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A CRITICAL ANALYSIS OF THE PASSIVE HOUSE STANDARD FOR THE CLIMATES OF THE UNITED STATES

BY

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THESIS

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Abstract

A "passive house" is a building that "can provide the necessary heating, cooling, and dehumidification through supply air ventilation" (Schneiders 2009). This study demonstrates that when using current technologies and practices, the functional definition of passive house as defined above by Schneiders and later redefined by Feist (Feist 2012) is not achievable in all US climate zones. To make possible the widespread adoption of this low energy standard, the standard itself needs to be adjusted and redefined. This thesis will answer the question of how the Passive House Standard's certification criteria could be adjusted to allow the Passive House Standard to become a readily usable metric throughout the United States.

To illustrate the need for the standard to be adjusted, the study demonstrates that climate optimized building cases cannot meet the supply air heating criteria of the Passive House Standard in every climate zone of the United States. It shows that the simulated building cannot be optimized to fulfill the functional definition of passive house or the intended passive house criteria using low energy building materials and techniques. Test cases were generated for a specific climate data location. These cases were also analyzed for 1000 additional data sets to determine trends and results for multiple locations. This process demonstrated the effect of specific climate characteristics, such as temperature and radiation, on the passive house energy metrics and the corresponding increases and decreases in energy use.

While a passive house can be defined by its ability to provide space conditioning through the supply air, the current Passive House Standard relies on four specific energy efficiency criteria to certify projects throughout the world. These four criteria must be met in order to be a certified passive house. These values: an Annual Space Heat Demand of 4.75 kBTU/ft^{2}yr (15 kWh/m^{2}a), a Peak Heating Load of 3.17 BTU/ft^{2}hr (10 W/m^2), an Annual Cooling Demand of

4.75 kBTU/ft^{2}yr (15 kWh/m^{2}a), and an Annual Primary (Source) Energy Demand of 38 kBTU/ft^{2}yr (120 kWh/m^{2}a) set a firm and stringent baseline measurement in most climates. However, for some climates, these numbers are simply unachievable. Even in climates where the certification criteria are achievable, including the vast majority of climate zones in the United States, supply air space conditioning is still not a realistic possibility.

Because the climate conditions in the United States are diverse, a precise adjustment is needed based on a project's exact location. Any adaptation of the Passive House Standard to many different climates needs to be customizable. To maintain precision between the climates, this thesis analyzes the simulated data for each passive house criteria against the data from within each climate set including temperature, radiation, dew point, and sky temperature. The analysis resulted in adjusted passive house criteria that were achievable for a specific climate data set's location. In this way, this thesis proposes a method for generating custom certification criteria for existing climate data sets in the United States, while also creating a repeatable method to be used in defining the adjusted passive house criteria for any location.

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Chapter 1

Development of the Passive House Standard

Roots in North America

The roots of the Passive House Standard first began in North America. The initial research and development for passive building techniques were brought about due factors in the worldwide energy market. In the late 1960's to early 1970's, US domestic oil production peaked and energy, both efficiency and production, began to become a mainstream concern. Shortly after the US oil production peaked, world oil production also peaked. While the effects of this peak continue to this day, the peak was followed by receding oil output until world oil production peaked once again in 2005 at 74 million barrels per day (Administration 2013). The economic recession that began in 2008 has since brought production down, but by 2011, the world was again producing more oil than it ever had before. Although not yet at its all time high, with new sources of domestic production, US oil production is forecast to rise above 1970 levels within the next 5 years at the current rate of drilling and exploration (Frum 2013). The term "peak oil" refers to the time when the maximum extraction point has been reached after which production will be in decline. Peak oil forecasts have been occurring for many decades, but in the mid 1990's, many experts agreed that in the next 20 years, the world's oil production would peak and that oil for energy will become more scarce. However, recent advances in technology and market conditions including hydraulic fracturing of rock to produce natural gas allowed for the continued extraction of oil resources for the foreseeable future and had changed the immediacy of the peak oil threat (Frum 2013).

In October 1973, members of the Organization of Arab Petroleum Exporting Countries (OAPEC) in response to U.S. aid of the Israeli military issued an oil embargo, which set off an oil crisis. The embargo lasted until May of 1974 and created a major energy crisis in the United

States, where sharp increases in energy prices were brought about by the lack of oil supply. It should be noted that after each energy crisis of the past forty years, the price of crude oil increased dramatically due to the restricted supply and increased demand. This price increase often triggers, or is a signifier of, an impending recession which occurred both in the mid 1970's and in July 2008 when crude oil hit a record price of $145 per barrel (Peak 2013). As oil prices increase and availability becomes scarce, the effective populations begin to look for alternatives. In the 1970's, this led to an increase in the importance of energy from renewable technologies, synthetic fuels, energy efficiency, nuclear and other sources of centralized power, and a sharp increase in domestic fossil fuel exploration and production.

Elsewhere, Canadian Harold Orr began pioneering ways in which buildings could use less energy even in very cold climates. One of Orr's projects, the Saskatchewan House, completed in 1977 in Regina Saskatchewan, became an icon for the fledgling low energy home movement. This house was one of the first examples of super insulation and, more importantly, it demonstrated that airtight construction was a feasible concept for conserving energy and increasing building durability. Because air infiltration was limited due to airtightness, the house used a ventilation system with an air to air heat exchanger. By 1982, this interest led to the creation of the R-2000 program through a partnership between the Canadian Home Builder's Association and Natural Resources Canada. To date, the R-2000 program has led to over 1000 built low energy homes and trained thousands of builders through its free training programs. The R-2000 program also instituted a requirement for a blower door test, becoming an early supporter of air tightness to eliminate air infiltration. Today, the Passive House Standard still requires the blower door testing to ensure air tightness and durability of the building shell.

In the United States, The University of Illinois Small Homes Council, later known as the Building Research Council, began experimenting with increased insulation levels and passive solar design. From 1920 to 1950, the council used research residences to study issues related to efficient building design and construction. In 1945, a University of Illinois Bulletin was issued by the Small Homes Council that described the use of solar orientation in home design. This work was the product of Bud Seichi Konzo and William H. Scheick and became the basis for research leading to the Lo-Cal House. The "Illinois Lo-Cal House" was developed from 1974 to 1976 by a team consisting of Wayne Schick, Rudard Jones, Warren Harris and Bud Konzo (McCulley 2010). This house was built using double stud construction with R-values in the wall of R-30 and in the roof of R-40 and triple glazed windows with nine percent glazing on the southern facade. This led to building concepts of increased insulation, air sealing, ventilation, heat recovery, attention to thermal bridges, and safer sealed combustion mechanical systems. During this time of research and exploration, Wayne Schick coined the term "superinsulation" (McCulley 2010). On September 26th, 1982, *The News-Gazette* ran a story titled "Computer Study Confirms Energy Savings of House." This study was performed on a house built in 1979 based on the "Illinois Lo-Cal House." The significance of this study was twofold. First, it was an early example of building simulation and the accuracy that simulation can provide in designing low energy buildings. Secondly, it was also an early example of a highly monitored project where simulation results were being validated by real world monitored data.

One of the most telling insights into the early passive house movement was a 1979 press release by William Shurcliff, a prominent physicist and Harvard Professor who was a central participant in the Manhattan Project in addition to being an inventor who held over 20 patents in optics while working for Polaroid in the 1940's. The following press release was a synopsis of

the points Shurcliff felt were essential to the design of the super insulated house and was republished in The Superinsulated Home Book (J.D. Ned Nisson 1985).

> *"1. Truly superb insulation.* ***Not just thick, but clever and thorough****. Excellent insulation is provided even at the most difficult places: sills, headers, foundation walls, windows, electric outlet boxes, etc.*
>
> *2. Envelope of house is* ***practically airtight****. Even on the windiest days the rate of air change is very low.*
>
> *3.* ***No provision of extra-large thermal mass****. (Down with Trombe walls! Down with water-filled drums and thick concrete floors!)*
>
> *4.* ***No provision of extra-large south windows****. Use normal number and size of south windows — say 100 square feet.*
>
> ***5. No conventional furnace. Merely steal a little heat, when and if needed, from the domestic hot water system. Or use a minuscule amount of electrical heating.***
>
> ***6. No conventional distribution system for such auxiliary heat. Inject the heat at one spot and let it diffuse throughout the house.***
>
> ***7. No weird shape of house, no weird architecture.***
>
> ***8. No big added expense. The costs of the extra insulation and extra care in construction are largely offset by the savings realized from not having huge areas of expensive Thermopane [windows], not having huge well-sealed insulating shutters for huge south windows, and not having a furnace or a big heat distribution system.***
>
> ***9. The passive solar heating is very modest — almost incidental.***
>
> ***10. Room humidity remains near 50 percent all winter. No need for humidifiers.***
>
> ***11. In summer the house stays cool automatically. There is no tendency for the south side to become too hot — because the south window area is small and the windows are shaded by eaves."***
>
> (J.D. Ned Nisson 1985)

The above points from the Shurcliff press release turned out to be quite visionary and are virtually the exact design parameters being used today to achieve passive houses and other extremely low energy buildings. For instance, "insulation that is thick, but also thorough" references the elimination of thermal bridging through a continuous insulation layer. A requirement for an airtightness test was called for in the press release. Both of these topics are fundamentals of current passive house design and integral to the current Passive House Standard. The idea that there did not need to be extra large south windows or extra provisions for additional massive surfaces was important given the state of energy efficient buildings in the 1970's and early1980's and the advent of "passive solar" technology. During that time, the building science community in the United States, and around much of the world, was split into two groups. The first was the "passive solar" community. Passive solar construction is a method by which large panes of glass gather heat from the sun during the day. The heat is absorbed by thermally massive features in the house, such as a concrete floor or barrels of water, and slowly released back out at night when the house begins to cool. The second group was the "super insulation" community. The builders that focused on super insulation believed that with enough insulation, they could make better performing homes that looked conventional and functioned without the necessary prescriptions for passive solar design, such as large, expensive glazing. Shurcliff's press release would place him in the later group due to his emphasis on insulation and modestly sized glazing.

Today's passive house movement contains elements from each group's vantage point. It has a focus on superinsulation, but in many climates, passive houses have sought to combine passive solar strategies that work with the environment to further reduce energy use. Despite two different strategies emerging on how best to build low energy homes, by 1985, it is

conservatively estimated that there were over 10,000 super insulated homes in North America. Though by most estimations and popular sentiment, the movement was stagnating behind low cost energy and a building economy focused on quick and cheap production.

While the information above shows a relatively linear progression through time, there have been many other significant contributors and significant projects from those contributors that have helped drive the culture of the passive building community. Many of these projects were discussed at a lecture given by Joseph Lstibruk, a principal of Building Science Corporation, at the 7th Annual North American Passive House Conference. Additional information is available in Appendix A.

Culmination in Europe

In the late 1980's and early 1990's Dr. Wolfgang Feist and Professor Bo Adamson began research on the contemporary Passive House Standard. They advanced the work and research already completed in the United States and abroad. The first Passive House, Kranichstein, was constructed in October 1990 in Darmstadt, Germany (Feist). This prototype has been the poster child and shining example of the passive house movement since its completion and continues to be monitored and studied. Following additional research and modifications on its design and energy efficiency, the Passivhaus Institute (PHI) was founded in 1996 - development and branding of the standard followed,

In the late 1990's, the Passive House Planning Package (PHPP), an energy modeling tool, was developed and initially released. The Passive House Planning Package (PHPP) is software designed for Microsoft Excel that was developed for analyzing passive houses and other low energy, super insulated and airtight buildings. The PHPP is used to determine the annual heating demand, the annual cooling demand, the heating load, the cooling load, and many other factors

based on a static model using monthly climate data for the demand values and twenty four hour averages for the load values. The PHPP also analyzes lighting, appliances, and other electricity uses in addition to mechanical systems for space conditioning, ventilation, and hot water to derive both site energy demands and a primary energy demand for passive houses (Wofgang Feist 2011). The PHPP has been continually refined with major updates released in 2001, 2004, 2007, Version 7 in 2012, and most recently, Version 8 in 2013.

Along with the development in energy modeling and the increasing understanding of building physics, came the development of certification criteria. Developing the defining criteria for certification also began the process of creating a marketable brand and product called Passivhaus. In 2007, the founder of the Passivhaus Institute, Dr. Wolfgang Feist, wrote that "A Passive House is a building in which thermal comfort [ISO 7730] can be ensured by only heating or cooling the supply air volume needed for sufficient air quality - without using additional circulating air" (Feist 2007). Supply air conditioning became the defining criteria for the Passivhaus standard. By using the ventilation system for conditioning, there can be a significant savings in both economic, operating, and lifecycle costs due to mechanical efficiency, which drives passive house towards being the economic optimum building. These savings are achieved by investment in the building envelope, which is offset by savings from the reduction in size or even the elimination of the furnace or heating system. The envelope investment reduces the space conditioning loads of the passive house until they are small enough to be distributed by the mechanical ventilation system. The Passive House Standard certification criteria are based on the basic premise that the elimination of the separate heating system provides the economic optimum building. Therefore, there is great importance placed on meeting the Heating Load, which is the

amount of heating able to be provided by the flow rate of the supply air ventilation, can be defined as:

$$P_H \leq 10 \text{ W/m}^2$$

The value of 10 W/m^2 for the Peak Heating Load calculation is based on the flow rate needed for ventilation, the specific heat capacity of the air, and the air temperature. In the central European climate fulfilling the peak heat load requirement led to an Annual Heating Demand of:

$$Q_H \leq 15 \text{ kWh/(m}^2\text{a)}$$

For controlling durability of the exterior envelope and limiting energy loss through infiltration, a requirement of building air tightness was added at:

$$n \leq .6 \text{ ACH}_{50}$$

In the central European climate the Annual Cooling Demand related well with the level of conditioning available using supply air conditioning. Therefore, the criteria for the Annual Space Cooling Demand was determined to be:

$$Q_K \leq 15 \text{ kWh/(m}^2\text{a)}$$

There is also a certification criteria that accounts for all of the energy used in the building. The term Primary Energy (PE) is often referred to as "source energy," which is the amount of power that must be produced at the power plant to provide energy for the entire building. On the other hand, site energy is the amount of energy the building actually consumes and uses locally. Traditionally, site energy for electricity has been multiplied by a factor of 2.7 to get to a value for Primary Energy. The latest PHPP has revised that number downward to 2.6 to account for the addition of more renewable energy and smart grid technologies in the European Union. A PE factor of 2.7 means that for every 1 unit of power consumed on site, 2.7 units of power must be produced by the power plant. The Primary Energy factor was also put in place to

act as a sustainability requirement to cover "resource conservation, emission minimization, and climate protection." [Feist 2007]. In the United States this value is closer to 3.1, but the certification criteria and Primary Energy factor at the time of writing remain at:

$$W_p \leq 120 \text{ kWh}/(\text{m}^2\text{a})$$

The Passive House Standard is a building standard where certification is determined in part by conformance with the energy model. The only required tested values from the building are gathered from the blower door test and ventilation commissioning report. These tests are designed to ensure high quality living spaces that are comfortable and have superior indoor air quality. The secondary purpose of the blower door test is to align the building's "as modeled" energy use with the "as built" energy use. Even though the leakage determined through the blower door test effects the energy balance, often, depending on climate, the infiltration results do not significantly contribute to the modeled results, nor the building's actual measured energy use.

In summary, the criteria of the passive house standard are defined as:

Criteria	**I.P. Units**	**S.I. Units**
Annual Space Heat Demand:	4.75 kBTU/ft^{2}yr	(15 kWh/(m^{2}a))
or Peak Heat Load:	3.17 BTU/ft^{2}hr	(10 W/m^2)
Annual Cooling Demand:	4.75 kBTU/ft^{2}yr	(15 kWh/(m^{2}a))
Annual Primary (Source) Energy Demand:	38 kBTU/ft^{2}yr	(120 kWh/(m^{2}a))
Air Infiltration rate :	n $\leq$ .6 ACH50	(air changes per hour at 50 Pascal's of pressure)

Figure 1.1: Passive House Criteria

In Europe, much work has been completed in the last twenty years advancing the passive house standard and developing Passivhaus as a brand. Starting with the first passive house in

1991, the movement and excitement around the concept accelerated. Figure 1.2 shows two phases. The first phase, which lasted until midway through 1997, was focused on proving the concept and generating groundbreaking examples. A second phase, post 1997, shows a widespread and exponential curve in the increasing adoption of passive house. By May 2000, the growth predicted by the Passivhaus Institute was bypassed by the actual number of constructed units. In the ten years from 1997 to 2007, over 10,000 passive house units were built in Germany and Austria. The United has the potential for an even faster adoption rate due to the foundation and research that developed elsewhere over the past twenty years had allowed for the physics and science behind these buildings to be well understood.

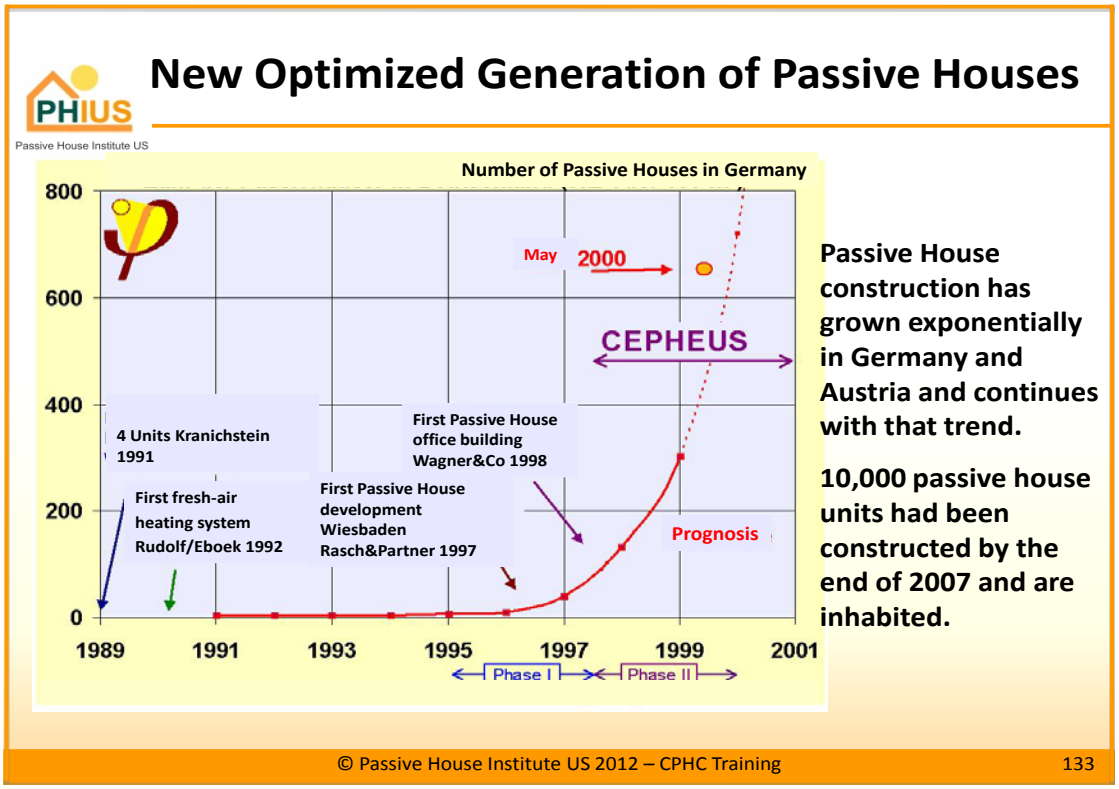


Figure 1.2: Passive House Adoption Curve

Passive house has been widely adopted throughout Europe as demonstrated by Figure 1.3, below, but it is also very evident that widespread adoption has been limited to Germany and Austria. However, token adoption has occurred in almost every major European country and in many other countries through the world including Japan, South Korea, Jamaica and other Caribbean Islands, Canada, and the United States.

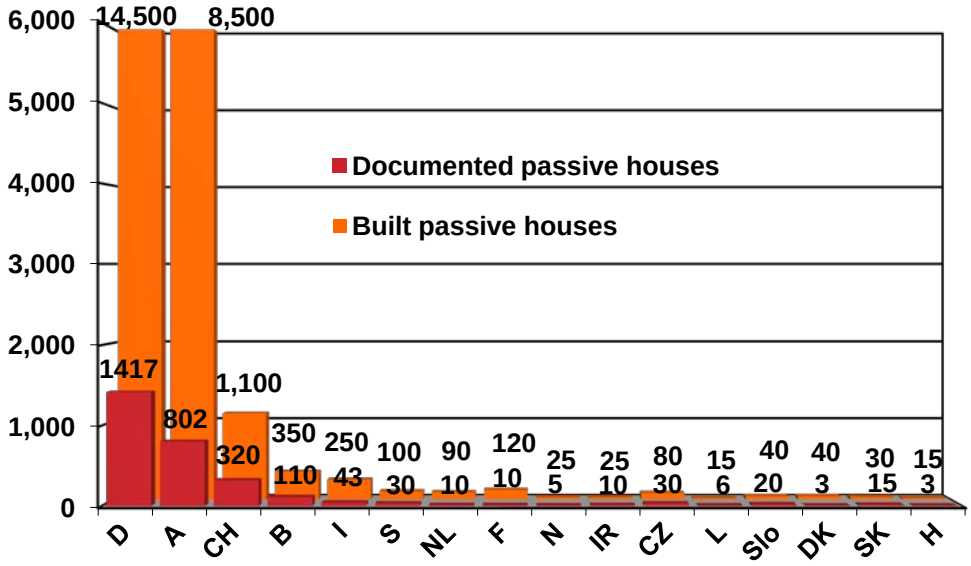


Figure 1.3: Passive House Adoption Bar Graph

Figure 1.7, below, is a comparison between the available solar radiation in the United States and Germany. This high solar energy potential in the United States is clearly evident due to the considerably higher radiation values in the United States than those in Germany. A solar panel placed in Ohio will produce an additional 20% more energy than the identical panel placed in Germany. Yet, Germany is the world's largest solar market and relies significantly on the passive solar gains from the sun to create both power and heat within the German building stock.

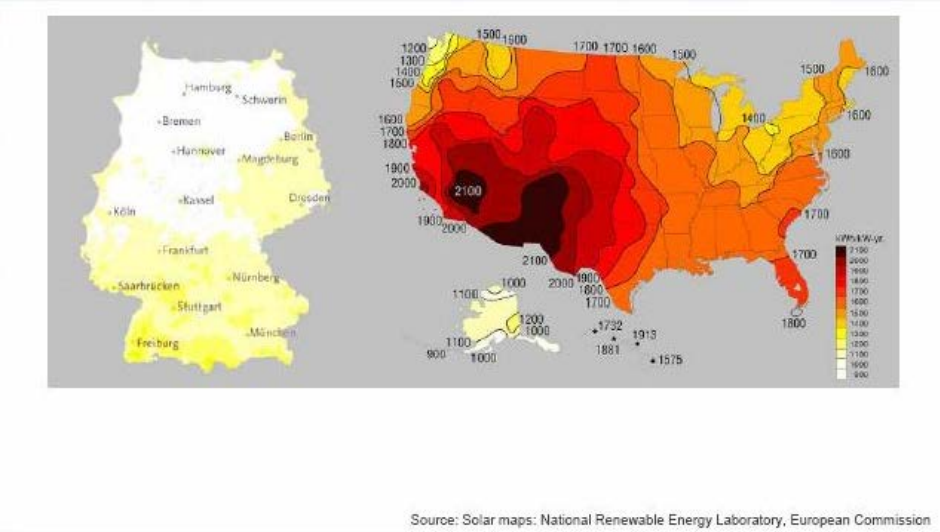


Figure 1.4: Solar Radiation - Germany and the United States

As seen in Figure 1.4, above, the potential for development of a construction method that relies on passive solar gain, such as the Passive House Standard, within the United States is great. Thus far, most of the development of the Passive House Standard has been in Europe and specifically tailored to the central European climate, which will be demonstrated throughout this thesis. The emphasis on central Europe, has created criteria for passive houses that may not be acceptable in all climate zones across the United States; However, the basic research and strategies have widespread applications in diverse locations throughout the world and once refined and developed further the potential for growth is large.

In Austria, the passive house concept has been widely adopted. Currently, passive houses hold a 20-30% market share in Austria. Figure 1.5 shows the percent market share of building types in Austria as compared to the United States. While there are tens of thousands of super insulated houses in the United States and nearly 100 certified projects, the passive house market share is less than .01% of all buildings being constructed every year.

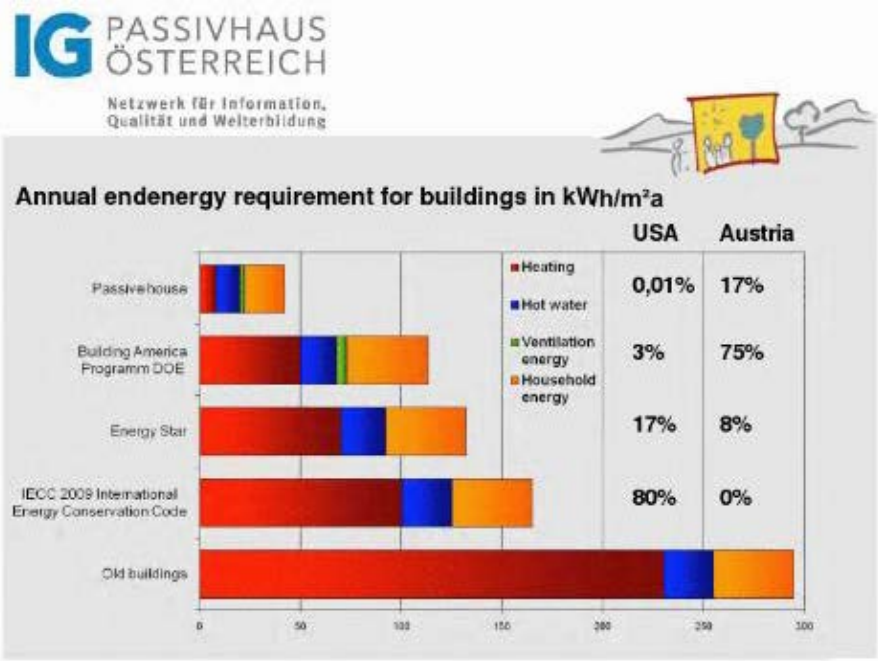


Figure 1.5: Passive House Market Share in Austria and the United States

Scandinavian countries have also been influenced by the Passive House Standard. However, there is a realization that above 60 degrees latitude, a passive house in Northern Europe becomes very difficult to achieve. Switzerland adopted the ideas of passive house into the voluntary building energy standard Minergie. Minergie was further developed into three categories, Minergie, Minergie-P, and Minergie-ECO. Minergie is an energy standard that is similar to the Energy Star standard in the United States. To be a Minergie building, the energy use must be 80% of the energy use of a building built in accordance with Switzerland's building energy code SIA 380/1 (Klaus Daniels 2009). The energy use of a Minergie-P building is limited to 20% of the energy use of a building built to the code. Reaching Minergie-P requires similar levels of envelope investment and design strategies roughly equivalent to those needed to reach the Passivhaus standard in Central Europe. Minergie-ECO has a larger emphasis on environmental impacts, such as recycled materials, of the building rather than energy use.

Between January of 1998 to December of 2001, a large study attempted to demonstrate the technical feasibility of low-cost passive houses (Institut 1998-2001). The Cost Efficient Passive Houses as European Standards (CEPHEUS) project tested over 250 different housing units in five different European countries. A group of 113 of the projects were measured and tested with the results shown in Figure 1.6 below.

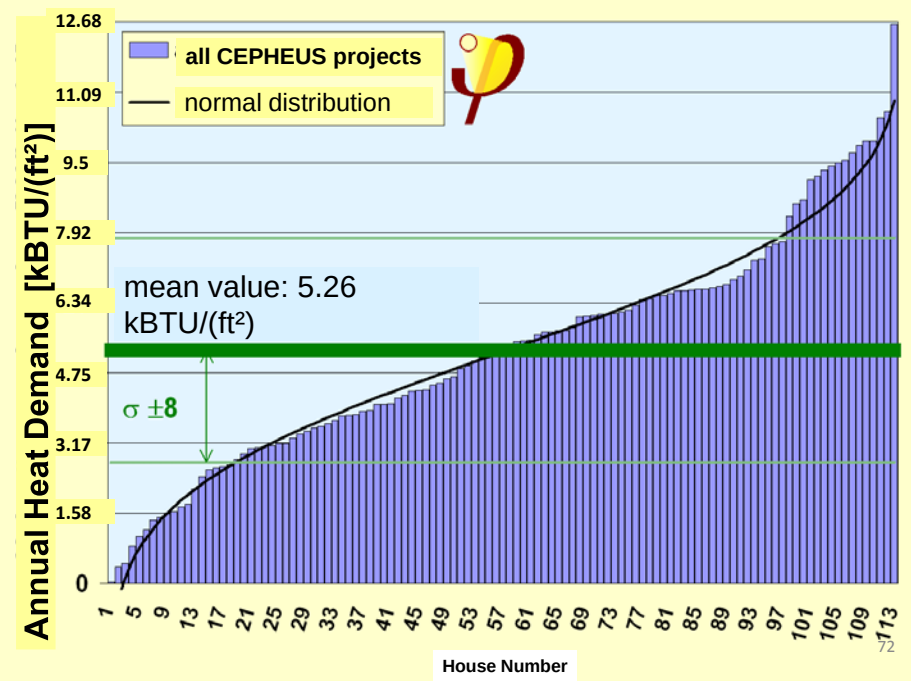


Figure 1.6: Measured Annual Heat Demand (CEPHEUS)

The y-axis of Figure 1.6 is the measured Annual Heat Demand of each case graphed from low to high heating energy use. The distribution shows a low value of 0.0 kBTU/(ft^2) and a high value of 12.68 kBTU/(ft^2) with a mean value of 5.26 kBTU/(ft^2). This shows that overall, the buildings performed worse than modeled by more than .5 kBTU/(ft^2) and that some projects used more than two and a half times the energy that they were modeled to use. This graph shows that there are wide differences and inconsistencies between projects that were modeled to be within a

rather small range of performance and shows that the units studied are underperforming as compared to the modeled energy use.

All building types are subject to this type of curve. Some projects use much more energy than others even when designed to the same standard. When the passive houses studied are compared to other building types such as code based or low energy buildings, the same curve exists. Therefore, the trend is constant across building types, but as the mean energy use in a given building type increases, those buildings that used the most energy perform worse. The occupant is the major driver of such discrepancies and deviation from modeled results. Assumptions must be made to account for human behavior and interaction with the building and those assumptions are not synonymous with the lifestyles of all building occupants. However, as seen in Figure 1.7, the most frugal occupant living in an existing building still uses more energy than even the most wasteful person studied who was living in a passive house. While the occupant cannot be fully controlled, it is possible to have an influent on their energy use based on the type of building they live in.

