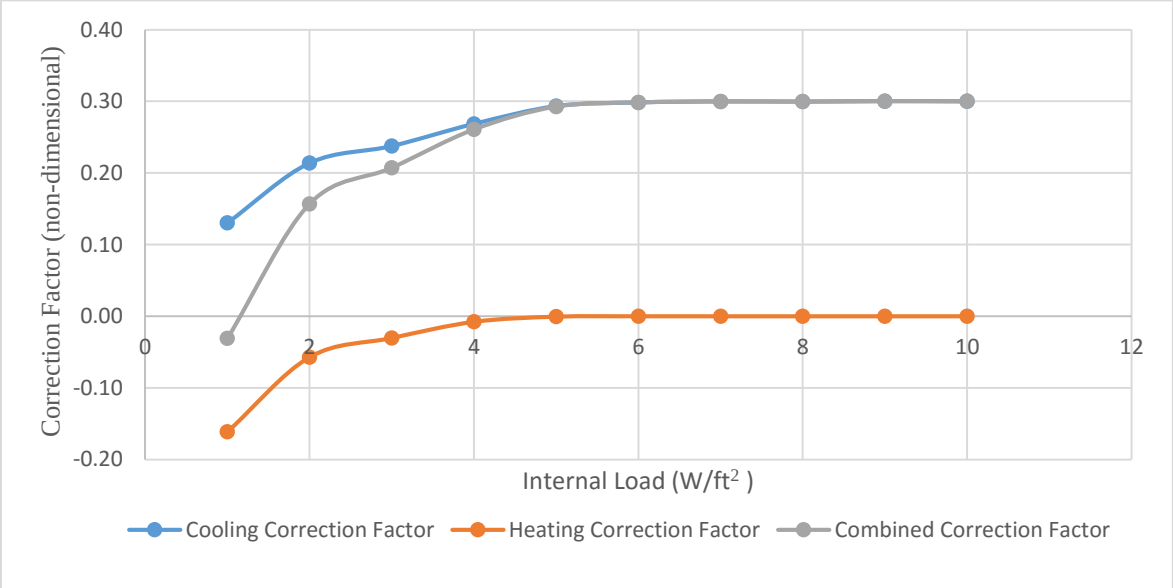

Figure 28 Air Cooled Chillier (1.1 kW/ton) Correction Factor Raleigh, NC Without Economizer

Figures and tables from the other cities are available in the appendix.

4.5 City Results

The same procedure was carried out with the other cities selected and the results are summarized. From the data it is clear that once the building becomes completely cooled only, the LCF becomes constant. Some cities will show a spike in cooling LCF before leveling off and those points were not considered when finding the LCF. This is likely because the building was right on the edge of cooling only and by reducing the lighting load it allowed the building to operate at a "floating" point between heating and cooling which does not require any mechanical heat removal. It is interesting to note that the model had to be expanded to include internal generations of 15 W/ft^2 for a building to require cooling only in Fairbanks, Alaska.

These plots include a heating correction factor as well as a combined correction factor. It is important to consider that often times heating and cooling are done using different techniques. Sometimes heating is done with steam, electricity, gas packs, hot water, oil and many others. Each one carries with it a different efficiency and sometimes widely varying cost. Cooling is typically done with a vapor compression cycle but, coefficients of performance can vary widely as well.

Since these buildings were modeled to be cooled only the results before the LCF become constant is not applicable for savings calculations. However, if modeling a building they could be used to do a sanity check. For these reasons a curve fit for all internal load values was not calculated.