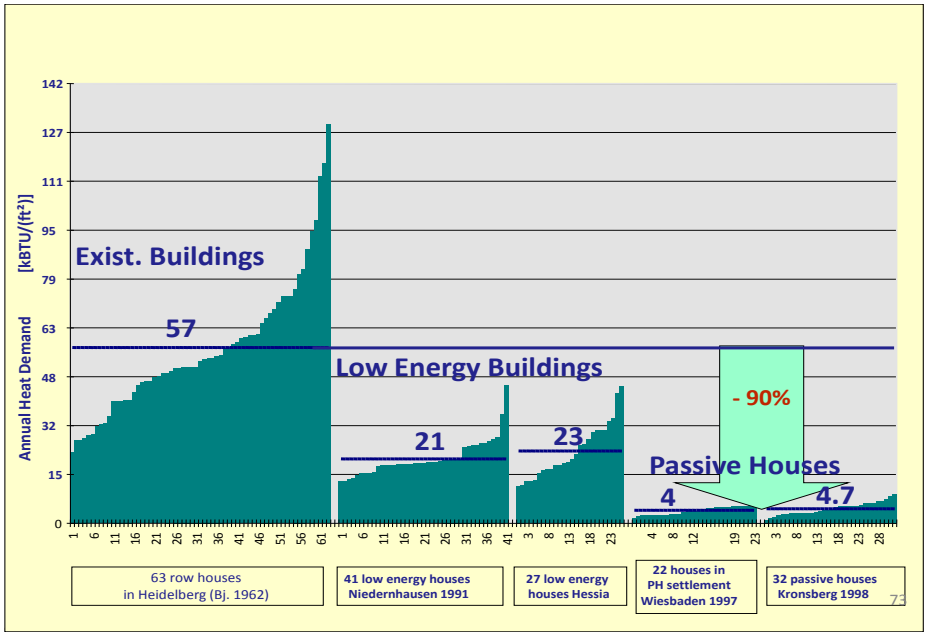


Figure 1.7: Measured Annual Heat Demand (CEPHEUS)

Current Developments

In the United States, the Passive House Standard as translated from Europe using the PHPP as the method of simulation, was first implemented in the Smith House in Urbana, Illinois by Katrin Klingenberg, co-founder of the Passive House Institute US (PHIUS). While never achieving official certification by the Passivhaus Institut, significant input into the project occurred from both within the United States and from Germany. On October 21st, 2002, ground was broken for the Smith House which was completed in 2003 (Knezovich 2002). This project was a significant achievement for many reasons including its use of triple pane Canadian windows with fiberglass frames and an imported German heat recovery ventilator with an earth tube, but most importantly, it was reasonably cost effective due to the architect-owner's knowledge and sweat equity.

Figure 1.8: Smith House

Figure 1.9: Smith House

The first officially certified *Passivhaus* in North America was constructed during 2005 and 2006 for the Waldsee BioHaus Environmental Living Center at the German Language Village in Bemidji, Minnesota (Village 2006). It received its certification from the PassivHaus Institute in 2006.

Figure 1.10: Waldsee BioHaus

The Passive House Institute US (PHIUS), a 501(c)3 non-profit organization, was founded in 2007. According to the PHIUS website, the organization "provides training, education and research to promote implementation of Passive House Building Energy standard, as well as the design approach and techniques to accomplish that standard" (US 2013). Between PHIUS' founding and the end of 2012, PHIUS trained over 800 passive house professionals with over 450 of them sitting for and passing the exam for the designation as a Certified Passive House Consultant (Klingenberg 2013). In addition to professional certification, project certification has also been on the rise since the founding of PHIUS. The development of passive house and the number of passive houses in the certification process has been on an exponential rise since the programs founding. By the end of 2012 there were almost 50 PHIUS+ Certified projects in the United States and 100 pre-certified PHIUS+ projects . These numbers are growing at their greatest rate of the past five years as the first wave of consultants have now had the time to design their first projects to meet the passive house standard. The fact that so many buildings are currently being designed throughout the country is one reason this thesis is important to the discourse of passive house in the United States.

Following the success of the Smith House, Fairview I was built at 1005 Fairview Avenue in Urbana, Illinois, in 2005. Fairview II was completed next door in 2007 at 1007 Fairview Avenue in Urbana, Illinois. Both of these projects were completed by e-colab, a non-profit organization that was the foundation of PHIUS. Upon a merger in 2007, e-colab became the non-profit building arm of PHIUS and has completed two more projects in Urbana, Illinois. One on Washington Avenue in 2011 and another at 1302 Dublin Avenue in August 2012 respectively. The projects completed by e-colab have not only created low cost, sustainable homes for the local community of Urbana, but have been experimental testing centers for the fledgling passive house community in the United States.

Other early showcases of passive houses in the United States were built as entries for the United States Department of Energy's Solar Decathlon. The Solar Decathlon is:

> "an award-winning program that challenges collegiate teams to design, build, and operate solar-powered houses that are cost-effective, energy-efficient, and attractive. The winner of the competition is the team that best blends affordability, consumer appeal, and design excellence with optimal energy production and maximum efficiency" (Energy 2013a).

In 2007, Team Germany brought a passive house to the National Mall in Washington DC and took home first place. In the 2009 Solar Decathlon competition, Team Germany again submitted a passive house, but another team, Team Illinois from the University of Illinois at Urbana-Champaign, also competed with a passive house design. The teams finished the competition in first and second place respectively, with the major difference being size of the installed solar systems on the two projects. The two houses also finished the competition for energy balance in first and second place, which meant the two homes were the largest net energy producers of the competition, which can be attributed to their meager energy consumption.

Figure 1.11: Team Germany 2007

Figure 1.12: Team Illinois 2009

Shortly after completion of the 2009 Decathlon, the first certified Passive House Retrofit was completed in Sonoma California. The O'Neill Residence, built in 2010, was a collaboration between Solar Knights and CPHC Jarrod Denton and was extensively analyzed by Graham Irwin of Essential Habitat Consulting. The house was a rehab of a "U shaped" ranch house that was slab on grade and was completely renovated on both the inside and the outside to add new insulation, windows, doors, and mechanical systems as well as cosmetic upgrades such as siding, roofing, flooring, kitchens, and baths. Not to detract from the accomplishment of such a retrofit or the project team responsible for such a project, but the climate in Sonoma, California, allows for the passive house standard to be achieved more easily than many other places in the United States. However, the project did utilize some pioneering innovations in the market in terms of materials (rockwool insulation, aerogel, and lift slide patio doors) and technological simulation methods (sensitivity analysis).

Figure 1.13: O'Neill Passive House

The year 2010 brought many evolutions to passive house design and adoption in the United States. More climate zones, in addition to the cold and mixed, were being experimented with for the first time. One of these, 204 Whit, was designed by Corey Saft a professor at University of Louisiana at Lafayette. The house which is located in Lafayette, LA used many of the basic passive house techniques from heating dominated climates, but most importantly it also used passive house energy modeling tools to design the house so that it met the passive house standard in a traditionally cooling dominated climate. Through this project, humidity and latent loading were analyzed for the first time in a built passive house in the United States. Problems with the energy recovery ventilator bringing excess humidity into the home were discovered upon occupation, but with adequate occupant training explaining how the system works, the problem was corrected and the passive house technique was shown to be successful in a high humidity, southern climate.

Figure 1.14: 204 Whit

Not only were different and sometimes extreme climates being explored, but so were varying types of buildings. The Center for Energy Efficient Design (CEED), designed and built by Adam Cohen of Structures Design Build, is a small school building. When built, it was the first school and one of the first non-residential buildings to meet the Passive House Standard in the United States. Mr. Cohen has continued to diversify the building types utilizing the Passive House Standard from dentist offices to religious structures, to the first large scale dormitory project in the United States which will house over 115 students at the College of Emory and Henry in Emory, Virginia. These buildings accelerated the process of determining the importance of process loads and the internal electricity loads, and therefore internal heat gains (IHG's), in passive houses. Though this has been done for European locations, it has now been pioneered using the typical consumption and usage patterns for the United States.

Small office buildings were also being designed. The Omega Institute for Women's Studies in Rhinebeck, New York, is a small office building attached to a much larger institutional complex. The consultant, Stephanie Bassler, worked with the Omega Institute and their contractor to develop a ten person office wing. This project is also notable because the

client has been using cutting edge energy efficiency standards on a campus that also includes a building that meets the Living Building Challenge which, among other things, distinguishes the building as both net zero energy, net zero water, and stringent materials limitations.

Another firm on the leading edge of the passive house movement is GO Logic, a design-build partnership in Belfast, Maine between builder, Alan Gibson, and architect, Matthew Omalia. The GO House, shown in Figure 1.15 has won numerous awards such as the U.S. Green Building Council (USGBC) 2011 LEED for Homes Project of the Year Award and the EcoHome Grand Award 2011 from EcoHome Magazine. It was also the first passive house in Maine and was certified LEED Platinum. The firm's next project, the TerraHaus, expanded on the concept and the form, but developed additional rooms for a small, ten occupant dormitory building at Unity College. The TerraHaus has also won multiple awards including a 2012 AIA New England Citation Design Award, the EcoHome Grand Award 2012 from EcoHome Magazine, and Eco Structure Magazine's 2012 Evergreen Award winner.

Figure 1.15: GO Home

Figure 1.16, outlines the adoption of passive houses in the United States by number of certified projects. The darker colors are those units that were built in previous years, while the

lighter colors signify units built in the current year. The projected bar indicates that 50 buildings would be certified in 2013 in the United States. This figure can be directly related to Figure 1.2, which shows the initial adoption curve for passive house in Europe. The trends shown in both figures have many similarities including a tremendous increase in built passive house projects in each location and a projection to continue experiencing exponential growth.

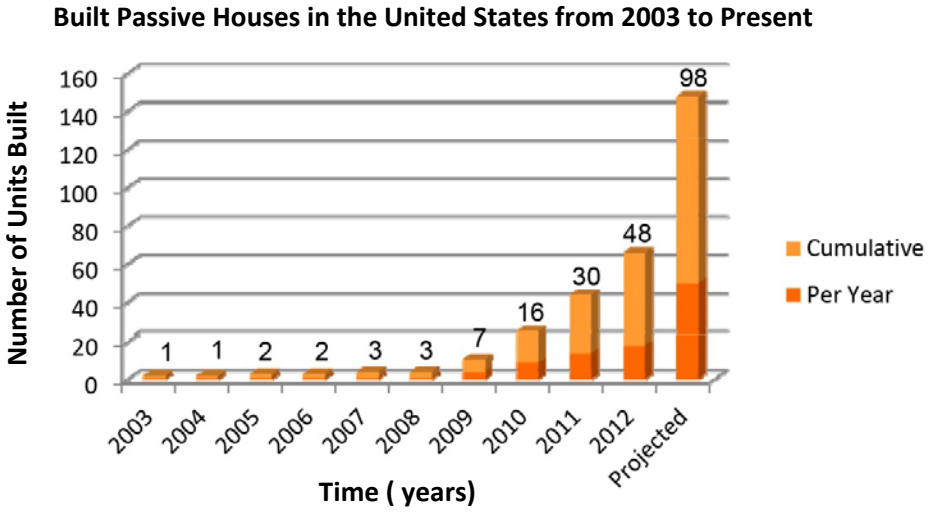


Figure 1.16: Certified Projects - PHIUS Data (North America)

Worldwide, passive house organizations have been developing along with the development of passive house as a certification standard. Many organizational and certifying bodies throughout the world also have membership organizations to drive collaboration, education, and marketing for the more technical bodies they represent. As mentioned earlier, the Passivhaus Institute (PHI) in Darmstadt, Germany was the originator of the Passivhaus Standard. The membership and marketing branch of the PHI is the International Passive House Association (iPHA). In the United States, the certifying and technical body is the Passive House Institute US (PHIUS) and its membership organization is the Passive House Alliance US (PHAUS). In many countries there are other certifiers and organizations working specifically in passive houses.

According to the PHI, there are 27 international certification bodies throughout the world able to certify to the Passivhaus Standard (Institut 2012).

On August 17th 2011, the PHI issued a letter entitled "Passive House: a public good" to the U.S. marketplace severing ties with PHIUS as a certifier and certified trainer of the Certified European Passive House (CEPH) Curriculum (Fiest 2011). There were many reasons and events that led to the split between the two largest passive house organizations in the United States, but a difference and mistrust between the specific personalities and visions of the two organizations were more at fault than any specific example, proposal, contract breach, or lapse of good faith.

One specific point of contention was about how projects would become certified. The Passive House Institute US was developing an additional certification process that required an onsite quality assurance and quality control component for every project. This requirement was to be completed by a third party verification agency. In many projects this became a Residential Energy Services Network (RESNET) Home Energy Rater. Through this requirement, all passive houses would be given a Home Energy Rating System (HERS) Index score.

The PHIUS+ Certification process was part of a larger effort to bring greater mainstream influence and acceptance to the passive house movement in the United States by joining with established programs in the United States that had similar goals as passive house. With a HERS Index score, project teams are well on their way to meeting other certifications such as the US Department of Energy's Challenge Home, the Environmental Protection Agency's Energy Star for Homes program, and being eligible for both government and local utility incentives.

These actions also began partnerships with many organizations both in government and the private sector. As mentioned earlier, the US Department of Energy and RESNET were major connections that passive house was able to develop while implementing PHIUS+. However,

there were other partnerships forged in 2012 such as a relationship with the Fraunhofer Institute of Building Physics (IBP), Building Science Corporation (BSC), and Green Expo 365.

To facilitate mainstream adoptation, builder training programs were introduced to change the paradigm of construction in the United States. The Fraunhofer Institute of Building Physics developed an additional software package to use in the modeling and verification of passive houses. Called WUFI Passive, this software was introduced to allow passive house modeling, a static model, and dynamic modeling capabilities using the same software. The software is a "black box" software package as compared to the fully programmable excel based PHPP. This type of approach has strengths and weaknesses but, for mainstream users, it is preferable because of its ability to remain corruption free, build project libraries, and update projects as the software is continually upgraded. For this study as mentioned earlier, the PHPP was utilized for its ability to be programmed and automated.

Figure 1.17 illustrates the annual energy usage for each of the following standards: Passive House, Building America, Energy Star, IECC 2009, and Old Buildings (the average existing building stock). The DOE Challenge Home program, mentioned on page 24, is difficult to compare directly with the efficiency of the Building America Program shown in the benchmark graph below, but Challenge Home does fall between Energy Star and Passive House. Below Figure 1.17, Figure 1.18 was created by the 2030 Challenge, headed by Edward Mazria. The target is to have every building be a net zero energy building by 2030 with periodic reductions as time moves towards that target. All passive houses are meeting the 70% reduction benchmark and most are meeting the 80% reduction benchmark. Those projects utilizing renewable energy are often meeting the 2030 Challenge benchmarks today.

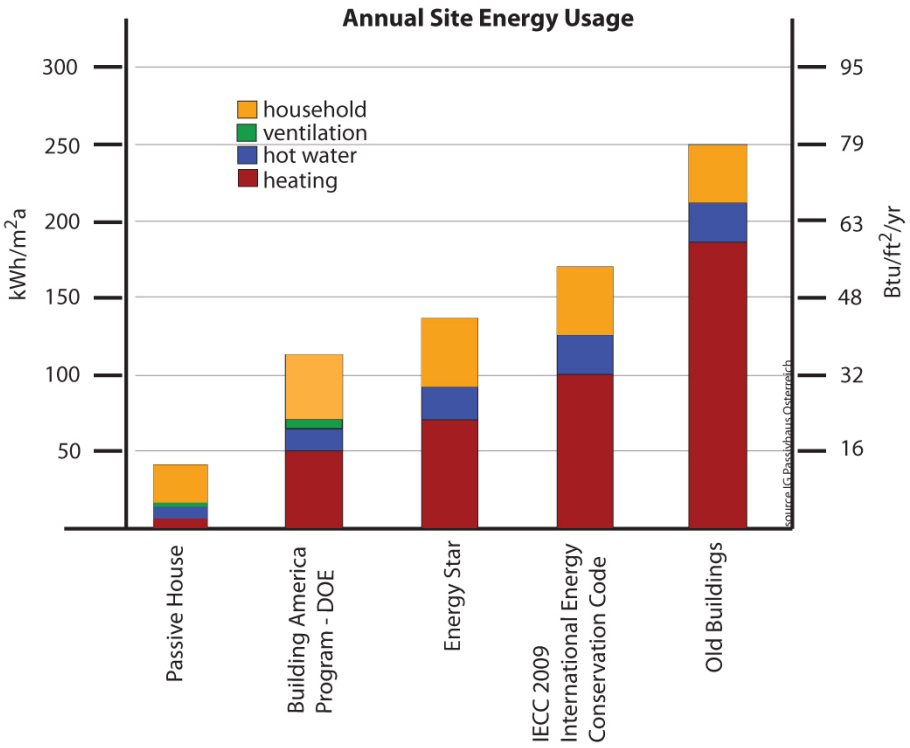


Figure 1.17: Energy Programs

U.S. Averages for Site Energy Use and 2030 Challenge Energy Reduction Targets by Space/Building Type[1] From the Environmental Protection Agency (EPA): Use this chart to find the site fossil-fuel energy targets									
Primary Space / Building Type[2]	Available in Target Finder[3]	Average Source EUI[4] (kBtu/Sq.Ft./Yr)	Average Percent Electric	Average Site EUI[4] (kBtu/Sq.Ft./Yr)	2030 Challenge Site EUI Targets (kBtu/Sq.Ft./Yr)				
					50% Target	60% Target	70% Target	80% Target	90% Target
Single-Family Detached		76.6	-	43.8	**21.9**	17.5	13.1	8.8	4.4
Single-Family Attached		70.7	-	43.7	**21.9**	17.5	13.1	8.7	4.4
Multi-Family, 2 to 4 units		93.2	-	58.2	**29.1**	23.3	17.5	11.6	5.8
Multi-Family, 5 or more units		99.4	-	49.5	**24.8**	19.8	14.9	9.9	5.0
Mobile Homes		153.2	-	73.4	**36.7**	29.4	22.0	14.7	7.3

Figure 1.18: Energy Programs

From the figures above, it can be reasoned that passive houses are some of the lowest energy houses on the market today. However, many builders are not stopping there and are pushing the energy efficiency of the home beyond passive house by utilizing onsite renewable resources and other technologies. Many passive houses can be net zero energy with the addition

of a small photovoltaic (pv) system, commonly known as solar panels. Solar thermal panels are often being utilized for creating hot water as many passive houses have a larger energy demand for hot water than they do for heating and cooling. There are also now positive energy buildings and buildings that are designed to have enough energy to power an electric car or other features of contemporary life.

Passive House Basics

In its most basic form, a Passive House is a low energy building that contains high levels of insulation and is nearly airtight. As a standard, passive house is a performance based and verifiable building energy metric that is based partially on global carbon reduction and therefore the economic feasibility to society (K. Klingenberg 2013). A passive house is a building that results in an energy efficient structure, by promoting efficiencies in the building envelope. Figure 1.19, below, shows the energy balance on a given building with heat losses on the left and heat gains on the right. All buildings must balance heat gain with heat loss. Any difference between the gains and losses must be made up by active conditioning or the interior temperature will not be held constant within a comfortable range. In the image below, the heat demand is the difference between the gains and losses. By reducing the losses, fewer gains are needed to balance the gain to loss equation. This equates to less heating energy needed to achieve balance. Therefore, the basis of the passive house concept is to limit the losses through the envelope to the point where the heating energy necessary to maintain comfortable conditions is very low.

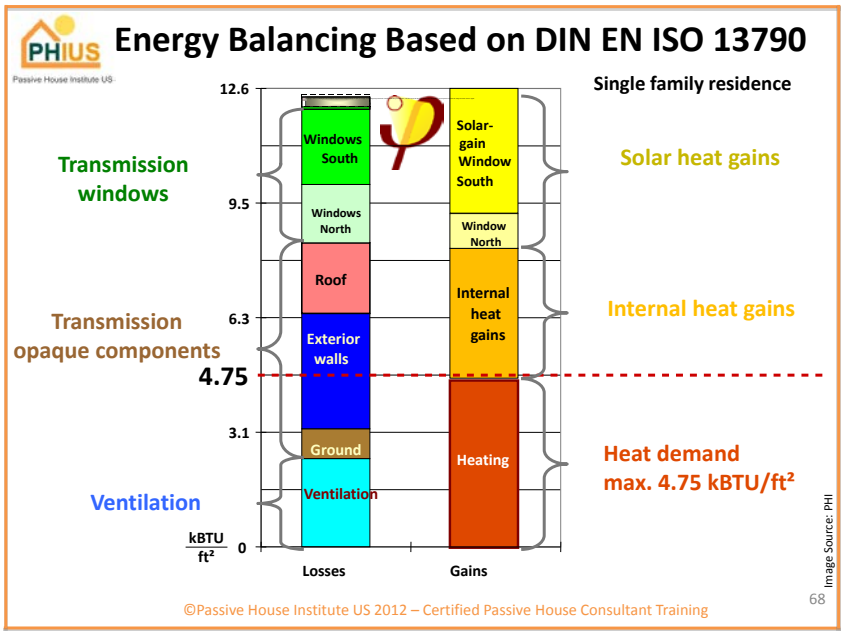


Figure 1.19: Energy Balance

To limit the heating energy, the building's envelope must be optimized according to its climate. Envelope optimization is an integral portion of the gain to loss energy balance because it has the largest impact on the losses of the building. The envelope components with the greatest surface area are generally the opaque surface areas. However, if the amount of glazing is extremely high, transparent areas can have higher losses. Therefore, careful consideration of amount of insulation for a given envelope assembly is of the utmost importance. Besides the criteria of lowering the losses to lower the annual heating demand, insulation thickness can be determined by the interior surface temperature necessary to maintain radiant comfort conditions. These criteria will be used later in the thesis to establish thresholds for insulation amounts and will be explained fully, but the important point is that as the temperature difference between inside and outside becomes more extreme, more insulation is needed to keep the interior surface temperature closer to the interior air temperature rather than the outdoor ambient air temperature.

The influence of surface temperature and comfort was one criteria used to determine the certification threshold for the central European climate.

Another source of envelope losses is through thermal bridging. The insulation must not just be thick, but it should also be continuous. Non-continuous insulation generally results in a thermal bridge. The technical details, formulas, and limits behind thermal bridging will be explained in detail in the next chapter. To achieve passive house certification, in most cases and all cases that are in heating dominated climates, the slab, basement, or crawlspace need to be insulated or the losses to the ground become too great to meet the standard. The most common method for insulating under slab is expanded polystyrene insulation. Without some type of insulated break, the ground to building connection can easily become a thermal bridge.

As shown in Figure 1.19, one of the largest causes of losses, as well as gains, are the windows. The windows are important because of the impact they have to both sides of the energy balance equation. As building components, windows have the ability to lower losses and increase the available free heat gains. Specifically, this ability is confined to the glazing itself. Window frames do not allow solar gains, and generally perform more poorly in limiting losses than the glazed portion of the window does. The performance values for glazing are the solar heat gain coefficient (SHGC) and the U-Value. As the SHGC goes up, the gains increase and as it goes down, the gains decrease. Likewise as the U-Value increases, heat losses increase and as the U-Value deceases, the heat losses decrease. For a passive house or any passive solar building, the ideal glazing is one that has a high SHGC and a low U-Value. However, in most instances the U-Value and SHGC have an inverse relationship. As the gains increase due to an increase in the SHGC the losses also increase due to an increase in the U-Value. Generally, glass that has an

extremely good U-Value does not have a high SHGC. To limit the transmission losses, in almost all cases, triple pane glazing must be used to meet the passive house standard.

The level of airtightness of a passive house severely limits the amount of infiltration and the corresponding heat loss due to infiltration is very low. However, the losses that are eliminated by low infiltration are replaced by the losses through ventilation air. Due to a lack of air changes from infiltration, mechanical ventilation is necessary to provide the fresh air necessary for good indoor air quality. The mechanical ventilation creates losses by exhausting conditioned air from the building and replacing it with outside air. The temperature difference between the exhaust and supply airstreams is the cause of the energy loss. This loss is tempered by the mechanical ventilator which contains a heat recovery device. This heat recovery allows for the efficient replacement of infiltration with ventilation while at the same time limiting losses and making the building more energy efficient overall.

The gains are composed of internal and solar gains. Internal gains occur in all buildings from people, appliances, pets, and other sources, and are greatly influenced by the usage patterns and impacts of the buildings occupancy. Solar gains are based on the amount of radiation that enters the building through the glazed surfaces. Combined, these gains help to offset the losses on the left side of Figure 1.19. When gains are less than the losses, heating is needed and when gains are larger than the losses, cooling is needed. The goal of passive house is to keep the gains and losses as close as possible and this requires optimization, specifically, the optimization of the building's envelope. But to optimize the envelope, other factors such as occupancy and mechanical systems should be as planned as precisely as possible. Because the internal gains can have a large impact, if the building is designed for a particular occupancy condition but is used differently from that condition, the optimum point of envelope optimization changes. This can

lead to a different envelope design to balance the gain to loss equation. Once the parameters are set, the envelope optimization should be based on cost, environmental impact, and comfort.

While the above describes the appearance and components used in most passive houses, it does not explain how the certification criteria came to be. In most climates, including central Europe, where the passive house certification criteria were established, meeting the criteria for heating is more difficult than meeting the criteria for cooling. A founding principal of the certification criteria was finding a cost effective approach to building low energy buildings. As shown in Figure 1.20, the capital cost to build increases as the amount of energy used in a building decreases. This increase is caused by the additional investment in insulation, windows, air sealing, and other energy conservation strategies used to construct low energy buildings. The cost of envelope investment, shown in Figure 1.20, in construction cost in Euro's per square meter, continues to increase until a certain point where the upfront construction cost drops. The point at which the downward spike occurs on the investment curve is where a traditional heating system can be removed and replaced with a minimized mechanical system. After that point, the investment cost again increases very quickly to a point where envelope investment may no longer be economical.

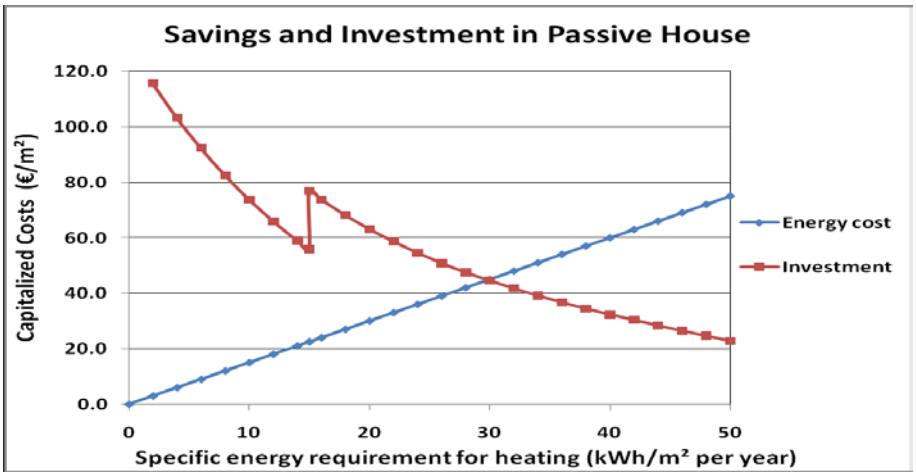


Figure 1.20: Initial Cost of Investment to Passive House

Figure 1.21 shows the same investment curve, but this time, the total cost including energy use over the buildings lifetime has been accounted for. The new curve shows that a passive house is the most cost effective building that can be built. It is more cost effective than many low energy houses because the cost savings of the mechanical system offsets the cost of additional insulation and components. The passive house is also more cost effective than net zero energy buildings because it forgoes the large investment in active renewable energy systems.

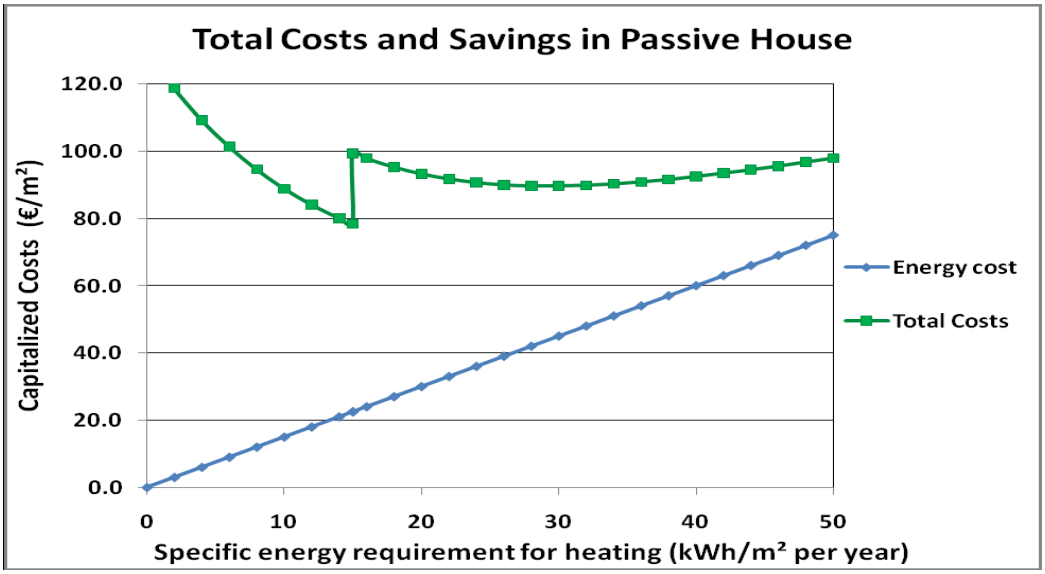


Figure 1.21: Total Cost of Investment to Passive House

As mentioned earlier, the drop in investment cost in the figures above is due to the downsizing of the mechanical system. This drop does not occur just because the loads are smaller and the space conditioning system is smaller. It is also a product of an entirely different system for supplying heat to a building. The traditional radiator system or the traditional air handler that takes return air and distributes it through a network of supply ducts into living spaces are removed and replaced by a mechanical ventilation system with heat recovery and an inline heating coil. The principle behind the system is that the mechanical system is minimized and that the amount of air flow necessary for ventilation is a very small amount. With the high

levels of envelope investment, the Heating Loads are also very small. The functional definition of passive house is that the supply air heating system is able to transport all the Heating Load. In the central European climate, the maximum heating load of 10 W/m² is the amount of heat able to be transported by the supply air of the mechanical ventilation system. The following equation shows the derivation of the amount of heat the supply airstream can carry.

$$\mathbf{P_{H,\,Supply} = V * \Delta\vartheta * \rho c_p} \quad (1.1)$$

$$\mathbf{In\ Metric = 1\ m^3/(hm^2) * 30\ K * 0.33\ Wh/(m^3K)} \quad (1.2)$$

$$\mathbf{In\ Imperial = 3.26\ ft^3/(hr.ft^2) * 54F * 0.018\ BTU/(hr.\ ft^3\ °F)} \quad (1.3)$$

$$\mathbf{= 10\ W/m^2\ (3.17\ BTU/ft^2hr)} \quad (1.4)$$

where:

V Ventilation rate (per person per area)

$\Delta\vartheta$ Difference between 68 F and 122 F (aka ΔT)

ρc_p Heat capacity of air (aka c_{air})

The amount of heat able to be carried by the ventilation air stream is very small. For this amount of heating to be provided by the supply air, the envelope must be good enough to limit the losses until they are also very small. In fact, in many climates, the supply air flow rate is not able to carry the amount of heat needed for space conditioning. Buildings in cold climates have an especially difficult time meeting the peak heat load criteria. In central Europe, a building with a peak heat load limit of 10 W/m² (3.17 BTU/ ft²hr) would have an annual space heat demand roughly equivalent to 15 kWh/(m²a) (4.75 kBTU/ft²yr). This relationship between annual and peak energy use varies depending on climate and the design of the building and does not hold true outside of climate zones that resemble central Europe.