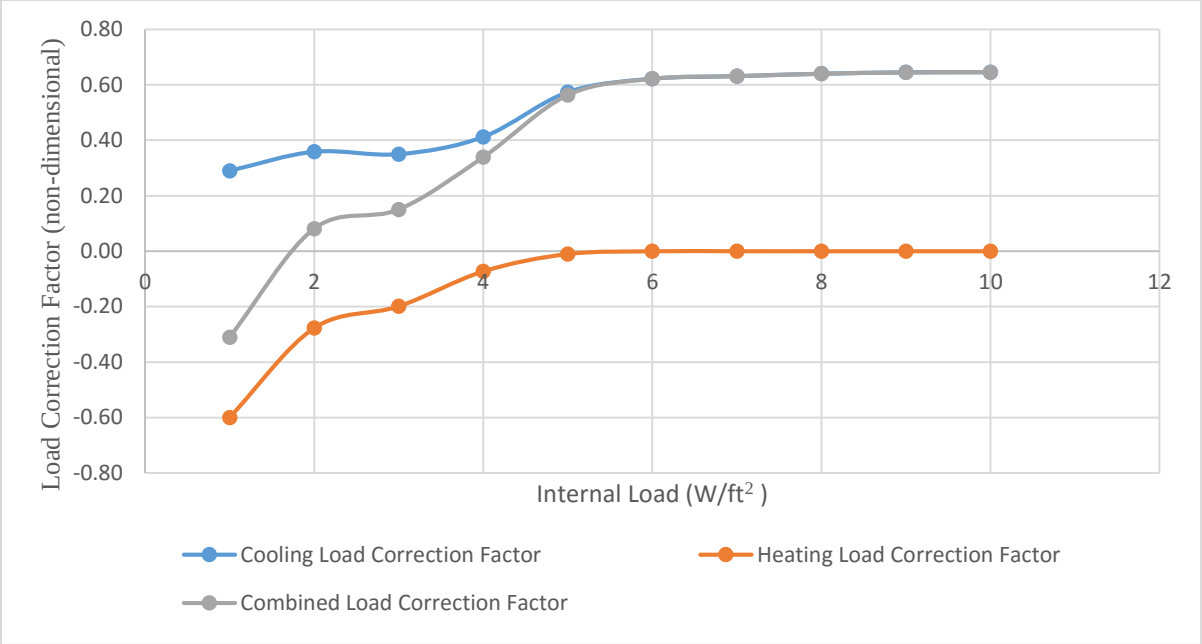

Figure 29 LCF New York With Economizers

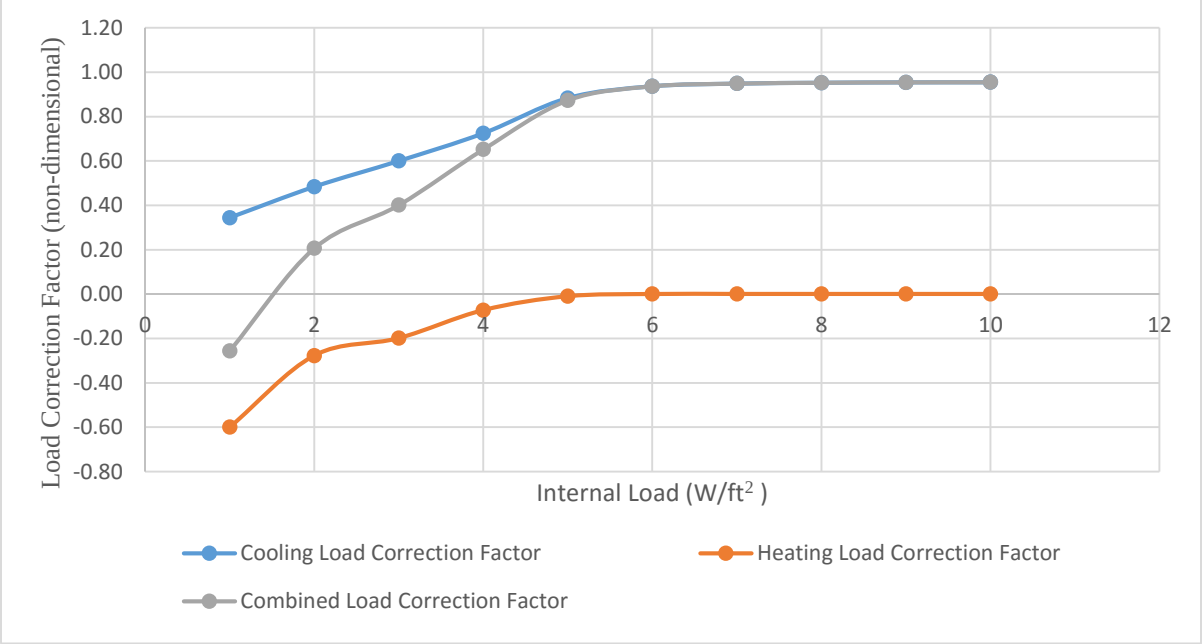

Figure 30 LCF New York Without Economizers

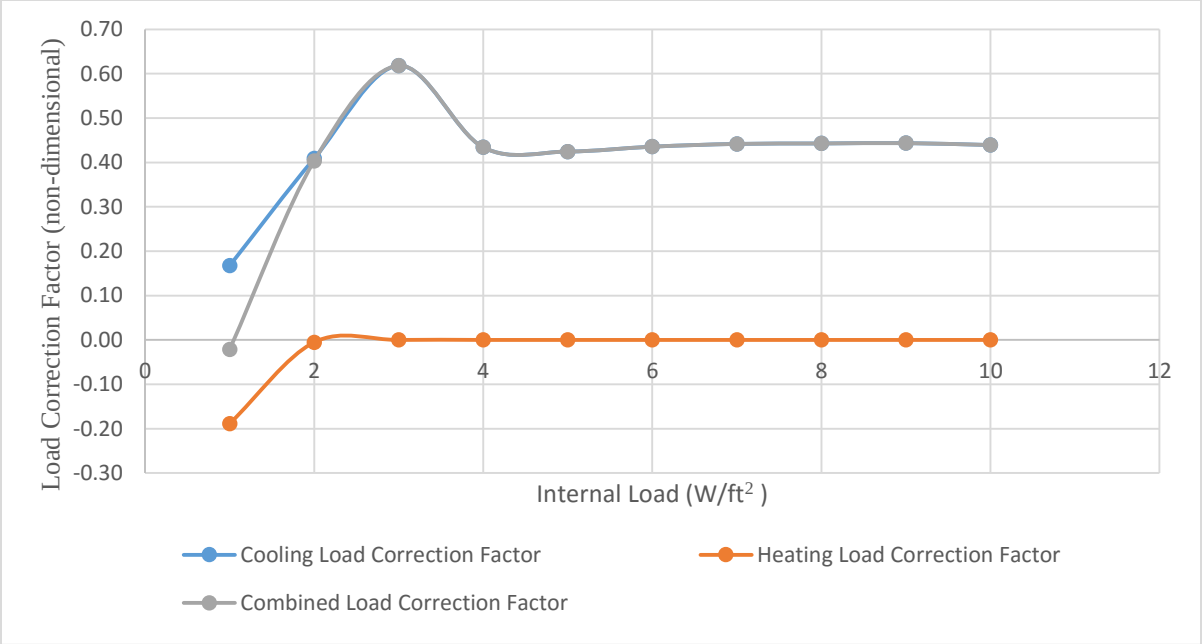

Figure 31 LCF Los Angeles With Economizers

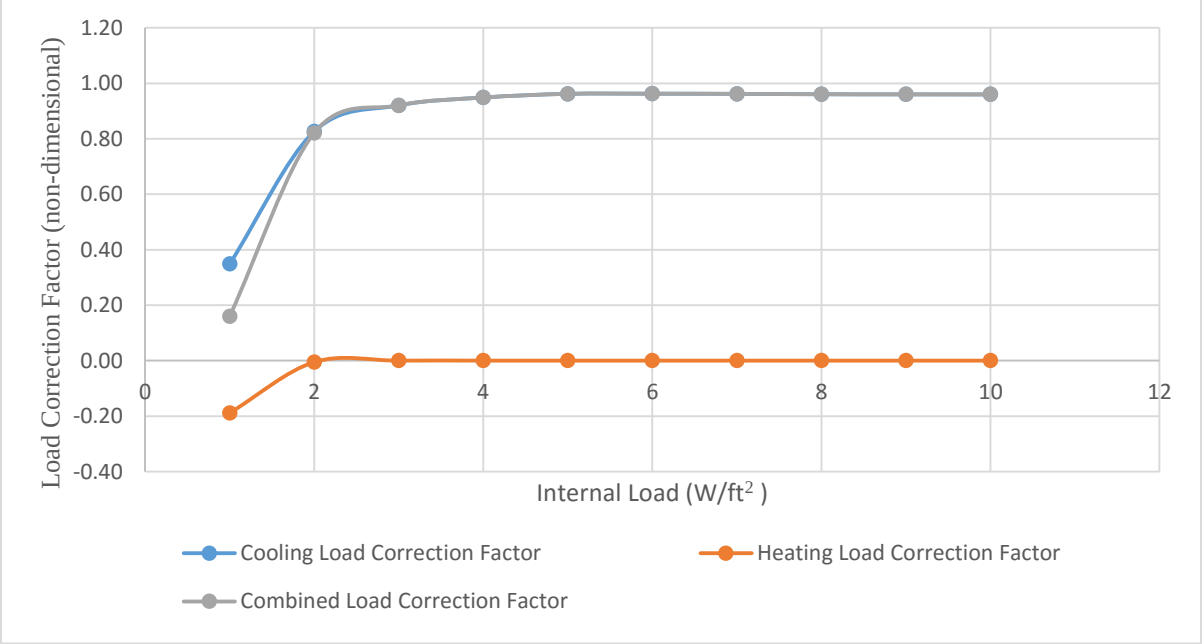

Figure 32 LCF Los Angeles Without Economizers

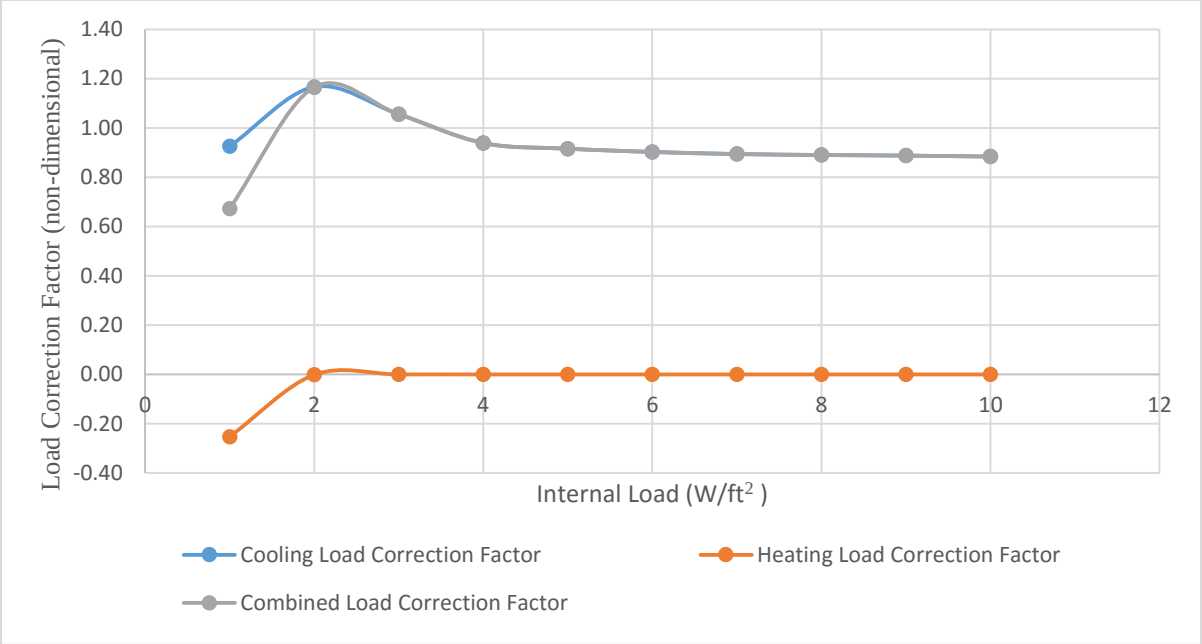

Figure 33 LCF Miami With Economizers

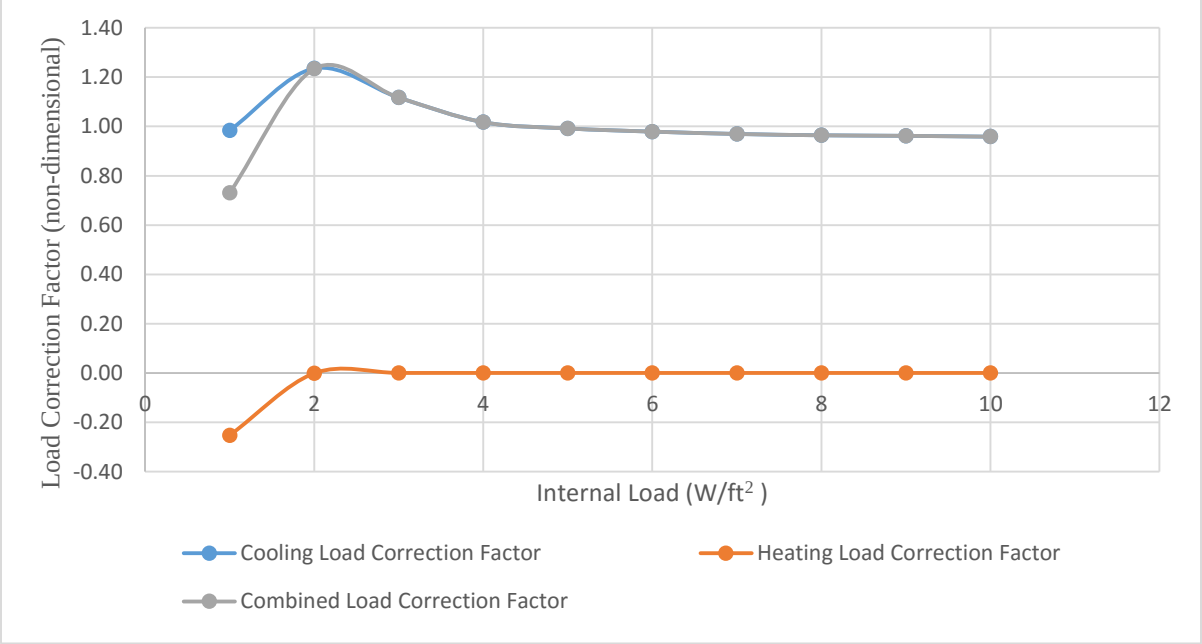

Figure 34 LCF Miami Without Economizers

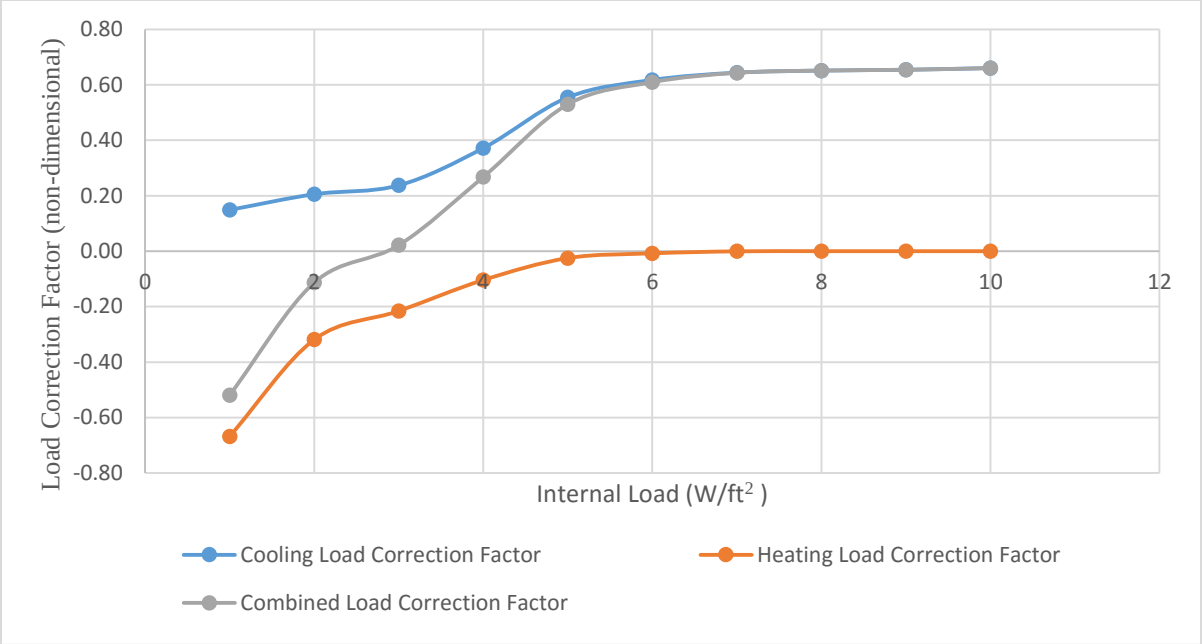

Figure 35 LCF Denver With Economizers

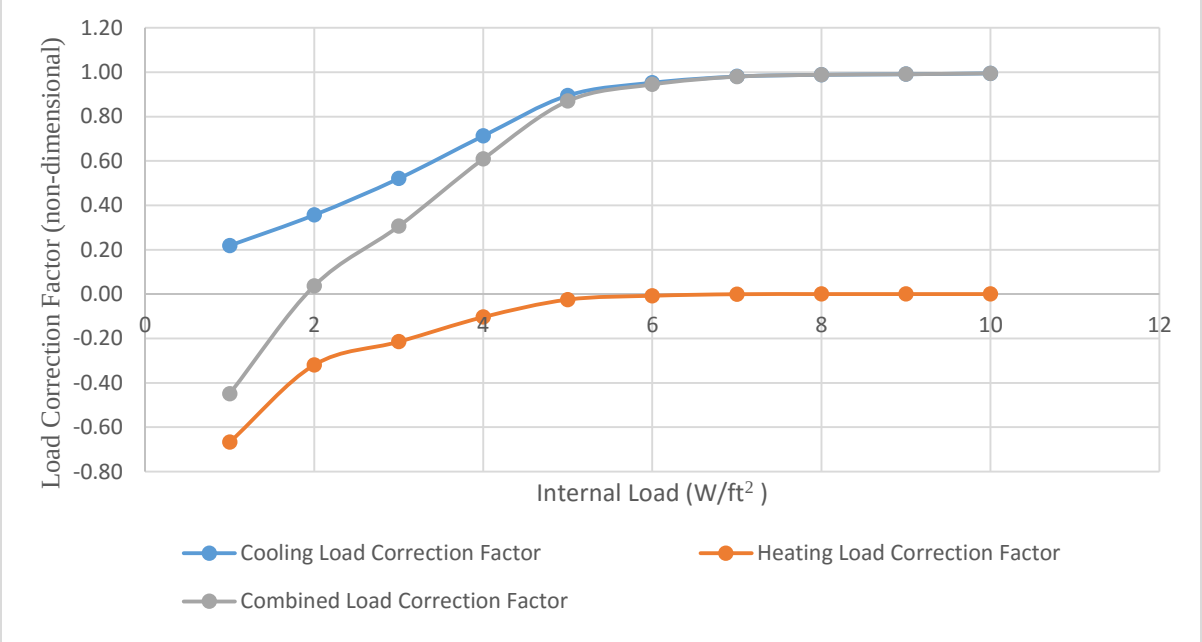

Figure 36 LCF Denver Without Economizers

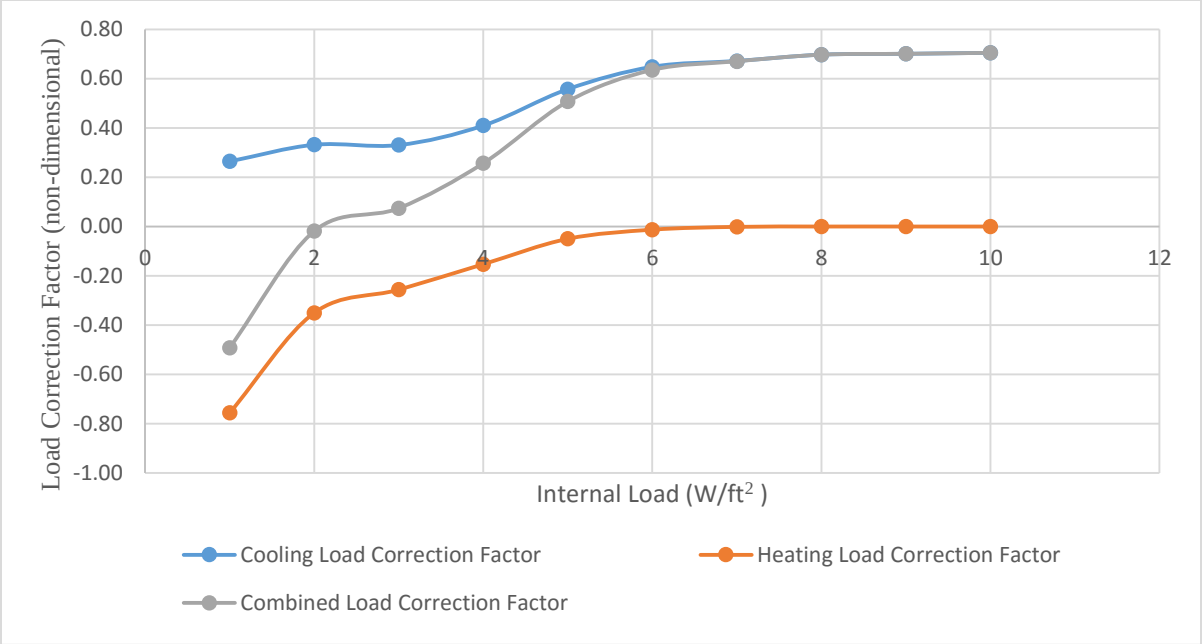

Figure 37 LCF Chicago With Economizers

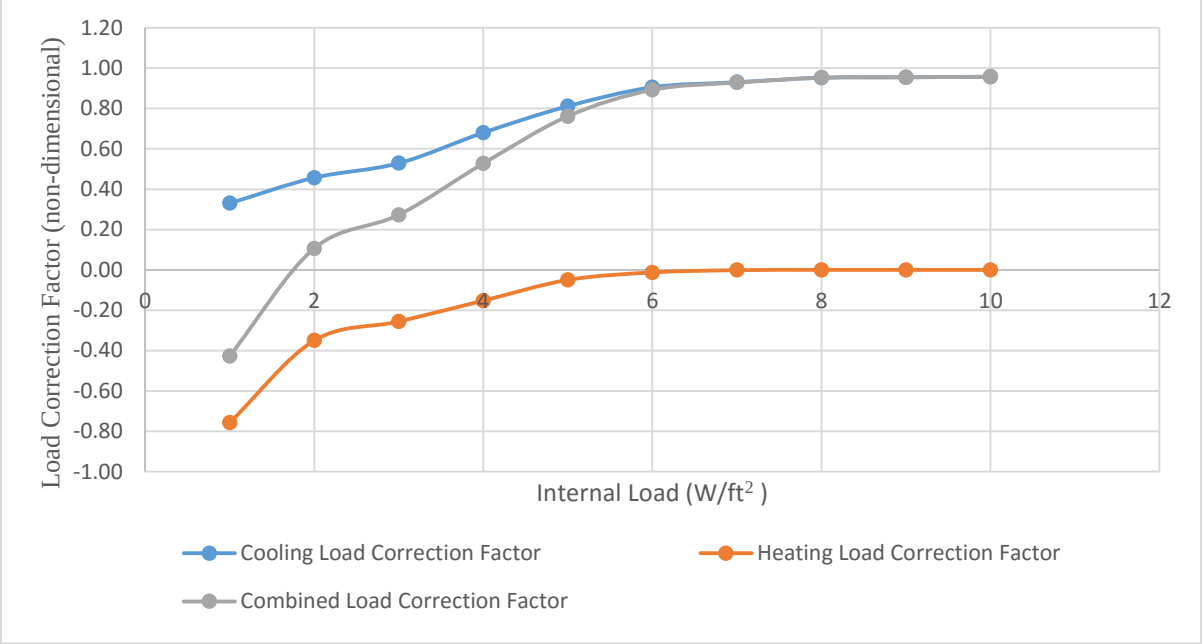

Figure 38 LCF Chicago Without Economizers

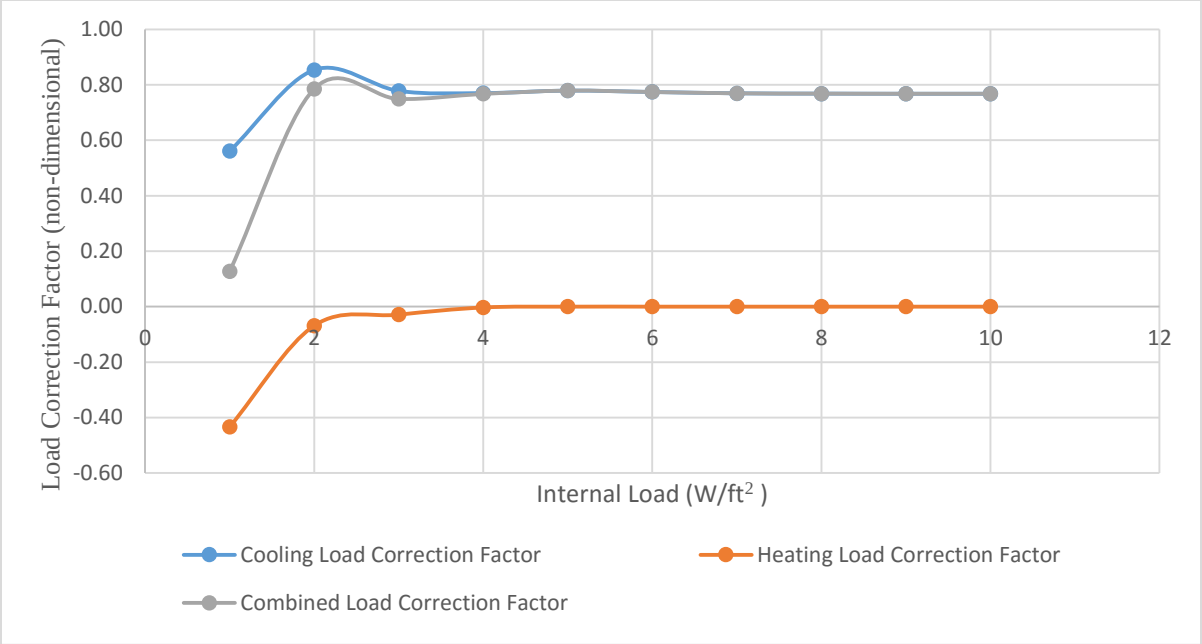

Figure 39 LCF Houston With Economizers

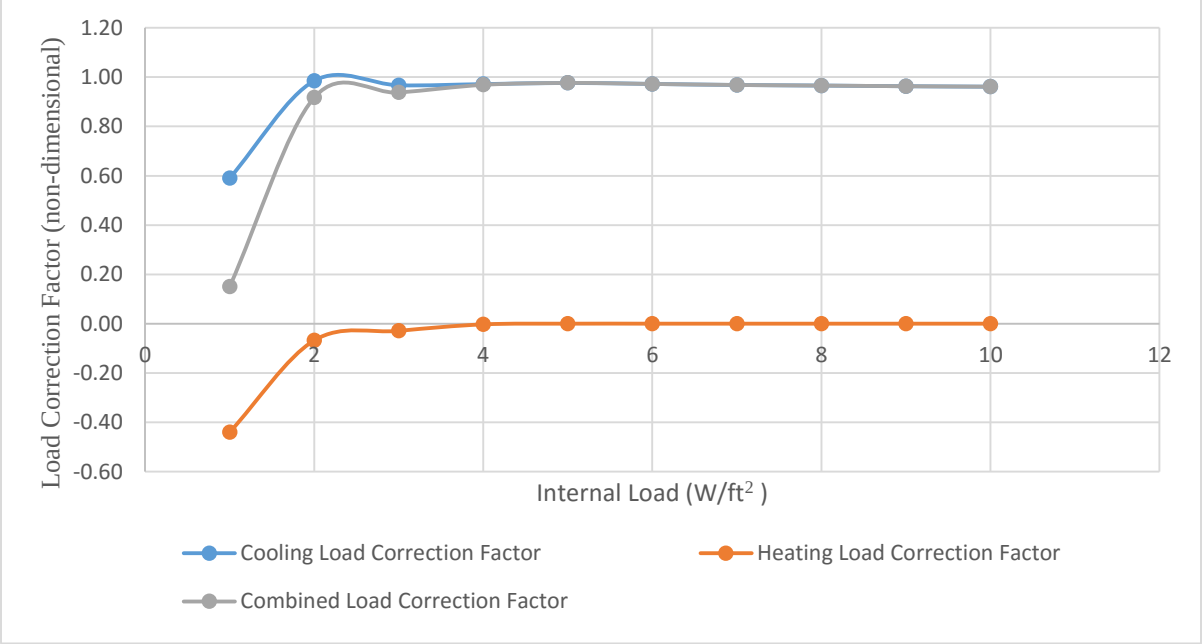

Figure 40 LCF Houston Without Economizers

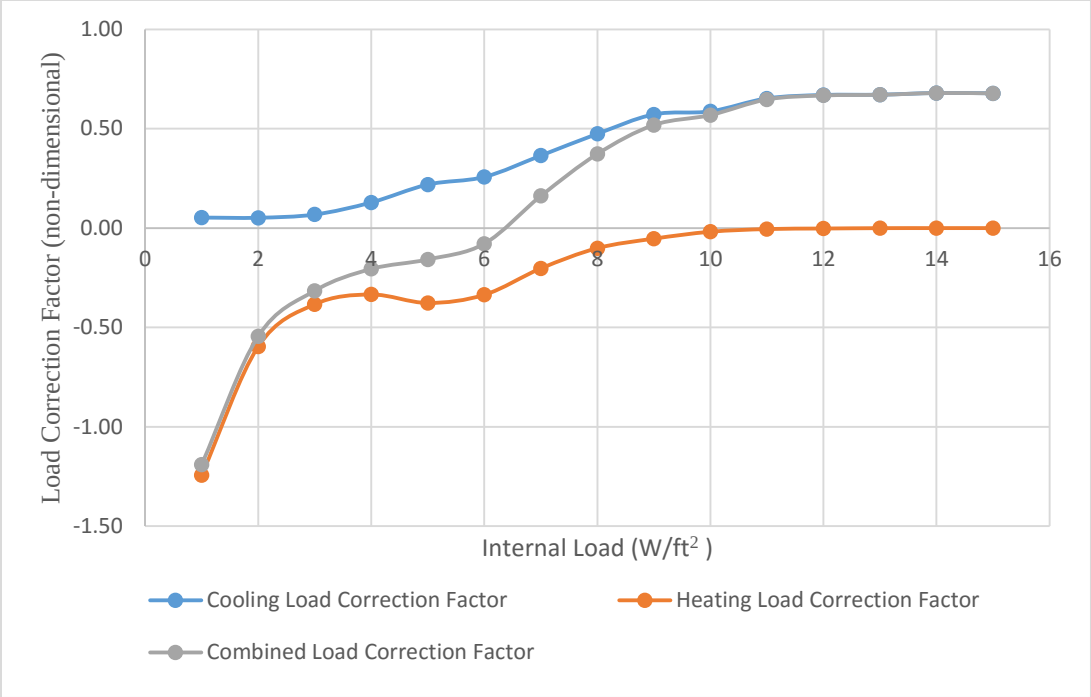

Figure 41 LCF Fairbanks With Economizers

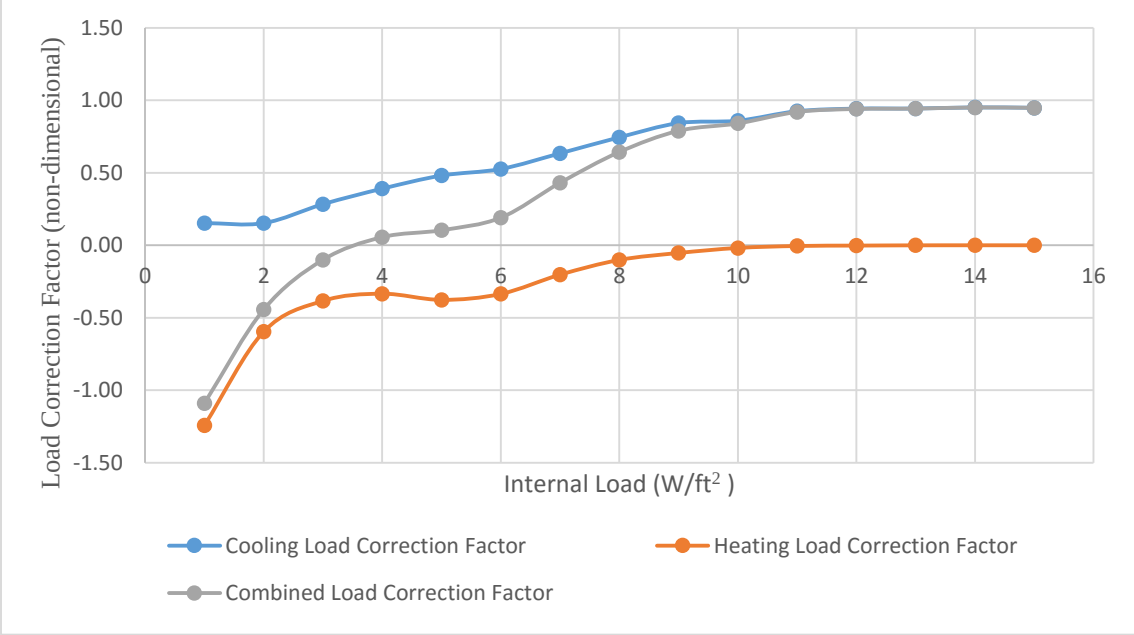

Figure 42 LCF Fairbanks Without Economizers

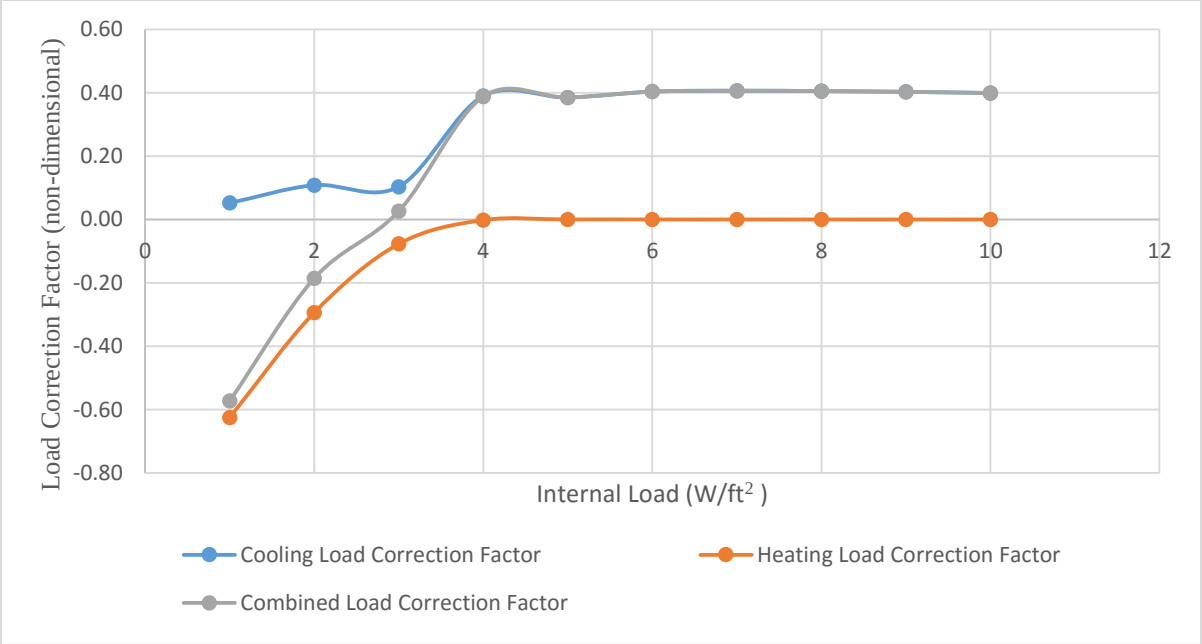

Figure 43 LCF Seattle With Economizers

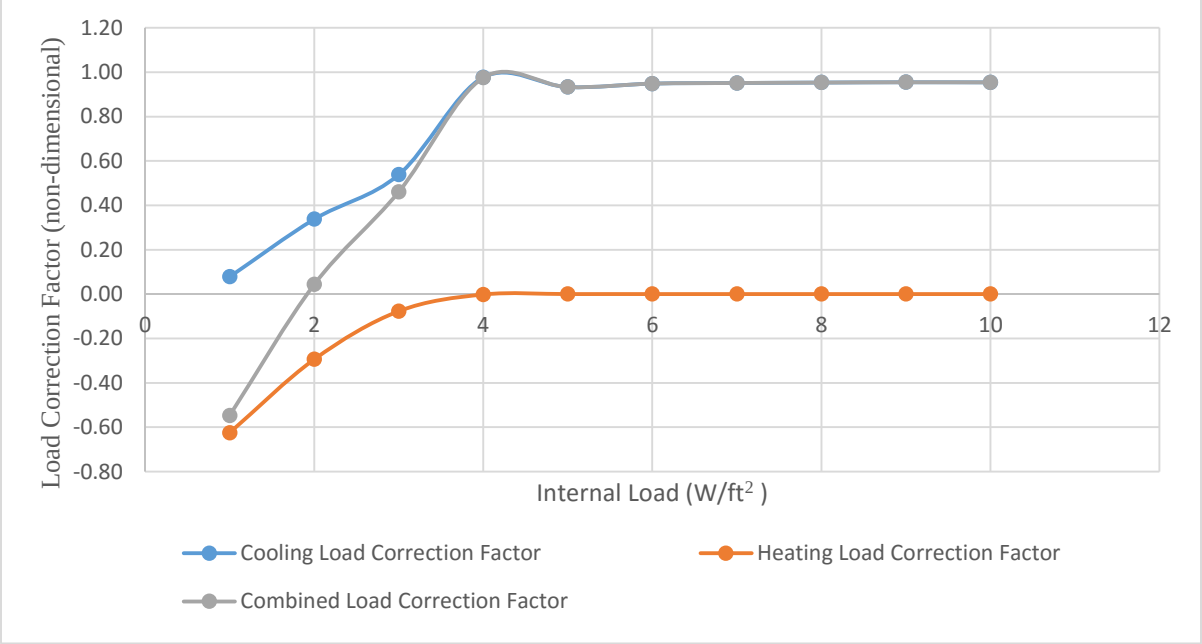

Figure 44 LCF Seattle Without Economizers

The table below shows at what internal load the LCF become constant in the various cities and climates.