It is very difficult to adjust the variables in Equation 1.1 to increase, or decrease, the amount of transportable heat. The ventilation rate is set at a constant. Adjustment of the rate would increase the amount of losses through the ventilation system and risk over ventilation, which can cause such problems as very dry air during the heating period. Ultimately, an increase in the ventilation rate leads to an increase in overall heating energy, which is counter to the goals of passive house. The temperature difference also cannot be adjusted. The interior temperature is set at a constant, comfortable temperature. To increase the heat above the limit of 122 degrees Farenheit will have an effect on indoor air quality and occupant comfort. For instance, dust particles begin to char and go through pyrolysis at some point above 122-126 degrees depending on source and other characteristics. The heat capacity of air is a constant value that is difficult to adjust in real-world settings. While it does vary in accordance with air temperature, pressure, and humidity, it does not vary widely, especially within the heated supply air and interior environment conditions. Therefore, for calculation purposes, it is left at the default. The combination of the above effects outlines the difficulty of providing more heat through the ventilation system. To achieve supply air conditioning, the only method is to lower the buildings losses until this small amount of heating is sufficient. This is the functional definition of a passive house.

For cooling and dehumidification purposes, Equation 1.1 works much the same way with many of the same limitations. In these cases, similar to the heating case outlined above, it is difficult to increase the conditioning capacity of the ventilation air. For cooling, the ability to use ventilation air for conditioning is further complicated because the temperature difference between the cooled air and the room temperature is even less than the 54 degrees that it would be assuming the heating temperature of 122 degrees Fahrenheit. Because the supply air coil

could freeze, the air simply cannot achieve low temperatures. With the temperature difference being roughly half that of the heating temperature difference, only about half of the load for conditioning can occur given the other variables are held constant as described above. Dehumidification through ventilation air works similarly to that of heating and cooling in passive houses. In a traditional building, dehumidification occurs as part of the cooling process. As air moves over a cold coil or loop, condensate forms and condenses out of the air stream thereby dehumidifying the air stream before it reaches the occupant. When the cooling load is very small, not enough dehumidification can occur because the amount of cooling needed is very small. While cooling is limited in a passive house, interior moisture sources, such as showers, baths, laundry, and cooking are similar to the moisture sources in a typical house. This leads to an imbalance where it is difficult to provide dehumidification exclusively through space conditioning, which is especially true in very humid climates where ventilation air also contributes to the interior humidity levels.

While the basic principle of the Passive House Standard criteria is the elimination of the traditional heating system so that supply air heating can be used to save energy and capital costs, there are other principles of passive houses that were byproducts of what was needed to achieve the standard criteria. Occupant comfort is written into the standard in the form of recommendations and best practices rather than distinct and precise criteria for certification. However, using the strategies needed to achieve the functional definition of passive house inherently creates a situation where superb occupant comfort can be found. Through insulation and glazing, warm interior surface temperatures are ensured. Along with warmer surface temperatures, temperature stratification does not occur. These warm temperatures reduce the radiation of heat from a warm body to a cold window or wall surface, thereby ensuring thermal

comfort. The level of airtightness needed to meet the criteria for energy use and for durability concerns also creates an environment that is draft free. The ventilation system brings in fresh air and uses highly rated MERV filters to clean the air. Bringing in fresh air while eliminating leaks in the building envelope leads to an indoor environment that has indoor air quality superior to that of conventional buildings. High levels of insulation, an airtight building envelope, and a low flow ventilation system all contribute to a very quiet environment with little noise penetration from the outside and very low noise generation on the inside.

Environmental concerns were a major component of the original concept for the development of the low energy building research that eventually resulted in the Passive House Standard. In the current standard, all of the environmental concerns get summed as energy use in the form of a Primary Energy Demand. The Primary Energy Demand is a measure of the energy use of the building and is thought to be a measure of impact on to the larger society and ecology. By using Primary Energy Demand, rather than site energy, quantifying the buildings energy use is a measure of the amount of energy produced at the power plant to feed the building's energy need. Primary Energy Demand impacts the creation of the energy, rather than just its usage on site and therefore, has further reaching implications than that of the buildings on site characteristics. Other concerns that are listed as environmental can often be thought of in terms of cost as well. One of the major concerns that critics of the standard have is that the levels of insulation or other products are not justified by the savings in energy or other benefits over the projects life cycle. More detailed examinations of environmental concerns are again not required to achieve the Passive House Standard, but life cycle costs, carbon neutrality, and sustainability are concerns that are addressed in an oblique way by the Passive House Standard either through the Primary Energy Demand, or recommendations and best practices.

Passive House Certification Criteria (for reference - Figure 1.1):

Criteria	**I.P. Units**	**S.I. Units**
Annual Heating Demand:	4.75 kBTU/ft2yr	(15 kWh/(m2a))
or Peak Heating Load:	3.17 BTU/ ft2hr	(10 W/m2)
Annual Cooling Demand:	4.75 kBTU/ft2yr	(15 kWh/(m2a))
Annual Primary (Source) Energy Demand:	38 kBTU/ft2yr	(120 kWh/(m2a))
Air Infiltration rate :	n $\leq$ .6 ACH50	(air changes per hour at 50 Pascal's of pressure)

This chapter has outlined the history of passive house, covered passive house basics, and explained the functional definition of passive house as being a building in which space conditioning can be provided through the fresh air ventilation system. The coming chapters will detail the design and results of an experiment that tests the feasibility of the Passive House Standard to be transplanted out of the central European climate and implemented throughout the various and diverse climate zones in the United States. When the Passive House Standard is transplanted into unique climates, it becomes apparent that the Peak Heating Load of 3.17 BTU/ft^{2}hr (10 W/m^2) does not equate to an Annual Heating Demand of 4.75 kBTU/ft^{2}yr (15 kWh/m^{2}a) as it does within central Europe. This relationship between the Peak Heating Load and the Annual Heating Demand is dependent on building design and most importantly the climate. This means that the optimum levels of envelope investment in terms of conserving energy, may not allow for space conditioning through supply air. This thesis seeks to find the point, for each climate data location in the United States, at which envelope investment is optimum using passive house standards. For many locations, the energy use requirement for space conditioning would need to be made less stringent to meet this optimum level, but for many other locations, a tightening of the space conditioning criteria would lead to more saving and buildings with optimum levels of envelope investment.

Chapter 2

Method

Outline and Process

This study utilizes a full factorial experiment to quantitatively analyze the Passive House Standard for use in the United States. The results were determined through multiple building energy simulations using the Passive House Planning Package (PHPP) to analyze existing criteria for the certification of buildings as passive houses including the Annual Heating Demand, Peak Heating Load, Annual Cooling Demand, Peak Cooling Load, and Primary Energy Demand. The full factorial experiment was able to distill the inherent complexity of a building into variables that could be quantitatively studied through multiple iterations. The first step in creating the experiment was determining which of the building's components would be held constant and which would be part of the independent variables. The constants consisted of a simulated building and the corresponding additional inputs needed for the energy model. There were also independent variables, shown in Figure 2.1, which were varied as part of the full factorial experiment. In each climate location, one value of the independent variables was changed until every possible combination was simulated. The dependent variables, also shown in Figure 2.1, are the major certification criteria used to certify buildings to the Passive House Standard. More information on the values used for the constants, variables, and climates will be described in-depth throughout this chapter.

Independent Variables	Dependent Variables
Wall R-Value	Annual Heating Demand
Roof R-Value	Peak Heating Load
Slab R-Value	Annual Cooling Demand
Window R-Value	Peak Cooling Load
Window SHGC	Primary Energy Demand
Glazing Percentage	

Figure 2.1 - Independent and Dependent Variables

As previously mentioned, the simulation was a full factorial study that varied the values of the independent variables at set thresholds. This was repeated for each climate location. The independent variables were represented by building components, such as windows and insulation, as numeric values. The independent variables in the full factorial experiment were the factors that had the largest percentage impacts on the energy balance of the building. The variables were chosen because of their relationship to the performance of the building envelope and energy conservation through passive means. These variables were most influenced by the outdoor climate. Therefore, they were the variables that were of the most interest when testing the applicability of the Passive House Standard for different climate zones. For example, increasing the efficiency of the ventilation system would save energy, but it would not relate to the envelope design because an increase in the system's efficiency would allow for better performance in every climate. In contrast, the Solar Heat Gain Coefficient of the glazing could have a large impact on the energy use and was very climate specific. Depending on whether the climate was heating or cooling dominated, a different value could produce the optimal outcome. Because of this inherent complexity and multitude of parts that comprise a building, the vast majority of the building's details were held constant. Most of these details have no effect on energy performance, but some of them do influence the energy performance values the study analyzed. However, most of these influences were minor, commonly standardized, or had typical values for most energy simulation purposes.

The independent variables were the wall R-Value, roof R-Value, slab R-Value, window R-Value, SHGC of the glazing, and Southern glazing percentage. A full factorial experiment consists of factors, shown above as the independent variables, and levels, or the possible values of those factors. Figure 2.2 shows the variables to be tested using small increments between the

values. Due to the number of levels, the intervals between the values within each variable are relatively fine. The six factors worked independently of one another and reached a high level of detail because the flexibility between the factors allowed them to discover the best case based on the climate data. Within this experiment, every value was tested in every possible combination, with all of the variables working independently of one another, until all unique combinations were tested.

Wall R-Value	Roof R-Value	Slab R-Value	Window R-Value	Glazing SHGC	South Glazing Percentage
10	30	0	2	.2	5
20	40	5	3	.25	10
30	50	10	4	.3	15
40	60	15	5	.35	20
50	70	20	6	.4	25
60	80	25	7	.45	30
70	90	30	8	.5	35
80	100	35	9	.55	40
90	110	40	10	.60	45
100	120	45	11	.65	50

Figure 2.2: Parametric Variables - Ideal

In a full factorial experiment, each factor is varied until every potential unique case has been simulated. This leads to large amounts of data because the number of combinations grows exponentially as a level or factor was added. For instance, if there were three factors, each with three levels, then the number of unique combinations would equal 3^3 or 27 total combinations. In Figure 2.2, above, there are 6 variables with each variable consisting of 10 levels, or values. In this case, the number of unique combinations would be 6^{10} or 60,466,176 combinations. That

many combinations would be difficult and costly to simulate, and nearly impossible to analyze, due to the overwhelming amount of data that would be generated for that many combinations for each of the 1000 climate datasets in the United States. To limit the number of combinations generated per simulation, the number of variables and their interactions were simplified. To do this, the R-Values for the wall and roof were linked so that they moved in tandem. This removed one variable and ten levels from the experiment's design. This decision limited the ability of these factors to work independently, but the effect on the final results was minimal because there were few instances where the wall value would be extremely high, such as R-100, while the roof value would be extremely low, such as R-30. Usually, the R-Value is increased consistently across all assemblies to keep the insulation at a cost effective level with slightly higher values in the roof due to the ease of installation and often slightly lower cost due to that fact. The slab was left independent from the other insulation values. Because the floor or slab insulation can have large impacts both on heating and cooling and in varied climates, the best results may be achieved by having very high roof and wall insulation while having very low or nonexistent slab insulation. Combining all insulation levels would have allowed for fewer cases and smaller data sets, but would have limited the program's ability to find the best combinations of insulation for all climates.

Additionally, the intervals between the variables for the windows were increased so only half of the levels per variable were simulated. The removal of these levels had a minimal impact on the outcome of the final results because the distance between the levels was still relatively small and representative of the window choices that are available in the current marketplace. Figure 2.3 shows the adjusted variables.

Wall R-Value	Roof R-Value	Slab R-Value	Window R-Value	Glazing SHGC	South Glazing Percentage
20	40	0	3	.2	5
30	50	5	5	.3	15
40	60	10	7	.4	25
50	70	15	9	.5	35
60	80	20	11	.6	45
70	90	25			
80	100	30			
90	110	35			
100	120	40			

Figure 2.3: Parametric Variables - Actual

There were five total factors, or variables, as the wall and roof have been combined to act as one variable. Therefore, two of the variables had nine levels and other three had five levels, this lead to 10,1025 unique cases. The cases were initially created using JMP Pro, but because JMP has a limit of 10,000 variables in full factorial experiment design, the final factor, the glazing percentage, was added to the test matrix manually within Excel before the simulation was run. The test matrix for the full factorial experiment was then imported into the simulation engine.

Before the experiment could be run, the constants were input into the Passive House Planning Package. These consisted of building characteristics of the baseline building and the additional inputs needed for the PHPP. Many of these additional inputs were default PHPP values based on the building characteristics listed below:

- Single family residence
- Two story, slab on grade

- 1600 square feet of treated floor area (~800 per floor)
- Interior floor plan dimensions 23 ft. x 38 ft.
- Orientated with long sides facing North / South
- 9 ft. ceiling heights
- Roof truss with horizontal ceiling insulation

Using these characteristics led to specific entries in the PHPP and assumptions based on occupancy, usage patterns, internal heat gains as well as additional implied information about the building such as the level of thermal mass, the mechanical system, and other details that were not directly pertinent to the tested variables. The constants entered in the PHPP and the reasoning behind the specific values chosen are discussed in Chapter 3 to allow for understanding of both the entries and the method to allow for the study to be reproduced for further research.

Simulation Engine

All simulations in the study were completed using the Passive House Planning Package (PHPP). The PHPP is a modeling tool developed by the Passivhaus Institut specifically for energy analysis of passive houses. The PHPP is a static, or steady state, model, which means the simulation occurs for a set condition, such as a set temperature difference for the calculation of transmission losses. In this case, the set condition varies monthly and is then summed to create annual results. This is in contrast to a dynamic model where the input values, mainly climate data, are varied on a more frequent time step, such as every hour or every fifteen minutes. While dynamic models are more robust and can assess different characteristics of the building, such as hygric buffering, interior comfort conditions, and thermal mass effects, for single family residential passive houses, this is generally not necessary. Steady state modeling is an adequate

method of simulation in a typical passive house due to passive houses having a single zone without stratification.

The PHPP was chosen as the simulation engine because it allows many calculations to be run in quick succession and it is fully customizable and programmable through both Excel functions and Visual Basic coding. The engine behind the PHPP is Microsoft Excel. The PHPP is a large Excel spreadsheet that is made up of over 25 interlinked sheets that correspond to different aspects of a building. There are sheets for the building geometry, assemblies, windows, hot water, electricity, and much more. The PHPP was originally created by the PHI using metric (SI) values. The version of the PHPP used in the study was a custom Imperial Units (IP) overlay. Many of the IP sheets reference the calculations being performed within the SI sheets, which are hidden in the basic IP version. The metric converter is not overly important to the thesis, but the overall alignment of the IP version as an overlay on the SI version, where the calculations occur is an important consideration because while the IP pages are customizable, to harness the true power of the program through customization, adjustments were made to the SI sheets within the IP version of the PHPP.

The main simulation was a full factorial experiment developed by programming a data table within Excel to reference the constant values through the use of a control panel linked to the baseline case as described in the following chapter. To program the PHPP to run through multiple calculations, the control panel contained a place to insert the independent variable matrix, which contained all possible combinations based on the factors and levels. This control panel was linked throughout the PHPP to allow control of every variable. For instance, on the control panel, there was a cell that allowed entry of a window type. This entry was referenced to all of the windows on the window sheet so that, as the control panel was changed, all of the

PHPP entries were updated. The control panel automated changing variables by creating a data table that was linked to a given case number that corresponded to a given combination of variables. The case number was referenced by a vertical lookup function. When the data table was recalculated, the next combination on the control panel was referenced and the data table was repopulated.

To aid in the task of running thousands of simulations based on many climate zones, VBA macro programming was used to automate the simulation runs. The following code takes the climate data out of a given list of locations to test and inserts it into the SI Climate sheet.

```
Sub Climate()
'
' Climate Macro
'
' Keyboard Shortcut: Ctrl+Shift+C
'
    Range("A1").Select
    Do While IsEmpty(ActiveCell) = False
    Range(ActiveCell, ActiveCell.Offset(8, 15)).Select
    Application.CutCopyMode = False
    Selection.Copy
    Sheets("Climate SI").Select
    Range("F88").Select
    Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
        :=False, Transpose:=False
    Sheets("MY").Select
    Application.CalculateFullRebuild
    Sheets("MY").Select
    Range("A12:AZ10142").Select
    Application.CutCopyMode = False
    Selection.Copy
    Sheets.Add
    Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
        :=False, Transpose:=False
    ActiveSheet.Name = Sheets("Climate SI").Range("F88").Value
    Sheets("Verification").Select
    Range("D31:F39").Select
    Application.CutCopyMode = False
    Selection.Copy
    Sheets("List").Select
```

```
    ActiveCell.Offset(0, 17).Select
    Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
      :=False, Transpose:=False
    ActiveCell.Offset(10, -17).Select
    Loop
End Sub
```

Upon this insertion, the full matrix was recalculated and the combinations were completed again for each new TMY3 climate data location. The table itself is the output of the results, which were then transferred to another sheet and saved before the table repopulates based on the next set of climate data. When the calculation finished, the results were copied and pasted into a blank sheet that was then named to match the corresponding climate set. Once all the cases were simulated for a given climate data set, another climate data set was selected and the previous results were saved for analysis. This loop repeated until there were no more climate files in the list to calculate. The automated PHPP simulation resulted in 10125 unique combinations for every TMY3 climate data location in the United States.

Analysis Criteria

An analysis plan was necessary to analyze the data produced by the study. After all combinations were run, the tables holding the results were separated by climate data set location. The results provided throughout the thesis were analyzed using multiple techniques for each location. The first step of the analysis was to plot the raw results without sorting. This non-sorted analysis provided a graphical analysis of trends for what was technically feasible, which showed the maximum and minimum values along with the relative distribution of the results. Most significantly, the unsorted analysis provided a range of values for the dependent variables, Annual Heating Demand, Peak Heating Load, Annual Cooling Demand, Peak Cooling Load, and Primary Energy, for each climate.

The data produced by the experiment led to climate specific recommendations for an adjustment to the Passive House Standard that was based on the climate data for a given location. The initial analysis graphs were set up to show the technical feasibility of the building cases in a given climate. Additional series of graphs were generated to display the correlation between building energy performance and a given climate data characteristic. The number of graphs and equations correspond to Figure 2.4.

Annual Heating Demand	**Peak Heating Load**	**Annual Cooling Demand**	**Peak Cooling Load**
Temperature	Temperature	Temperature	Temperature
N Radiation	N Radiation	N Radiation	N Radiation
E Radiation	E Radiation	E Radiation	E Radiation
S Radiation	S Radiation	S Radiation	S Radiation
W Radiation	W Radiation	W Radiation	W Radiation
H Radiation	H Radiation	H Radiation	H Radiation
Dew Point	Av. Radiation	Dew Point	Av. Radiation
Sky Temp		Sky Temp	
Latitude	Latitude	Latitude	Latitude
Longitude	Longitude	Longitude	Longitude
Elevation	Elevation	Elevation	Elevation

Figure 2.4: Climate Attribute per Dependent Variable

Figure 2.4 shows that each of the factors, such as temperature, radiation, and elevation that combine to make a complete climate set, has an impact on the resulting energy use in the form of the Annual Heating Demand, Heating Load, Annual Cooling Demand, and Cooling Load. By analyzing these factors, a given climate could be compared against the resulting graphs

and the certification criteria were derived from the results. For instance, if there was a two point graph that had the temperature at 20 degrees Fahrenheit equating to a target Annual Heating Demand of 5.4 kBTU/ft^{2}yr and a temperature at 30 degrees Fahrenheit that showed the target Annual Heating Demand of 4.4 kBTU/ft^{2}yr, then if there was a climate that had a temperature of 25 degrees Fahrenheit, the target Annual Heating Demand should be 4.9 kBTU/ft^{2}yr. Though this is a simplified example, the concept works in much the same way for larger amounts of data as well.

When the data for energy use was plotted against the climate data factors, trends, such as heating energy increased as temperature decreased, were easily recognizable. The magnitude of the energy use data was also of great importance. Using the same heating energy example, it was possible to find the temperature below which it was no longer feasible to attempt to build a passive house. Similarly, it became possible to ascertain what the new criteria for heating energy should be to keep it feasible based on a given exterior temperature. These results are summarized in Chapter 4.

The second step of the analysis was to sort out certain building characteristics that would not work in a particular location. The factors and levels as described by the full factorial simulation may not have been set realistically for each and every climate location. For example, R-20 walls and R-40 roofs in Climate Zone 7 are below code levels and are therefore not feasible for new construction. Additionally, the data tables were sorted and filtered based on the following analysis criteria:

Thermal Comfort

Economics

Ecology and Sustainability

Thermal comfort is ensured through a combination of interrelated factors such as the air temperature, the radiant surface temperature, the relative humidity, and air movement. It is also a factor of the occupants themselves, their clothing, and their activity level. Many of these criteria cannot be modeled solely through the PHPP. For example, the PHPP does not make an assumption about the occupants or the air movement past a person's skin. Also, the PHPP does not ensure compliance with the radiant surface temperature, but rather compliance is assumed based on the high levels of insulation. This assumption is not always true, especially in very cold climates, in rooms with high amounts of glazing, or in large buildings. To meet the same energy criteria as small buildings, large buildings need less insulation because the envelope losses are spread over a larger square footage. This leads to a case where the amount of envelope investment does not need to be as high, which could lead to comfort problems. The examples below explain the limits for the temperature related portions of thermal comfort that can be easily discerned through the inputs that are already needed for the PHPP.

Acceptable indoor temperature and humidity ranges can be derived from the psychometric chart for a given location. The Passive House Standard modeling protocol assumes a winter temperature of 68 degrees Fahrenheit and a summer temperature of 77 degrees Fahrenheit. Whenever the indoor temperature deviates from this range either heating or cooling energy is needed to maintain a comfortable indoor environment and constant interior temperature. Therefore, maintaining comfort, from the standpoint of temperature or humidity, is about how much energy input is necessary to maintain comfortable conditions. An un-insulated building can still be comfortable if enough energy is used to maintain a constant indoor environment. However, because low energy is a goal of the Passive House Standard, the amount of energy for space conditioning is reduced through measures such as insulation, orientation, and

air tightness. The result still must be a comfortable space at a given temperature set point. For this study, the set point temperatures will remain constant as defined by the Passive House Planning Package. It can be argued that the interior temperature of a building in Fairbanks, AK does not need to be held to the same standard as a building in Chicago, IL or Baltimore, MD. Because of this, it is possible that 66 degrees Fahrenheit may be acceptable for the majority of occupants in Fairbanks during times where it is negative 35 degrees Fahrenheit outside, whereas, in Chicago, where the winters are not as extreme, 66 degrees Fahrenheit may be deemed uncomfortable. For this study, these effects have been held constant to limit variables and to create comparable data between cases and climates. The magnitude of this effect can also be determined by adjusting the set points of heating and cooling for the base case.

Temperatures of room surfaces have a large impact on the perceived comfort of occupants. To maintain comfortable conditions, the surface temperature in passive houses should differ from the air by less than 4.2 degrees Kelvin, 7.56 degrees Fahrenheit (Institute 2012). The equation to calculate the interior surface temperature is shown in Equation 2.1.

$$\mathbf{\Theta_{si} = \Theta_i - U * R_{si} * (\Theta_i - \Theta_e)} \qquad (2.1)$$

Where:

Θ_{si} Interior Surface Temperature

Θ_i Room Temperature

U U-Value of the Assembly

R_{si} Interior Surface Film Resistance

Θ_e Exterior Temperature

Equation, 2.1, is a commonly found equation which is derived from Equation 2.2 below, which is a balanced equation that is set up as a ratio of heat flow between inside and the exterior

against the heat flow between the inside and the inside surface film. This ratio means that the amount of heat flow across the whole assembly is proportional to the amount of heat flow across just the surface film. Because heat flow can be summarized as $Q = U*A*\Delta T$, when substituted into the ratio below, Equation 2.2 remains and acts like a ratio, but is now based on the difference in temperatures and U-Values between inside and out as described above. If the ΔT is substituted with the surface temperatures and the area is divided out so that the equation is no longer area dependent, then all of the variables for the final equation are now present in the equation. By converting the $U_{i\text{-}si}$ into R_{si} and $U_{i\text{-}e}$ into U, all the variables are in place. Then, it is only a matter of balancing the equation to solve for the variable in question, in this case Θ_{si}. This derivation is shown in Equation 2.2-2.9.

$$\mathbf{Q_{i\text{-}e} = Q_{i\text{-}si}} \quad (2.2)$$

$$\mathbf{U_{i\text{-}e} * A * \Delta T_{i\text{-}e} = U_{i\text{-}si} * A * \Delta T_{i\text{-}si}} \quad (2.3)$$

$$\mathbf{U_{i\text{-}e} * A * (\Theta_i - \Theta_e) = U_{i\text{-}si} * A * (\Theta_i - \Theta_{si})} \quad (2.4)$$

$$\mathbf{U_{i\text{-}e} * (\Theta_i - \Theta_e) = U_{i\text{-}si} * (\Theta_i - \Theta_{si})} \quad (2.5)$$

$$\mathbf{U_{i\text{-}e} * (1/U_{i\text{-}si}) * (\Theta_i - \Theta_e) = (\Theta_i - \Theta_{si})} \quad (2.6)$$

$$\mathbf{U_{i\text{-}e} * (R_{i\text{-}si}) * (\Theta_i - \Theta_e) = (\Theta_i - \Theta_{si})} \quad (2.7)$$

$$\mathbf{U * R_{si} * (\Theta_i - \Theta_e) = \Theta_i - \Theta_{si}} \quad (2.8)$$

$$\mathbf{\Theta_{si} = \Theta_i - U * R_{si} * (\Theta_i - \Theta_e)} \quad (2.9)$$

One example of using this equation would be the calculation of a surface temperature for an assembly with a given R-value. Equations 2.10-2.14 calculate the surface temperature for a window with a R-Value of 5.0 hr.ft2.°F/BTU (U-Value of 0.2 BTU/hr.ft2.°F) using the heating design day temperature of Chicago. This example was chosen because R-5 is currently the value

being suggested by the United States government as a high performance window for mass manufacturing. However, this window will typically not meet the needs of the majority of passive house projects in cold, cool, or mixed climates.

$$\Theta_{si} = \Theta_i - U * R_{si} * (\Theta_i - \Theta_e) \quad (2.10)$$

$$\Theta_{si} = 68 - .2 * .74 * (68 - 13) \quad (2.11)$$

$$\Theta_{si} = 68 - .2 * .74 * (55) \quad (2.12)$$

$$\Theta_{si} = 68\text{-}8.14 \quad (2.13)$$

$$\Theta_{si} = 59.86 \quad (2.14)$$

An interior surface temperature of 59.86 does not fulfill the comfort criteria for passive house because the difference in temperature between 68 degrees F and 59.86 degrees F is 8.14 degrees F which is larger than 7.56 degrees F. Alternatively, using this method we can calculate the U-Value needed to make the comfort criteria work in a given climate by rearranging Equation 2.15 to Equation 2.16. Equations 2.17-2.19 use the 68 degrees Fahrenheit interior set point and the 7.56 degrees Fahrenheit allowable difference to determine the maximum U-Value based on exterior temperature.

$$\Theta_{si} = \Theta_i - U * R_{si} * (\Theta_i - \Theta_e) \quad (2.15)$$

$$U = -(\Theta_{si} - \Theta_i / (R_{si} * (\Theta_i - \Theta_e))) \quad (2.16)$$

$$U = -((60.44 - 68) / (.74 * (68 - 13))) \quad (2.17)$$

$$U = -((-7.56) / (40.7)) \quad (2.18)$$

$$U = 0.1857 \quad (2.19)$$

Therefore, in the Chicago climate, when the temperature of the outdoor air is 13 degrees F, the center of glass R-Value must be R 5.385 hr.ft2.°F/BTU (U-Value of 0.1857 BTU/hr.ft2.°F), or the comfort criteria cannot be fulfilled. This simple result demonstrates that most insulated walls will meet the comfort criteria except in climates of extreme cold and minimal R-Value. A temperature of -40 degrees F on an R-10 wall would result in a temperature difference of 7.992 degrees F, which is just above the 7.56 degrees F to ensure comfort conditions have been met. Once the R-Value for walls and roofs are designed to minimum code requirements in most of the United States, the comfort criteria are fulfilled. Therefore, to check for comfort compliance, the glazing U-Values were checked and any cases that were not able to meet the comfort criteria were filtered out.

There is debate within the passive house community in the United States on whether surface temperature alone or mean radiant temperature, or a combination of the two are the best criteria for understanding and quantifying comfort conditions (Grondzik 2011). Parallel to this discussion is the decision to use U_{WIN} or U_{COG} as the value being tested. In almost all cases, the U_{COG} is lower than the U_{WIN} due to the fact that the glass is more insulating than the window frame and it does not include the effects of the psi-spacer and *psi*-install, which can significantly impact total window performance. The deciding factor should be determined based on the specific facade. If the facade contains a large glass area, it follows that using the U_{COG} criteria is appropriate. If the facade is mainly punched openings of a small size, most likely U_{WIN} should be used. U_{WIN} is also the conservative choice as the U-Value is lower. Therefore, the lower the U_{WIN} or U_{COG}, the greater chance that the building will not meet the comfort criteria.

The same calculation to find radiant surface temperature can be performed for climates where the cooling energy demand is dominant. However, less information is readily available

regarding radiant surface temperatures in cooling conditions. Due to both the solar load and the ambient temperature acting in tandem on a piece of glazing, the glazing's radiant temperature may be much higher than even the cooling design load ambient temperature. Another method of determining comfort is the temperature swing a building undergoes over the course of a day. The main cause of large daily swings is an overly large solar load. Internal gains based on occupancy patterns and ambient temperature swings also contribute to a daily temperature swing, but in a passive house these effects are minimized. The high levels of insulation, thermal mass, and air tightness help to eliminate swings based on ambient conditions with the creation of a lag effect. This leaves the solar load as the major impact on the daily temperature swing, as shown by Equation 2.20:

Daily Temperature Swing = Solar load * (1/1000) / (Spec. Capacity * A_{TFA}) (2.20)

where:

Spec. Capacity	A Value of the Specific Heat Capacity (Measure of Thermal Mass)
Solar Load	P_S - Solar Heat Gains for Cooling Load
A_{TFA}	Treated Floor Area

The daily temperature swing should be limited to less than 3 degrees Kelvin or the calculation within the PHPP for the frequency of overheating, and through it the Annual Cooling Demand, is deemed unreliable due to the overly large daily swing. For comfort, at a temperature set point of 77 degrees F, a 3 degrees Kelvin swing is the largest a person could tolerate without feeling uncomfortable. A much lower swing would be preferable. Designs that initiate daily swings above 3 degrees Kelvin were not included in the study as they create potentially uncomfortable conditions even though energy efficiency may be increased in some instances.

Therefore, the two comfort criteria that were used for sorting the cases were limiting the daily temperature swing below 3 degrees Kelvin (5.76 degrees Farenheit) and ensuring the

surface temperature of the window assembly was above 60.44 degrees Fahrenheit, based on U_{WIN}.

For the Passive House Standard to thrive, it must be cost effective. The term "cost effective" can have many definitions and financial cost effectiveness, including a low upfront cost with a short payback time, may be needed to ensure the widespread adoption of passive house and super insulated buildings. Currently, some clients will pay more for green features and greater energy efficiency beyond what a traditional return on investment (ROI) calculation may deem as cost effective. However, the premium up-charge must be modest or the clients may decide not to move forward with building a passive house.