Table 18 Internal Load Where LCF Becomes Constant

City	Minimum Internal Load (W/ft^2)
Raleigh, NC	5
New York, NY	5
Los Angeles, CA	4
Miami, FL	4
Denver	6
Chicago	6
Houston, TX	3
Fairbanks, AK	11
Seattle, WA	4
Average	5.33

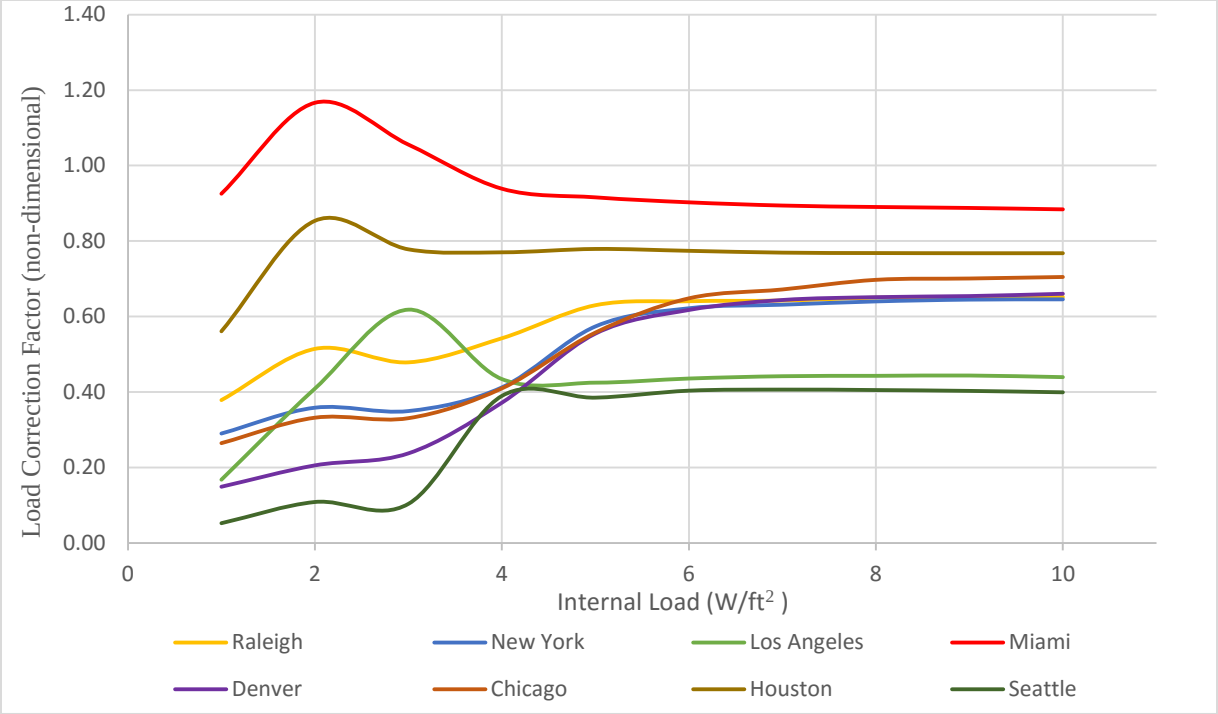

Figure 45 Load Correction Factors With Economizers

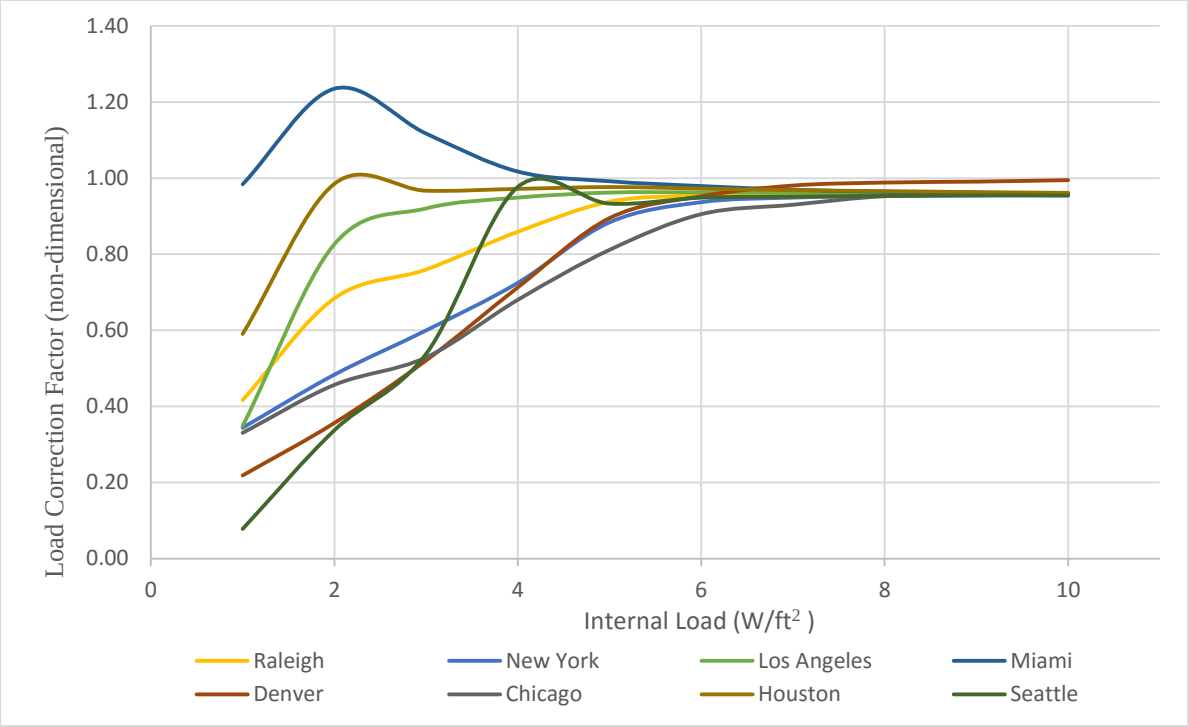

Figure 46 Load Correction Factors without Economizers

Next, the LCF for each city can be seen. There is a different LCF for buildings with and without economizers. Users should pick the city based on geography and climate zone in addition to whether or not the building has economizers. Finally using correction factor equation, the correction factor can be determined.

Table 19 Load Correction Factor By City and With or Without Economizers

City	Load Correction Factor	
	With Economizers	Without Economizers
Raleigh, NC	0.64	0.95
New York, NY	0.62	0.94
Los Angeles, CA	0.44	0.96
Miami, FL	0.90	0.98
Denver	0.64	0.98
Chicago	0.68	0.94
Houston, TX	0.77	0.96
Fairbanks, AK	0.67	0.94
Seattle, WA	0.40	0.95
Average	0.64	0.96

4.6 Discussion of Results

In models without economizers it is interesting to note that the LCF is nearly constant in every location. This makes sense because the models use a set point for internal space temperature. The shell loads are constant for cooled only buildings along with ventilation loads. Therefore, it makes sense that by reducing the internal load by one kWh the cooling load would reduce by one kWh. This applies to buildings that are cooled year around. Based on that logic, analytical solutions would suggest that the LCF without economizers would be 1. The model output shows and average of 0.96 which is very close. Therefore, in buildings that are cooled only without economizers, regardless of their location or internal load generation, the LCF is 0.96.

With economizers, the LCF varies significantly with geography. This is because the number of hours in which air side economizers can be used is greatly affected by the climate. This

climate factor is dependent on both the temperature and the humidity in the area. For buildings that are cooled only, the table should be used to determine a LCF.

In addition, it is interesting that the amount of internal load required for a building to be cooled only varies with geography and climate. This is because of the varying shell loads along with ventilation loads in different climates. For example in Houston, TX it only requires 3 W/ft^2 in the model for a building to be cooled only. But, in Fairbanks, AK it requires 11 W/ft^2 to be cooled only. These numbers are useful for doing basic checks when modeling buildings of this type.

Finally, it is interesting note that because the LCF and CF is constant once the building is cooled only, thus the user does not need to calculate the internal load generation. If the user knows that their building is cooled only they can simply look up the LCF value in the table and convert it into a CF value. This is significant because it is likely to be difficult to calculate the internal load for some buildings. One way would be to take the monthly energy bills and subtract the energy that is rejected outside of the building such as chillers and air compressors.

4.7 Applications to Sensible Load Reductions

There are additional applications for the results found in this study that can be applied to any sensible heat load reductions. The loads created by the lights were modeled assuming that they were simply 100% sensible loads, and therefore the results should be applicable to any sensible load reduction in the building. For example, people produce both a sensible and latent load and if a space was to require significantly less people then the correction factor could be applied to the sensible heat gain of the reduced people in an area.

In addition, most electronics are pure sensible loads, therefore more efficient computers, monitors, servers or TV's would also result in a cooling load savings. This could be very useful in applications with data centers in which customers are considering upgrading equipment, many of these types of centers are also cooled only buildings. This would also apply to most plug loads.

Another example could be tied closer to industrial facilities. If the facility is considering upgrading its production equipment and it is purely sensible, there would be a cooling energy correction.

5 Comparison to Existing Methods

5.1 Rundquist et al. Method 1993 [8]

This method provides a complete guide to calculate utility and cost impacts of installed lighting changes in commercial buildings. This method considers lighting energy and demand along with cooling energy and demand. Next, heating energy is considered along with the cost of new lighting and any rebates available. The final result gives a simple payback in years.

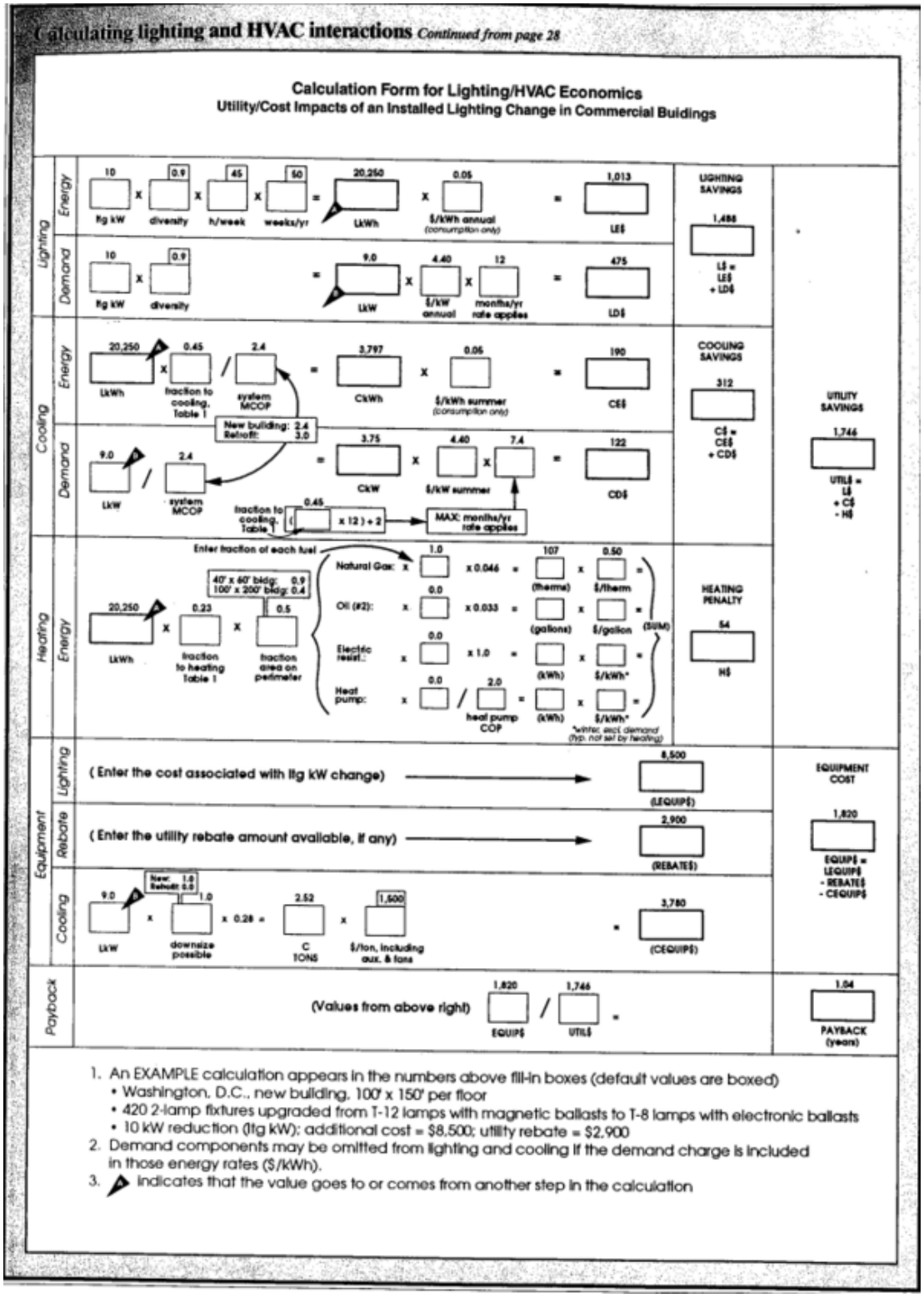

Figure 47 Rundquist Method 1993 [8]

The steps listed in the method above present an excellent way to calculate the overall simple payback for a lighting retrofit. A close inspection of the technique shows that a similar method is used to calculate a Load Correction Factor (LCF). Focusing in on the Cooling Energy correction it is calculated by multiplying the kWh of lighting saved by “fraction to cooling” that can be looked up in a table. This fraction to cooling value functions the same way as the LCF is calculated.

Location	Fraction Lighting to: Cool	Heat
ALABAMA		
Birmingham	0.57	0.09
Huntsville	0.53	0.11
Mobile	0.66	0.01
Montgomery	0.61	0.06
ARIZONA		
Flagstaff	0.32	0.37
Phoenix	0.71	0.00
Tucson	0.69	0.02
ARKANSAS		
Blytheville	0.51	0.16
Fort Smith	0.53	0.14
Little Rock	0.54	0.11
CALIFORNIA		
Barstow	0.56	0.10
Bishop	0.53	0.15
Los Angeles	0.56	0.00
Sacramento	0.49	0.04
San Diego	0.52	0.00
San Francisco	0.38	0.02
Santa Barbara	0.21	0.05
COLORADO		
Colorado Springs	0.37	0.29
Denver	0.39	0.29
Grand Junction	0.41	0.29
Trinidad	0.44	0.30
DELAWARE		
Dover	0.41	0.23
Wilmington	0.41	0.32
FLORIDA		
Miami	0.87	0.00
Jacksonville	0.72	0.02
Orlando	0.80	0.00
Pensacola	0.66	0.01
Tampa	0.80	0.00
GEORGIA		
Atlanta	0.52	0.10
Augusta	0.61	0.08
Macon	0.60	0.06
Savannah	0.66	0.05
Valdosta	0.67	0.02
IDAHO		
Boise	0.34	0.26
Lewiston	0.33	0.24
Pocatello	0.33	0.35
ILLINOIS		
Champaign	0.41	0.31
Chicago	0.36	0.33
Peoria	0.42	0.31
Rockford	0.36	0.35
INDIANA		
Fort Wayne	0.39	0.32
Indianapolis	0.41	0.29
South Bend	0.37	0.32
Terre Haute	0.43	0.32
IOWA		
Council Bluffs	0.40	0.32
Mason City	0.34	0.39
Sioux City	0.38	0.36
KANSAS		
Dodge City	0.44	0.26
Goodland	0.41	0.30
Kansas City	0.44	0.22
Wichita	0.47	0.19
KENTUCKY		
Covington	0.42	0.25
Hopkinville	0.49	0.17
Louisville	0.46	0.22

Location	Fraction Lighting to: Cool	Heat
LOUISIANA		
Alexandria	0.64	0.03
Lake Charles	0.68	0.02
New Orleans	0.69	0.02
Shreveport	0.61	0.05
MAINE		
Portland	0.27	0.36
MASSACHUSETTS		
Boston	0.34	0.27
Springfield	0.35	0.35
MICHIGAN		
Detroit	0.33	0.31
Grand Rapids	0.33	0.35
Lansing	0.34	0.32
Saulte Sainte Marie	0.22	0.41
Traverse City	0.29	0.38
MINNESOTA		
Duluth	0.22	0.42
International Falls	0.24	0.44
Minneapolis	0.33	0.39
MISSISSIPPI		
Biloxi	0.65	0.01
Columbus	0.59	0.10
Jackson	0.61	0.07
MISSOURI		
Columbia	0.44	0.26
Kansas City	0.44	0.22
St. Louis	0.46	0.25
Springfield	0.47	0.22
MONTANA		
Billings	0.32	0.36
Glasgow	0.30	0.41
Great Falls	0.29	0.37
Helena	0.27	0.38
NEBRASKA		
Grand Island	0.39	0.34
North Platte	0.38	0.35
Omaha	0.40	0.32
NEVADA		
Ely	0.35	0.36
Las Vegas	0.61	0.05
Reno	0.36	0.25
Winnemucca	0.39	0.30
NEW HAMPSHIRE		
Manchester	0.33	0.37
NEW JERSEY		
Trenton	0.40	0.28
NEW MEXICO		
Alamogordo	0.56	0.14
Albuquerque	0.47	0.20
Clovis	0.51	0.17
NEW YORK		
Albany	0.34	0.35
Buffalo	0.33	0.34
Syracuse	0.34	0.35
New York City	0.35	0.24
NORTH CAROLINA		
Greensboro	0.49	0.16
Raleigh	0.52	0.14
Wilmington	0.58	0.05
NORTH DAKOTA		
Bismarck	0.32	0.42
Fargo	0.29	0.42
Grand Forks	0.29	0.42
Minot	0.28	0.42

Location	Fraction Lighting to: Cool	Heat
OHIO		
Cincinnatti	0.42	0.25
Cleveland	0.36	0.31
Columbus	0.41	0.27
Dayton	0.42	0.29
Toledo	0.37	0.33
OKLAHOMA		
Altus	0.54	0.02
Enid	0.49	0.16
Oklahoma City	0.51	0.17
Tulsa	0.51	0.17
OREGON		
Burns	0.30	0.35
Eugene	0.26	0.14
Medford	0.37	0.19
Pendleton	0.35	0.24
Portland	0.27	0.14
PENNSYLVANIA		
Philadelphia	0.41	0.24
Pittsburgh	0.38	0.30
Scranton	0.35	0.34
Williamsport	0.36	0.31
RHODE ISLAND		
Providence	0.32	0.29
SOUTH CAROLINA		
Charleston	0.62	0.05
Columbia	0.58	0.09
Myrtle Beach	0.56	0.08
SOUTH DAKOTA		
Huron	0.35	0.41
Rapid City	0.34	0.36
Sioux Falls	0.35	0.39
TENNESSEE		
Knoxville	0.50	0.16
Memphis	0.53	0.13
Nashville	0.49	0.14
TEXAS		
Amarillo	0.49	0.19
Corpus Christi	0.74	0.01
Dallas	0.60	0.07
Houston	0.73	0.02
Lubbock	0.53	0.14
San Antonio	0.71	0.03
UTAH		
Salt Lake City	0.34	0.29
Wendover	0.37	0.29
VERMONT		
Burlington	0.29	0.39
VIRGINIA		
Richmond	0.46	0.16
Roanoke	0.46	0.18
WASHINGTON		
Seattle	0.16	0.17
Spokane	0.27	0.32
WEST VIRGINIA		
Charleston	0.45	0.22
Clarksburg	0.39	0.30
WISCONSIN		
Green Bay	0.30	0.39
Madison	0.35	0.38
Milwaukee	0.36	0.36
WYOMING		
Casper	0.33	0.37
Cheyenne	0.32	0.35
Rock Springs	0.29	0.40
WASHINGTON, DC	0.45	0.23

Note: Heating fraction is of perimeter zone lighting heat.
Note: Table cooling values assume economizer operation; if no economizer, see below:

Size Building	Use for "Frac...to Cool"	Example (Washington, DC)
Small (2,000 ft² per floor)	0.2 + 0.8 × "Frac...to Cool" in Table	0.2 + 0.8 × 0.45 = 0.56
Large (20,000 ft² per floor)	0.5 + 0.5 × "Frac...to Cool" in Table	0.5 + 0.5 × 0.45 = 0.73
Intermediate size	Weighted average of above	(0.56 + 0.73)/2 = 0.65

Figure 48 Fraction Lighting [8]

This method provides both an option for with and without economizers. The cooling table provides values assuming economizers and free cooling and has an equation at the bottom to correct for if economizers are used. It should be noted that these values are independent of the internal load and are mostly a function of climate and location.