One concept that may lead to higher rates of adoption for the Passive House Standard is the idea of "cost parity." Cost parity occurs when the mortgage plus the energy cost in the passive house is equal to or less than the mortgage plus energy cost of a non-passive house of the same design. When the cost to the client is less than a conventional building built to code, using passive house techniques becomes the common sense approach to building. For this to occur, the energy saved must offset the cost of the increased cost of the mortgage due to passive house upgrades. Therefore, the upfront cost is seen as an investment, much like a traditional ROI, but due to the way the lending industry works, it is more favorable to attempt cost parity because the ROI of a given upgrade or the total upgrade package may be 10 years, which is too long to count on in terms of seeing the return, but if a conventional 30 year mortgage is brought into the equation the investment looks better because benefits are realized instantaneously. With the low interest rates currently in the lending marketplace, financing energy efficiency to achieve cost parity is an even more enticing option.

To determine the cost of insulation against its benefits, the transmission losses through each assembly were recorded. It was then possible to plot the transmission losses of a given assembly against the heat losses for that assembly. For example, the wall transmission losses were plotted against the R-Value of the wall. This R-Value varied based on the matrix above for each case. The culmination was a graph that demonstrated that the thicker the wall, the less energy is used, but also the less impact additional insulation makes compared to the starting insulation. Instead of determining real world costs, which is difficult due to the complexity of pricing across the country and the large difference in costs between insulation choices such as cellulose, fiberglass, rockwool, eps, xps, closed cell foam, and open cell foam, the graphs show approximately at what thickness the insulation began to exhibit extreme diminishing returns. When the insulation is not as effective because the return on energy savings versus thickness is diminishing, the return on the investment, ROI, for thicker dimensions of insulation also diminish. At some point, they diminish below cost effective levels. In this way, the effectiveness of all levels of insulation can be determined. The performance effectiveness is similar to the cost effectiveness if it is assumed that each additional inch of insulation has the same marginal cost.

Ecology and sustainability are important byproducts of energy efficient buildings. However, many aspects of the built environment deal with sustainability, while energy efficiency is just one aspect of a sustainable building. Setting the criteria for Primary Energy use was one way to incorporate some measure of environmental responsibility into the Passive House Standard; however, it is not a comprehensive solution or even an indication of the issue of sustainability in buildings. Because of the high levels of insulation investment in passive houses, using toxic chemicals and harmful blowing agents as part of the insulation package is inherently unsustainable, but is not checked by the current standard. The purpose of this study is not to

create a sustainability component to passive house, but it does acknowledge that for passive houses to be worth building, they must not be built at a terrible consequence to the environment.

To quantify the sustainable impact of a building, this study will use the total building energy usage through the Primary Energy factor to gauge whether the building is sustainable. This is a very rough approach meant to eliminate the very worst cases and to rule out cases that include excessive amounts of envelope investment given the return on energy efficiency. For example, if the Primary Energy use was very high and a significant increase in insulation, say from R-40 to R-80 in the wall, did not significantly lower it, the case was eliminated because the increased investment was not energy cost effective despite the impact it may have had on space conditioning. In this example, the Primary Energy would most likely be driven by internal or mechanical loads rather than by envelope loads and therefore, not a direct concern of this thesis. For instance, if a higher efficiency refrigerator saves more energy than adding a few inches of insulation around an entire building, it may be better to install the refrigerator rather than (over) insulate more thoroughly.

One set of criteria that are associated with the Primary Energy calculation within the PHPP is CO_2 emissions. Each source of energy, gas, electric, and other fuels all have a Primary Energy Factor. In addition to this, they also have a value for carbon emissions assigned to the given fuel type. Within this thesis, the carbon emissions due to energy use will not be reported, but within the PHPP carbon pollution can be monitored and even offset with the addition of renewable energy sources such as photovoltaic arrays.

The results show how the data was filtered and the analysis of the data was performed to get results that allowed for the analysis of the Passive House Standard as a whole. The filtering that occurred for each simulation contained all of the following methods: thermal comfort,

effectiveness, code requirements, and sustainability so as to limit any non-realistic cases from influencing the results of the analysis. Through this method, many cases remain possibilities. Therefore, choices for passive house designers and consultants to use different strategies based on a given situation still exist. At the same time, the strategies a designer would choose not to use because they are unfeasible were eliminated through the data sorting process.

Limitations

The study has a number of limitations that influenced the results. Some of these have already been mentioned. A major set of limitations arose from the variables and criteria that could not be taken into account in the study. There are many reasons why a given variable was not tested. One primary reason was that the difference the variable would make would have been negligible, or uniform, on the results. Another reason was that the variable had a relatively standard input or accepted default value agreed upon among building scientists. Many of the standard or default inputs were standardized because they also had very little impact on the end results. Because of the large number of data points already in the study, some variables that would have been overly complex to calculate or that have complex or dynamic interactions, were not included. Some of these are complex enough that either the PHPP, as a steady state model, does not deal well with them or that the building science community at large does not understand these effects.

As described above, the PHPP itself was a limitation. The fact that it is a steady state model leaves it unable to calculate as accurately as possible some aspects of the building. However, as mentioned earlier there was also a large advantage to this type of model in terms of simulation time and computing power as compared to a dynamic model. Another limitation of

the PHPP was how it handles latent loads and humidity. Many of the internal latent gains are at set defaults and the exterior latent gains are only based on the dew point and temperature. Because of this, and several other factors, the space conditioning in terms of the Annual Cooling Demand is shown without the latent component. In most of the United States, the latent energy load is larger than the sensible cooling load. Therefore, not incorporating that cooling energy into the calculation is a large limitation of the software because the true effect of adding an amount of latent energy that is larger than the sensible cooling energy will significantly increase the total cooling energy needed. In some cases, the energy could be between two and ten times the sensible energy needed.

Defaults within the PHPP calculation were also a potential limitation, but this effect was mitigated by holding all the entries that were not listed as variables as constant throughout all of the simulations. Therefore, if one value, for instance, the dishwasher, had a slightly higher or lower energy use than intended, it was slightly higher or lower for all simulations. Because of this all simulations are similar in relations to each other. If a simulation was inaccurate as compared to real world conditions due to unforeseen circumstances, it will still be assured that in relation to the other simulations it is still comparable. In other words, if one simulation was inaccurate due to a default being wrong, all of them will be adjusted by a similar amount. While the simulated building's energy use should be close to the building's measured performance, if the building was built and tested, it is possible that they would not be identical.

Chapter 3

SIMULATION CONTROLS

Explanation of Entries

As discussed in Chapter 2, this thesis analyzes the Passive House Standard by performing a full factorial simulation that tests six dependent variables at a number levels per variable in over 1000 climate data locations across the United States. The simulation was run using the Passive House Planning Package (PHPP). This software contains a framework for entering in a building to be simulated. Within this framework, the software accepts entries, but to facilitate quicker simulations is pre-populated with default values. Chapter 3 explains the necessary entries and defaults the software needs to complete a simulation.

The PHPP begins with the Verification Sheet that outlines some basic instructions and the overall page structure of the spreadsheet. It is also the first page of the PHPP that requires information to be filled in for the results to populate. The top of the sheet contains places to enter the building's name, address, type, location, date of construction and information on the client, the architect, and the mechanical engineer. It then asks for the "number of dwelling units." In a single family home, this value is generally "1". However, in other types of buildings this number may be modified. The main effect that the number of units has on the simulated results is on how many appliances are populated into the sheets for domestic electricity in the PHPP. However, these values can also be custom entered on the sheets if, for instance, a single unit project has a second refrigerator. For the case of this study, the building was a single-family structure and the number of dwelling units was left at one.

The next value that can be entered is the set point interior temperature. The default temperature is 68 degrees Fahrenheit. This should not generally be adjusted and adjusting it can

have significant impact on the heating energy needed. This temperature set point is only for the heating conditions. The cooling condition set point is entered later in the PHPP on the Summer Sheet and is set at 77 degrees Fahrenheit. All calculations are based on these set point temperatures and do not account for nighttime cooling or slight temperature differences between rooms, or across the building, that may slightly effect transmission and ventilation heat loss calculations. One justification for lowering the set point below 68 degrees in the heating season is for buildings with partial uses or setback temperatures. These building types are generally schools, offices, or religious buildings that have intermittent occupancies. Determining the value of an intermittent set point can be completed with Equation 3.1 and the table of Figure 3.1 which is specific to the static energy balance calculation.

$$\mathbf{T_{target} + \Delta\Phi = T_{average}} \qquad (3.1)$$

Operation on workdays from:	Solid Construction	Light Construction
7:00 to 14:00	-1.0 K	-1.0 K
7:00 to 18:00	-0.6 K	-0.6 K

Figure 3.1 - ΔΦ Correction Table

For example, the 68 degree Fahrenheit set point in a building that operates from 7:00 AM to 2:00 PM, such as a school, can be adjusted to a 67 degree Fahrenheit set point by subtracting 1 degree Kelvin from the base set point temperature of 68 degrees Fahrenheit. Another condition where different temperatures are acceptable is for different building types such as hospitals or assisted living centers where higher or lower temperatures may be desirable.

In a sample building located in the Chicago, IL climate, the winter interior temperature set point is 68 degrees. The corresponding Annual Heating Demand and Annual Cooling Demand are 4.63 kBTU/(ft²yr) and 0.75 kBTU/(ft²yr), respectfully. When the temperature is adjusted to 67 degrees, the values are adjusted to 4.31 kBTU/(ft²yr) and 0.75 kBTU/(ft²yr), respectively. When the temperature is increased to 69 degrees, the difference in heating energy is 4.97 kBTU/(ft²yr) and again, the cooling energy stayed the same 0.75 kBTU/(ft²yr). This is because the interior temperature set point of 68 degrees affects only the Annual Heating Demand. The cooling demand has a summer set point temperature with a default of 77 degrees. When this is increased to 78 degrees, the Annual Cooling Demand decreases to 0.58 kBTU/(ft²yr). When this is decreased to 76 degrees, the Annual Cooling Demand increases to 0.97 kBTU/(ft²yr).

Altering the climate data can mimic the same effect. When the yearly average temperature is adjusted each way by one degree, the results are 4.31 kBTU/(ft²yr) and 0.75 kBTU/(ft²yr) respectfully for a reduction of 1 degree in the average yearly temperature and 4.96 kBTU/(ft²yr) and 0.59 kBTU/(ft²yr) respectfully for an increase of 1 degree in the average yearly temperature. The overall trends affecting the set point temperature make sense. As the temperature increases, the need for heating decreases and the need for cooling increases and vice versa. The magnitude of the increases and decrease of this mini study are relatively small compared to some of the built passive house projects. Upwards of 20% differences have been noted due to a one-degree drop in temperature, but these were buildings in mild climates with thinner envelopes. There may be some validity to the argument that the set point temperature can be lowered for extreme climate conditions, where greater interior temperature differences may be

tolerable. However, for the cases being simulated in this study, the set point temperatures for both the heating and the cooling conditions remained at their respective defaults.

The next entry on the Verification page requires the planned number of occupants to be entered. Whether this number is used is based on which of the methods of calculation the PHPP is set to. The first choice is whether to use the Verification or the Design as the method of calculation for planned number of occupants. When the Verification tab is used, the number of occupants is constant according to Equation 3.2.

$$\textbf{Occupant Number} = \frac{\textbf{Treated floor Area}}{\textbf{377 square feet}} \qquad (3.2)$$

For the simulated building, based on 1600 square feet of treated floor area, the number of occupants was 4.2 people. This means that most appliances and other heat gains were based on four full people plus an additional .2 of a person, which accounts for adults, children, pets, and other occupants that may not have the same heat gain as a full person according to the PHPP. These values, at least the internal heat gain contribution from a person, are also dependent on activity level of the occupants and based on activity, the IHG's can be halved or doubled and otherwise vary widely. Due to these facts, the PHPP default number of occupants was used as the number of occupants for the simulation.

The other calculation option if Verification was not used is Design. When Design is chosen, the number of occupants used is the number entered into that cell. As mentioned above, this influences the internal heat gains from both people and appliances. The number of people in the building also has a large impact on the Primary Energy, which is mainly caused by an increase or decrease in domestic hot water use and the effects of the number of appliance uses. Verification was used in this study as a comparative feature so that all permutations of the

simulated building was calculated with the same number of occupants and therefore a default value of internal heat gains of .666 BTU/ft^{2}hr.

Other menus on the Verification page contain choices that effect the default internal heat gain value. There is a dropdown for Building Type, Utilization Pattern, and the Type of Value Used. For this study, the building type was Residential and the Utilization Pattern was Dwelling. Other combinations include Residential and Assisted Living and Non-Residential and Office. Each of these combinations of Building Type and Utilization Pattern has their own default internal heat gain. The dropdown for the Type of Value used was set to Standard for the default. This dropdown allows the standard internal heat gain to be used. It can also be changed to "PHPP Calculation" which requires the internal heat gain sheet, near the end of the PHPP, to be completed so that a custom IHG is used based on the actual building rather than on a default based on type and occupancy. Whenever the "Design" option is chosen, the type of values used must be based upon "PHPP Calculation" or else a false situation will occur where the amount of people, their energy use, and their heat gains do not relate to each other. To simplify the simulations, and not rely too heavily on the impact of internal heat gains on the final outcome, the default value was used.

The Verification Sheet is also used as a summary, where the Annual Heat Demand, Pressurization Test Results, Primary Energy Demand, Heating Load, Frequency of Overheating, Annual Cooling Demand, and Cooling Load are all displayed so that the major criteria can be viewed in a single location. This is also the place where conformance to the Passive House Standard is determined by check boxes that say either "yes" or "no" next to each corresponding criteria.

Several other values are also loaded into the Verification sheet, but they are referenced from other places within the spreadsheet. An addition to the PHPP utilized in this study is a sheet called "Reference Dimensions" where the treated floor area, slab conditions, gross volume, and net volume are calculated. Many of these dimensions, areas, and volumes will be explained at their appropriate reference in the PHPP rather than upfront on the Reference Dimensions sheet. Figures 3.2-3.7, part of an unpublished PHIUS Document on PHPP entries, explain the calculation used to determine the Treated Floor Area (TFA). The TFA is an extremely important concept when using the PHPP as an energy model and when analyzing the Passive House Standard. Every certification criteria is divided by the TFA to get the amount of energy in terms of square feet. This means that errors in the calculaiton of the TFA will effect every other calculation throughout the PHPP. The TFA is based on the German Floor Area Ordinance (Wohnflächenverordnung [WofIV]), and follows the rules below (Fiest 2007).

General Rules Table

Calculate at 100%	Calculate at 60%	Calculate at 0%
-All Habitable Spaces. These include: living rooms, dining rooms, bedrooms, bathrooms, kitchens, Entries -All Closets (no matter how small) -All Laundry -Interior Doorways	All full height Mechanical Spaces (regardless of whether or not under stairs) All Basements unless (1)deemed livable by building official having jurisdiction (2) Window area >8% of floor area AND 1 legal egress	Exterior Doorways Basement with no habitable spaces Stairs (& Landings) with more than 3 resting places Areas where height <1 meter Columns and partitions (Low enough partitions are 100%)

*Any space with a height between 3' and 6' should be counted at 50%.

Figure 3.2 - Treated Floor Area

First Floor:

100%:

- All Habitable Spaces. These include: living rooms, dining rooms, bedrooms, bathrooms, kitchens
- All Closets
- All Laundry
-Interior Doorways

60%:

- Area with mechanical use

0%:

- Stairs and landing
- Interior walls
- Exterior Doorways

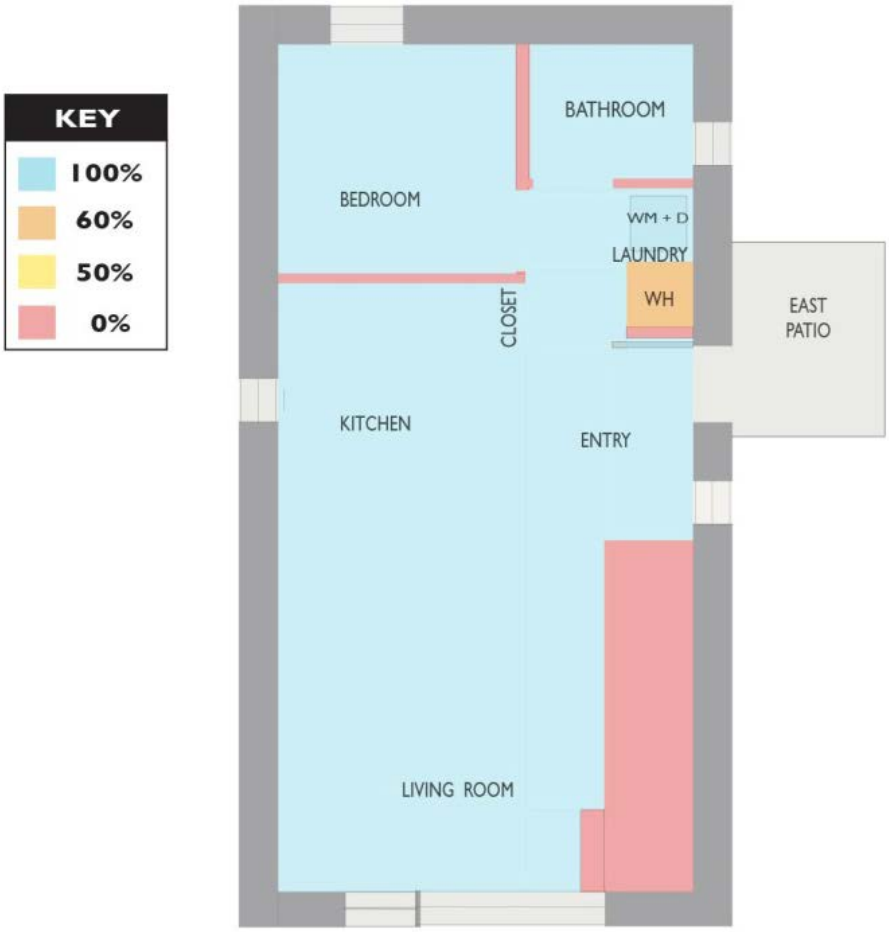


Figure 3.3 - First Floor

Second Floor:

<u>100%:</u>

- All Habitable Spaces. These include: living rooms, dining rooms, bedrooms, bathrooms, kitchens
- All Closets (other than mechanical)
- Interior Doorways

<u>60%:</u>

-Mechanical closet

<u>0%:</u>

-Stairs

- Interior Walls

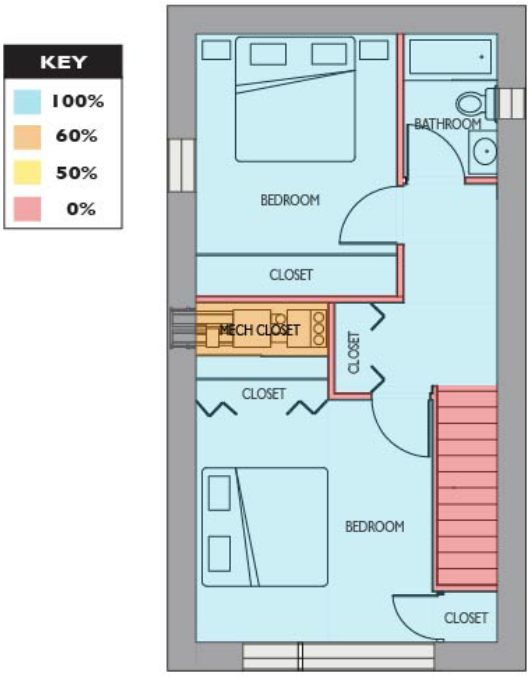


Figure 3.4 - Second Floor

Basements:

<u>100%:</u>

- All Habitable Spaces. These include: living room, Bedroom
- Interior Doorways

<u>60%:</u>

- Storage

<u>0%:</u>

- Stairs
- Interior Walls

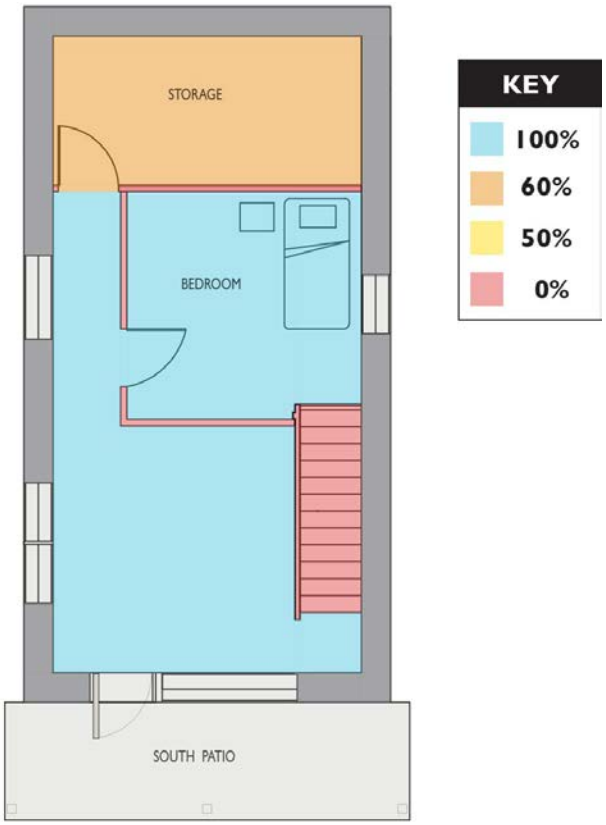


Figure 3.5 - Basement Floor

Special Cases:

- If the ERV is over laundry, still counts at 100% as long as its 2m above ground
- If the area under the stairs is being utilized for mechanical purposes, all area 1m in height and above is counted at 60%. (pictured right)
- If the area under the stairs is being utilized for non-mechanical purposes, it follows normal guidelines. Spaces between 1-2m in height are counted at 50% and 2m+ are counted at 100%. (pictured right)

**If the area under the stairs is not being used, it does not count at all.

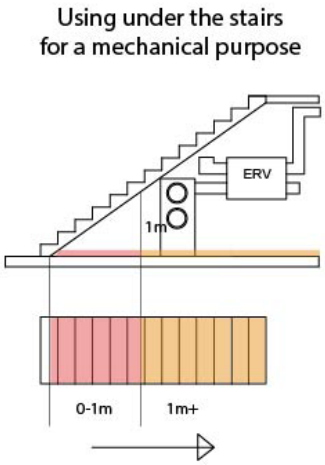


Figure 3.6 - Stair (Mechanical)

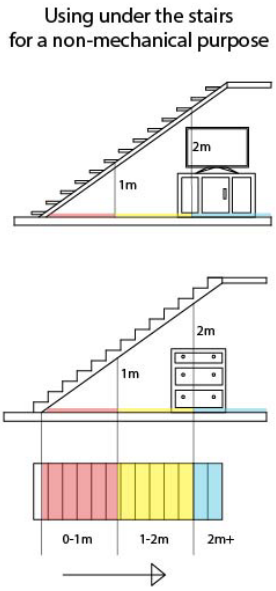


Figure 3.7 - Stair (Living)

In the simulated building, the treated floor area was calculated by taking the exterior dimensions of the building based on a 1' thick exterior wall (25' x 40') and subtracting the a stairwell and a rough estimate of the area of partition walls. This left an 800 sq ft area per floor on the inside of the building to be counted as Treated Floor Area.

On the Verification sheet, the PHPP uses two different methods for the calculation of the Annual Heat Demand. The first is the Annual Method which was the first method to be

implemented into the PHPP and calculates the Annual Heating Demand based on a heating period, or the time in which heating is needed throughout the year, which is a constant 205 days. The second is the Monthly Method, which calculates demand and the heating period in a more exact and detailed manner and adds in calculations for factors such as radiation through opaque surfaces, thermal mass, and many more variables discussed in the next few paragraphs. To determine which calculation method should be used, the PHPP manual states that the ratio of free heat to losses should be calculated. Based on the free heat to loss ratio, the correct method can be chosen. While there are differences and similarities between the two methods, it is the author's opinion that to achieve accurate results for passive house projects in the United States the Monthly Method should always be used because it takes into account additional factors that the Annual Method ignores. The following paragraphs will support this claim.

In the Annual Method, the heating period (d/a) is set at a constant 205 days per year, to simulate the average heating period in central Europe and appears on the Annual Heat Demand Sheet in Cell I62. This cell determines the amount of internal gains for the building before they are reduced by the Ratio Free Heat to Losses, which are located on the same Annual Heat Demand Sheet. In the Monthly Method, these gains increase or decrease based on the size or length of the heating period. The heating period in this case is calculated by looking month by month and determining if there is any heating demand necessary in that month. If heating is required for more than 10% of the monthly duration, the number of hours in that month (days*24) is summed and becomes the total amount of hours of heating needed. This is divided by 24 again and used in the Monthly Method calculation. The heating period calculation is determined in part by the climate set, but it is also determined by the actual building and how it is performing when the Monthly Method is used.

This difference in how the heating period is calculated is very important. While many passive houses come close to the 205-day heating period, which is also the case in Central Europe, there are some unique or extremely warm or cold climates where this varies significantly. The further the length of the heating period moves from the default 205 days of the Annual Method, the more consideration using the Monthly Method should receive. If the difference is large, the error in the calculation can become rather large and a switch from the Annual to Monthly Method would be prudent. The internal heat gains that can be utilized to offset the need for heating for the Annual Heat Demand is based on the heating period. Therefore, in buildings with high internal heat gains (IHG), the importance of making the heating period match what the heating period should be based on the specific building and specific climate set becomes greater. Buildings that have less area and higher internal gains fit into this category. Types of buildings that fit these criteria include some single-family homes, but mainly consist of schools, apartments, high rises, factories, offices, and many others large building typologies. To eliminate any influence of this effect within the study, the Monthly Method was used for all calculations.

The calculation of the required number of heating degree days varies between the two methods. The heating degree days are expressed in the variable G_T. In the Annual Method, G_T is calculated by taking the result on the climate page and multiplying it by the heating period and hours per day (divided by 1000). The heating degree days are calculated for each month and then summed together. For each month, Equation 3.3 is used:

HDD = Heating * Days * ΔT (3.3)

Where:

Heating	Heating Needed - yes (1) or no(0))
Days	Number of Days in the Month
ΔT	Temperature difference between 20 degrees C (ambient) and the exterior

For example, if the average temperature in January is 28 degrees Fahrenheit, heating is needed for 31 days. Equations 3.4-3.5 is used to find the HDD as follows:

HDD = 1 * 31 * (68-28=40) (3.4)

HDD = 1240 (3.5)

With an average January temperature of 28 degrees F, there are 1240 heating degree days. Each total from every month is summed to yield the heating degree days. For the Annual Method, the "Heating Needed" question in the HDD equation (above) is set as a default that is equivalent to the 205 day heating period set as the default for that method. Therefore, the heating demand that may occur outside of the 205 day heating period default is not properly counted. This is the reason that many climates in the US do not have heating degree days that match those of their local climate data.

In the Monthly Method, the G_T calculation becomes more complex. It is the sum of three parts divided by the total "losses." The first part is hours per month, which is calculated by multiplying the days in a given month times the hours in a day. For the month of December, multiply 31 days by 24 hours to get 744 hours per month. The second part is a sum of the time when there is convective heat loss (this is a negative value). The third part is a sum of the heat loss due to radiation (this is a positive value). The sum of the three parts (time per month plus the time convection and radiation impact the building) is divided by the total time multiplied by a

loss factor. This loss factor is determined by the heat loss equation (Columns G, I, K at the top of the Monthly Method Sheet within the PHPP and the ventilation losses below them).

The calculation of heating degree days is based on formulas in the PHPP that take the simplified hourly data that resulted in the monthly average within the climate set and extrapolate the monthly average back to the hourly data. However, because the HDD calculation generates exact hourly data from an average value, assumptions must be made in the formula. Coupled with the potential for rounding errors and other outlying factors it should be expected that the HDD's are only "close" when they are derived based on monthly averages. This fact is not central to the study as the PHPP uses the G_T value directly for the calculation and the PHPP software has been calibrated to the use of the G_T value, not the heating degree days, but when comparisons are made between different energy models and other third party climate data sets, it should be noted the HDD's may not match up even if the results of the simulations correlate.

The monthly method also accounts for the effects of thermal mass and effects of the building specific ventilation heat losses. Additionally, solar gains through opaque surfaces are only accounted for in the Monthly Method. These results are based on the radiation balance entries from the Areas Sheet located in Columns AD-AH and are transferred to the Monthly Sheet in Row 61.

Per the recommendations from the Passive House Institute (PHI), when the Gain to Losses Ratio on the Annual Heat Demand sheet is above .7, the monthly method should be utilized. The same can be true in buildings with extremely low Annual Heat Demand's. If the Annual Heat Demand is below 2.54 kBTU/ft^{2}yr the PHI recommends using the Monthly Method (PHPP Manual). This makes sense given the information above, which explains that specific thermal mass and other factors are only accounted for in the Monthly Method. These factors

generally play a more significant role in high gain to loss buildings and therefore, the Monthly Method should be used. The gain to loss ratio is calculated by simply dividing the total gains by the total losses for each method. This means that the ratio calculated by the Annual Method will be different than the ratio calculated by the Monthly Method. The formula is as follows:

$$\textbf{Ratio of Free Heat to Losses} = \frac{Q_S + Q_I}{Q_T + Q_V} \quad (3.6)$$

Q_S Available Solar Heat Gains

Q_I Available Internal Heat Gains

Q_T Transmission Heat Losses

Q_V Ventilation Heat Losses

In regards to the choice between simulation methods within the PHPP, cooling has not yet been mentioned and is a topic all unto itself, but it is interesting to note that the Annual Cooling Demand is only calculated by the Monthly Method and does not have a basic calculation using the Annual Method. Again, this points toward the need to use the Monthly Method in all high gain situations where thermal mass, and in this case, night cooling and ventilation, play a major role in the building's performance. This includes conditions where shoulder season overheating may occur due to overly large glazing areas when the temperature is moderate and the sun angle is low.

The areas sheet is where the areas of the assembly are entered. They are also matched with the assembly types, and therefore the assembly R-Values on this sheet. To the far right on this sheet, radiation balances need to be inserted for every opaque surface and assembly. This includes values for: emissivity, absorptivity, orientation, and shading. Generally, approximate values are acceptable for this data. In fact, in the heating climates of Central Europe, entering

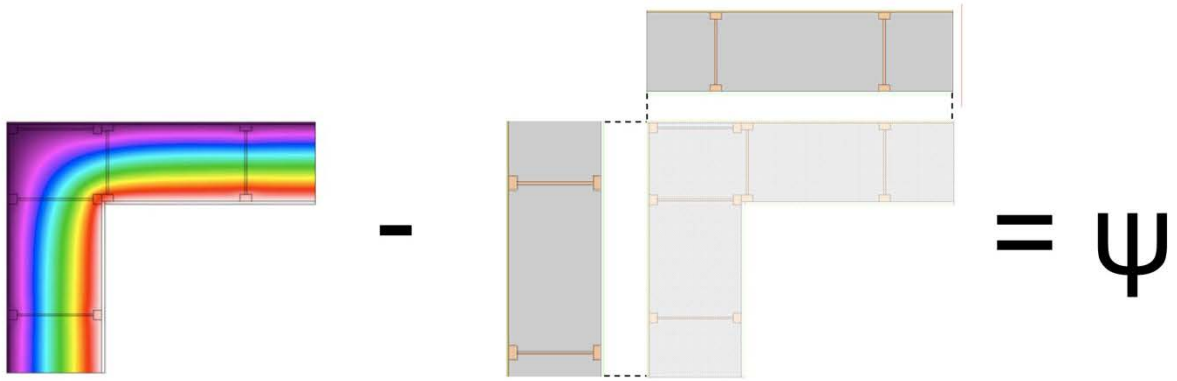
radiation values are not necessary because the effects of radiation into an assembly during the day and back out to the night sky are relatively similar and do not affect the balance with respect to Annual Heat Demand. However, in the United States these values should be entered because the radiation to the night sky may not always equal the radiation absorbed by the surface during the day. Below are the typical values recommended within the PHPP.

Exterior Absorptivity:	Exterior Emissivity:	Shading:
Black: 0.95	Most Building Material: 0.9	Un-shaded: 1
Roof Tiles: 0.8	Bright Metal: 0.15	Rural/Suburban Areas: 0.7
White Paint: 0.4		Inner City/Large Overhangs: 0.4
Special Colors: down to 0.1		

At the bottom of the Areas sheet is the location where all types of thermal bridging are accounted for. There are two distinct categories of thermal bridges that may need to be accounted for in the PHPP. The first is geometric thermal bridges. Geometric thermal bridges are created due to the way the PHPP accepts dimensions. When an area is entered into the PHPP, it should be entered based on its exterior dimensions. This means that the heat loss associated with a given wall is using the largest area possible. Figure 3.8 below is a graphic representation of the *psi* (Ψ) value calculation. The first image is a two dimensional heat flow calculation performed by THERM, software developed by Lawrence Berkeley National Lab. THERM is a program developed to determine the U-Values of wall assemblies, facade details, and with the use of additional programs, frame and glazing profiles for National Fenestration Ratings Council (NFRC) Certification. The second image in the graphic shows how the PHPP looks at a wall assembly. It does not know where the framing is or how the corners interact with the rest of the building, only that the R-Value of the assembly is uniformly spread over the given area using the exterior dimensions of the thermal envelope. This is illustrated by the difference between the as-

built wall, the light grey color, and the way PHPP views the wall, the medium grey color. To understand the *psi* value conceptually, the two one-dimensional calculations, the second image, in this case, one for each wall, should be subtracted from the two dimensional calculation. The result is *psi*.

Two Dimensional Calculation - One Dimensional Calculation = *Psi*



THERM Analysis PHPP Representation Thermal Bridge Value

Figure 3.8: Thermal Bridge Calculation Representation

By using exterior dimensions, the heat loss is overestimated. The corner overlaps are essentially being double counted. This overestimation is offset by the fact that in corners, there is often structural material and other objects that have a lower R-Value than the insulation. When a *psi* value is calculated, it needs to be analyzed as to whether it is a thermal bridge. If the *psi* value for linear transmittance is greater than 0.01 W/(mK) or 0.006 BTU/(hr.ft°F) there is a thermal bridge present that must be accounted for. Thermal Bridges less than the 0.01 W/(mK) or 0.006 BTU/(hr.ft°F) limit can be ignored as the result on the overall heat loss is minimal. Because of the double counting of the exterior corners, if the corner assembly is a majority of insulation and thermally broken, there is a chance that the thermal bridge could be negative. In this case, the PHPP is assuming more heat loss than is actually occurring at a given connection. The opposite

is also true. If the thermal bridge value is positive, the PHPP is not counting enough heat loss at a given connection and the additional heat loss due to the thermal bridge must be entered.

A wall to wall section has been used here as an example, but the same condition occurs at the slab to wall and wall to roof connections. The height dimensions used to calculate the areas are also to exterior dimensions. This means the wall dimension should be measured from the bottom of the sub slab insulation to the top of the roof insulation. This adds considerable overlap and additional heat loss to all buildings and unfairly penalizes small buildings that have excessive insulation values, such as those in very cold climates. While the best method is to design thermal bridge free, there may be times where thermal bridging is unavoidable, such as a retrofit situation. There are other times, where a project may be calculated at slightly above the Annual Heat Demand Criteria, but has exceptional detailing. For this case, the thermal bridges can be calculated and if they are negative enough, the project's total heat loss could fall within the certification range of passive house.

The second type of thermal bridge is a material thermal bridge. Material thermal bridges occur where two materials with significantly different conductivities occur. One of the simplest is a metal stud wall insulated with spray foam. The difference in the R-Value of the two materials in the assembly is so large that the metal stud is said to be thermally bridging the spray foam. The corresponding heat loss across the stud is much greater than it is across the insulation. This difference creates a material thermal bridge.

Both types of thermal bridges are subjected to a variety of boundary conditions. Many thermal bridges are exposed to ambient air, such as a material thermal bridge of a balcony interrupting an insulating plane. Thermal bridges also occur underground such as a column support running through the sub slab insulation. The last type of condition a thermal bridge can

be subjected to is a perimeter condition. Thus far in the United States, perimeter thermal bridges are the most common due to the prevalence of slab on grade foundation systems in passive houses due to their ease of insulating under the slab. A perimeter thermal bridge is not just exposed to the ambient air and is also not just exposed to the ground, but rather feels the lag effect of the ground, and its warmer temperature, and the daily temperature swing due to the diurnal cycle. The PHPP allows for *psi* values to be entered on the areas sheet and applies the correct boundary condition to each value at that time.

One major impact on the transmission losses and therefore the energy balance is the R-Values of the given assembly. The R-Values for the roof, the slab, and the walls were varied in this study. However, the conditions they are exposed to and those they represent will not vary except due to the effects of the changes in R-Values. For instance, the surface film coefficients that make up a small fraction of the R-Values will remain constant. For horizontal heat transfer through the walls, the interior surface coefficient was .74. For upward heat transfer through the roof, the interior surface coefficient was .57 and for the downward heat transfer through the slab, the interior surface coefficient was .97. These surface coefficients are caused by the properties of air and friction that allows a thin layer of air to "stick" to a surface. This air layer, or air film, adds to the overall R-Value of the assembly and is already taken to account in the R-Value for the simulation. Exterior surface film coefficients also exist. For a typical surface, the surface film coefficient is .23, which represents an unscreened condition. Many surfaces are also screened, which means they are covered by another material that helps to prevent wind washing. Screened surfaces, such as the simulated building's wall, which is covered with a rain screen, and the simulated building's roof, which is covered by the roof pitch, have a surface film coefficient of .45.

For the this study, the ground condition is a slab on grade with a gross slab area of 1000 square feet (25x40) and a perimeter of 130 linear feet which contains a minimal amount of perimeter insulation. The perimeter insulation will extend 12 inches in the vertical direction and contain 4 inches of R-4 per inch insulation for a total of R-16. The ground type and conditions will also remain constant throughout the study. The R-Value of the floor slab must also be entered into the ground sheet. Like the verification sheet, the ground sheet contains defaults as well. The ground defaults are .07 $hr.ft^2F/BTUin$ for the thermal resistance of the ground and 2.0 $MJ/(m^3K)$ for the heat capacity of ground. All these factors combined result in a ground reduction factor that tempers the heat flow from the floor assembly to the ground based on the parameters entered. The ground reduction based on this information is also climate dependent and will adjust based on the temperatures listed in the climate data set.

To get the correct wall to window ratio within the simulation, most of the windows will be varied by size, glazing type, and frame type. However, other window performance values will be locked in as constants. The *psi*-spacer will be set as a default of .02 BTU/hr.ft.°F, which approximates a warm edge spacer with good thermal performance. The *psi*-install will be defaulted at .023 BTU/hr.ft.°F. This is a typical value for a frame that contains only minimal insulation, but that is installed in the insulation plane of a stud wall. A *psi*-install value of .050 BTU/hr.ft.°F would be indicative of a window that was installed into a masonry wall with no insulation around the frame. On paper, *psi*-install values can be as low as 0.00 BTU/hr.ft.°F or even lower, but a more reasonable value factoring in real world installation conditions and tolerance is between .010 BTU/hr.ft.°F and .015 BTU/hr.ft.°F. A *psi* value is a term for linear thermal conductance and a *psi*-install is the difference in conductance between the window and the wall. Therefore, a *psi*-install is the change due to the window and wall interface. More

insulation in this interface lowers the *psi*-install. Working to design a better *psi*-install would be one way to lower energy use beyond the levels used in this study.

The window frame dimensions will also be fixed at 3.5 inches and the windows will be treated as a mix of operable and fixed windows. Often times, operable windows have frames larger than 4 inches and fixed picture windows often have frame widths of less than 3 inches. Using the 3.5 inch dimension allows for the conditions in this study to resemble a mixture of window types according to the design. The remaining window values: frame R-Value, glass U-Value, and glass SHGC will be variables in the parametric study.

Holding the frame dimensions constant allows the shading factors to be held constant as well because shading in the PHPP is determined by four things: 1) horizontal shading 2) reveal shading 3) overhang shading 4) additional shading factors. The horizontal shading factor is best used to describe the effects of buildings and other constant obstructions on the horizon. For the simulated building, the horizontal shading will be ignored. The reveal shading is shading from the window jambs that occurs due to the window being inset into the wall assembly for over insulation purposes. Another use of reveal shading would be to approximate self shading due to an offset in the facade. For this study, the reveal shading will be equivalent to the window frame dimensions and set back into the wall 3 inches. Overhang shading is due to overhead obstructions such as roof overhangs. If there is not a roof overhang present, the reveal dimensions are often identical to the overhang dimensions. In the simulated building, the first floor windows will use the reveal numbers and the second floor will use a 24" overhang 18" above the window.

The last piece of information regarding shading is the additional shading factor. The additional shading factor can be difficult to enter accurately and is highly variable between

different building sites. This factor allows for trees and other objects to be taken into account. Because of this the summer and winter values may differ significantly. For the simulated building, the additional shading reduction factor for heating will be .85. It will be .70 for cooling to reflect the fact that more leaves should be on the trees. The lower the shading factor, the less light gets through. For example, 1.0 would be full sun and 0.0 would be a full blackout condition. In the summer shading sheet, another shading factor, the temporary reduction factor, is used in addition to the additional shading factor. The temporary reduction factor gets applied only in months where there is an Annual Cooling Demand. The best use for the temporary reduction factor is for blinds whether internal or external. For the simulated building, white internal blinds will be used and a .70 temporary reduction factor will be entered for all windows.

The last piece of information that the energy model needs to calculate the Annual Heat Demand is the heat loss due to air exchanges and ventilation within the building. The simulated building was a balanced heat recovery system where the fresh air that enters the building was equivalent to the amount of exhaust air that is being removed from the building. With this system, the only heat loss from the building is the energy that is not able to be recovered due to heat recovery systems inefficiency. For this study, an energy recovery ventilator (ERV) will be selected that has a sensible, without moisture, heat recovery efficiency of 85% and fan energy efficiency of .70 w/cfm. The minimum ERV efficiency for certification is 75% and there are ERV's on the market that have efficiencies up to 96%. Other constants were the ventilation flow rate, duct dimensions, and duct insulation, as these factors impact the total system heat recovery efficiency. The duct dimensions were held constant at 6" which is large enough to carry 200 cfm and is 10 feet long for both supply and exhaust trunks between the ERV and the building's envelope. However, at that flow rate, the velocity is high enough that the duct is no longer

acoustically quiet. The amount of duct insulation was limited to 4 inches of thickness at an R-Value of R-4 per inch and was not foil faced.

The amount of airflow that was supplied for ventilation is related to occupant needs and the building's volume. The passive house recommendation for ventilation air flow is .3 air changes per hour. The simulated building has a volume of just over 13,120 cubic feet based on the TFA multiplied by a default floor height of 8.2 feet. At .30 air changes per hour, this leads to an average air flow rate for ventilation of 65 cfm which was the value used.

The other air exchange that occurs is through infiltration due to envelope leakage. The limit for passive house certification for infiltration at 50 Pascal of pressure is .6 air changes per hour. This was the default value used for the simulated building. One component that makes up the infiltration calculation is the air volume calculated based on the building's geometry to be 14,952 cubic feet. There are also wind protection coefficients that effect how the air change rate under pressure relates to a natural infiltration air change rate that the software needs for calculating the heat loss. The screening coefficient used in this study was .07 to represent a moderate screening condition such as a building would experience in a suburban setting. The second wind protection coefficient was set at 15 to signify a building that is above grade with multiple sides exposed. Based on these entries, the building's natural air infiltration rate was .048 air changes per hour. The simulated building was also supplied with a subsoil heat exchanger, such as a glycol ground loop, for pre-heating of the incoming air in the winter and pre-cooling and pre-dehumidification of the incoming air in the summer months. The subsoil heat exchanger's efficiency was set to sixty percent.

The entries already made to the energy model for the simulated building contain most of the information to calculate the Annual Cooling Demand. Summer shading, summer set point

temperatures, and the basic cooling system were already discussed. The additional factors that influence cooling are located on the Summer sheet of the PHPP. The entry for thermal mass occurs on this page. This is a simplified value for the whole building and is calculated by Equation 3.7 with n(heavy) being the number of "heavy" surfaces on each side of a cube if each room of the building is imagined as the cube. Heavy surfaces are those beneficial for increasing thermal mass and would include concrete, tile, and water; However, the PHPP does not define a threshold for what is considered "heavy."

Specific Heat Capacity = [60+n(heavy)*24]*0.176 BTU/ft²F (3.7)

For this study, the specific heat capacity was set at 13 BTU/°F per ft². This value is rather conservative regarding the influence of thermal mass in the building, but does give a slight benefit for the simulated building's concrete slab and 5/8" drywall.

The summer condition calculation also requires ventilation flow rates. There is an entry for mechanical ventilation in case the mechanical ventilation rate differs between the heating and cooling conditions. For this study, the rate will remain identical to the winter rate of .30 air changes per hour. Many ERV's contain a summer bypass option that will bypass heat recovery when it is beneficial to do so based on the temperature differential between the inside and the outside. Summer bypass was used in the simulation. There are also entries for natural ventilation flow rates for both the day and night. The air change rate by natural ventilation through window and leakages is entered as .1 air change per hour to account for a slight daytime air exchange rate. The nighttime ventilation for the building was provided manually by opening and closing the windows. The air exchange rate used was .30 air changes per hour. This entry is conservative due to the effects the occupants have on opening and closing the windows. It is also

conservative because the PHPP is not able to consider that in many climates using night ventilation to reduce sensible cooling demand, latent loads may be introduced if the temperature is low, but humidity is high.

Primary Energy (PE) is the passive house criterion that contains all of the energy produced at the power plant to supply the building's energy needs. The majority of this study does not require this calculation, but the analysis criteria which sorts the data was influenced by this value. The Primary Energy Demand criteria was created to act as a sustainability requirement (Wofgang Feist 2011). Therefore, buildings where the primary energy value was very large, given the low heating and cooling energy, were deemed unacceptable solutions. To find this value, the electrical energy from appliances and mechanical systems was accounted for. The appliance values were left at the PHPP defaults and the lighting levels were assumed to be supplied by 100% compact fluorescent light bulbs. The energy use for the dishwasher was set at 1.20 kWh/Use. The clothes washer's energy was set at 1.0 kWh/Use and the clothes dryer was set at 3.5 kWh/Use at a residual dampness of .60, which is typical for the average clothes washer's spin cycle. The default for refrigeration in the PHPP is set for both refrigerating and freezing separately. The refrigerator was set at .78 kWh/day and the freezer is set at .88 kWh/day. An efficient all in one refrigerator solution uses about 1.0 kWh/day while the larger high end units or cheaper low end units use closer to 1.5 kWh/day. Therefore, the default used is relatively close to the real world performance. The energy used for cooking was set at .25 kWh/use, which is the equivalent of a gas range and the number of uses were set based on occupancy. The usage of laptops cell phones, and other consumer electronics in the home was set at a constant 80 watts for the study. The PHPP Manual recommends increasing this value to 150 watts if the building is an office.

Hot water usage is significant part of the building's total energy usage and a significant part of the primary energy of the building. The hot water system and its components were constants for this study. The hot water temperature was 120 degrees Fahrenheit with an incoming cold water temperature of 50 degrees Fahrenheit. The PHPP default for hot water consumption is 6.6 gallons of hot water per day and that value was also used. The hot water system for the study was an electric heat pump hot water heater with a storage tank. The storage losses were 246.5 BTU/hr based on the above temperature difference, a room temperature of 68 degrees Fahrenheit, and a specific storage heat loss value of 4.74 BTU/hr.°F. Heat losses are also calculated along the length of the hot water piping. The pipe length for the simulated building was set at 150.0 linear feet, which is typical for a building of this size. The pipe losses are calculated by assuming that the entire quantity of water in the pipe that runs to each fixture is turned on three times a day. In between each use, it is assumed to cool down from the hot water temperature to the room temperature. Accurate pipe lengths are determined from the fixture to the tank for each fixture even if the fixtures share trunk piping for the majority of the run. For the heat loss calculation through the pipe, the exterior pipe diameter must be entered. In the simulated building, the diameter was entered as .625 inches, which is the exterior dimension of .5 inch nominal pipe.

Primary energy is also a product of the fuel source that is supplying the energy to the building. The house is fully electric and supplied with an electric mix that has a PE Value of 2.7. The heating system for this house is a mini-split heat pump. The multiple heat pumps in the simulated building work against each other because the hot water heater is stealing the interior heat to heat water thus making the heating system use more energy to heat the building. To compensate, the annual coefficient of performance (COP) for the water heater was entered as 1.7

when the manufacturer's specification would be upwards of 2.6. The heat pump for space conditioning requires values for heating and values for cooling to be entered because the COP is temperature dependent. The heating season COP was set at 2.85 with a total system performance ratio (1/COP) of .35. The cooling season COP was set at 5.0 to approximate the COP of a mini-split with a 26 SEER (season energy efficiency ratio). Combined, these values are multiplied by the primary energy factor to get a total primary energy use.

The previous section thus far has explained all of the default entries that were kept constant throughout the study. As a summary for those familiar with the IP version of the PHPP 2007, the entries that were used, their cell label, and their description are located in Appendix III.

Climate

The performance of a building, especially a low energy building such as a passive house is integrally related to and dependent on the climate in which it is placed. In the PHPP, a climate data set consists of two parts. The first contains the monthly data, which consists of the data that is used to generate the annual results for heating, cooling, and primary energy demand on the verification sheet of the PHPP. The second part consists of the last three columns of every data set and contains information used to determine the heating and cooling loads of the building. The first two of these final columns are for the heating load, while the last column is for cooling load data. The heat load calculation consists of two columns, because the PHPP calculates the heating load based on two conditions and chooses the worst case.

Each set consists of: average temperatures, radiation values (North, East, South, West, Global), sky temperature, and dew point. It is worth mentioning here that the ground temperature shown on the climate page is not actually part of the data set, but is calculated based upon the

building's geometry and assemblies as entered in the ground sheet of the PHPP. This data is then referenced in the climate data sheet. It is also worth mentioning that the load data in the last three columns does not include dew point or sky temperature values. This fact makes the generation of peak latent conditions very difficult for system sizing.

Creating climate data sets for North America uses the same methods and principles that are used to generate climate data throughout the world. But, there are unique challenges in North America because the climates range from heating, cooling, or even latent dominated, and in general, are much less uniform than the available data points which are far less dense than in other places in the world due to the size of North America and lack of proximity of station locations. Finally, there are some very extreme microclimate situations that occur in very small geographical areas. The United States has radiation values that are significantly higher than many other places in the world, most noticeably, Europe, where the Passive House Standard began. These can have large effects on the calculations if the shading and window design is not performed correctly for a given climate.

The process of generating a climate data set begins by using a Swiss software application called Meteonorm to generate the base data set. Generally, a setting is chosen to have Meteonorm pull data directly from the Typical Meteorological Year 3 (TMY3) station point and place it in the PHPP format. Below is a description from the Energy Plus website (a common repository for weather data sets) about TMY3 data sets and there functions:

> The TMY3s are data sets of hourly values of solar radiation and meteorological elements for a 1-year period. Their intended use is for computer simulations of solar energy conversion systems and building systems to facilitate performance comparisons of different system types, configurations, and locations in the United States and its territories. Because they represent typical

> rather than extreme conditions, they are not suited for designing systems to meet the worst-case conditions occurring at a location. The source data are available for download from the National Renewable Energy Laboratory for download.
>
> (Energy 2013b)

The information in the data set is transferred directly from a Meteonorm output file and into the official climate file, which is an Excel based format. This format allows easy transfer into the PHPP and when compiled into a list, allows for the macro automation of the experiment. Meteonorm can also apply other functions to generate datasets. It can interpolate to exact locations including preprogrammed locations such as cities and partial stations, and most interestingly, it also has the ability to add modifiers for microclimate sites such as sea/lakes, valleys, slopes of hills/mountains. These modifiers are rarely used, but they can benefit sets by normalizing microclimate effects on a project-by-project basis. A set like this has been used in <1% of all passive house projects built in the United States to date and should only be utilized when the other options are not going to provide accurate results. Another additional feature of Meteonorm that was released with the most recent version update, is the ability to use some predictive models to look forward into the future to generate sets of data that can be used for analysis of buildings based on a changing climate as the planet warms. More information regarding Meteonorm and its algorithms can be found on Meteotest's Meteonorm webpage at the link below: http://meteonorm.com/download/software/mn70/.

While the data used throughout this study are base data taken directly from TMY3 station locations, generating custom data sets through Meteonorm is possible as mentioned above. The basic rule of thumb is that no project should certify with data for a location of more than fifty linear miles from their project location. Even projects within this range can benefit from

localized generated data if there is a closer station point. This is especially true if there are microclimate issues or impacts from geographical features, such as altitude changes, between the project site and the station. Site elevation is a modifier on the climate page in the PHPP that is often overlooked. If the difference in elevation between the project site and station location is greater than 300-400 feet the elevation modifier on the climate page in the PHPP should be used, or a new climate set should be generated. The climate modifier in the PHPP adjusts the data by taking every 1000 feet of elevation change and adjusting it up or down by 3.6 degrees Fahrenheit. Some very large discrepancies due to this adjustment can occur because often times, the real world conditions for high elevation changes consist of microclimate situations that are difficult for the linear scaling of the modifier to accurately reflect. If there is not a station location within 300-400 feet of the project site the climate set should be compared to any available local data sources. The elevation modifier can also be used to adjust a data set to local data sources. This is helpful in cases where there may not be a TMY3 station for over 50 miles, or there may be microclimate effects that occur at a given project location that are not able to be accounted for in the base data set. By using the modifier, a PHPP set can be adjusted up or down to account for the difference between temperatures between the generated data set and local, measured values.

Using accurate climate data is of utmost importance because in passive houses, the energy loads are reduced so dramatically that small changes in climate make a proportionally large difference in the overall energy balances. These small changes, for instance, 1 degree Fahrenheit, in the average temperature throughout the year can have dramatic effects. For a building meeting passive house criteria that had 2000 square feet of treated floor area in San Francisco, the difference was ~15% for the Annual Heat Demand based on that small

temperature difference with the radiation and all of the factors held constant. For another project location in Massachusetts, a data set was generated directly from the TMY3 data at the station and then a second data set was generated based on interpolation through Meteonorm to the exact same coordinates of the station. The result was a variance of +/- 4 degrees Fahrenheit as compared to the base non-interpolated values which equated to ~25% difference in Annual Heat Demand in that particular project. Nothing changed about the location, just the method of generation, straight derivation of TMY3 data or interpolation. Therefore, to eliminate as much error as possible attributable to the climate data, base TMY3 data formatted by Meteonorm was used in this study.

The PHPP climate data is a simple set of values that represent a given climate. Those values are monthly averages and not very detailed despite the locations being very precise. There are single variables for each month which are averages of the measured values, but there is not any finer grained representation of the data. The PHPP was designed to be a steady state model, which means it calculate one given set of conditions. In the PHPP, this has been expanded slightly to calculate a new monthly average condition for each month. Because of this, the climate data was created in a way that does not require very small increments or time steps in the calculation. The data sets are a representation of the hourly data from TMY3 sets. The hourly or even quarter hourly values found within the TMY3 data have been broken down into month-by-month averages instead of a larger set with values every 15 minutes or every hour. If greater specificity is needed in terms of time steps a different energy modeling program that has dynamic calculation capabilities instead of PHPP's standard static model should be used. In many cases, this is not necessary as the PHPP has been set up to simulate dynamic modeling for passive house buildings in a steady state model. This is reinforced because short-term

fluctuations are limited as the lag effect, due to super insulation, air-tightness, and thermal mass, provides a buffer against isolated peak conditions.

Prolonged peak conditions, can have a large effect in terms of real world performance. However, there is a real difference between weather and climate. The climate is an average of many years, while the weather is what occurs at any given time. Climate data is unable to predict any given trend in the future weather. It is important to reiterate that the climate is a typical condition and is not equivalent to the weather of a given year. This is especially true when comparing Heating Degree Days (HDD's) as most HDD calculations in the US use a Base of 65 degrees F while the PHPP uses a Base of 68 degrees F. Adjusting between the two will get the HDD's very close. Any remaining discrepancy can be again attributed to the granularity of the data and the intricacies of the PHPP HDD calculation as shown in the Heating Degree Day section above. For instance, since there is only monthly data, the PHPP has to decide for the swing months how many hours are needed for heating. This is an algorithm and not a measurement from the data like calculating HDD's off of an hourly set would be.

Humidity can be determined through the dew point temperature and average temperature within the climate data set. As mentioned earlier, this is a monthly value and not as specific as may be needed for some modeling methods, but should be fine with the PHPP calculation. However, also as mentioned earlier, the heating and cooling load data do not have the necessary data (dew point) to create an accurate calculation based on the peak load. This is assumed to be because peak latent is not considerably different than the level of latent moisture throughout other parts of the year. However, it does mean that cooling systems sizing occurs only for sensible cooling loads in the PHPP. Therefore, within this study, the latent peak loads were not criteria and will require further research.

One other advantage of the PHPP climate sets being based on TMY3 data is the fine and specific granularity the set locations can have. Throughout the United States, there are over 1000 TMY3 data points with a wide distribution of locations. For this study, all 1000 locations were analyzed. The reason for using all of the data sets was twofold. First, the distribution covers the whole of the United States and is widespread enough to ensure that there are not any climate locations that have not been quantified. Secondly, the more data points that were used to compare climate data to the parametrically simulated results the more precise the end analysis. Because the adjustment to the certification criteria was determined by finding the relationship between climate characteristics and the data for the certification criteria, having more locations of comparison was the best option and using all of the data sets ensured the widest distribution possible.

Equations

As a piece of software, the Passive House Planning Package is built upon a set of equations that delivers the results needed for certification of Passive Houses. Each of the criteria that is listed on the Verification sheet of the PHPP, which displays a summary of the building's information and simulation results, and can be calculated by an equation embedded within the PHPP. There is an equation for the Annual Heating Demand (Q_H), the Annual Cooling Demand (Q_K), the Heat Load (P_H), and the Cooling Load (P_C) for which the results of each of those separate equations are copied to the results section of the Verification Sheet at the beginning of the PHPP.

The equation for the Annual Heating Demand is a heat balance equation where the amount of heating energy going out of the building must be equivalent to the amount of heating

energy going into the building. If this is not the case, the difference is made up by the mechanical system, and for the purposes of finding the Annual Heating Demand, any shortfall is made up by a heating element within the building. Equation 3.8 shows the Annual Heating Demand.

$$\mathbf{Q_H = Q_L - Q_G} \quad (3.8)$$

where:

Q_H Annual Heat Demand

Q_L Total Heat Losses - Sum of Transmission and Ventilation Losses

Q_G Total Heat Gains - Sum of Solar and Internal Gains

Equation 3.8 is broken down further by separating the total heat losses and the total heat gains into their respective parts. The heat losses are caused by transmission losses through the envelope and losses through the ventilation system, which is bringing in cold air from the outside and exhausting warm air from the inside creating a net loss. Heat gains occur through solar radiation and internal gains such as waste heat from people and appliances. Equation 3.9 shows the breakdown.

$$\mathbf{Q_H = Q_T + Q_V + Q_S + Q_I} \quad (3.9)$$

where:

Q_H Annual Heat Demand

Q_T Transmission Heat Losses

Q_V Ventilation Heat Losses

Q_S Available Solar Heat Gains

Q_I Available Internal Heat Gains

The transmission losses can be broken down further. For each component of a building (wall, roof, window, slab, door, thermal bridge) a basic transmission heat loss calculation occurs. That formula is shown by Figure 3.10.

$$\mathbf{Q_T = A * U * f_T * G_t} \quad (3.10)$$

where:

Q_T Transmission Heat Losses

A Area

U U-Value

f_T Reduction Factor

G_T Heating Degree Day (HDD) Conversion

The heat loss can be calculated through the three heat transfer mechanisms: conduction, convection and radiation. Those effects are summed as transmission values within the PHPP. In most cases, conduction is the driving mechanism of heat transfer for an opaque passive house envelope. To find conductive heat loss, the calculation for Q_T is used, which is a notation for transmission heat losses. The PHPP needs to know the area that heat is passing through, to get a total amount of heat because the values for conductivity are based on a per unit area basis. The equation in the PHPP for any given area is listed on the Areas sheet is shown as Figure 3.11 below.