Table 20 Comparsion of Results With Economizers

City	With Economizers		Percent Difference
	Results	Rundquist	
Raleigh, NC	0.64	0.52	21%
New York, NY	0.62	0.35	56%
Los Angeles, CA	0.44	0.56	25%
Miami, FL	0.90	0.87	4%
Denver	0.64	0.39	49%
Chicago	0.68	0.36	62%
Houston, TX	0.77	0.73	5%
Seattle, WA	0.40	0.16	85%

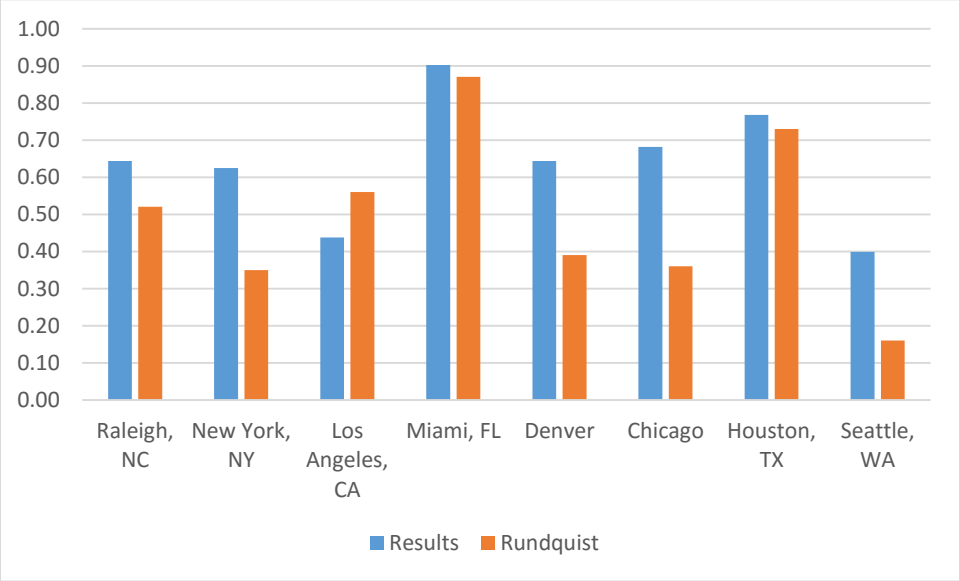

Figure 49 Comparsion of Results With Economizers

It is clear that in every instance the Rundquist method underestimates the correction factor required even with the use of economizers. This makes sense because Rundquist does not consider the variability in internal loads of building and how it effects the heating and cooling season that building experiences. The analysis done in the Rundquist method studies heating and cooling hours along with degree day data to generate a cooling season fraction expressed as the fraction of the year in which cooling is needed. It is unclear what if any internal load is assumed in this study.

Table 21 Comparison Without Economizers

City	Without Economizers		Percent Difference
	Results	Rundquist	
Raleigh, NC	0.95	0.76	23%
New York, NY	0.94	0.675	32%
Los Angeles, CA	0.96	0.78	21%
Miami, FL	0.98	0.935	4%
Denver	0.98	0.695	34%
Chicago	0.94	0.68	32%
Houston, TX	0.96	0.865	11%
Seattle, WA	0.95	0.58	49%

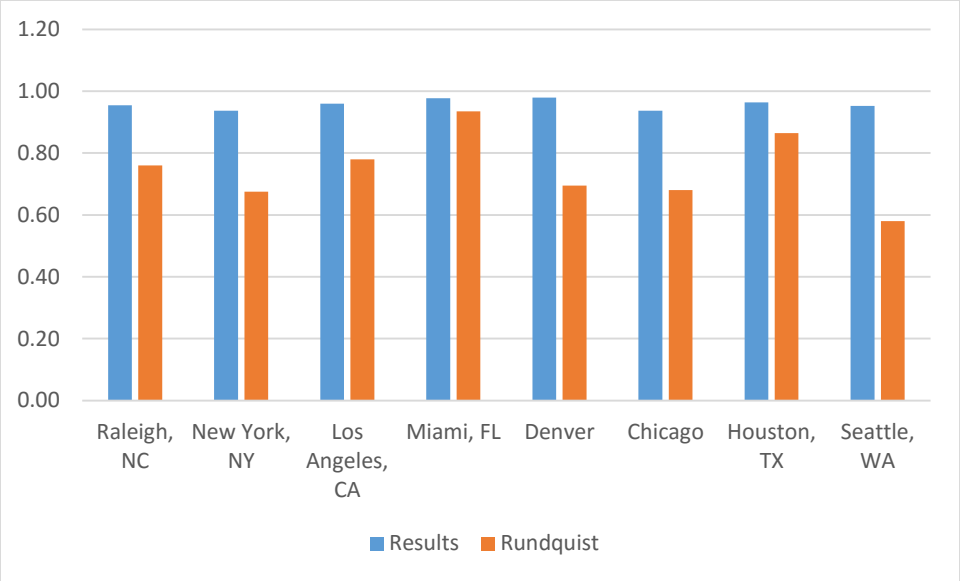

Figure 50 Comparison Without Economizers

Finally, using the correction equation provided to account for buildings without economizers the Rundquist method still underestimates LCF which is expected. The only exception is with Miami where almost the entire year is cooling season making nearly all buildings in that climate behave as cooled only. This in fact confirms that the model operates in the same way accurately reflecting how the building will behave.

In sum, the Rundquist method is an excellent way to consider the simple payback of a lighting retrofit project. The cooling load correction used likely will work well for the majority of buildings that it is applied to. When considering cooled only buildings the LCF calculated in the results can easily be substituted into Rundquist method to give an accurate reflection of the economics of a lighting retrofit.

5.2 Sezgen et al. 1994 [3]

The results of this study are difficult to compare because the input parameters are unclear. For example, the internal load and number of hours of operation are not clear. This study looked at ten building types and both new and current vintages. Looking at the results hospitals seems to be the closest because all locations have a heating LCF of between 0.01 and 0.13. This suggests there is little to no heating is required in these buildings.

Table 22 Heating and Cooling Coincidence Factors for Hospitals

Location	Vintage	Light. Conservation Load Factor	Coincidence Factors					
			Annual		Demand		Utility Demand	
			Heat.	Cool.	Heat.	Cool.	Heat.	Cool.
Chicago	Current	0.71	0.06	0.94	0.13	0.95	0.13	0.92
"	Old	0.71	0.11	0.88	0.51	0.95	0.22	0.92
Los Angeles	Current	0.71	0.01	0.99	0.08	0.95	0.00	0.92
"	Old	0.71	0.01	0.99	0.07	0.95	0.01	0.92
Lake Charles	Current	0.71	0.03	0.96	0.11	0.95	0.05	0.92
"	Old	0.71	0.03	0.96	0.13	0.95	0.08	0.92
Miami	Current	0.71	0.00	0.99	0.07	0.95	0.00	0.92
"	Old	0.71	0.00	1.00	0.09	0.95	0.00	0.92
Minneapolis	Current	0.71	0.07	0.92	0.18	0.95	0.15	0.92
"	Old	0.71	0.13	0.85	0.36	0.95	0.25	0.92
New York	Current	0.71	0.06	0.92	0.09	0.95	0.13	0.92
"	Old	0.71	0.11	0.86	0.32	0.95	0.22	0.92
Phoenix	Current	0.71	0.01	0.99	0.08	0.96	0.01	0.92
"	Old	0.71	0.01	0.99	0.09	0.96	0.01	0.92
San Francisco	Current	0.71	0.03	0.96	0.08	0.95	0.05	0.93
"	Old	0.71	0.04	0.95	0.08	0.95	0.06	0.93
Washington	Current	0.71	0.03	0.96	0.11	0.95	0.08	0.92
"	Old	0.71	0.07	0.91	0.30	0.95	0.16	0.92

The results without economizers will be analyzed first. The Sezgen 1994 study assumes that none of the buildings use economizers. This is likely a good assumption for most of the building types shown. But, for cooled only buildings a significant number will make use of economizers because they likely have a high number of hours during the year that they can be used. The common cities will be compared using the old stock listed in the Sezgen study

because any lighting upgrades will be done on already existing facilities. The comparison is between LCF cooling of this study and Sezgen 1994 showing the percent difference (difference divided by mean).

Table 23 Comparison Without Economizers

City	Cooling Load Correction Factor (LCF)		Difference
	Results	Sezgen 1994 (Old)	
New York, NY	0.94	0.92	2%
Los Angeles, CA	0.96	0.99	3%
Miami, FL	0.98	1.00	2%
Chicago	0.94	0.94	0%

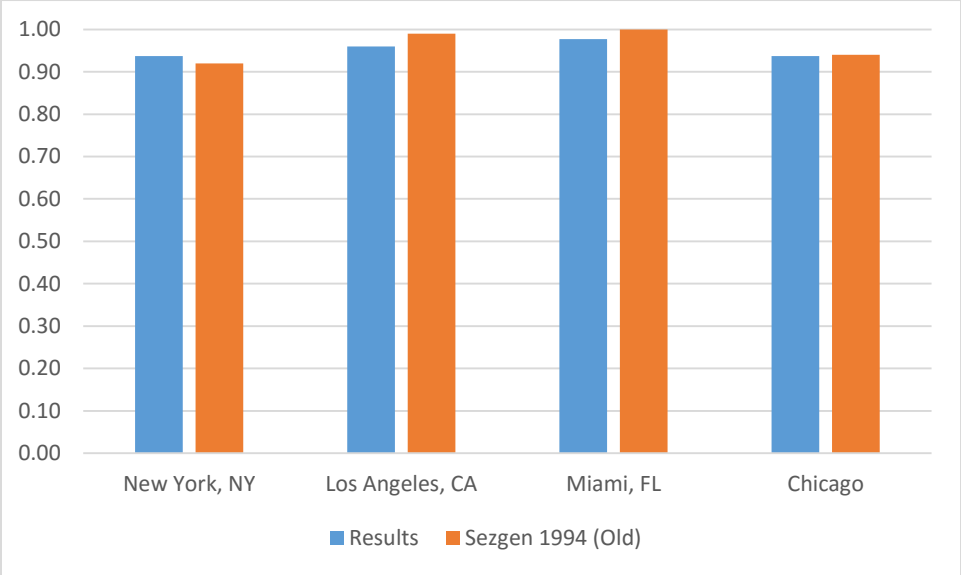

Figure 51 Comparison Without Economizers

It is clear that the results are confirmed against the 1994 study and the differences are very negligible. Next, it the same comparison will be done except using the results with economizers.

Table 24 Comparsion With Economizers

City	Cooling Load Correction Factor (LCF)		Difference
	Results	Sezgen 1994 (Old)	
New York, NY	0.62	0.92	38%
Los Angeles, CA	0.44	0.99	77%
Miami, FL	0.90	1.00	10%
Chicago	0.68	0.94	32%

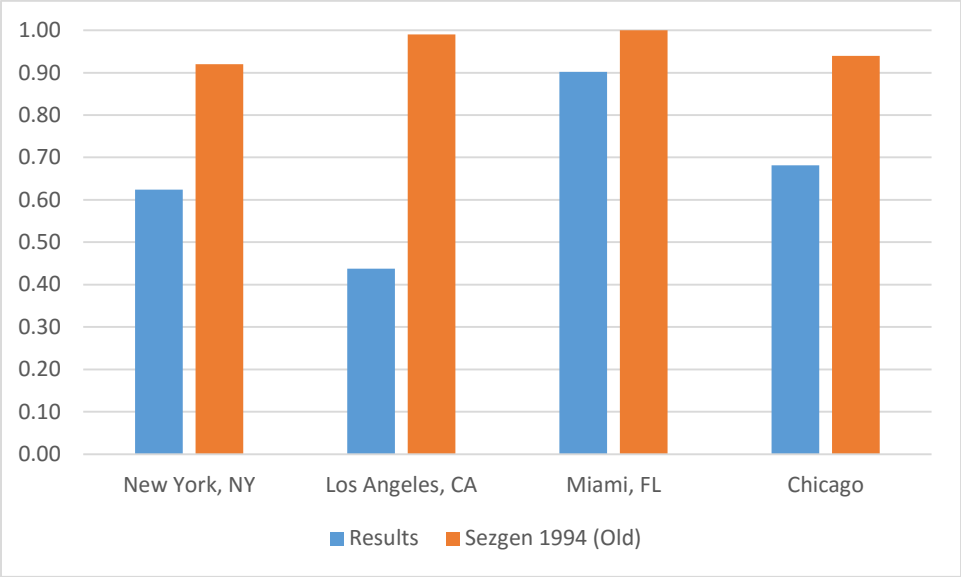

Figure 52 Comparison With Economizers

It is clear that the use of economizers makes an appreciable difference. The likely reason that there is so much variance in the percent difference is that some climates will have more hours during the year that economizers can be used.

5.3 Viola 2015 [10]

This work was very exploratory in nature, considering industrial building in general. Four facilities were considered, one was heated only, one was heated and cooled and the final two

were cooled only. From this preliminary work it was clear that cooled only buildings were the most interesting. Each one can be viewed as a case study.

In this study, buildings were done in a more generic way but the specific geometry of the facility was considered. In addition, the air side system was considered as well which results in some savings from fans. This means that the focus is on energy use and not loads. This means that the efficiency of the method of providing and removing heat is critical when considering energy use. In addition, there are many different air side systems and they can result in drastically different reactions when reducing heating and cooling loads. Thus these results are not independent of air side systems choice or heat addition and removal equipment. None of the facilities were modeled using economizers. All of the facilities were located in central North Carolina.

The first building that was cooled only was a paperboard facility. The conclusion found an overall correction factor of 0.36. Further exploration found that the cooling efficiency was assumed to be an EER of 8.5. This results in a load correction factor of 0.90. This facility was not modeled using economizers.

The second building analyzed was a plastic injection molding facility. This resulted in a correction factor of 0.34 using an EER of 8.5. This converted into a 0.89 LCF, the LCF for Raleigh in the current study without economizers is 0.95.

Table 25 Comparison of Results to Viola 2015

Facility	LCF Viola	LCF	Percent Difference
Paperboard Packaging	0.90	0.95	5.8%
Plastic Injection Molding	0.89	0.95	6.9%

The results show that the LCF is very close however, it is difficult to do a direct comparison because the Viola results include air side fan savings and the current study is independent of air side system type.

However, it should be noted that conclusions are somewhat different. In the Viola result, a linear fit is made with the slope being internal load.

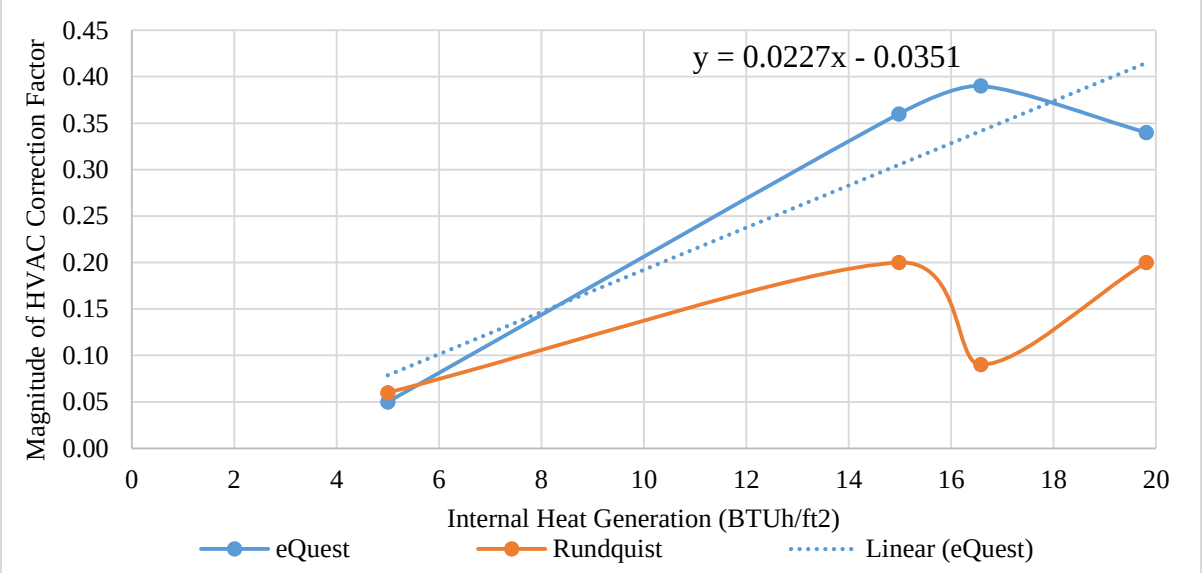

Figure 53 Internal Heat Generation Compared to Magnitude of HVAC Correction Factor

The y axis of the figure above shows a correction factor and not a load correction factor so the numbers cannot be compared directly but, the difference in the trends is critical.

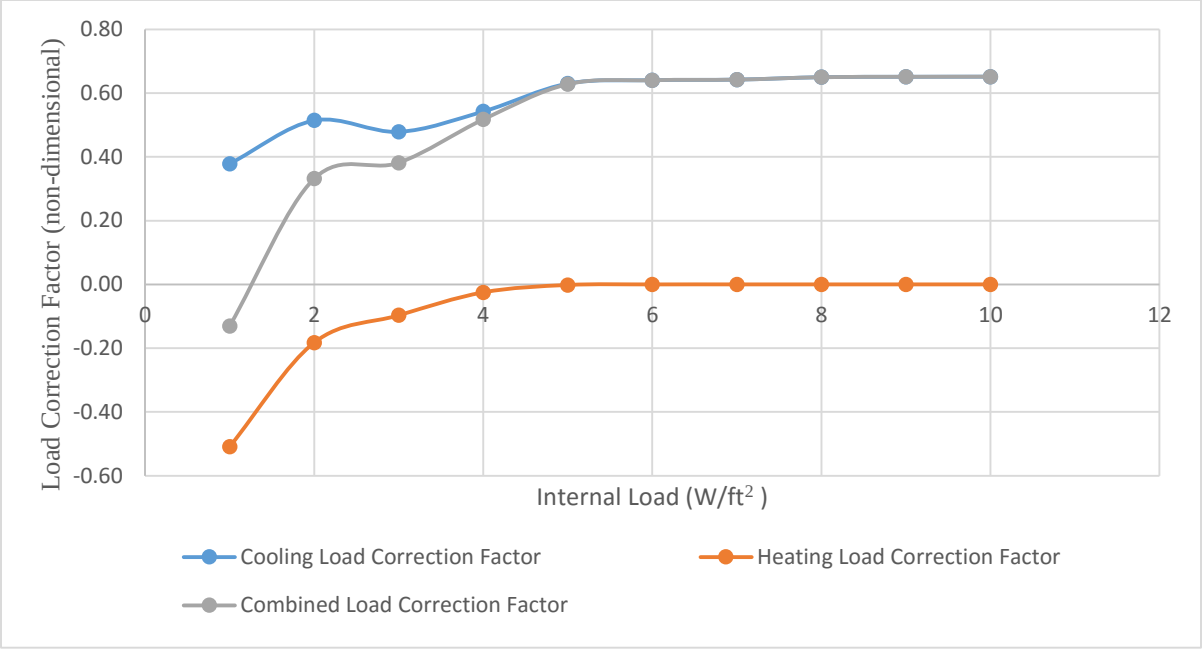

Figure 54 LCF vs. Internal Load Raleigh With Economizers

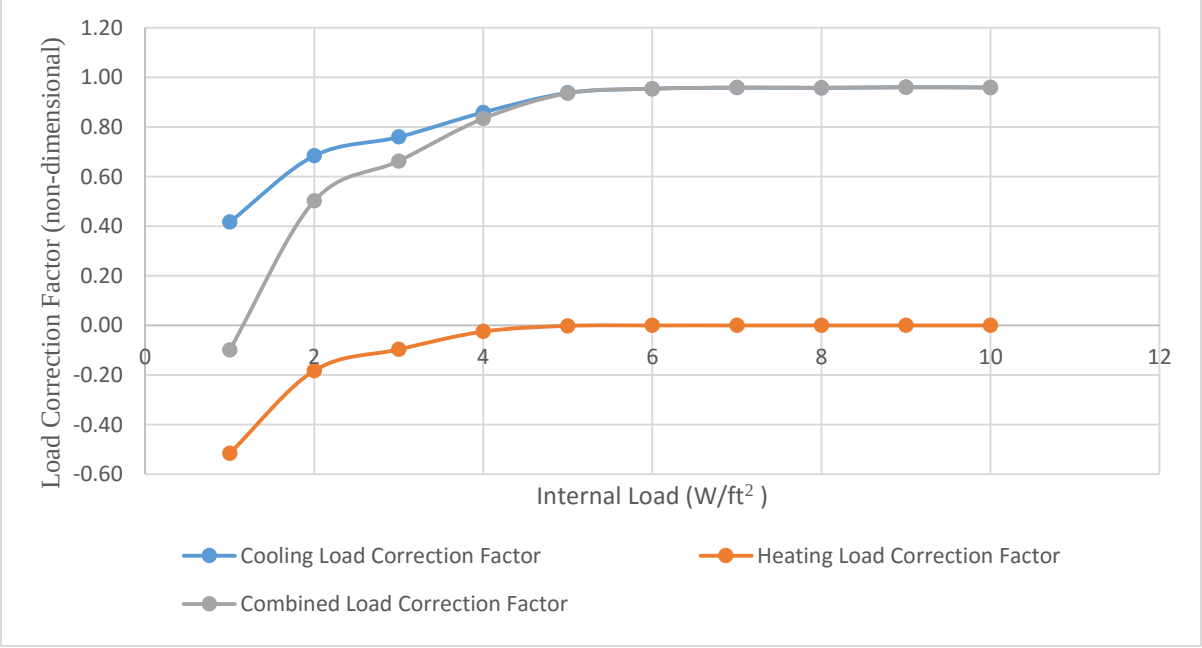

Figure 55 LCF vs. Internal Load Raleigh Without Economizers

The results of the current study show that the LCF and CF increase linearly with internal load while the building is both heated and cooled but begin to level off once the building is cooled only, at higher internal loads. As stated before it makes sense for the CF and LCF to level off once the building is purely cooled only.

While the results of the two buildings modeled in the Viola study show similar results this study calls into question the linear relationship between LCF and internal load at higher loads when the building is cooled only.

6 Cooling Correction Factor User Guide

This guide is meant for users who are calculating savings for lighting upgrades in cooled only buildings. The result is a coefficient that can be used to include cooling load reductions. This can be applied not only to lighting energy reductions but also to any sensible load reduction such as using more efficient machines. By using more efficient lighting there will be direct savings from energy (kWh) and demand (kW) along with possible savings or increase in maintenance costs. In addition, there will be an HVAC interaction that could lead to an increase or decrease in costs. This guide is for users whose facilities are cooled only.

Cooling demand reduction is ignored in this study because many industrial facilities are undersized and may not have any demand reduction associated with cooling. In addition, fan power reductions were ignored as well so that this correction factor is independent of air side system type. There are likely additional savings from fans but they are not considered in this CF.

First, the user needs to determine whether or not their facility is using economizers. Next, determine which city is in the best location, either closest to the facility or in a similar climate zone.

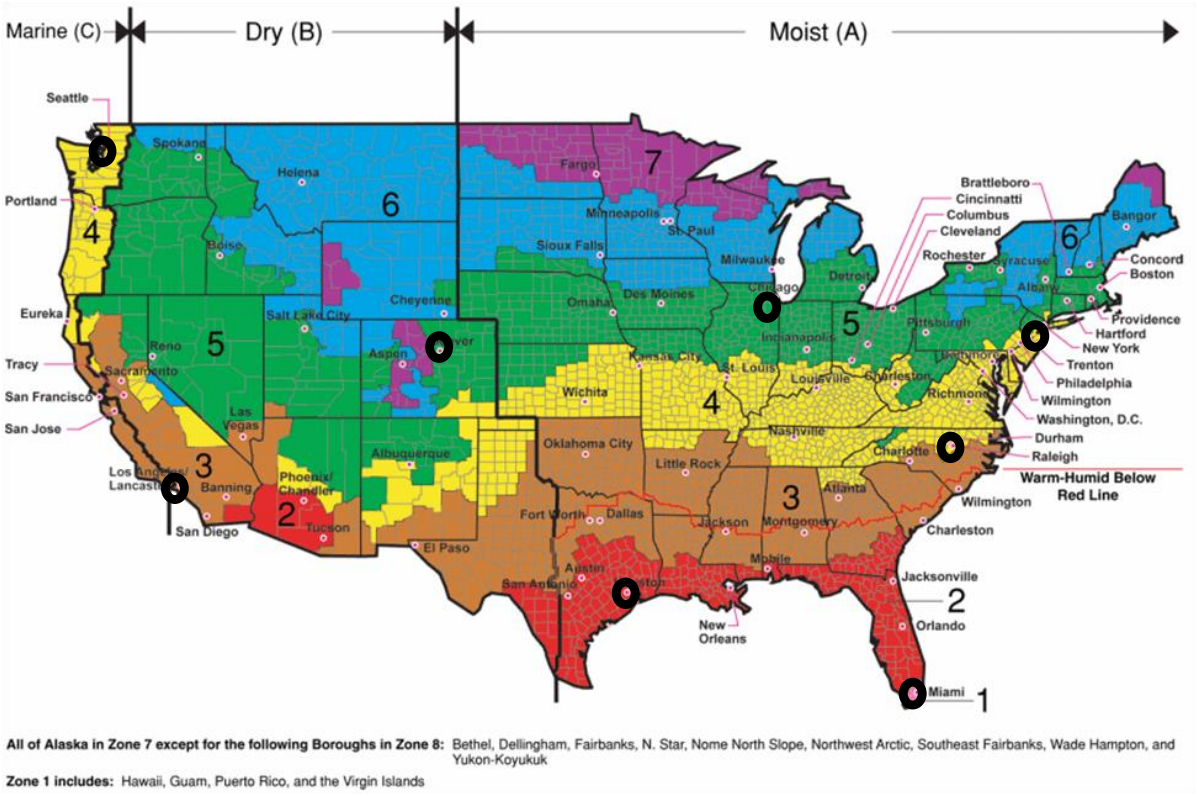

Figure 56 Climate Zones ASHRAE 90.1-2004 [1]

Table 26 Selected Cities

City	Climate Zone
Raleigh, NC	4A
New York, NY	4A
Los Angeles, CA	3B
Miami, FL	1A
Denver, CO	5B
Chicago, IL	5A
Houston, TX	2A
Fairbanks, AK	8
Seattle, WA	4C

After determining the best location, the user should find the corresponding Load Correction Factor (LCF). This value reflects the change in cooling loads only not how much energy is saved.

Table 27 Load Correction Factor By City and With or Without Economizers

City	Load Correction Factor	
	With Economizers	Without Economizers
Raleigh, NC	0.64	0.95
New York, NY	0.62	0.94
Los Angeles, CA	0.44	0.96
Miami, FL	0.90	0.98
Denver, CO	0.64	0.98
Chicago, IL	0.68	0.94
Houston, TX	0.77	0.96
Fairbanks, AK	0.67	0.94
Seattle, WA	0.40	0.95
Average	0.64	0.96

Insert the LCF into the equation below to find the overall correction factor. Some users may be able to find specifications for chiller or unit efficiency in kW/ton, COP, SEER or EER. If these are not available a good value to use is 0.7 kW/ton for water cooled chillers or 1.1 kW/ton for air cooled chillers or package units. Water cooled chillers will reject heat through a cooling tower and air cooled chillers will reject heat through a radiator with fans, often in a packaged unit.

$$CF = LCF \ x\ 0.284\ [ton/kW]\ x\ eff[\frac{kw}{ton}]$$

$$CF = \frac{LCF}{eff[Coeffecient\ of\ Performance]} \quad (8)$$

Next, the Correction Factor (CF) is multiplied by the kWh of lighting savings to find the amount of cooling savings.

$$Lighting\ Energy\ Savings\ (kWh) x CF = Cooling\ Energy\ Savings\ (kWh) \quad (9)$$

The cooling energy savings is then added to the lighting energy savings to give a total energy savings. This will give further justification for lighting projects by giving a more accurate and shorter simple payback.

7 Air Side Economizer Energy Savings Analysis

It was noted that during the process of collecting data for the lighting analysis energy data was collected for a model with and without economizers in all of the cities. In the lighting study it was critical to distinguish between buildings that had or did not have economizers because it made a big difference especially in some climates. Now by taking buildings at different loads and looking at the difference between with and without economizers energy savings can be estimated for a project that added economizers to a facility. This was then divided by the square footage of the building to get a normalized result.

Table 28 Raleigh Economizer Cooling Load Load Savings (kWh/ft^2)

Internal Load (W/ft^2)	Economizer Cooling Load Savings (kWh/ft^2)
1	0.1
2	1.4
3	3.6
4	6.5
5	9.2
6	11.9
7	14.7
8	17.5
9	20.2
10	22.9

Because this data was not collected for the sole purpose of analyzing economizer savings it is not recommended to be used to justify energy projects. In addition, the air side system used can have a major effect on the economizer savings although the loads shown above are independent of air side system.

This is very useful for preliminary estimates, back of the envelope calculations and to check model results.

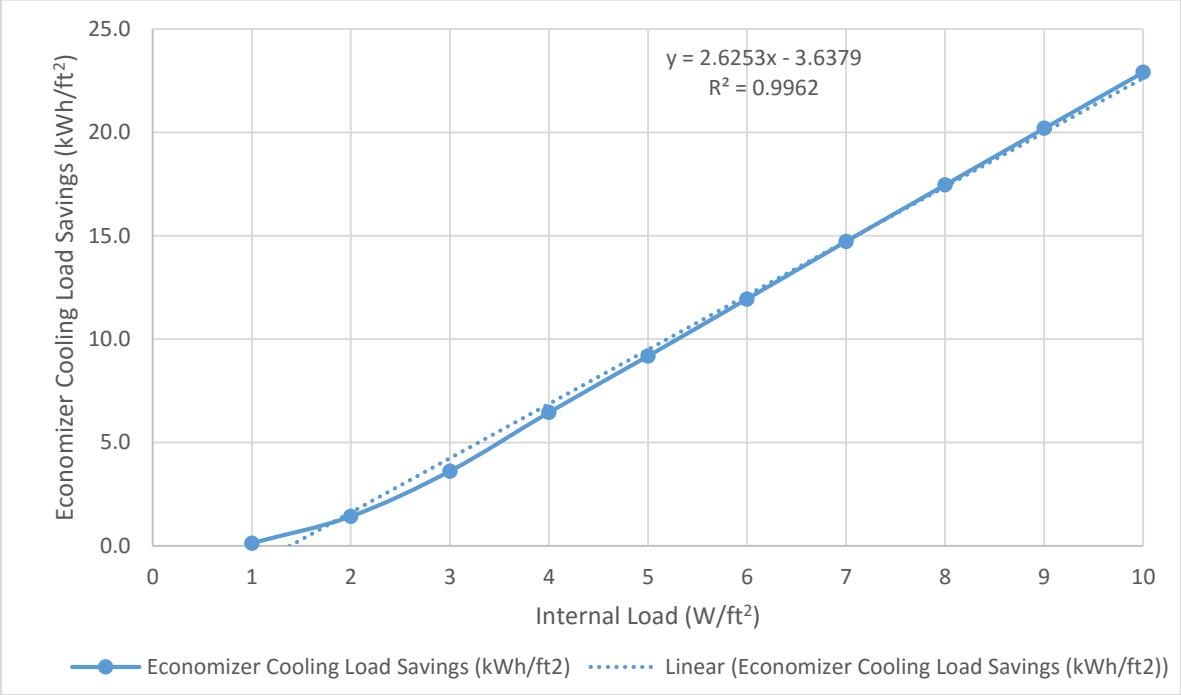

Figure 57 Raleigh Internal Load Vs Cooling Load Savings With Economizers

This represents the Economizer Cooling Load Savings (ECLS) which can be converted to Energy Savings (ES) using the following equations. It should be noted that these curve fits are only valid for the range shown in the figure.

$$ECLS = Slope\ x\ Internal\ Load\ \left[\frac{W}{ft^2}\right] + y\ intercept \qquad (10)$$

$$ES = \frac{ECLS\ x\ Building\ Floor\ Area\ [ft^2]}{eff[COP\}} \quad (11)$$

With the estimated Energy Savings (ES) rough calculations can help users see if this energy conservation measure should be further analyzed.

Table 29 ECLS In Selected Cities

City	Economizer Cooling Load Savings (kWh/ft^2)			
	Slope	Y intercept	Internal Load Min (W/ft^2)	Internal Load Max (W/ft^2)
Raleigh, NC	2.63	-3.64	1.00	10
New York, NY	2.57	-3.83	1.00	10
Los Angeles, CA	4.38	-5.47	1.00	10
Miami, FL	0.65	-0.41	1.00	10
Denver	2.80	-4.51	1.00	10
Chicago	2.12	-3.00	1.00	10
Houston, TX	1.68	-2.17	1.00	10
Fairbanks, AK	2.16	-3.37	1.00	15
Seattle, WA	4.47	-7.24	1.00	10

The significance of the slope is the number of thousand hours per year that economizers can be used fulfill the buildings cooling needs. The table above shows how this can vary in different climates.

Next, the ECLS was normalized by dividing by the original cooling load to give an estimated percentage of cooling load reduction. By putting in economizer this value shows the percentage cooling load reduction the building will experience.

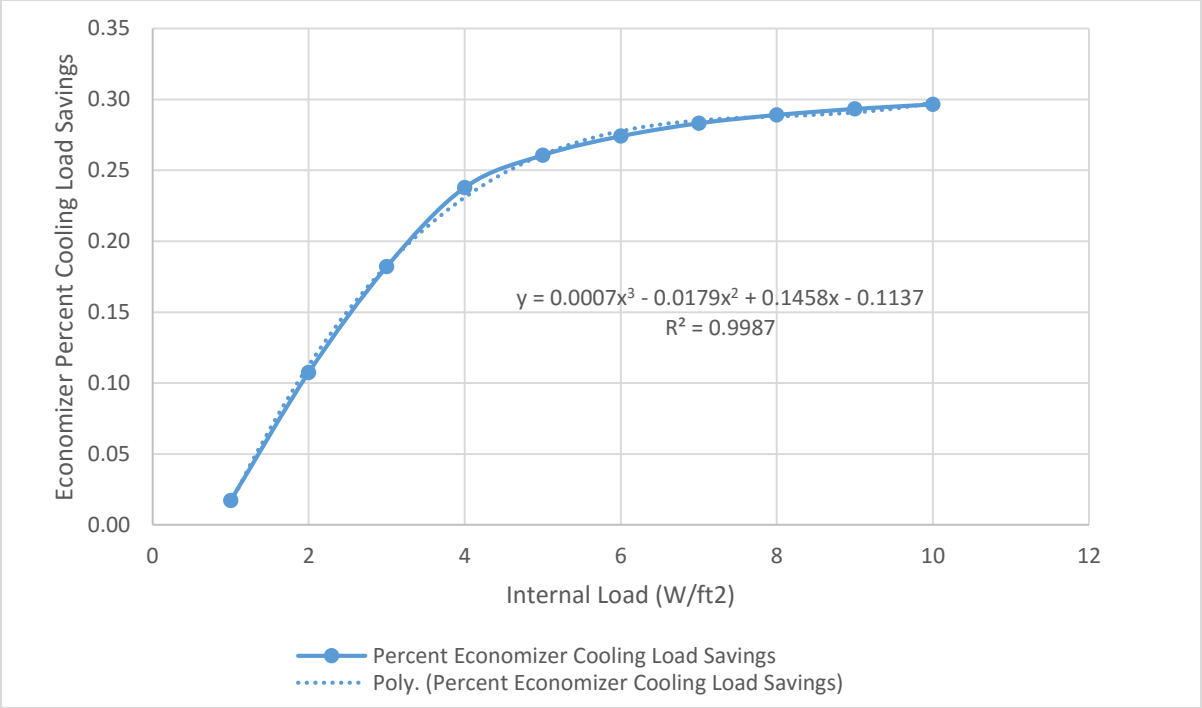

Figure 58 Raleigh Economizer Percent Cooling Load Reduction+

Table 30 Curve Fits for Percent Cooling Load Reduction

City	Percent Economizer Cooling Load Savings Coefficients					
	x^5	x^4	x^3	x^2	x^1	y intercept
Raleigh, NC	0.000E+00	0.000E+00	7.419E-04	-1.789E-02	1.458E-01	-1.137E-01
New York, NY	0.000E+00	0.000E+00	9.401E-04	-2.236E-02	1.731E-01	-1.082E-01
Los Angeles, CA	0.000E+00	0.000E+00	1.340E-03	-2.742E-02	1.839E-01	9.217E-02
Miami, FL	0.000E+00	0.000E+00	3.724E-05	-1.103E-03	1.279E-02	3.834E-03
Denver	0.000E+00	-4.479E-04	1.320E-02	-1.411E-01	6.386E-01	-6.269E-01
Chicago	0.000E+00	0.000E+00	9.925E-04	-2.290E-02	1.681E-01	-9.891E-02
Houston, TX	0.000E+00	0.000E+00	1.887E-04	-5.350E-03	5.502E-02	-4.466E-02
Fairbanks, AK	0.000E+00	0.000E+00	1.296E-03	-2.945E-02	1.750E-01	3.492E-01
Seattle, WA	2.045E-04	-6.854E-03	8.874E-02	-5.501E-01	1.604E+00	-1.075E+00

The table and figures showing curve fits for percent cooling load reductions may be easier for users to consider. If the amount of cooling used in the building is known then it can be multiplied by the Percent Cooling Load Reduction and divided by COP to find the energy savings of using economizers in their particular building. Further figures and tables are available in the appendix.

8 Conclusion

This study has explored the relationship between cooling loads and lighting power reduction. It is clear that in buildings that are cooled only there is a significant cooling load, electrical and monetary savings that is often ignored when considering upgrading light fixtures to more efficient ones.

A baseline building model was made and then iterations were created for lighting power reductions at various internal loads. Next, a correction factor is found that can be used to calculate the additional savings from upgrading to more efficient light fixtures a various internal loads.

The data shows that once a building has a high enough load that it is cooled only, the correction factor is constant. This is expected because once the building is cooled year around the shell and ventilation loads are constant so the only way to remove heat is mechanically or with economizers. This means that users will not need to calculate their internal load in order to use this correction factor. If the user knows that their building is cooled only then they can use the correction factor in the table. Results were calculated for buildings both with and without economizers. Since only cooling loads were considered in the study it is independent of the air side system type and efficiency of heat removal system.

Looking at the available literature there are correction factors available that consider high internal load buildings but not economizers. In addition, there is a method that considers the effect of economizers but ignores high internal load cooled only buildings. This combination of high internal load cooled only buildings and economizers was not available before this study.

For this study lighting reductions were modeled as purely sensible loads. This means that the results of this study and correction factors produced are applicable to any sensible load reduction. This could be applied to data centers considering more efficient electronics, industrial facilities considering more efficient equipment, office buildings reducing plug loads or any other sensible load reduction.

Also, during the course of this study data was collected in various cities for buildings both with and without economizers. This data was analyzed to help make back of the envelope and other feasibility estimates for how much energy can be saved by adding economizers to buildings that are cooled only.

8.1 Future Work

This study has found solutions that did not exist through original research however, there is room for further research. The effects of waterside economizers as they apply to both lighting correction factors and economizers savings could be explored. In addition, the savings associated with both air and waterside economizers could be studied further both from an analytical standpoint and a modeling perspective. This could give insight as to how much more efficient a waterside economizer could be as opposed to air side economizers.

Also, this study could be repeated for more climate zones not just in the United States but, worldwide. This would provide more correction factors throughout the world. In addition, this could help to confirm the conclusions from cooled only buildings without economizers.

Finally, further examinations could be done on buildings that are heated only or both heated and cooled. These types of buildings have been studied more extensively all ready at this time but, there is likely a gap in some way that could be explored.