A = Quantity x L x W + Additional Area - Sub Area - Sub Window Area (3.11)

where:

Quanity	The amount of a given assembly (usually 1)
L and W	Lenth and Width - dimensions that make up the area
Sub Area	Ability to adjust for non rectangular shapes and irregularities
Sub Window Area	This entry makes the wall areas easier to calculate

Often times in the United States, instead of using a U-Value, an R-Value is used. Equation 3.12 shows how to calculate a total assembly R-Value.

$$\mathbf{R_T = R_{si} + (d_1 * R_1) + (d_2 * R_2) + (d_3 * R_3) + (d_4 * R_4) + R_{se}} \quad (3.12)$$

where:

R_T R-Value of the total assembly

d_n Thickness of a layer

R_n R-Value of a layer

R_{si} Interior surface film resistance

R_{se} Exterior surface film resistance

If each individual layer is already calculated, the R-Value calcualtion becomes a simple summation of the layers to find the total. The simplified formula is shown in Equation 3.13.

$$\mathbf{R_T = R_{si} + R_1 + R_2 + R_3 + R_4 + R_{se}} \quad (3.13)$$

To use the R-Value in the transmission heat loss calculation it needs to be converted to a U-Value. This conversion is listed below in two forms. The second equation uses thermal conductivity (λ_n) instead of an R-Value. Using Equations 3.14 or 3.15 allows for the easiest way to incorporate manufacturers data in many formats into the PHPP calculation.

$$U = \frac{1}{R_T} \quad (3.14)$$

or

$$U = \frac{1}{R_{si} + d_1/\lambda_1 + d_2/\lambda_2 + d_3/\lambda_3 + d_4/\lambda_4 + R_{se}} \quad (3.15)$$

The previous equations make the assumption that the R-Value or U-Value is homogenous in a given layer. Examples of homogeneous layers are materials like drywall, sheathing, and continuous exterior foam. However, almost all buildings consist of at least one non-homogeneous layer. An example of a non-homogeneous layer would be a stud wall cavity filled with cellulose. That assembly contains a percentage of wood (studs, top plates, sill plates, window framing) in addition to a percentage of insulation (in this case cellulose). This calculation can be determined through the following equation.

$$U = \frac{1}{R_T} = \frac{1}{(R'_T + R''_T)/2} \quad (3.16)$$

where:

R'_T Upper Limit of the R-Value

R''_T Lower Limit of the R-Value

This can be followed with Equations 3.17-3.20, which are used to calculate R'_T and R''_T for a given assembly. The main difference between the two methods for the determination of R is whether the calculation is performed in total of each material cut or by layer of the assembly. Using the example of the stud wall with cellulose infill, Equation 3.17 calculates as a section cut

through the assembly from inside to outside. The primary section would be cellulose (and the interior drywall and exterior sheathing) while the secondary calculation would be wood studs (and the interior drywall and exterior sheathing). In this simplified case, there is not a tertiary material.

$$R'_T = 1/(R_1*d_1) + 1/(R_2*d_2) + 1/(R_3*d_3) \quad (3.17)$$

where:

$$R_{1,2,3} = 1/[(R_{si} + (R_n) + R_{se}] \quad (3.18)$$

On the other hand, Equation 3.19 cuts the assembly into longitudinal slices that are calculated individually. For a sample wall assembly, the equation would first calculate the homogeneous drywall layer, then the non-homogeneous stud wall, and finally the homogeneous sheathing. The PHPP has the ability to calculate eight of these layers and sum them together.

$$R''_T = R_{si} + (\Sigma R_n) + R_{se} \quad (3.19)$$

where:

$$R_n = 1/[(R_1* d_1) + (R_2*d_2) + (R_3*d_3)]*(1/1000)*(d) \quad (3.20)$$

where:

R_N R-Value per a given layer

R_1 R-Value of primary material

R_2 R-Value of secondary material

R_3 R-Value of tertiary material

d_1 Percentage of primary material in the layer

d_2 Percentage of secondary material in the layer

d_3 Percentage of tertiary material in the layer

d Thickness of the layer

All opaque assembly areas for the building are treated and calculated this same way within the PHPP. Earlier, it was mentioned that the windows were subtracted out of this area. The transmission losses of the windows are calculated separately because of their complexity and also because later in the equation, the glazing area comes back into the formula in terms of solar heat gain. A window is made up of multiple components. The main two pieces being the frame (U_f) and the glass (U_g). In the PHPP, the window has two additional components that contribute to heat loss: the Ψ_{spacer} and the $\Psi_{install}$. The difference between U-Values of the glass and frame and the *Psi*-Values of the spacer and install is that the U-Value is used in conjunction with an area measurement that heat is traveling through whereas the *Psi*-Value is based on a linear length, in this case, the length of the frame and glass connection and the length of the outside frame dimensions. Finding the U-Value for a given window is completed using Equation 3.21.

$$U_W = \frac{U_g * A_g + U_f * A_f + \Psi_{Spacer} * l_{Spacer} + \Psi_{install} * l_{install}}{A_g + A_f} \quad (3.21)$$

where:

U_w U-Value of the window

U_g U-Value of the glass

A_g Area of the glass

U_f U-Value of the frame

Ψ_{Spacer} *Psi*-Value of the spacer

l_{Spacer} Length of the Spacer

Ψ_{Spacer} *Psi*-Value of the spacer

l_{Spacer} Length of the Spacer

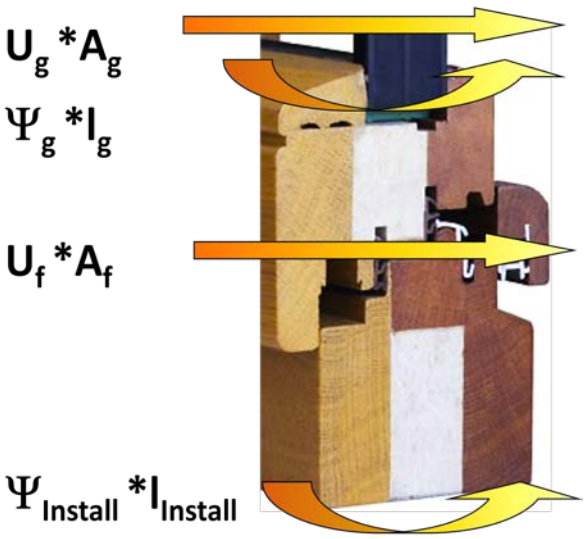


Figure 3.9: Paths of Heat Transfer Through a Window

Figure 3.9 shows the paths of heat transfer through a window frame from all of the different components. All of these methods of heat loss summed together are the total heat loss the window experiences, which is balanced against the gains through the glazing area.

Once the U-Values and Areas have been calculated, the next variable in the equation is a temperature correction factor denoted as f_T. One of the uses for this correction factor is where the building meets the ground. Another use is a tempered zone, such as an unheated garage or attic, denoted by condition "x, y, or z" on the Areas sheet of the PHPP. This correction factor reduces the heat losses through a given assembly because it is being multiplied, it reduces the temperature difference or the number of heating degree days a given assembly is exposed to.

Ground contact is modeled on a separate sheet in the PHPP and the reduction factor that is derived from that sheet is brought into the calculation in the form of f_T. The full calculation for ground contact is shown in Equations 3.22-3.27.

$$f_{tG} = \frac{\textbf{Total Heat Loss During Heating Period}}{\textbf{[(Slab Effects) + (Basement Wall Effects)] * Heating Degree Hours}} \quad (3.22)$$

$$f_{tG} = \frac{Q_{tot}}{(U_{f'} * A * \Psi_{p,stat*l}) + (Z * U_{wb} * P)} \quad (3.23)$$

where:

Q_{tot} Total Heat Loss

$U_{f'}$ U-Value of Floor Slab

A Area

$\Psi_{p,stat*l}$ Steady State Fraction

Z Basement Depth

U_{wb} U-Value of Below Grade Wall

P Perimeter

$$\mathbf{Q_{tot} = (\Phi_{stat} + \Phi_{harm}) * n * (8.76/12)} \quad (3.24)$$

where:

Q_{tot} Total Heat Loss

Φ_{stat} Steady State Heat Flow

Φ_{harm} Periodic Heat Flow

n Length of the Heating Period

$$\mathbf{\Phi_{stat} = L_S * (T_i - T_{g,ave})} \quad (3.25)$$

where:

L_s Steady State Transmittance

T_i Average Indoor Temperature During the Heating Period

$T_{g,ave}$ Average Ground Surface Temperature

For a slab:

$$\mathbf{L_S = U_o * A + \Delta\Psi * P + G_w} \quad (3.26)$$

where:

U_o Steady State Transmittance

A Average Indoor Temperature During the Heating Period

$\Delta\Psi$ Perimeter Insulation Correction

P Length of the Perimeter

G_w Ground Water Correction Factor

$$\mathbf{\Phi_{harm} = L_{pe} * 6 / (n * 2sin(pl())/12*n) * (cos(pl() / 6 * \beta) * T_{g,\wedge}} \quad (3.27)$$

where:

L_{pe} Exterior Periodic Transmittance

n Length of the Heating Period

$T_{g,\wedge}$ Amplitude of $T_{g,ave}$

β Phase Shift in Months

The L_{pe} is based on the thermal conductivity and heat capacity of the ground as well as the periodic penetration depth that the amplitude can effect. It also factors in an equivalent insulation thickness for the perimeter insulation as well as the depth of the perimeter insulation. All of this is calculated into the periodic transmittance. This equation is complex and beyond the scope necessary to understand the findings within this research. It is important at this point to reiterate that the PHPP is a steady state model that uses constant temperatures, and in this case a sine wave to develop values for harmonic phase shifts. The only way that these can be accurately modeled is through a dynamic simulation software with extremely detailed building and climate data. The sine wave and phase shift are trying to establish a ground lag effect that would be seen in dynamic modeling, or the real world in a simplified steady state model. These effects are summed together in the base equation to get a ground reduction factor (f_{tg}) that can be used in the overall transmission heat loss calculation explained above.

The tranmission heat loss equation has been explained for the U-Value, the areas, and the f_t. The last piece of the equation is the value G_t. G_t requires a discussion of climate and how the PHPP utilizes the information contained in the climate data. Specifically, the climate data is analyzed by the PHPP to provide a G_t value that can be used by the heat loss calcuation. Equation 3.28 shows a general heat loss equation.

$$\mathbf{Q = U * A * \Delta T} \qquad (3.28)$$

where:

Q Heat Loss

A Area

U U-Value

ΔT Difference in temperature on each side of the component being calculated

The difference in the PHPP's specific calculation is the ΔT value. Because the PHPP is calculating the heat loss based on an annual basis the ΔT value must be adjusted to represent a time period. Typically, in most building science equations, ΔT is replaced with a measure called Heating Degree Days (HDD). One HDD is equivalent to one day of time where the temperature is one degree less than the base temperature. Conventionally, the base temperature is 65 degrees Fahrenheit, but the PHPP uses 68 degrees Fahrenheit for its base temperature. To solve for Gt from a given number of HDD, Equation 3.29 is used.

$$\mathbf{G_t = HDD * Hours\ in\ a\ Day / 1000} \quad (3.29)$$

Dividing by 1000 adjusts the units of G_t which are in kKh/a. HDD's are calculated directly from the climate data set selected in the PHPP. This is how the temperature displayed as part of the climate set effects the transmission losses of the building.

Transmission heat losses are usually calculated as heat loss through a given area. However, linear heat loss (or point heat loss) can also occur, most commonly this happens through thermal bridging between different assemblies or materials. When this occurs, the area (A) changes to the length (L) while the U-Value (U) changes to a *psi* value (Ψ). A similar equation also exists for point heat losses (such as through a bolt) by using a chi value, but these are much less common and will not be featured in this thesis. The linear transmission heat loss is shown by Equation 3.30.

$$\mathbf{Q_T = L * \Psi * f_T * G_T} \quad (3.30)$$

where:

Q_T Transmission Heat Losses

L Length

Ψ *Psi* Value (linear transmittance)

f_T Reduction Factor

G_T Heating Degree Day (HDD) Conversion

Equation 3.31 is another way to write the transmission heat loss equation.

$$\mathbf{H_T = \Sigma A_j U_j + \Sigma \Psi_j l_j + \Sigma X_j} \quad (3.31)$$

where:

H_T Total Transmission Heat Losses

$\Sigma A_j U_j$ Sum of Envelope Transmission Heat Losses

$\Sigma \Psi_j l_j$ Sum of Linear Transmission Heat Losses - Linear Thermal Bridges

ΣX_j Sum of Point Transmission Heat Losses - Point Thermal Bridges

Besides transmission heat losses through the envelope, the rest of the heat loss occurs through the mechanical ventilation system. The total ventilation heat losses can be calculated by the using Equations 3.32-3.36.

$$\mathbf{Q_v = Q_{v,a} + Q_{v,e}} \quad (3.32)$$

where:

Q_v Ventilation Heat Losses

$Q_{v,a}$ Ventilation Heat Losses Ambient

$Q_{v,e}$ Ventilation Heat Losses Ground (Subsoil Heat Exchanger or Earth Tube)

$$\mathbf{Q_v = n_v * V_{rax} * c_p\rho * G_t} \quad (3.33)$$

where:

Q_v Ventilation Heat Losses

n_v Energetically Effective Air Exchange Rate

V_{rax} Effective Air Volume

$c_p\rho$ Specific Heat Capacity of Air (set at a constant of 0.018 BTU/ft^{3}F)

G_T Heating Degree Day (HDD) Conversion

$$\mathbf{n_V = n_{v,system} * \eta^*_{SHX} * \eta_{HR} + n_{V,Res}} \quad (3.34)$$

where:

n_V Energetically Effective Air Exchange Rate

$n_{v,system}$ Mechanical Air Exchange Rate

η^*_{SHX} Efficiency of Subsoil Heat Exchanger

η_{HR} Efficiency of Heat Recovery

$n_{V,Res}$ Infiltration Air Change Rate

$$\mathbf{V_{rax} = A_{tfa} * H} \quad (3.35)$$

where:

V_{rax} Effective Air Volume

A_{tfa} Treated Floor Area

H Clear Room Height (2.5 meter default)

$$\mathbf{n_{v\ res} = Vn_{50} / V_{rax} * n_{50} * e/(1+f/e*((excess\ extract\ air/n_{50})^2)} \quad (3.36)$$

where:

$n_{V,Res}$ Infiltration Air Change Rate

Vn_{50} Net enclosed air volume

V_{rax} Effective Air Volume

e Wind screening coefficient

f Wind protection coefficient

n_{50} Air changes at 50 Pascals of Pressure

The Ventilation Heat Losses are summed to form the total heat losses by Equation 3.37.

$$\mathbf{Q_l = Q_t + Q_v} \quad (3.37)$$

where:

Q_l Total Heat Losses

Q_t Transmission Heat Losses

Q_v Ventilation Heat Losses

The Available Solar Heat Gains (Qs) are calculated per orientation: North, East, South, West, and Horizontal by using Equation 3.38.

$$\mathbf{Q_s = Q_{sn} + Q_{se} + Q_{ss} + Q_{sw} + Q_{sh} + Q_{sa}} \quad (3.38)$$

where:

Q_{sn} Available Solar Heat Gains - North

Q_{se} Available Solar Heat Gains - East

Q_{ss} Available Solar Heat Gains - South

Q_{sw} Available Solar Heat Gains - West

Q_{sh} Available Solar Heat Gains - Horizontal

Q_{sa} Available Solar Heat Gains - Opaque Areas

The available solar heat gains for the opaque areas are retrieved from the radiation balances for each of the opaque surfaces as entered in the areas sheet of the PHPP. These may have a negative or positive influence on the available heat gains to offset the annual heat demand. Each portion of Equation 3.38 above is calculated in the same way for each orientation using Equation 3.39.

$$\mathbf{Q_s = r * g * Aw * G} \quad (3.39)$$

where:

r Shading * Dirt * Non Perpendicular Incident Radiation * Glazing Fraction

g Solar Heat Gain Coefficient

A_w Area of the window

G From the climate file

The solar gain reduction factor is due to shading, dirt, non-perpendicular incident radiation, and the gazing fraction due to the window frame, which does not produce solar gains. The reduction factors are found using Equations 3.40-3.41.

$$\mathbf{r = r_{shade} * r_{dirt} * r_{npi} * r_{frame\%}} \quad (3.40)$$

where:

r_{shade} Total Shading Reduction Factor

r_{dirt} Reduction due to dirt on glazing

r_{npi} Reduction due to Non Perpendicular Incident Radiation

$r_{frame\%}$ Reduction due to frame % of overall window

$$\mathbf{r_{shade} = r_H + r_R + r_O + r_{other}} \quad (3.41)$$

where:

r_H Horizontal Shading Reduction Factor

r_R Reveal Shading Reduction Factor

r_O Overhang Shading Reduction Factor

r_{other} Additional Shading Reduction Factor

The internal heat gains consist of heat generating sources within the thermal envelope. These include heat from people, waste heat from electrical appliances, waste heat from lighting, excess heat from cooking and other activities and many other functions. However, the internal heat gain calculation also takes into account negative heat gains such as cold water and evaporation from clothes drying and from potted plants, towels and other objects. The internal heat gains have a direct impact on the transmission losses through the envelope. Though, as seen in Equation 3.42, the internal heat gains are based on time and the amount of time they are useful for heating or detrimental for cooling.

$$\mathbf{Q_I = t_{Heat} * q_i * TFA} \quad (3.42)$$

where:

Q_I Internal Heat Gains

t_{Heat} Length of the heating season (converted to hours)

q_i Internal Heat Load in BTU/(hr.Ft^2)

TFA Treated Floor Area

The Annual Heating Demand in its simplified form is listed again as Equation 3.43 and brought directly from the beginning of this section. Equation 3.44 adds an adjustment factor, calculated by Equation 3.45 with input from Equation 3.46, to account for time when the internal and solar gains may not be beneficial, such as when overheating occurs and subtracts the gains from the losses.

$$\mathbf{Q_H = Q_T + Q_V + Q_S + Q_I} \quad (3.43)$$

where:

Q_H Annual Heat Demand

Q_T Transmission Heat Losses

Q_V Ventilation Heat Losses

Q_S Available Solar Heat Gains

Q_I Available Internal Heat Gains

$$\mathbf{Q_H = Q_T + Q_V - \eta*(Q_S + Q_I)} \quad (3.44)$$

where:

η Utilization Percentage of Free Heat

$$\eta = (\mathbf{Q_L - Q_H}) / \mathbf{Q_F} \quad (3.45)$$

where:

Q_L Total Heat Losses

Q_H Annual Heat Demand

Q_F Free Heat

$$\mathbf{Q_F = Q_S + Q_I} \quad (3.46)$$

where:

Q_F Free Heat

Q_S Available Solar Heat Gains

Q_I Internal Heat Gains

The equations above are the formulas that are used to determine the Annual Heating Demand. Various adjustments occur to these equations when they are used for the other three criteria. The Heating Load is calculated very similarly, but the climate conditions are represented by a different time period. The Heating Load is determined by finding the energy balance at a given point in time. This point in time is determined by the climate file and results in the conditions for which the peak load occurs. For the Heating Load, there are two conditions that are calculated. The first is a cold, but sunny day and the second is a cool, but cloudy day. This ensures that the PHPP accurately reflects the fact that cloud cover often helps the temperature stay slightly warmer. Both of these conditions are calculated and at the end of the calculation, the worst case situation is chosen and to become the Heating Load. Which condition is worse depends on many factors, but often comes down to the amount of glazing and the window to wall ratio. If the building has large amounts of glazing, it is relying on the solar gain to offset any transmission heat loses through the glass. Therefore, on the sunny/cold day, it does quite well and on the cloudy/cool day, it can perform considerably worse. On the other hand, a building

with smaller glazed openings will be less reliant on the solar gains. The heat loss in this type of building is controlled more by the temperature difference between the inside and the outside. Therefore, on the sunny/cold day, it does not perform quite as well as it would on the cloudy, cool day.

Another difference in the calculation that can affect the peak heat load is how partition walls are treated. Heat loss through the partition walls are not a part of the Annual Heat Demand Criteria. However, for the Peak Heating Load, the heat loss through partition walls is calculated, but at a discounted rate. This occurs so that if the neighboring unit is unoccupied or conditioned to a different set point, the mechanical system is able to handle the increase in the Peak Heating Load. Equation 3.47 is the basic Peak Heating Load calculation.

$$\mathbf{P_H = P_L + P_G} \qquad (3.47)$$

where:

$P_L = P_T + P_V$

$P_G = P_S + P_I$

The peak tranmission heat loss, Equation 3.48, is in the same format as the annual transmision heat loss equation except that the climate or temperature difference has changed from the annual value of Gt to a new value of $\Delta\vartheta$. Similarily, the ventilation heat loss, Equation 3.49, has changed very little except for the climate value from Gt to $\Delta\vartheta$. Both equations follow:

$$\mathbf{P_T = A * U * f_T * \Delta\vartheta} \qquad (3.48)$$

$$\mathbf{P_v = n_V * V_V * c_p\rho * \Delta\vartheta} \qquad (3.49)$$

where:

$\Delta\vartheta$ Worst Case Temperature Difference Between Inside and Outside

Following the same trend, for the Heat Load, the Available Solar Gains have been adjusted only by the last variable, which is now signified by G_{worst}. G_{worst} is the worst case condition for global radiation. Peak solar gains are described by Equation 3.50.

$$\mathbf{P_S = r * g * A_w * G_{worst}} \quad (3.50)$$

where:

G_{worst} Worst Case Global Radiation Value

The peak internal gains are are based on a default value unless overwritten by the custom calculation within the PHPP software. The default used for the peak internal gains is 0.51 BTU/(hr.ft^2), which is lower than the standard default setting of 0.66 BTU/(hr.ft^2). This difference accounts for the chance that the building may be unoccupied and therefore, ensures the mechanical heating system will be large enough to cover the building's Heating Load even when there are no occupants or if the user behavior is non standard. Equation 3.51 is identical to the internal gain formula for the Annual Heat Demand except that there is not a variable describing the length of the heating period as all of the lowered internal gains go straight to heating.

$$\mathbf{P_I = q_i * TFA} \quad (3.51)$$

The formulas used to calculate the Annual Cooling Demand are similar to the formulas used for heating demand, but there are a few additional portions. The transmission losses are still denoted as Q_T, but there is a note within the PHPP that names them as negative heat loads. In a cooling situation, losses, which were heat flowing to the outside for the Annual Heating Demand now consist of heat flowing to the inside of the buildings instead.

Conceptually, it is easy to understand that when moving from heating to cooling, the flow of heat through the assembly is reversed, but it is essential to maintain the correct sign (negative

or positive) when using the formulas. Equation 3.52 is the formula for the Annual Cooling Demand.

$$\mathbf{Q_K = Q_T + Q_V + Q_S + Q_I} \quad (3.52)$$

where:

Q_K Annual Cooling Demand

Q_T Transmission Heat Losses

Q_V Ventilation Heat Losses

Q_S Available Solar Heat Gains

Q_I Available Internal Heat Gains

Differences in the equation occur specifically on how the utilization factor (η) is calculated. For the Annual Heat Demand, η was denoted as the utilization factor heat gains. For the Annual Cooling Demand, η is denoted as the utilization factor heat losses. Additionally, the ratio of free heat gains to losses is now the ratio of losses to heat gains. This holds with the reversing of the direction of heat flow in the Annual Cooling Demand calculation. The other difference is in regard to the Ventilation Heat Losses (Q_V). Q_V has an additional component called Heat Losses Summer Ventilation. This component adjusts the overall Ventilation Heat Losses to account for the effect of natural ventilation and additional nighttime mechanical ventilation. Though there are some slight differences, the overall structure of the calculation remains the same between the heating and cooling calculations.

Similarly to how the Peak Heating Load differed from the Annual Heating demand, so too does the Peak Cooling Load differ from the Peak Cooling demand. Equations 3.53-3.54 show the annual and peak transmission losses respectively.

$$\mathbf{Q_T = A * U * f_T * G_t} \quad (3.53)$$

$$\mathbf{P_T = A * U * f_T * \Delta\vartheta} \quad (3.54)$$

where:

$\Delta\vartheta$ Worst Case Temperature Difference Between Inside and Outside

The Peak Cooling Load is shown by Equation 3.55.

$$\mathbf{P_C = P_T + P_V + P_S + P_I} \quad (3.55)$$

Each of the values from the previous equations for Annual Heating Demand, Annual Cooling Demand, Peak Heat Load, and Peak Cooling Load, need to be processed one step further before they are equivalent measures of the passive house criteria. Each value must be divided by the treated floor area to get the passive house criteria. The results that are now in a per square foot basis are transferred to the summary on the Verification sheet.

The equations, defaults, and variable inputs discussed throughout Chapter 3 allow the simulation to run and the raw data to be gathered. The analysis of the data is shown in the results sections in Chapter 4 and Chapter 5.

Chapter 4

Raw Data Analysis

This chapter presents the analysis of the raw data before filtering occurs. The simulations were analyzed without any adjustments to the data, which allowed for general trends to be understood and for the maximum and minimum values of the dependent variables, such as the Annual Heat Demand, to be found. These maximum and minimum values represent the boundaries of the range of technically possible values for a given climate data set location based on the simulated building and the variables that were tested. The given ranges show all cases from the best to worst. Each of these climate data locations was graphically represented to allow quick processing of the data for further analysis.

To explain the initial analysis, Alaska was chosen as the state to be representative of how the method was utilized. Alaska is one of the states with the most climate data locations. It is also generally a heating dominated state, but the climates range widely from locations in the Aleutian Island chain, which are moderated by the ocean, to locations near the Arctic Circle, which were the coldest locations covered in the study. Figure 4.1, below, shows the full calculation for the state of Alaska. The cases were plotted along the x-axis from highest energy use, on the left, to lowest energy use, to the right. Each curve represents one climate data location. For each location, the resulting Annual Heating Demand, Heating Load, Annual Cooling Demand, and Cooling Load were each plotted in their own graph. Figure 4.1 shows the Annual Heating Demand for Alaska with the higher energy consumption cases to the left and lower energy consumption cases on the right. Each case is a specific combination of the variables of the simulation as explained in Chapter 2. For all climate locations, the vertical dotted line visible

near case 7200 on the x-axis will be explained later in the chapter and can be ignored for the initial analysis. The graphs for every state are located in the Appendix F.

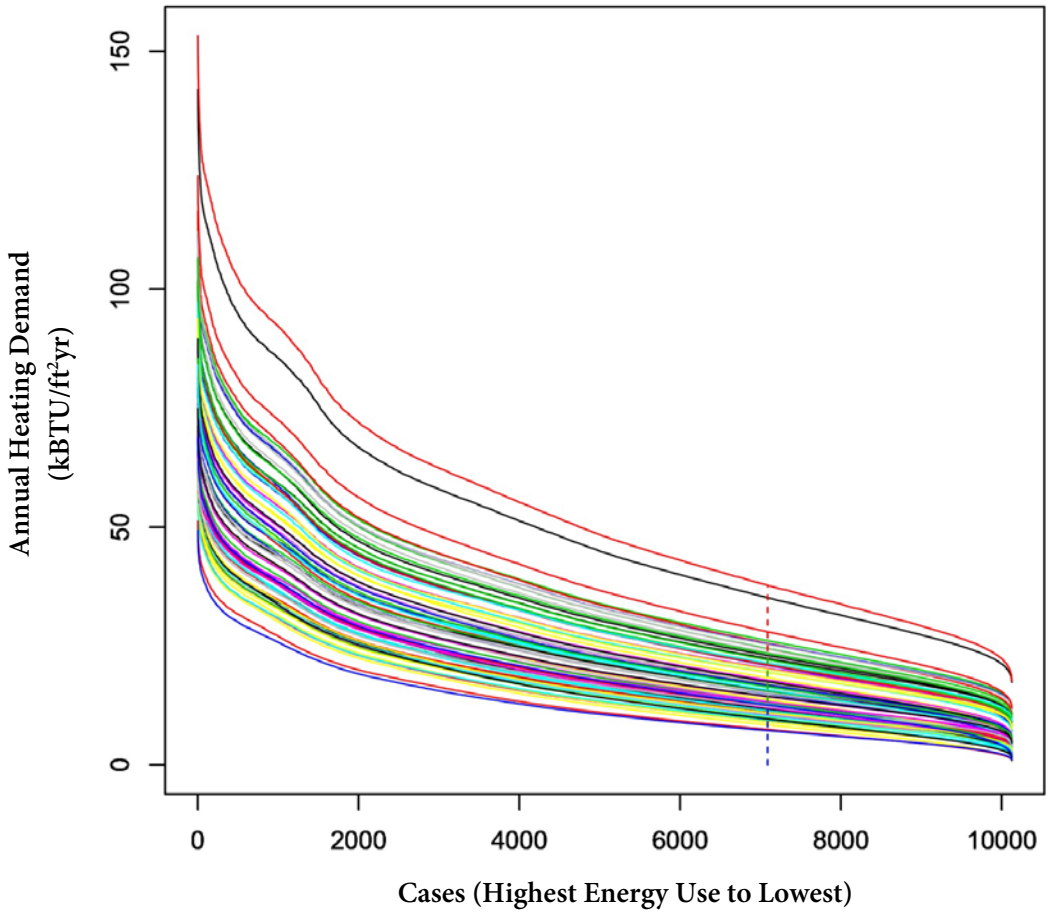


Figure 4.1 - Alaska - Heating Demand - Full Values

The data plotted in Figure 4.1 displays certain characteristics that are common to many of the analysis graphs by state. One readily apparent characteristic of the graph is that the trend comparisons between different climate locations are very similar. The uniform shape of the curve from case to case shows high precision between the results of the simulations for the different climate locations. Within Alaska, the output shows a similar results curve between each location.

The simulated combinations for each location were identical. Because of this, the only reason that the curves do not lie directly on top of each other is due to the difference in the climate data, such as higher or lower temperature and radiation values. As the climate becomes more extreme, the Annual Heating Demand Values go up for each case. However, the increase from the best performing climate to the worst performing climate for the best case, right side of the graph, is much smaller than the increase in energy use for the worst performing case, left side of the graph. This could have implications for building design in a future where more and more extreme climates are occurring through climate change. If buildings are constructed that are low energy use, they are more insulated from the effects of a changing climate and will always perform better than buildings that are not analyzed to meet low energy goals.

Figure 4.2 is a graphical representation of the same data in Figure 4.1, the Annual Heating Demand for Alaska. However, in Figure 4.2, each individual climate location is plotted as a vertical bar. Instead of a curve, each data point on the vertical bar is representative of a five percent value. This means all of the 10125 data points for each location do not need to be plotted for the trends to be understood. If the furthest left climate and furthest right climate are compared, the range in energy use is much greater for climates that are more extreme. Another trend that occurs within each individual climate location is that the cases on the end of the range perform either very well or very poorly depending on which side of the range they are on. The marginal performance of each case on the graph is significantly greater at the ends of the graph's range. Therefore, the cases that are poor performing in a given climate perform very poorly and the cases that are good performers are very good performers. This means that the strategies that were tested, such as increases in glazing percentage or the amount of insulation, work very well in locations where they are well suited and do not work well in locations where they are not well

suited. This could lead to implications on design and certification of passive houses due to the fact that some strategies that work very well may need to be utilized to reach the very low energy goals. Projects not using these strategies would automatically be at a disadvantage when confronted with reaching the criteria for passive house certification.

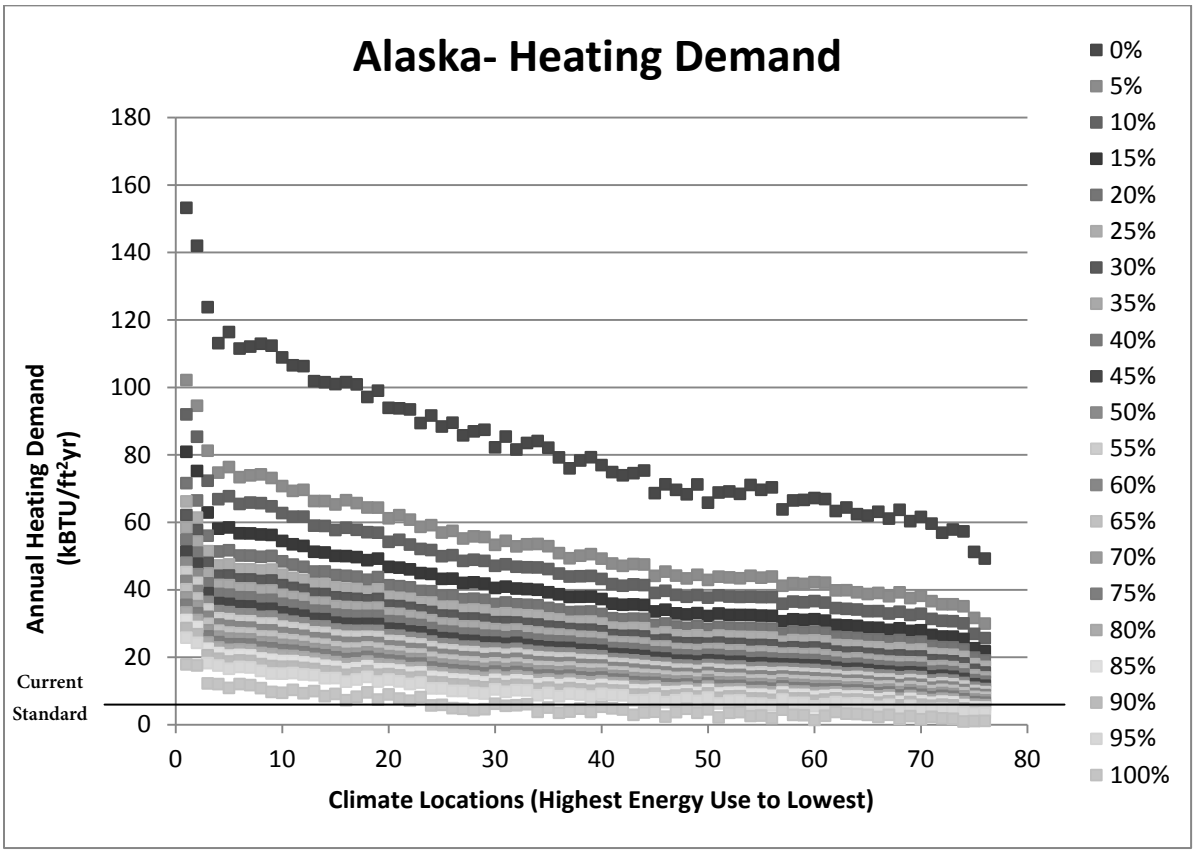


Figure 4.2 - Alaska - Heating Demand - 5% Values

It is worth noting the scale of the energy use in terms of Annual Heat Demand in the figure above. The current passive house criteria of 4.75 kBTU/ft2yr for the Annual Heat Demand is very low in its placement on the graph. By that cutoff, very few of the buildings and climates simulated meet the passive house standard. This is to be expected to some extent because many of the cases simulated had very low levels of insulation and low amounts of heat gain, both of which are very detrimental to buildings pursuing low energy targets in heating dominate climates

such as most of those in Alaska. However, even the best cases in many locations, did not achieve the current passive house criteria and in all locations, beyond the best performing 20%, none of the cases would meet the Passive House Standard. This graph alone shows the need for research and development within the standard so that it is more accessible for extreme climates, which would allow for widespread adoption of passive house as a low energy standard in all climate zones.