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APPENDIX

9.1 Matlab Code to Pull Values from .SIM file

```
tic
clear
clc
%specify file name, city then econ or no econ
BaseName='fairbanks no econo';
%specify number of sims
simnum=15;
%specify which lines of the sim doc to look at
range=2500:3000;
%strings to make file names
x=' - ';
PL='PL ';
Light='Light ';
Sim='.SIM';
% z=0:simnum-1;
%
% z=z';
% z=num2str(z);

%generate list of file names for Process Load sims
names=cell(simnum,1);
for i=1:simnum
    z=i-1;
    z=num2str(z);
    names{i}=strcat([BaseName,x,PL,z,Sim]);
end
%generate list of file names for light sims
for i=1:simnum
     z=i-1;
    z=num2str(z);
    names{i+simnum}=strcat([BaseName,x,Light,z,Sim]);
end
% pull values from sim files
for j=1:2*simnum
    %import text file
dataset=importdata(names{j},'%s');
% look for report SS-D
c=strfind(dataset(range),'SS-D');
% print iteration number
j
% find line that contains string
rloc=find(not(cellfun('isempty',c)));
%pull line that has cooling and heating loads
totals(j,1)=cellstr(dataset(rloc+39+range(1)-1));
%find line that containts report SS-M
m=strfind(dataset(range),'SS-M');

rloc=find(not(cellfun('isempty',m)));
%Import cooling fan data
totals(j,2)=cellstr(dataset(rloc+37+range(1)-1));
end
```

```
%split lines into values
for k=1:2*simnum
    %cooling load
split=strsplit(totals{k,1});
value(k,1)=split(2);
%heating load
value(k,2)=split(3);
%cooling hours fan load
splitfan=strsplit(totals{k,2});
value(k,3)=splitfan(4);
end
% change to numbers
value=str2double(value);
% format values to input in tables
value=[value(1:simnum,1:3),value(simnum+1:simnum*2,1:3)];
%all loads considered positive
value=abs(value)
%formatting
value=int64(value)

toc
```

9.2 eQUEST Simulation Heating and Cooling Load Data For Lighting

Table 31 Raleigh Load Data With Economizers

Internal Load (W/ft^2)	Before Lighting Upgrade		After Lighting Upgrade		Lighting Energy Reduction (kWh)
	Cooling Load (kWh)	Heating Load (kWh)	Cooling Load (kWh)	Heating Load (kWh)	
1	1,860,085	868,876	1,450,516	1,419,651	1,082,295
2	2,952,571	365,611	2,396,117	563,217	1,082,295
3	4,054,690	107,103	3,536,802	212,051	1,082,295
4	5,164,696	10,180	4,577,745	37,204	1,082,295
5	6,504,470	98	5,822,809	1,994	1,082,295
6	7,904,551	9	7,211,474	31	1,082,295
7	9,313,678	0	8,618,602	0	1,082,295
8	10,733,312	0	10,029,987	0	1,082,295
9	12,157,639	0	11,452,937	0	1,082,295
10	13,583,179	0	12,877,985	0	1,082,295

Table 32 Raleigh Load Data Without Economizers

Internal Load (W/ft^2)	Before Lighting Upgrade		After Lighting Upgrade		Lighting Energy Reduction (kWh)
	Cooling Load (kWh)	Heating Load (kWh)	Cooling Load (kWh)	Heating Load (kWh)	
1	1,892,561	867,934	1,441,643	1,426,019	1,082,295
2	3,308,085	364,816	2,567,820	562,096	1,082,295
3	4,957,281	106,707	4,135,037	211,573	1,082,295
4	6,777,422	10,084	5,847,757	36,932	1,082,295
5	8,799,142	94	7,784,027	1,972	1,082,295
6	10,889,914	9	9,856,834	31	1,082,295
7	12,994,412	0	11,956,508	0	1,082,295
8	15,098,889	0	14,061,936	0	1,082,295
9	17,205,361	0	16,165,882	0	1,082,295
10	19,308,742	0	18,270,362	0	1,082,295

Table 33 New York Load Data With Economizers

Internal Load (W/ft^2)	Before Lighting Upgrade		After Lighting Upgrade		Lighting Energy Reduction (kWh)
	Cooling Load (kWh)	Heating Load (kWh)	Cooling Load (kWh)	Heating Load (kWh)	
1	1,043,152	1,492,193	729,459	2,141,328	1,082,295
2	1,791,784	760,390	1,404,021	1,060,493	1,082,295
3	2,585,119	285,257	2,206,980	500,622	1,082,295
4	3,375,436	47,351	2,929,513	126,166	1,082,295
5	4,569,468	3,096	3,948,646	14,144	1,082,295
6	5,920,848	45	5,247,875	350	1,082,295
7	7,304,267	0	6,621,154	11	1,082,295
8	8,704,526	0	8,011,915	0	1,082,295
9	10,116,188	0	9,418,408	0	1,082,295
10	11,530,321	0	10,831,811	0	1,082,295

Table 34 New York Load Data Without Economizers

Internal Load (W/ft^2)	Before Lighting Upgrade		After Lighting Upgrade		Lighting Energy Reduction (kWh)
	Cooling Load (kWh)	Heating Load (kWh)	Cooling Load (kWh)	Heating Load (kWh)	
1	1,098,375	1,492,121	726,252	2,141,719	1,082,295
2	2,093,075	760,241	1,569,938	1,060,342	1,082,295
3	3,354,599	285,096	2,705,513	500,448	1,082,295
4	4,832,795	47,304	4,048,431	126,079	1,082,295
5	6,711,108	3,093	5,754,685	14,121	1,082,295
6	8,752,385	44	7,738,475	350	1,082,295
7	10,832,838	0	9,805,963	11	1,082,295
8	12,923,086	0	11,891,878	0	1,082,295
9	15,018,703	0	13,985,665	0	1,082,295
10	17,115,250	0	16,081,952	0	1,082,295

Table 35 Los Angeles Load Data With Economizers

Internal Load (W/ft^2)	Before Lighting Upgrade		After Lighting Upgrade		Lighting Energy Reduction (kWh)
	Cooling Load (kWh)	Heating Load (kWh)	Cooling Load (kWh)	Heating Load (kWh)	
1	390,082	53,210	208,898	257,337	1,082,295
2	1,119,932	313	677,426	6,081	1,082,295
3	2,407,826	0	1,738,811	0	1,082,295
4	3,355,999	0	2,886,209	0	1,082,295
5	4,289,889	0	3,830,333	0	1,082,295
6	5,232,534	0	4,761,121	0	1,082,295
7	6,190,739	0	5,712,635	0	1,082,295
8	7,154,371	0	6,675,213	0	1,082,295
9	8,116,329	0	7,636,275	0	1,082,295
10	9,069,042	0	8,593,643	0	1,082,295

Table 36 Los Angeles Load Data Without Economizers

Internal Load (W/ft^2)	Before Lighting Upgrade		After Lighting Upgrade		Lighting Energy Reduction (kWh)
	Cooling Load (kWh)	Heating Load (kWh)	Cooling Load (kWh)	Heating Load (kWh)	
1	491,504	52,207	114,557	256,342	1,082,295
2	2,050,607	293	1,156,458	5,866	1,082,295
3	4,061,703	0	3,065,612	0	1,082,295
4	6,127,710	0	5,100,889	0	1,082,295
5	8,235,928	0	7,194,736	0	1,082,295
6	10,349,429	0	9,307,655	0	1,082,295
7	12,462,496	0	11,421,356	0	1,082,295
8	14,572,050	0	13,532,431	0	1,082,295
9	16,680,121	0	15,640,957	0	1,082,295
10	18,787,157	0	17,748,273	0	1,082,295

Table 37 Miami Load Data With Economizers

Internal Load (W/ft^2)	Before Lighting Upgrade		After Lighting Upgrade		Lighting Energy Reduction (kWh)
	Cooling Load (kWh)	Heating Load (kWh)	Cooling Load (kWh)	Heating Load (kWh)	
1	5,839,922	18,184	4,838,442	291,244	1,082,295
2	8,416,150	0	7,153,686	1,466	1,082,295
3	10,841,220	0	9,698,773	0	1,082,295
4	12,920,654	0	11,904,770	0	1,082,295
5	14,939,710	0	13,948,576	0	1,082,295
6	16,924,478	0	15,947,650	0	1,082,295
7	18,887,738	0	17,920,148	0	1,082,295
8	20,840,402	0	19,876,943	0	1,082,295
9	22,788,508	0	21,827,767	0	1,082,295
10	24,729,628	0	23,772,977	0	1,082,295

Table 38 Miami Load Data Without Economizers

Internal Load (W/ft^2)	Before Lighting Upgrade		After Lighting Upgrade		Lighting Energy Reduction (kWh)
	Cooling Load (kWh)	Heating Load (kWh)	Cooling Load (kWh)	Heating Load (kWh)	
1	5,927,249	18,184	4,862,535	292,124	1,082,295
2	8,653,738	0	7,317,083	1,466	1,082,295
3	11,198,104	0	9,989,105	0	1,082,295
4	13,453,637	0	12,352,701	0	1,082,295
5	15,641,658	0	14,568,189	0	1,082,295
6	17,795,547	0	16,735,893	0	1,082,295
7	19,927,166	0	18,877,850	0	1,082,295
8	22,047,121	0	21,003,664	0	1,082,295
9	24,160,541	0	23,119,420	0	1,082,295
10	26,267,634	0	25,230,286	0	1,082,295

Table 39 Denver Load Data With Economizers

Internal Load (W/ft^2)	Before Lighting Upgrade		After Lighting Upgrade		Lighting Energy Reduction (kWh)
	Cooling Load (kWh)	Heating Load (kWh)	Cooling Load (kWh)	Heating Load (kWh)	
1	617,042	1,772,394	456,002	2,495,078	1,082,295
2	1,028,634	938,844	806,319	1,284,054	1,082,295
3	1,522,690	417,362	1,265,904	650,826	1,082,295
4	2,230,450	111,746	1,828,337	224,372	1,082,295
5	3,366,563	27,863	2,766,335	54,847	1,082,295
6	4,700,285	2,933	4,032,197	11,439	1,082,295
7	6,093,027	0	5,396,337	587	1,082,295
8	7,521,116	0	6,816,247	0	1,082,295
9	8,955,135	0	8,247,162	0	1,082,295
10	10,400,480	0	9,685,997	0	1,082,295

Table 40 Denver Load Data Without Economizers

Internal Load (W/ft^2)	Before Lighting Upgrade		After Lighting Upgrade		Lighting Energy Reduction (kWh)
	Cooling Load (kWh)	Heating Load (kWh)	Cooling Load (kWh)	Heating Load (kWh)	
1	553,071	1,771,807	316,553	2,494,491	1,082,295
2	1,256,718	937,084	870,980	1,282,881	1,082,295
3	2,300,010	416,482	1,736,467	649,360	1,082,295
4	3,757,932	111,160	2,986,481	223,492	1,082,295
5	5,643,992	27,570	4,675,471	54,553	1,082,295
6	7,717,395	2,933	6,686,569	11,145	1,082,295
7	9,852,639	0	8,791,473	587	1,082,295
8	12,023,320	0	10,953,684	0	1,082,295
9	14,199,390	0	13,127,073	0	1,082,295
10	16,381,901	0	15,305,325	0	1,082,295

Table 41 Chicago Load Data With Economizers

Internal Load (W/ft^2)	Before Lighting Upgrade		After Lighting Upgrade		Lighting Energy Reduction (kWh)
	Cooling Load (kWh)	Heating Load (kWh)	Cooling Load (kWh)	Heating Load (kWh)	
1	991,340	2,112,325	705,296	2,930,624	1,082,295
2	1,679,654	1,213,663	1,320,603	1,592,896	1,082,295
3	2,433,344	623,549	2,075,681	901,008	1,082,295
4	3,189,887	210,881	2,746,667	376,300	1,082,295
5	4,311,263	48,981	3,708,072	102,947	1,082,295
6	5,689,153	7,332	4,987,757	21,117	1,082,295
7	7,152,263	293	6,425,325	1,760	1,082,295
8	8,675,295	0	7,920,788	0	1,082,295
9	10,161,845	0	9,403,489	0	1,082,295
10	11,704,846	0	10,942,119	0	1,082,295

Table 42 Chicago Load Data Without Economizers

Internal Load (W/ft^2)	Before Lighting Upgrade		After Lighting Upgrade		Lighting Energy Reduction (kWh)
	Cooling Load (kWh)	Heating Load (kWh)	Cooling Load (kWh)	Heating Load (kWh)	
1	1,043,029	2,112,032	685,419	2,932,090	1,082,295
2	1,981,075	1,213,370	1,486,912	1,592,603	1,082,295
3	3,102,010	623,549	2,529,671	900,715	1,082,295
4	4,444,678	210,881	3,708,611	376,007	1,082,295
5	6,130,121	48,981	5,251,884	102,947	1,082,295
6	8,073,326	7,332	7,093,589	21,117	1,082,295
7	10,103,980	293	9,097,393	1,760	1,082,295
8	12,192,144	0	11,161,213	0	1,082,295
9	14,231,667	0	13,198,143	0	1,082,295
10	16,334,104	0	15,297,587	0	1,082,295

Table 43 Houston Load Data With Economizers

Internal Load (W/ft^2)	Before Lighting Upgrade		After Lighting Upgrade		Lighting Energy Reduction (kWh)
	Cooling Load (kWh)	Heating Load (kWh)	Cooling Load (kWh)	Heating Load (kWh)	
1	4,024,699	328,199	3,417,843	797,475	1,082,295
2	5,886,176	97,668	4,962,297	171,872	1,082,295
3	7,678,225	17,305	6,836,268	48,687	1,082,295
4	9,340,458	587	8,506,977	3,813	1,082,295
5	11,045,482	0	10,202,364	0	1,082,295
6	12,745,403	0	11,907,648	0	1,082,295
7	14,434,446	0	13,601,894	0	1,082,295
8	16,117,592	0	15,286,244	0	1,082,295
9	17,800,588	0	16,969,744	0	1,082,295
10	19,480,454	0	18,649,574	0	1,082,295

Table 44 Houston Load Data Without Economizers

Internal Load (W/ft^2)	Before Lighting Upgrade		After Lighting Upgrade		Lighting Energy Reduction (kWh)
	Cooling Load (kWh)	Heating Load (kWh)	Cooling Load (kWh)	Heating Load (kWh)	
1	4,051,028	326,146	3,412,056	802,754	1,082,295
2	6,151,817	97,375	5,085,796	170,992	1,082,295
3	8,314,456	17,011	7,267,975	48,687	1,082,295
4	10,426,117	587	9,374,403	3,813	1,082,295
5	12,565,533	0	11,508,686	0	1,082,295
6	14,702,592	0	13,650,107	0	1,082,295
7	16,829,702	0	15,781,802	0	1,082,295
8	18,950,266	0	17,904,884	0	1,082,295
9	21,064,321	0	20,021,899	0	1,082,295
10	23,172,946	0	22,132,522	0	1,082,295

Table 45 Fairbanks Load Data Wtih Economizers

Internal Load (W/ft^2)	Before Lighting Upgrade		After Lighting Upgrade		Lighting Energy Reduction (kWh)
	Cooling Load (kWh)	Heating Load (kWh)	Cooling Load (kWh)	Heating Load (kWh)	
1	136,090	6,149,558	79,042	7,494,912	1,082,295
2	142,489	4,427,318	86,490	5,072,865	1,082,295
3	278,700	3,439,201	205,092	3,854,509	1,082,295
4	502,395	2,622,075	363,103	2,984,004	1,082,295
5	942,624	1,817,268	705,840	2,225,244	1,082,295
6	1,470,540	1,009,528	1,192,312	1,373,217	1,082,295
7	2,207,163	490,979	1,812,633	710,952	1,082,295
8	3,182,306	221,146	2,669,200	330,839	1,082,295
9	4,370,981	83,883	3,752,045	141,662	1,082,295
10	5,669,677	24,930	5,034,118	45,168	1,082,295
11	7,075,812	9,679	6,369,855	15,251	1,082,295
12	8,533,360	2,640	7,808,718	5,279	1,082,295
13	10,006,446	1,173	9,280,099	1,760	1,082,295
14	11,495,413	293	10,759,844	587	1,082,295
15	12,985,070	0	12,251,181	293	1,082,295

Table 46 Fairbanks Load Data Without Economizers

Internal Load (W/ft^2)	Before Lighting Upgrade		After Lighting Upgrade		Lighting Energy Reduction (kWh)
	Cooling Load (kWh)	Heating Load (kWh)	Cooling Load (kWh)	Heating Load (kWh)	
1	290,071	6,149,558	124,483	7,494,912	1,082,295
2	290,965	4,427,025	125,722	5,072,572	1,082,295
3	851,636	3,438,907	544,875	3,854,509	1,082,295
4	1,650,223	2,622,075	1,227,786	2,984,004	1,082,295
5	2,667,525	1,817,268	2,147,291	2,225,244	1,082,295
6	3,784,438	1,009,528	3,214,965	1,373,217	1,082,295
7	5,113,957	490,979	4,427,813	710,952	1,082,295
8	6,684,974	221,146	5,879,191	330,839	1,082,295
9	8,469,375	83,883	7,557,121	141,662	1,082,295
10	10,365,606	24,930	9,435,646	45,168	1,082,295
11	12,374,361	9,679	11,373,442	15,251	1,082,296
12	14,431,291	2,640	13,411,071	5,279	1,082,297
13	16,503,395	1,173	15,482,426	1,760	1,082,298
14	18,591,495	293	17,562,112	587	1,082,299
15	20,678,039	0	19,651,562	293	1,082,300

Table 47 Seattle Load Data With Economizers

Internal Load (W/ft^2)	Before Lighting Upgrade		After Lighting Upgrade		Lighting Energy Reduction (kWh)
	Cooling Load (kWh)	Heating Load (kWh)	Cooling Load (kWh)	Heating Load (kWh)	
1	114,326	1,128,607	57,910	1,804,950	1,082,295
2	317,730	322,333	200,504	640,561	1,082,295
3	568,767	25,224	456,867	108,813	1,082,295
4	1,152,324	0	730,745	2,053	1,082,295
5	1,980,560	0	1,564,005	0	1,082,295
6	2,852,946	0	2,416,341	0	1,082,295
7	3,739,881	0	3,300,184	0	1,082,295
8	4,625,541	0	4,187,127	0	1,082,295
9	5,506,874	0	5,070,927	0	1,082,295
10	6,379,290	0	5,947,411	0	1,082,295

Table 48 Seattle Load Data Without Economizers

Internal Load (W/ft^2)	Before Lighting Upgrade		After Lighting Upgrade		Lighting Energy Reduction (kWh)
	Cooling Load (kWh)	Heating Load (kWh)	Cooling Load (kWh)	Heating Load (kWh)	
1	121,615	1,128,607	37,325	1,804,950	1,082,295
2	694,002	322,040	328,950	640,561	1,082,295
3	1,749,249	24,930	1,167,013	108,520	1,082,295
4	3,503,658	0	2,446,399	2,053	1,082,295
5	5,529,542	0	4,519,817	0	1,082,295
6	7,607,921	0	6,581,253	0	1,082,295
7	9,695,006	0	8,665,296	0	1,082,295
8	11,787,803	0	10,756,064	0	1,082,295
9	13,883,671	0	12,850,352	0	1,082,295
10	15,978,830	0	14,946,093	0	1,082,295

9.3 Economizer Load Savings in Selected Cities

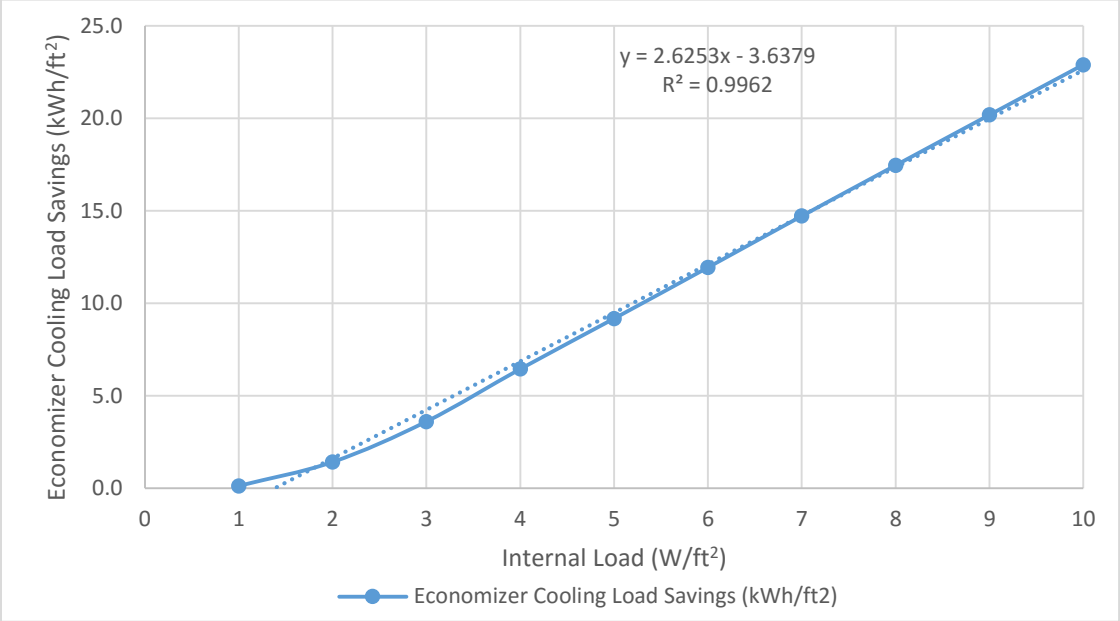

Figure 59 Raleigh Economizer Cooling Load Savings (kWh/ft²)