The following pages show a comparison between two of the locations in Alaska that were part of the above analysis. One is Ambler, AK, shown in Figure 4.3. Located near the Arctic Circle, Ambler is a small, remote outpost of roughly 250 individuals where the low temperatures can dip down to -70 degrees Fahrenheit in the heating season. The other climate location for comparison is Adak, AK, which is located near the Western end of the Aleutian Island Chain and is also visible in Figure 4.3. Due to the moderating effect of the ocean, the climate is much milder. Adak is in a sub-polar climate zone that features overcast skies and moderate temperatures with the average temperature range being between 20 and 60 degrees Fahrenheit.

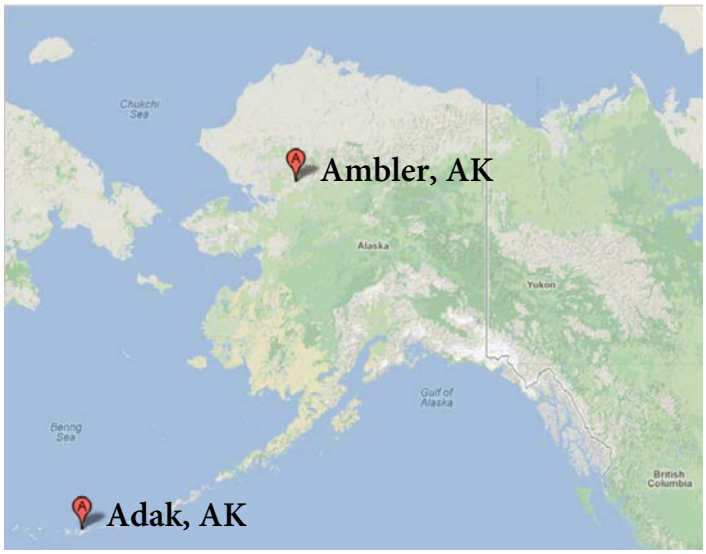


Figure 4.3 - Map of Ambler and Adak, Alaska

Figures 4.4 below shows the Annual Heat Demand for Ambler and Adak. Due to the more extreme climate, all cases in Ambler perform significantly worse than the same cases located in Adak. The point of note within the figure is the performance of the low energy cases. As a passive house, the best performing case in Adak would meet the criteria for the Annual Heat Demand, where as in Ambler it is not possible to get below 4.75 kBTU/ft^{2}yr. It is not possible despite the insulation levels being near or over R-100 and the windows being better performing than almost all commercially viable options at R-11 with a .6 Solar Heat Gain Coefficient. Going to this level and especially beyond would be deemed unreasonable and certainly not an effective use of materials, resources, and capital, but in Ambler, that is the level of envelope investment necessary to meet the Annual Heat Demand. The advent of new technology and better material performance may allow buildings in Ambler to meet the standard, but those materials and strategies are either unavailable, non-existent, experimental, or extremely costly.

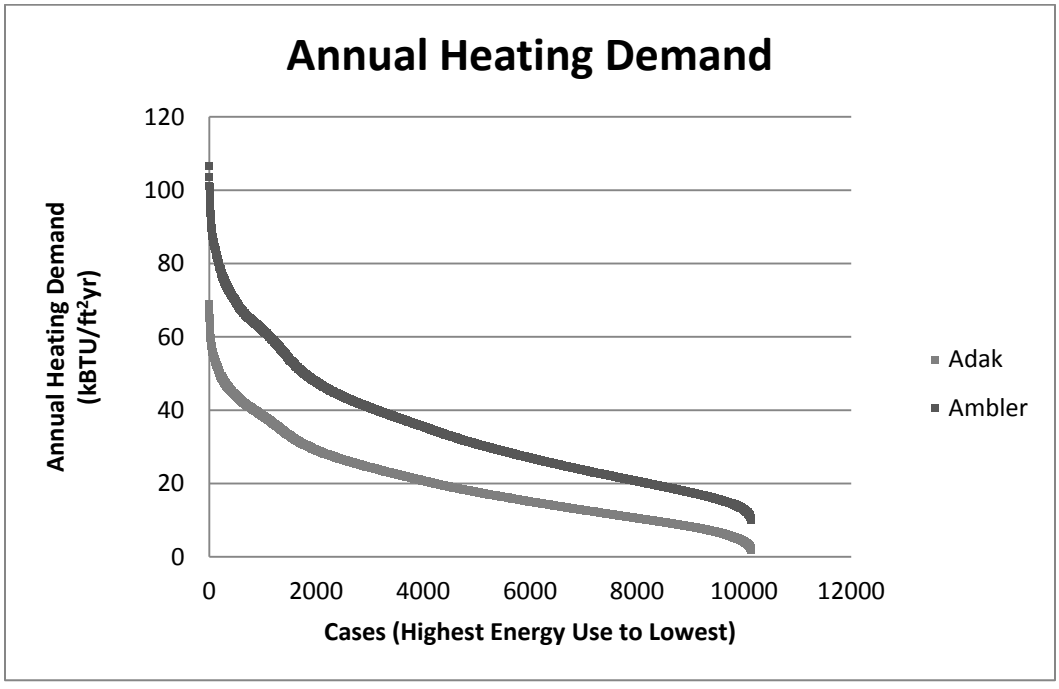


Figure 4.4 - Annual Heating Demand - Ambler, AK and Adak, AK

Figure 4.5 shows the Heating Load in the same format that Figure 4.4 shows the Annual Heating Demand. The conclusion seen in this figure is very similar to that of Figure 4.4. Ambler, which has a larger heating demand, also has a larger heating load. The Passive House Standard Heating Load threshold is limited at 3.17 BTU/ft^{2}hr. As with the Annual Heating Demand, the best case for Ambler does not meet the Heating Load criteria while the best case for Adak does. In both locations, the worst cases do not come close to meeting this standard. The extreme cases still perform marginally better, or worse, than the cases that are moderate in terms of marginal performance. In Figure 4.6, there is a distinct bump between cases 1000 and 1500. This bump can be attributed to a trend that gets marginally better until that factor is maxed out, and then the next factor begins to change. For instance, the possible combinations of the building could remain constant except for the insulation of the wall/roof. As that insulation increases, the performance increases until the wall and roof insulation are maxed. At that point, the simulation program begins to increase the next most marginally effective variable, which creates a greater slope than the performance increases near the end of the wall/roof insulation spectrum. This is the reason that in most of the graphs, there is a slight rolling effect along the sweep of the curve.

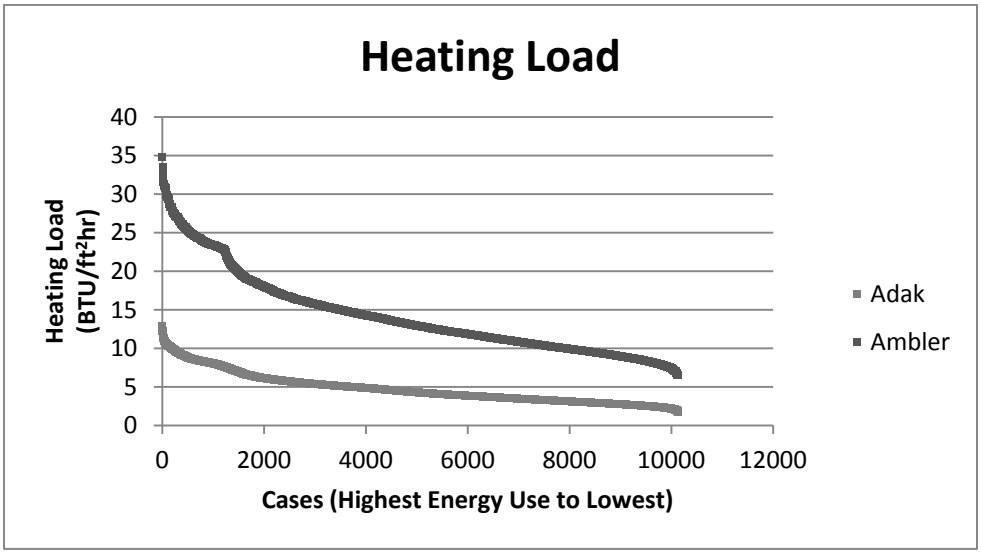


Figure 4.5 - Heating Load - Ambler, AK and Adak, AK

The Annual Cooling Demand is also higher in Ambler than it is in Adak, which comes as a surprise given the more southerly location of the later climate. However, in this case the moderating effect of the ocean outweighs some of the other climate characteristics. Another contributor is that the diurnal cycle is significantly affected near the poles. This leads to an increase in radiation in the cooling season due to the long length of the daytime hours. This combination increases the cooling needed in Ambler. However, both Adak and Ambler meet the Passive House Standard criteria for Annual Cooling Demand. Though, it can be relatively assured that if the shading defaults used in the simulation were increased, Ambler would potentially have the lower of the two cooling demands. Since both climates consist of over 4000 building cases that have an Annual Cooling Demand of 0.00 kBTU/ft^{2}yr. Meeting the Annual Cooling Demand is possible even with the very worst case buildings.

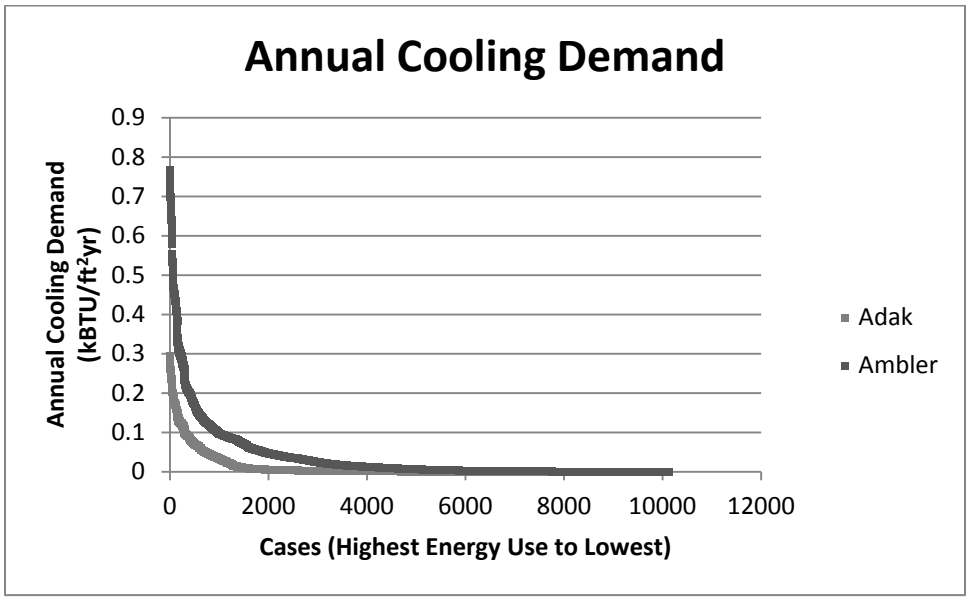


Figure 4.6 - Annual Cooling Demand - Ambler, AK and Adak, AK

The Cooling Load in Figure 4.7 for both locations is zero. This makes clear the understanding that in this climate, cooling is not an issue and that many building types can

support very low cooling energy values. It also raises the possibility of trading heating energy for cooling energy. For instance, as solar gains increase, heating goes down and cooling goes up. In this type of climate, since there is not a cooling demand or load, one possible strategy would be to increase the solar gains, through increased windows size or the SHGC, to drive down the Annual Heating Demand until an Annual Cooling Demand and Cooling Load begin to appear.

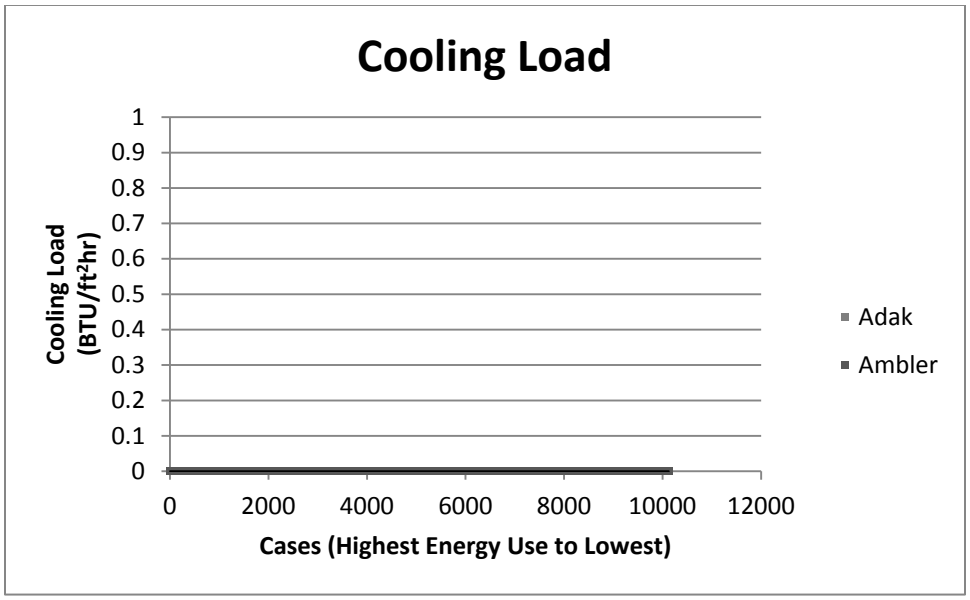


Figure 4.7 - Cooling Load - Ambler, AK and Adak, AK

From the individual graphs located in the appendices, the trends that were just shown for Ambler and Adak can be understood through a similar analysis of the data. By reviewing the figures for each state, it is possible to determine the mix of heating and cooling dominated climates within the simulation zone and the range of the best and worst cases. However, a more in-depth analysis of the data is possible. The next example undertakes such an analysis for the state of Illinois and analyzes the values of Annual Heating Demand, Heating Load, Annual Cooling Demand, and Cooling Load.

In Figure 4.8, below, the Annual Heating Demand for each climate data location in Illinois has been plotted. The number of cases is shown from highest energy use to lowest energy use along the x-axis. The y-axis of all of the following graphs is either Heating/Cooling Demand ($kBTU/ft^2yr$) or Heating/Cooling Load (BTU/ft^2hr) depending on the figure's title. Each climate data set location is a different color curve.

If increasing the adoption of the Passive House Standard is one of the goals of attempting to set a recommendation for a new Passive House Standard set of criteria for the United States, then the value that is chosen must be achievable by more projects than the "perfect" project. Therefore, choosing the very best case as the new criteria for a certification standard that needs to be surpassed is not a viable option. If this were the case, many projects would be unable to obtain certification. If the site was not quite perfect, in terms of solar access, for instance, certification would be unobtainable for the building. Also, since the simulated building is rather compact if the actual building attempting to be certified differed slightly from the simulated case, in shape, size, or treated floor area, then certification would again be unobtainable. If for some reason the most effective strategy could not be used, based on the figures above where it was shown that the strategies that worked, worked very well, the best case is again unobtainable.

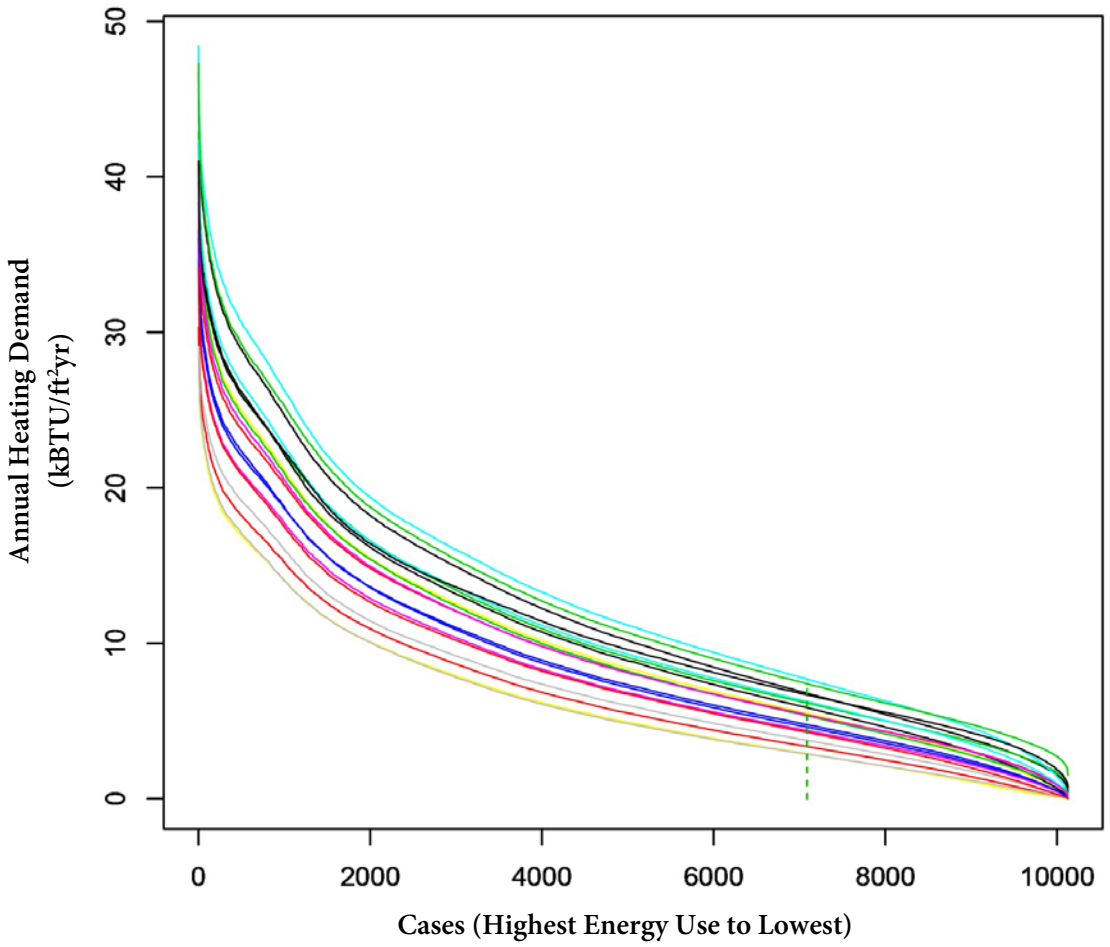


Figure 4.8 - IL - Heating Demand Full - Sample Chart

When looking at the full curve of the Illinois simulations in Figure 4.8, the buildings that meet current certification criteria are near the right side of the graph in the higher case numbers. As stated in the previous paragraph, it does not make sense to create criteria at the far right edge of the figure. It also does not make sense to create target criteria on the left side of the graph. Such a target would be too easy to achieve and would ignore significant energy savings that would be relatively easy to realize. Therefore, the criteria should be somewhere between the far right and the far left, but pushed as far right as is reasonable and feasible so that the energy savings are maximized.

To determine the point at which the adjusted criteria should be set, a method was created that relied on the principle of marginal effectiveness between the cases. The marginal effectiveness increased at both the beginning and end of the full range of cases. Since finding the marginal effectiveness only in the area of good energy performance is of value, the cases of high energy use could be discarded. Marginal effectiveness as described within this paragraph is a measure of the slope of a line between two points. In this example, it is the slope of a line between two cases of a given climate data location. The larger the slope, the larger the marginal effectiveness, and therefore, the more impact the difference in strategies between the two cases had. The slope, or marginal effectiveness, can also be found by using a single point by first deriving a line tangent to the graphical curve at a given point. Using the slope of the line shows the marginal effectiveness at a given case compared to the cases on either side, as determined by the bordering cases tangent lines.

Using a statistical criterion, Bayesian Information Criterion (BIC), linear tangent lines could be tested by using logarithmic functions and an Analysis of Variance (ANOVA). The program 'r' was used to complete the analysis by comparing the tangent lines at each point. At each data point, the tangent was found and its fit was judged using the shape of the curves to each side of the point. The analysis cycled through the points until the best fit for both curves is found. This point happens to be the point where the slope begins to steepen and an increase in marginal effectiveness begins to occur. By finding this point, the standard criteria can be set in a way that maintains high standards for energy efficiency, yet still allows room for improvement or room to be more efficient than the standard demands. As mentioned earlier, this room allows for design freedom and the possibility of creating an architecturally compelling building, along with freedom for the designer to use specific strategies customized for a given set of restraints.

The double curve shape of the full graph showing all 10,125 cases does not allow for a simple fitting of slope curves because the curve on the left side of the analysis will be trying to fit a spectrum that is closer to exponential in shape than linear. To allow the analysis to fit the curve, the excess cases that were not important to the results, those on the far left, were discarded. For most locations, cases 0-7999 were removed from the analysis. Cases 8000-10125 were analyzed and plotted. On the graph, at the point that is determined from the best fit lines explained above, a vertical dotted line is drawn down to the x-axis. This is the point when the x-axis shows the case number and the y-axis shows the energy use value that will become the new standard criteria for that given climate. Each analysis simulation produced numerical values in data form, Appendix E. These are plotted on a graph, Appendix F. One analysis was performed for each state, except the state of California, which was broken into two portions, to make the simulation easier to manage in terms of size and time.

The Annual Heating Demand for the state of Illinois using cases 8000-10125 is shown in Figure 4.09, below. In this figure, it is possible to determine the point where the marginal effectiveness begins to increase by using the two-slope method as described above. The vertical lines mark the points where the new criteria are plotted. The energy values that correspond to these lines were saved and utilized for further analysis. Note how the values chosen were pushed far to the right so that only the most efficient ten percent, or so, became the points and values chosen. At the same time, the most efficient cases are still able to surpass the certification criteria. In Illinois, the values for heat demand that were chosen would constitute a slight tightening when compared to the Passive House Standard's current criteria.

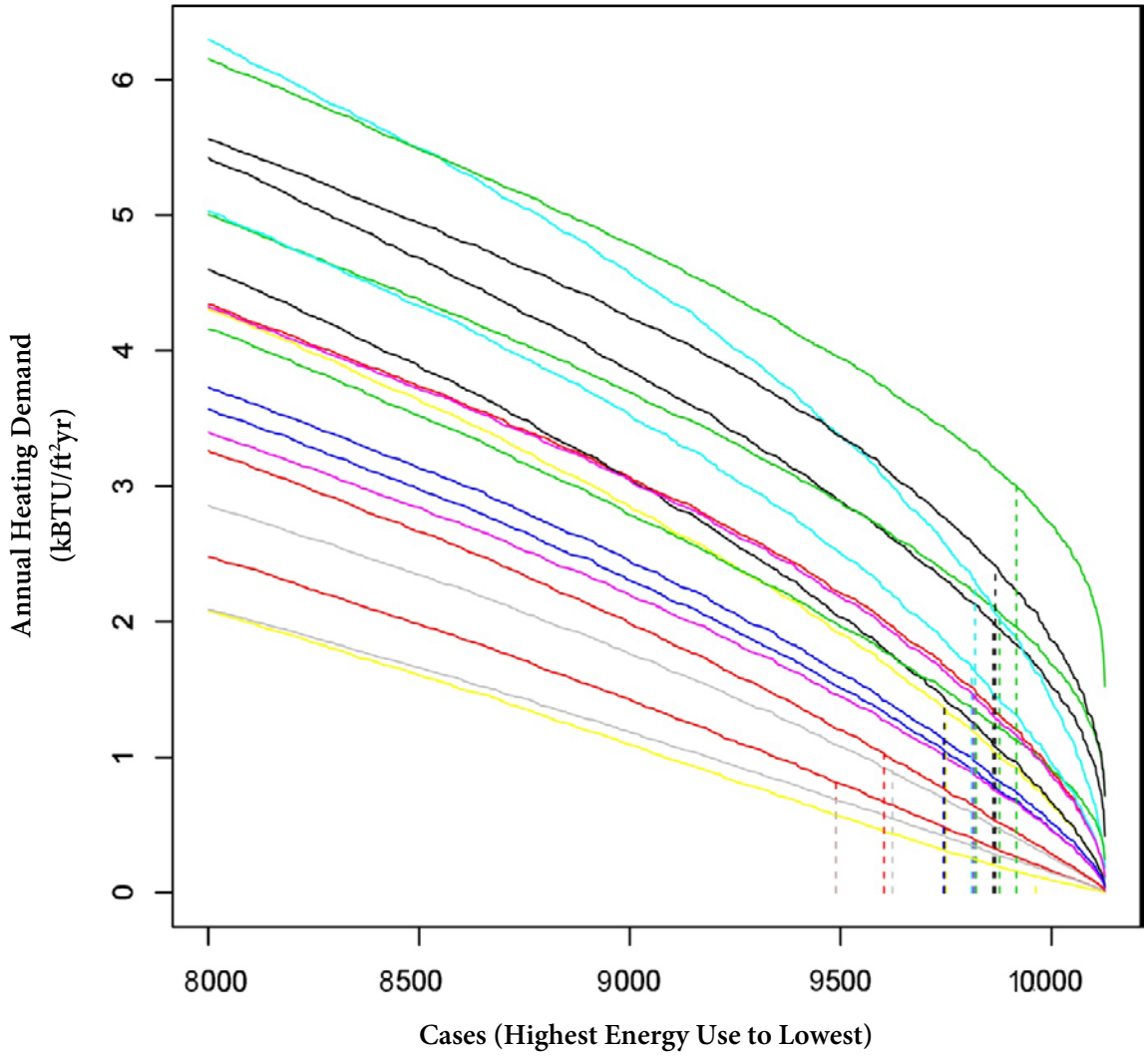


Figure 4.9 - IL - Heating Demand - Cases 8000-10125

Figure 4.10 shows the full results and Figure 4.11 shows the best performing cases, cases 8000-10125, for the Heating Load, Annual Cooling Demand, and Cooling Load for Illinois. Both of these graphs show the similar trend to the Annual Heating Demand.

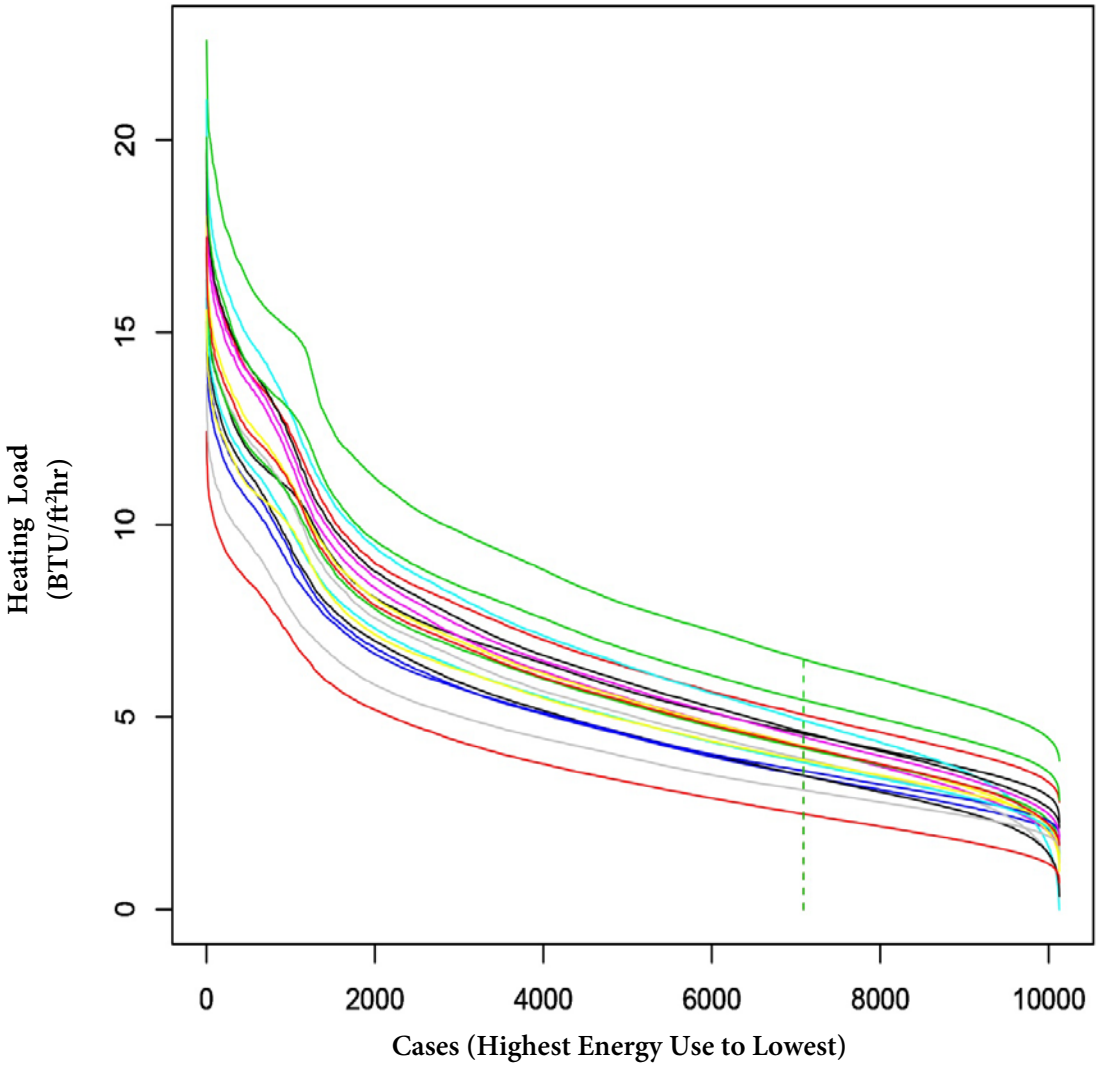


Figure 4.10 - IL - Heating Load - Full

The Heating Load results plotted in Figure 4.11 show the same trend as the Annual Heating Demand, but are enlightening due to their values. The current criteria for the Heating Load is 3.17 BTU/hr*ft^2. The loads for some locations in Illinois will meet that criterion, while the loads for others will not. Since all of the climate locations in Illinois can meet the Annual Heat Demand criteria, if the certification criteria between Demand and Load values were matched in a way that if you meet one heating criteria, you meet the other, much like the current Passive House Standard as it pertains to Central Europe, it would follow that every climate in

Illinois should be able to meet the Heating Load as well. This proves that the assumption that a given Annual Heat Demand, 15 kWh/m^2yr (4.75 kBTU/ft^2yr) in central Europe, equates to a given Heating Load, 10 W/m^2 (3.17 BTU/hr*ft^2) in central Europe, is not accurate and that there are other factors that influence these two criteria at different rates.