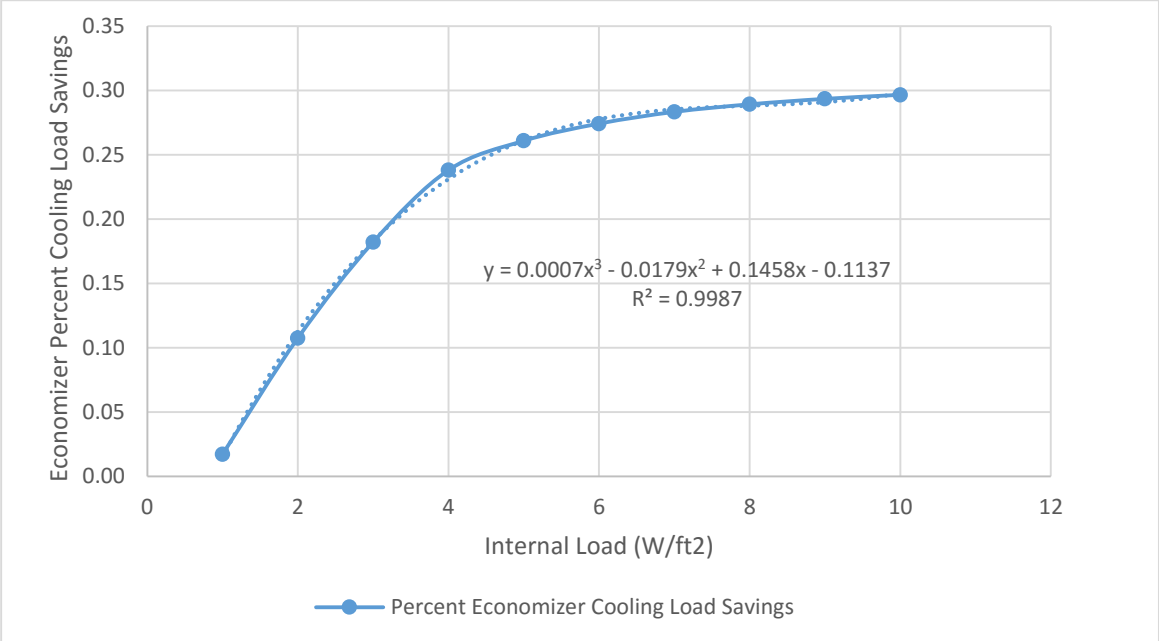

Figure 60 Raleigh Economizer Percent of Cooling Load Reduction

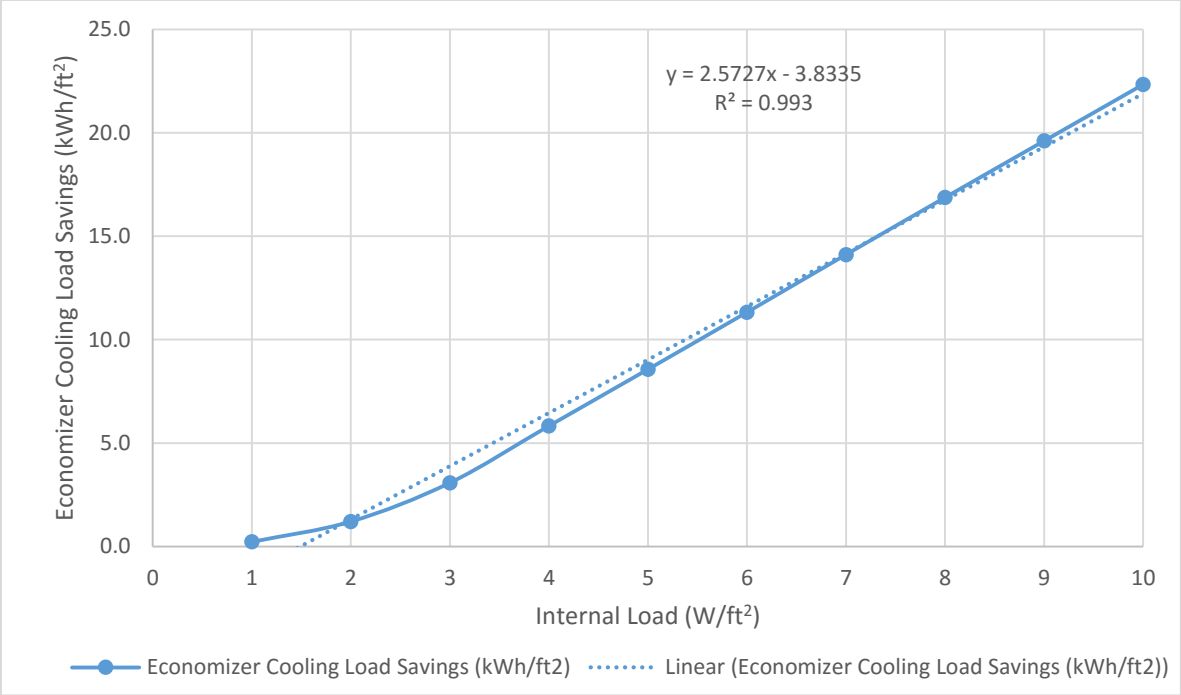

Figure 61 New York Economizer Cooling Load Savings (kWh/ft²)

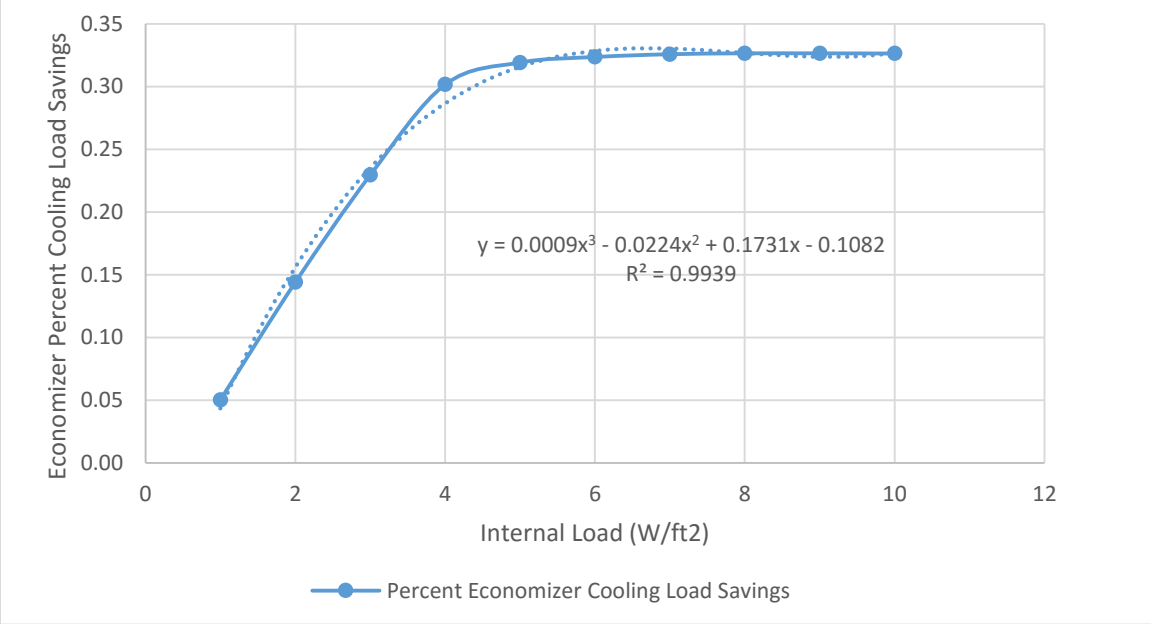

Figure 62 New York Economizer Percent of Cooling Load Reduction

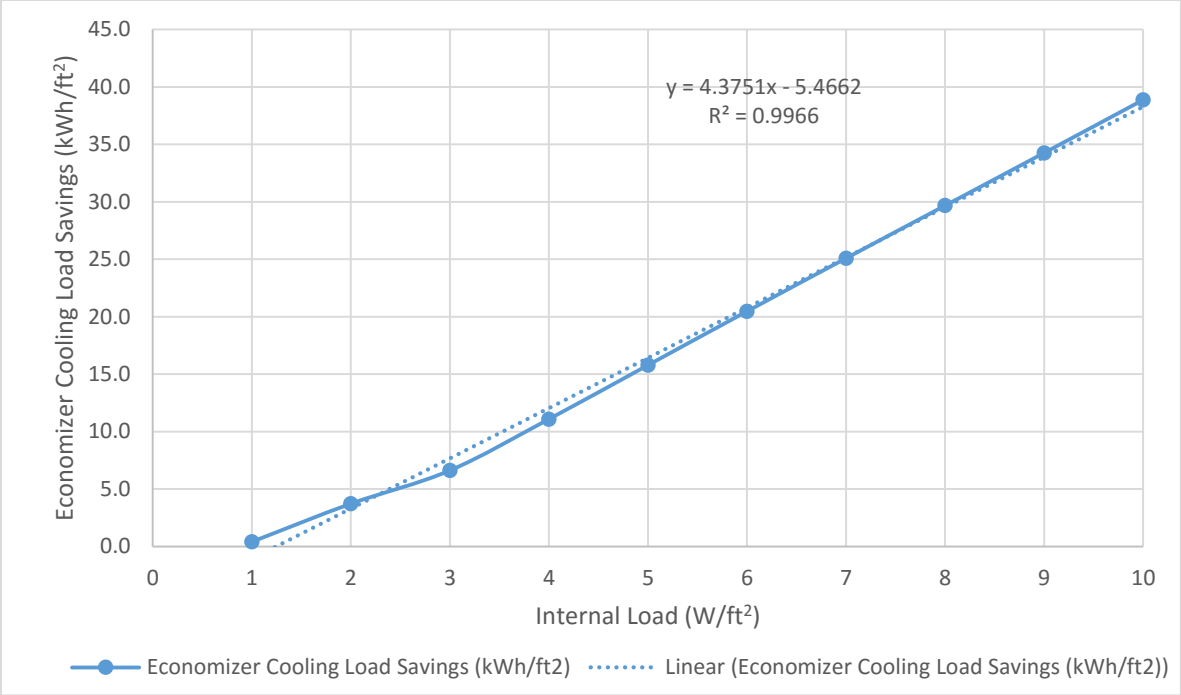

Figure 63 Los Angeles Economizer Cooling Load Savings (kWh/ft²)

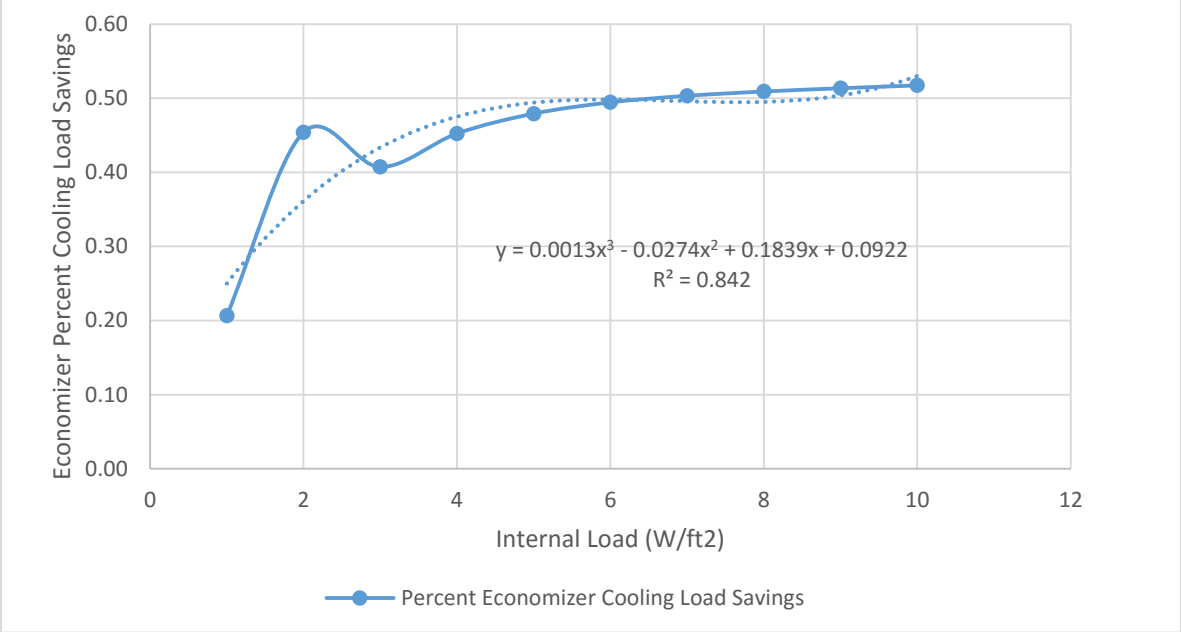

Figure 64 Los Angeles Economizer Percent of Cooling Load Reduction

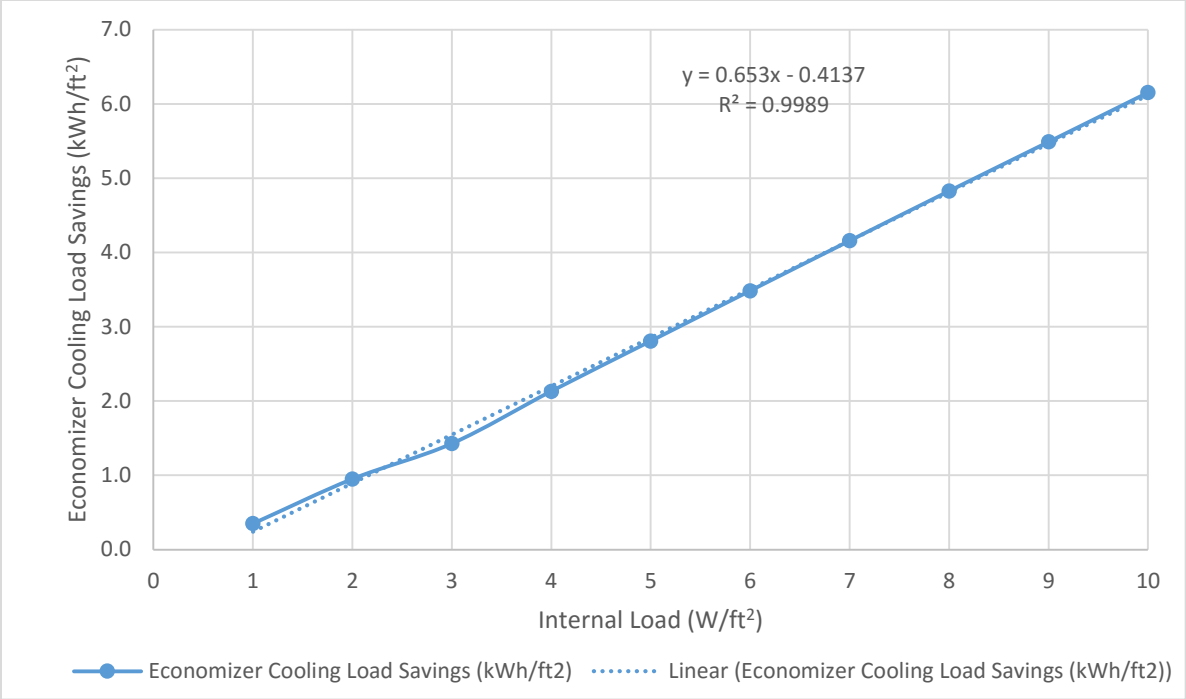

Figure 65 Miami Economizer Cooling Load Savings (kWh/ft^2)

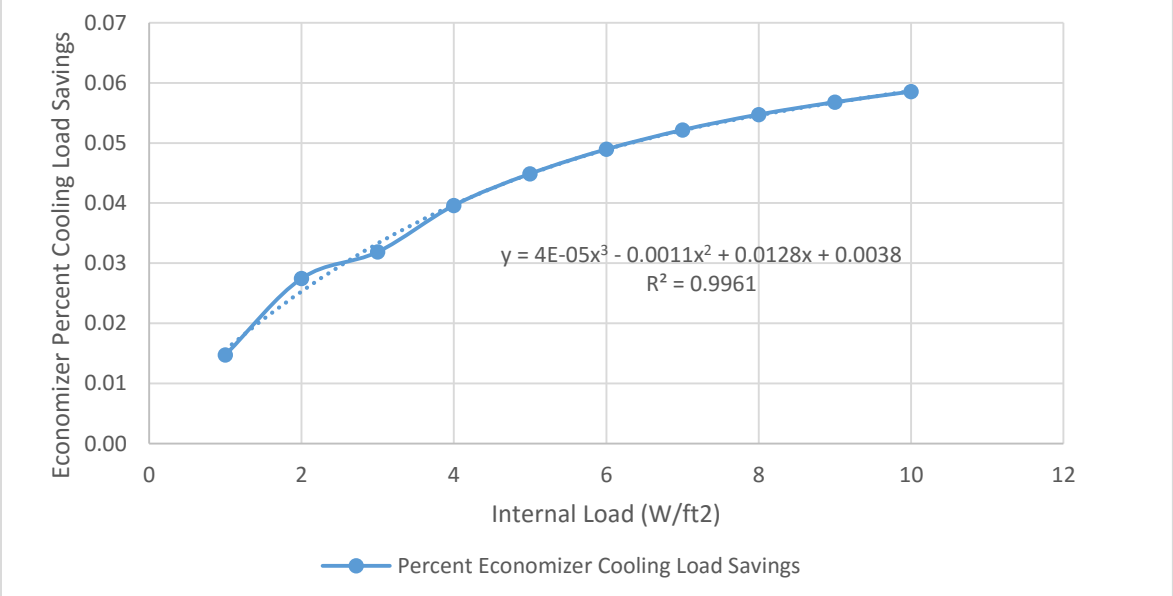

Figure 66 Miami Economizer Percent of Cooling Load Reduction

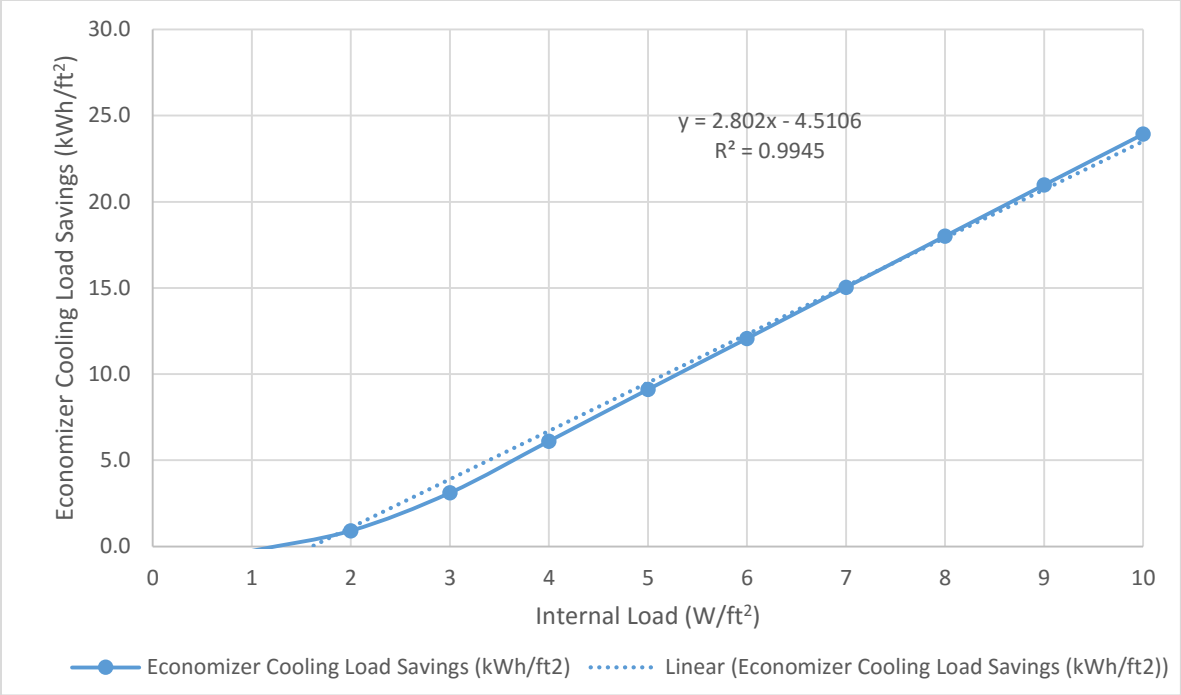

Figure 67 Denver Economizer Cooling Load Savings (kWh/ft^2)

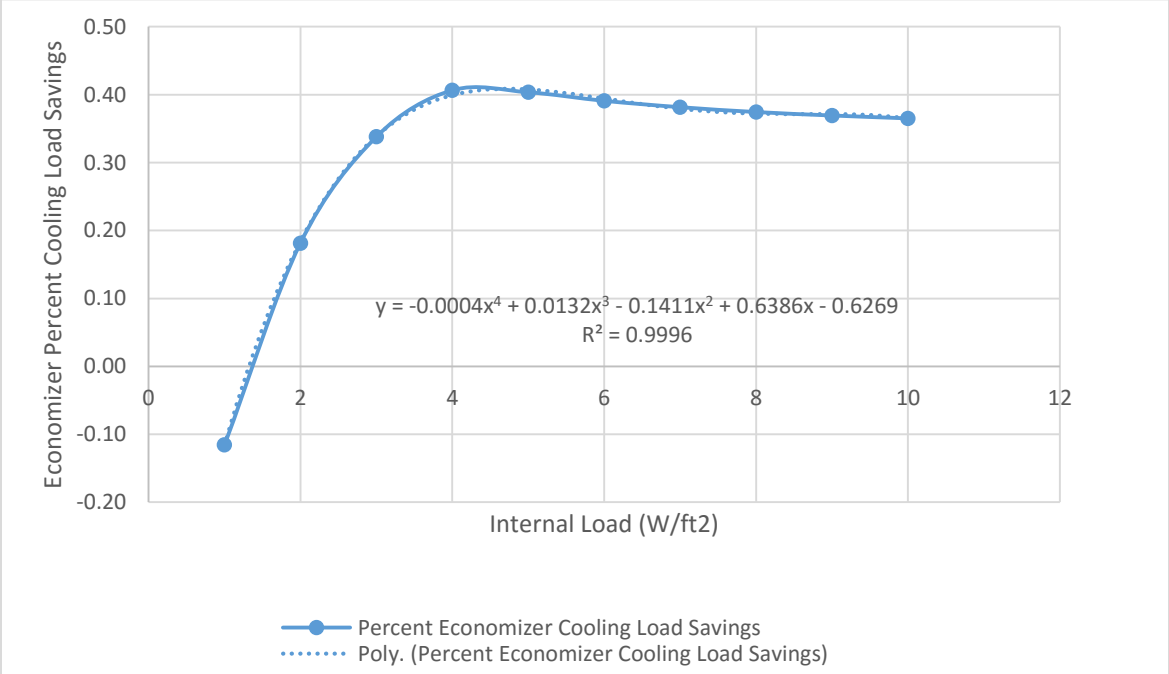

Figure 68 Denver Economizer Percent of Cooling Load Reduction

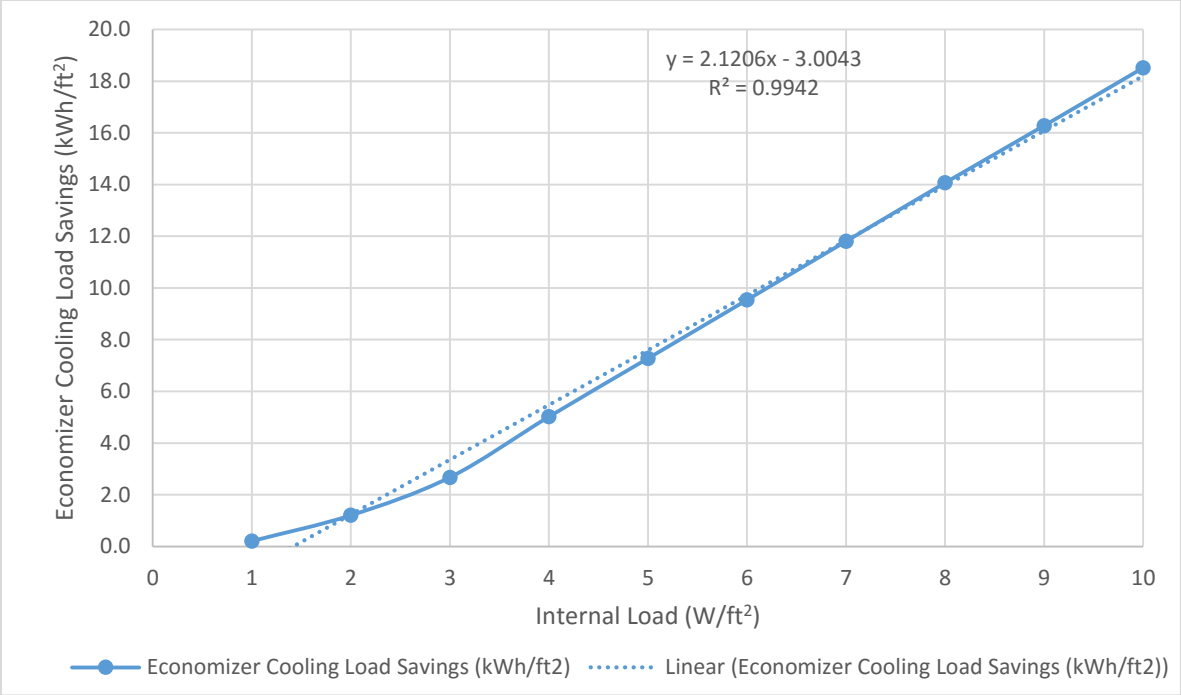

Figure 69 Chicago Economizer Cooling Load Savings (kWh/ft^2)

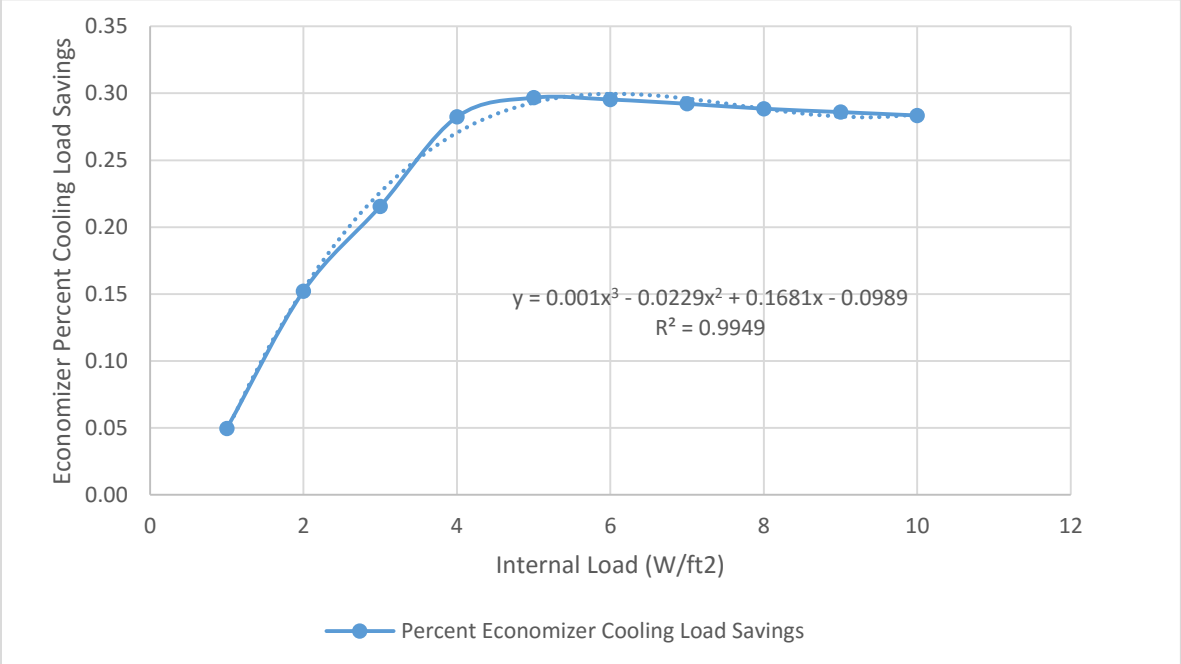

Figure 70 Chicago Economizer Percent of Cooling Load Reduction

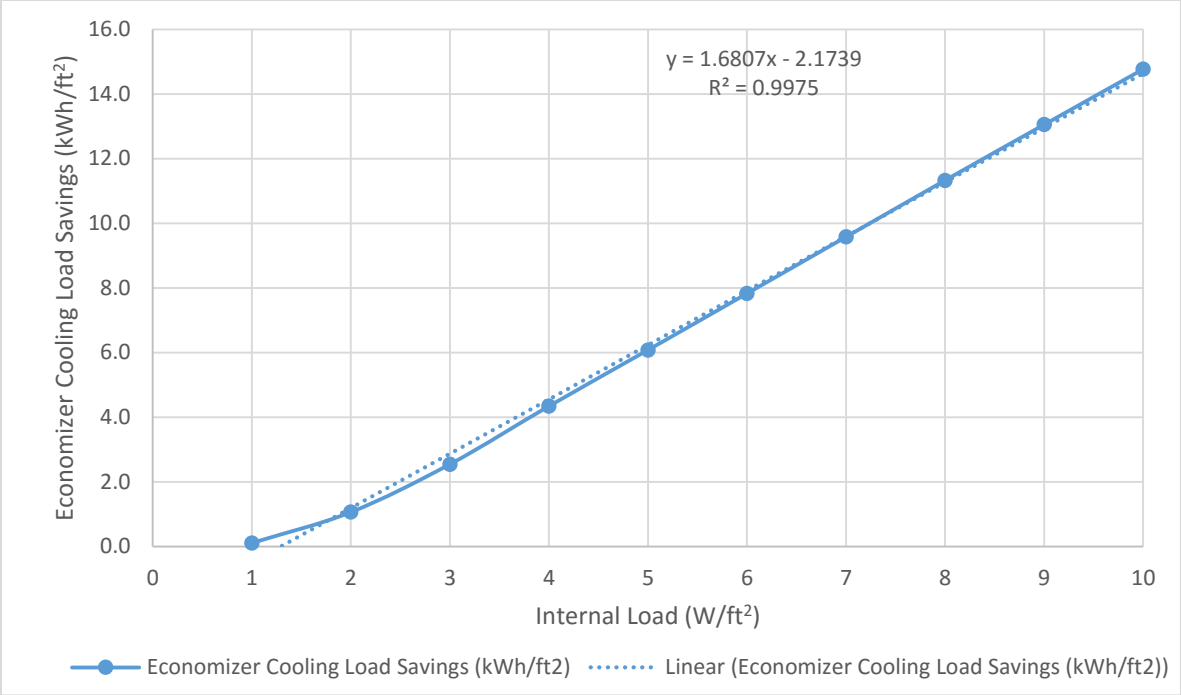

Figure 71 Houston Economizer Cooling Load Savings (kWh/ft^2)

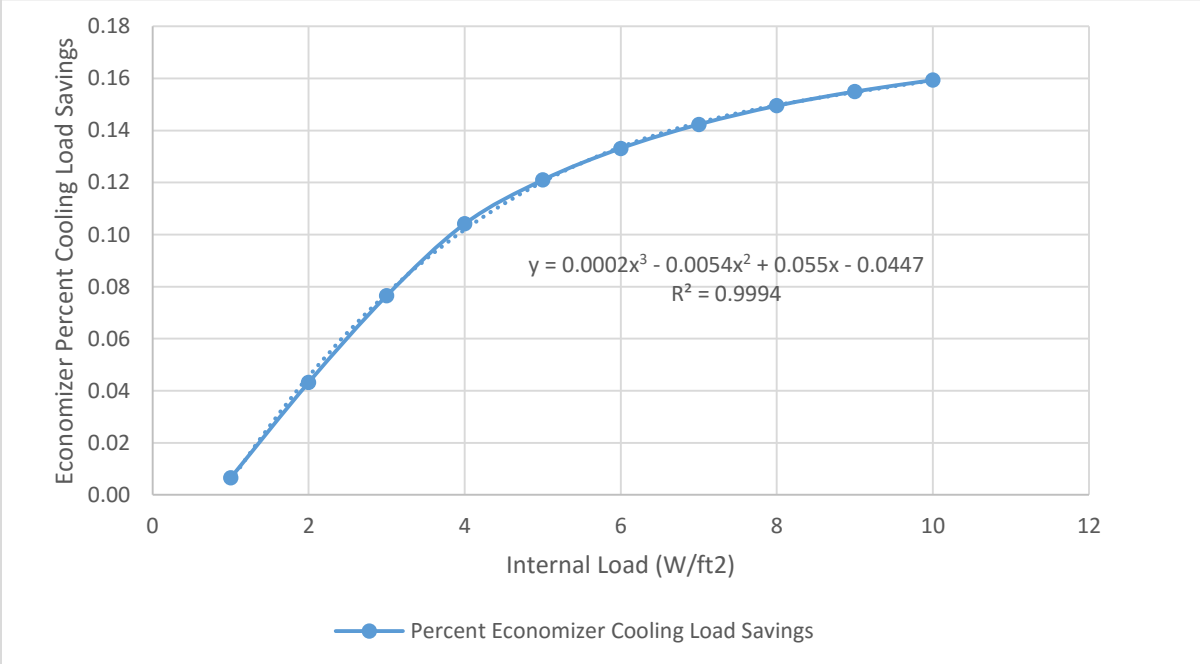

Figure 72 Houston Economizer Percent of Cooling Load Reduction

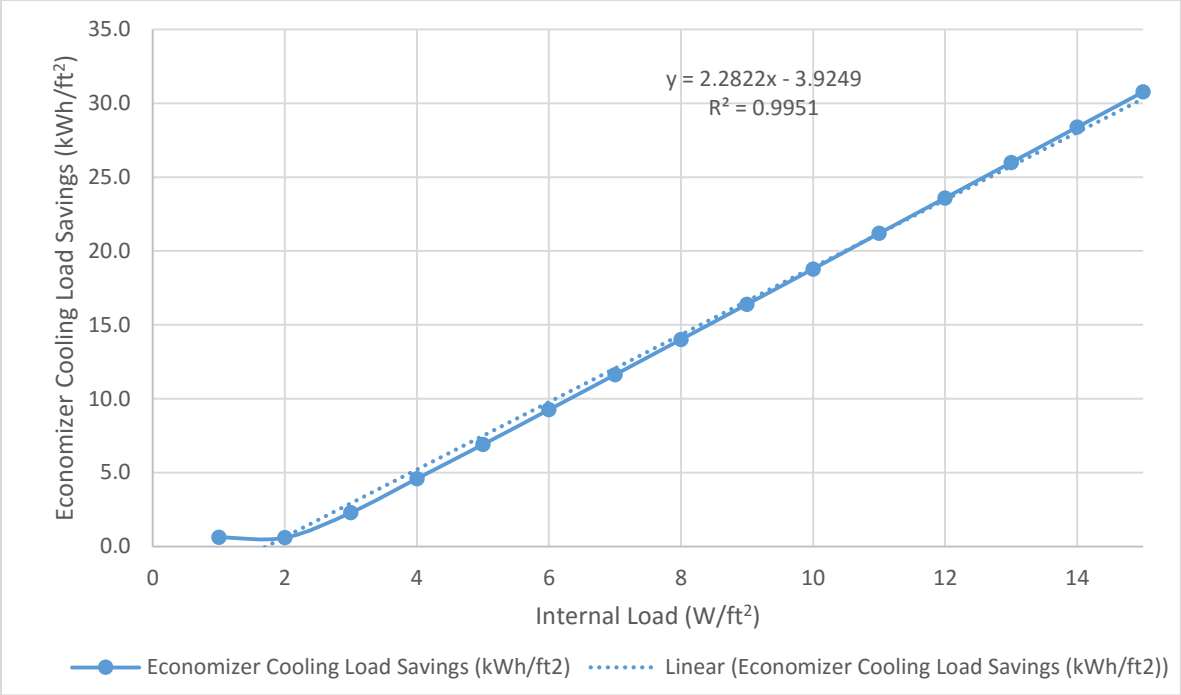

Figure 73 Fairbanks Economizer Cooling Load Savings (kWh/ft^2)

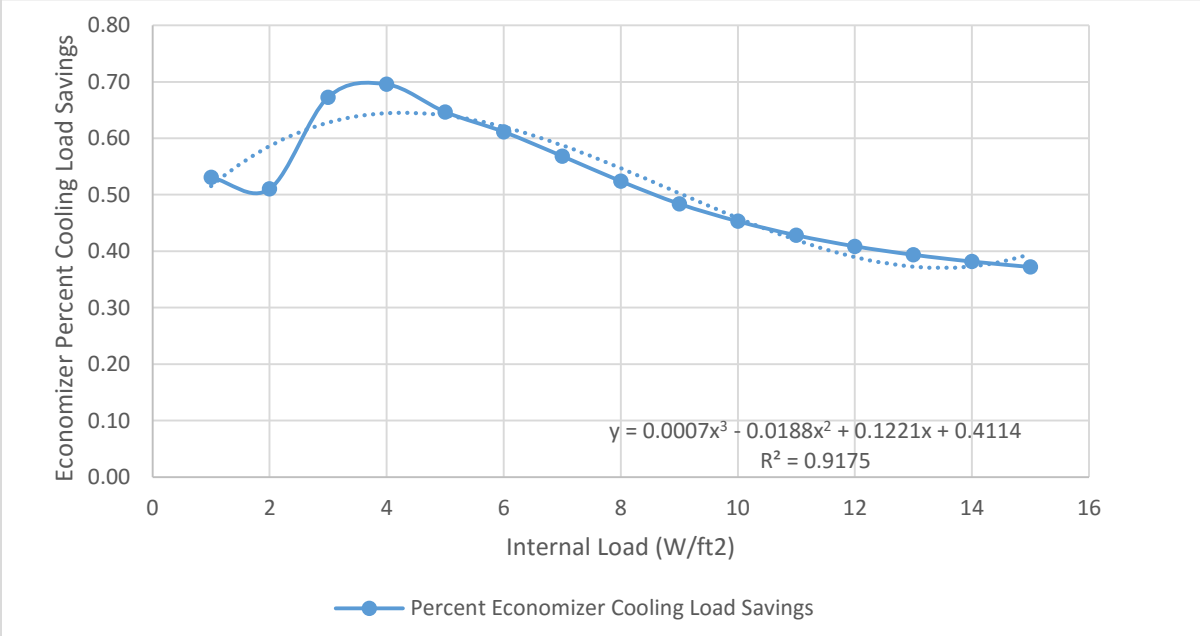

Figure 74 Fairbanks Economizer Percent of Cooling Load Reduction

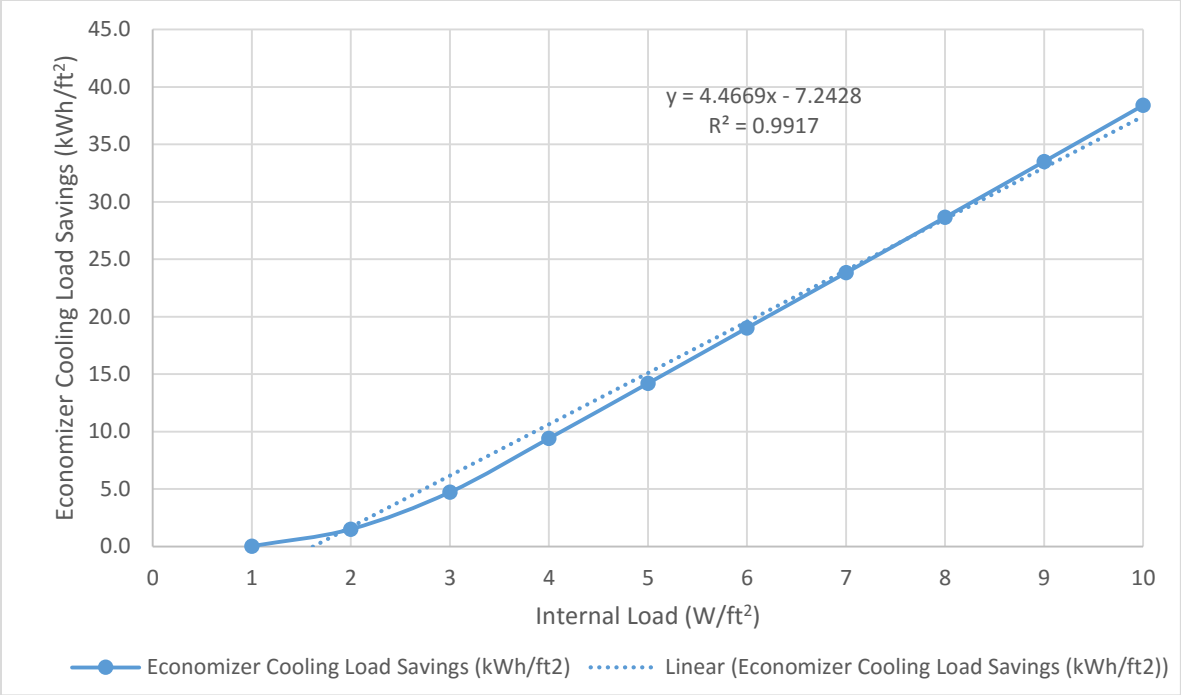

Figure 75 Seattle Economizer Cooling Load Savings (kWh/ft^2)

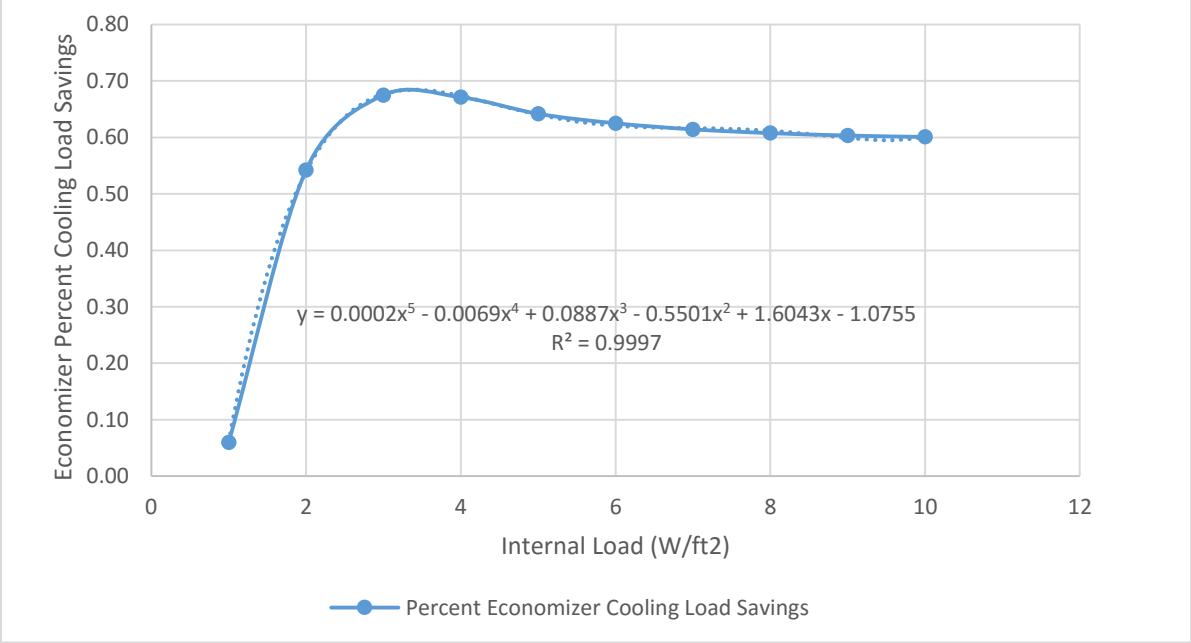

Figure 76 Seattle Economizer Percent of Cooling Load Reduction