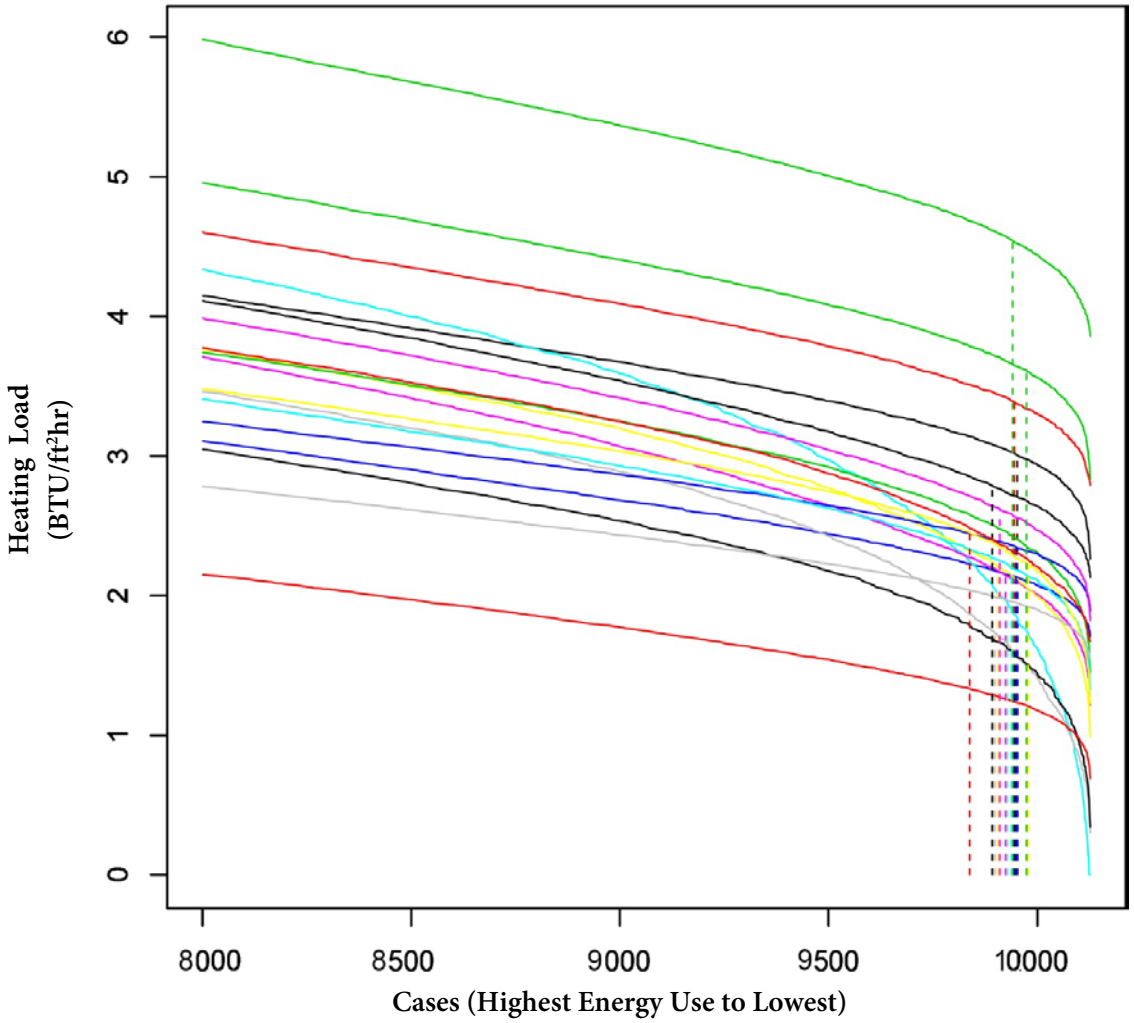


Figure 4.11 - IL - Heating Load - Cases 8000-10125

The cooling cases for both demand and load are shown on the following pages.

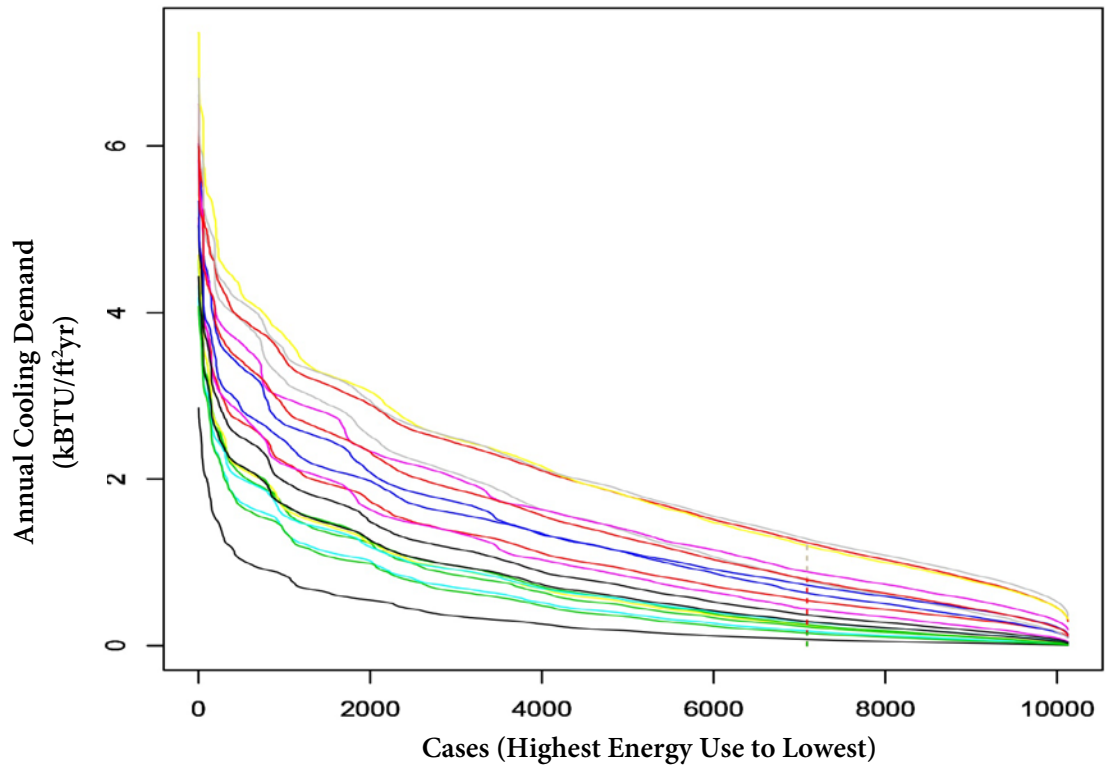


Figure 4.12 - IL - Cooling Demand - Full

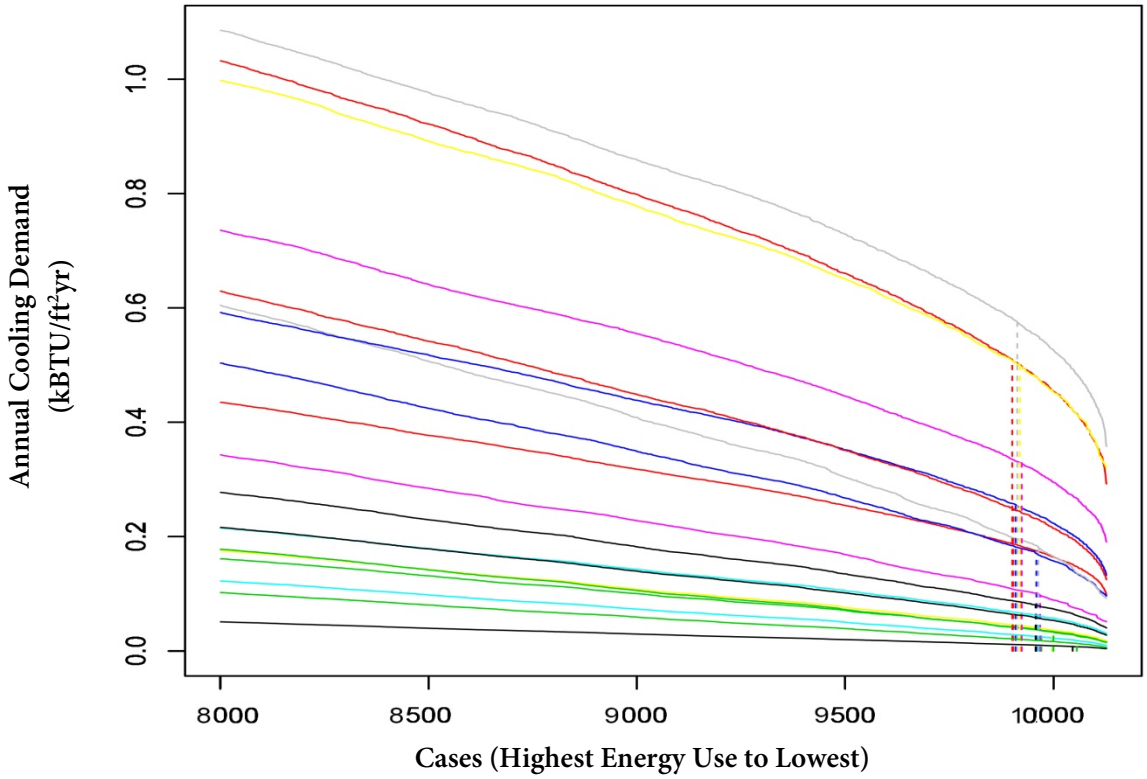


Figure 4.13 - IL - Cooling Demand - Cases 8000-10125

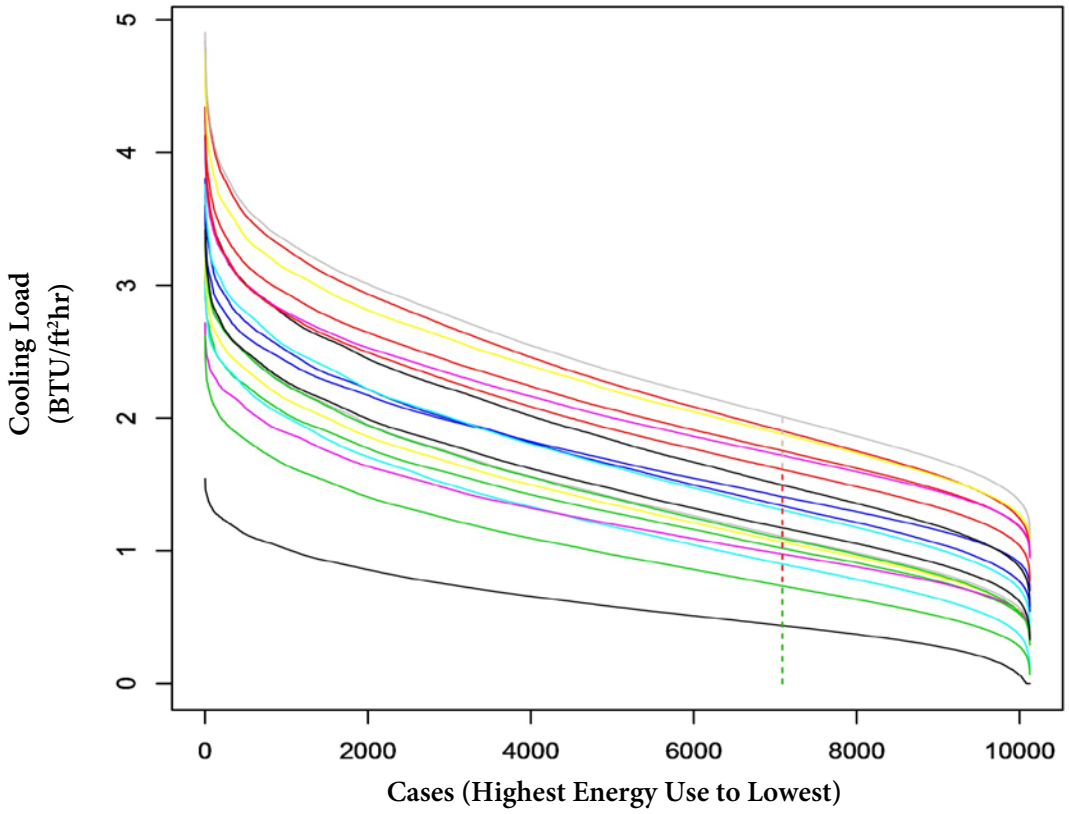


Figure 4.14 - IL - Cooling Load - Full

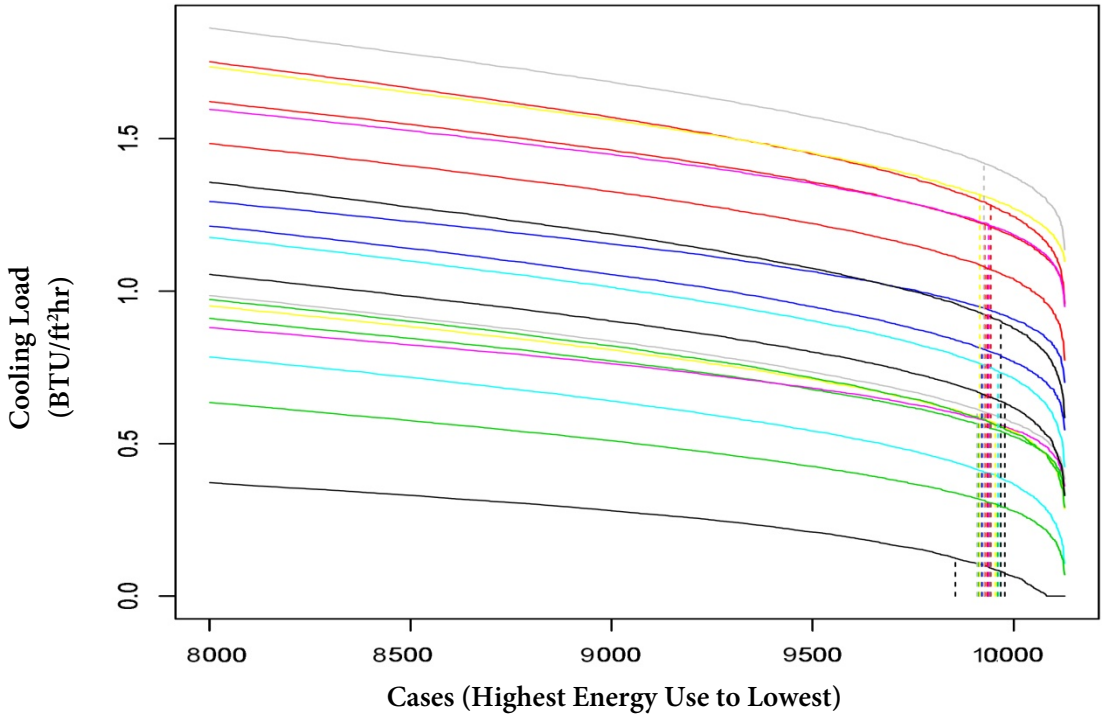


Figure 4.15 - IL - Cooling Load - Cases 8000-10125

For Illinois, nearly all of the graphs showed an increase in marginal effectiveness on both ends of the range of cases. When the marginal effectiveness does not increase and decrease at extremes, in most instances, the resulting criteria value should be a zero because many of the cases are able to read an energy use of zero. Figures 4.16 and 4.17 show the Annual Heating Demand for the state of New Mexico. From the full graph, Figure 4.16, it can be seen that the trend from earlier examples where marginal effectiveness is greatest at the extremes does not hold true because the marginal effectiveness does not increase for the highest performing cases.

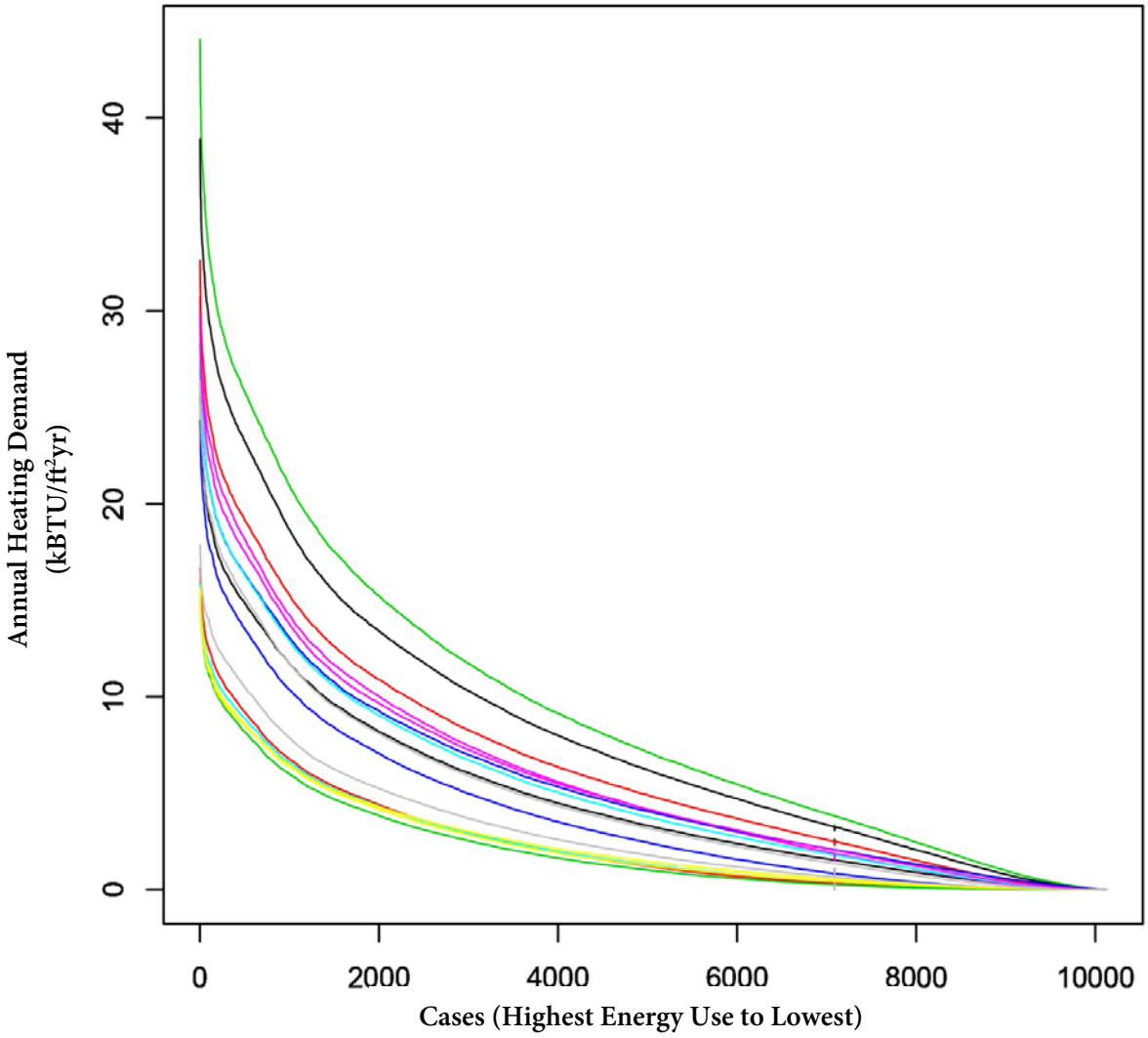


Figure 4.16 - NM - Heating Demand - Full

In Figure 4.17, where only the very well performing cases from New Mexico are analyzed, the slope showing the marginal energy use of each case begins to flatten. However, the values are very small. The proposed new criteria for climate locations in New Mexico for the Annual Heating Demand vary between ~0 kBTU/ft^{2}yr and ~0.4 kBTU/ft^{2}yr. These values would equate to tightening the standard by over 90% and every location still has well over 500 of the 10,125 cases that go beyond the values chosen. This means that there are still many methods and strategies that would work to achieve the low values evident from this analysis.

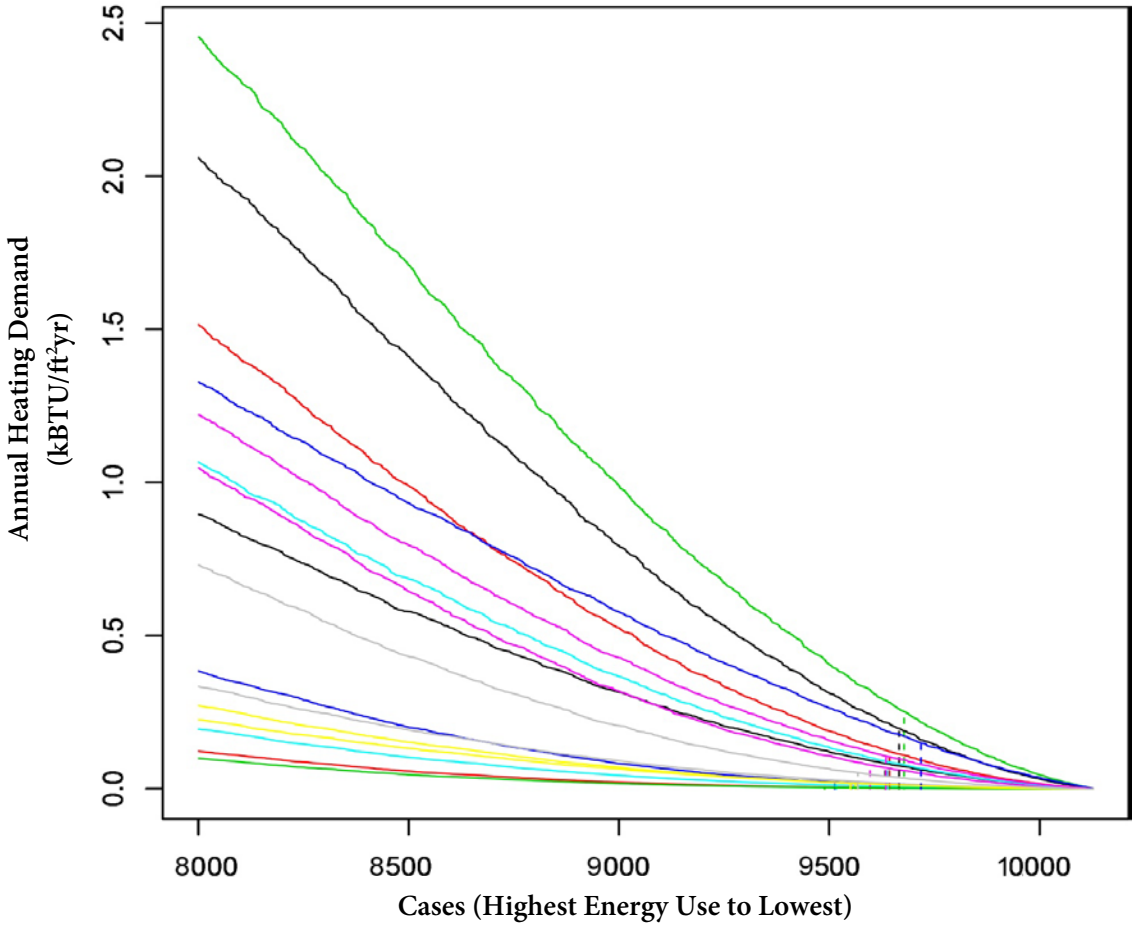


Figure 4.17 - NM - Heating Demand - Cases 8000-10125

The entirety of the plots for every state as seen above is located in Appendix F.

Once the values for the Annual Heating Demand, Heating Load, Annual Cooling Demand, and Cooling Load were determined for every climate location, they were plotted against the characteristics of the climate location. The first graph, Figure 4.18, below, shows the relationship between the Annual Heating Demand and the average yearly temperature. Each of the plotted points represent the best fit case, found through the statistical analysis, for each climate data location. As expected, as the temperature decreases, the amount of heating energy needed increases. The trend is rather linear once the temperature is cold enough to create a heating demand. The cooling dominated and mixed climates are also plotted on the graph, which creates a significant grouping of cases that have a near zero Annual Heating Demand.

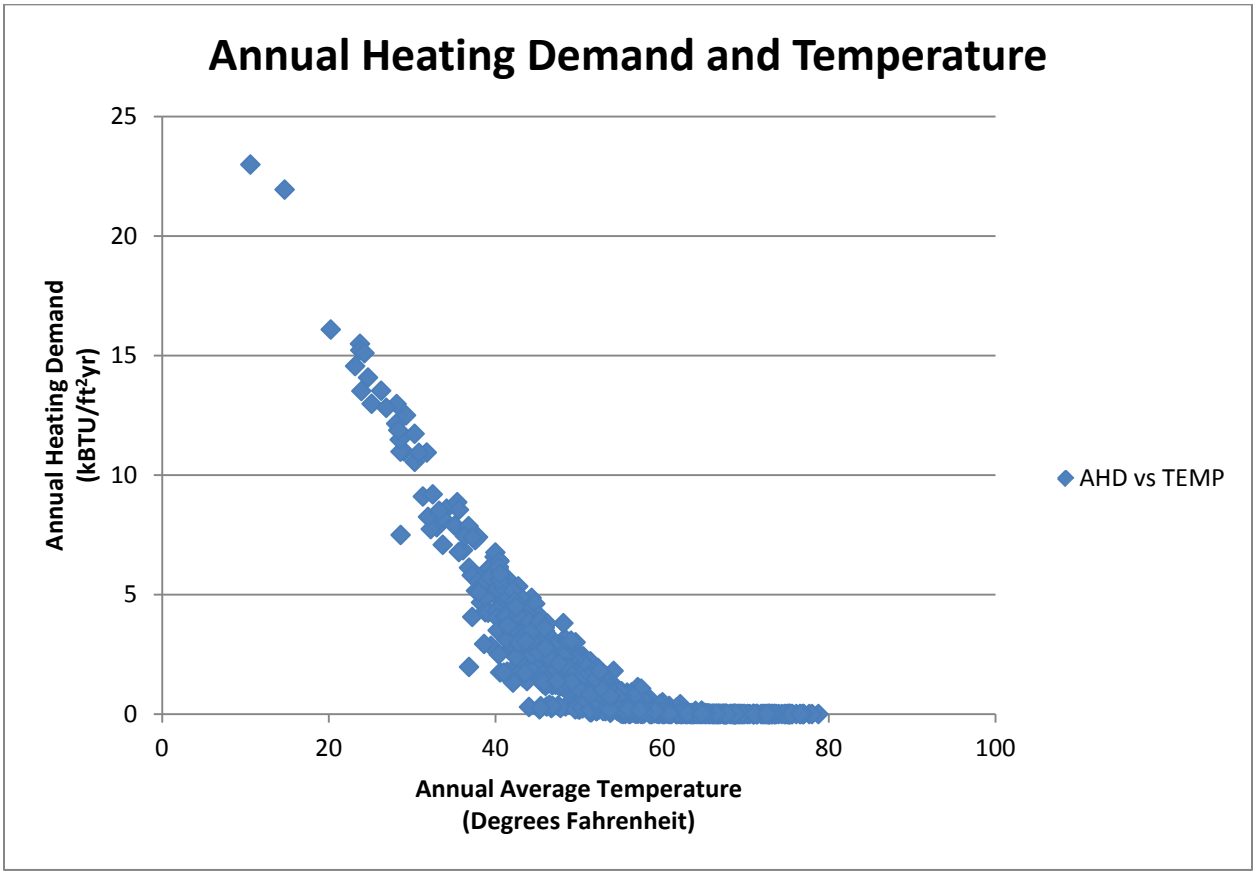


Figure 4.18 - Relationship between Annual Heating Demand and Temperature

The relationship between the Annual Cooling Demand and temperature that is shown in Figure 4.19 is very similar to the relationship between Annual Heating Demand and average temperature except that as temperature increases, the Annual Cooling Demand also increases. Another difference is the rate at which the energy use increases with the temperature. The slope of that increase is visibly steeper than that of the Annual Heating Demand. The magnitude is also not nearly as great when compared to heating energy. Both of these characteristics can be partially attributed to the fact that the temperature difference for heating is very large as compared to cooling. The larger temperature difference for heating equates to a larger heating energy use overall and the smaller temperature difference for cooling allows the increase in energy use to be stacked closer to vertical. In addition, the Annual Cooling Demand only measures sensible cooling. If latent energy were added into the equation, the cooling energy would be significantly higher and more in line with, or surpass, the heating energy depending on climate location.

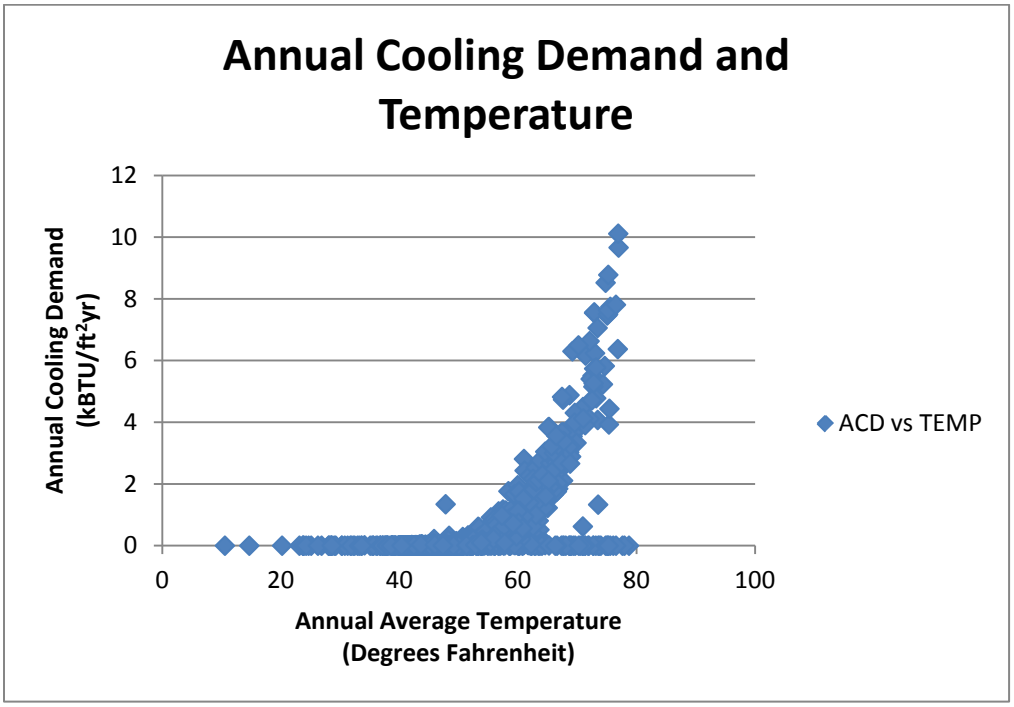


Figure 4.19 - Relationship between Annual Cooling Demand and Temperature

Figure 4.20 shows the relationship between Heating Load and temperature. The temperature used in the analysis was the average of the two temperatures for the Heating Load calculation, which consists of a cold/sunny day and a warm/cloudy day. Since the temperature is no longer the annual average, the temperature is much colder than the annual average temperature used in the calculation of the relationship between temperature and the Annual Heating Demand. However, the same overall distribution and trends hold true for the Heating Load and temperature as for the Annual Heating Demand and temperature. There was one outlying case and a few specialized climates where the temperature was rather low, but the Heating Load was also very low and in some cases zero. With that in mind, the trend was very linear and there was a strong visual correlation.

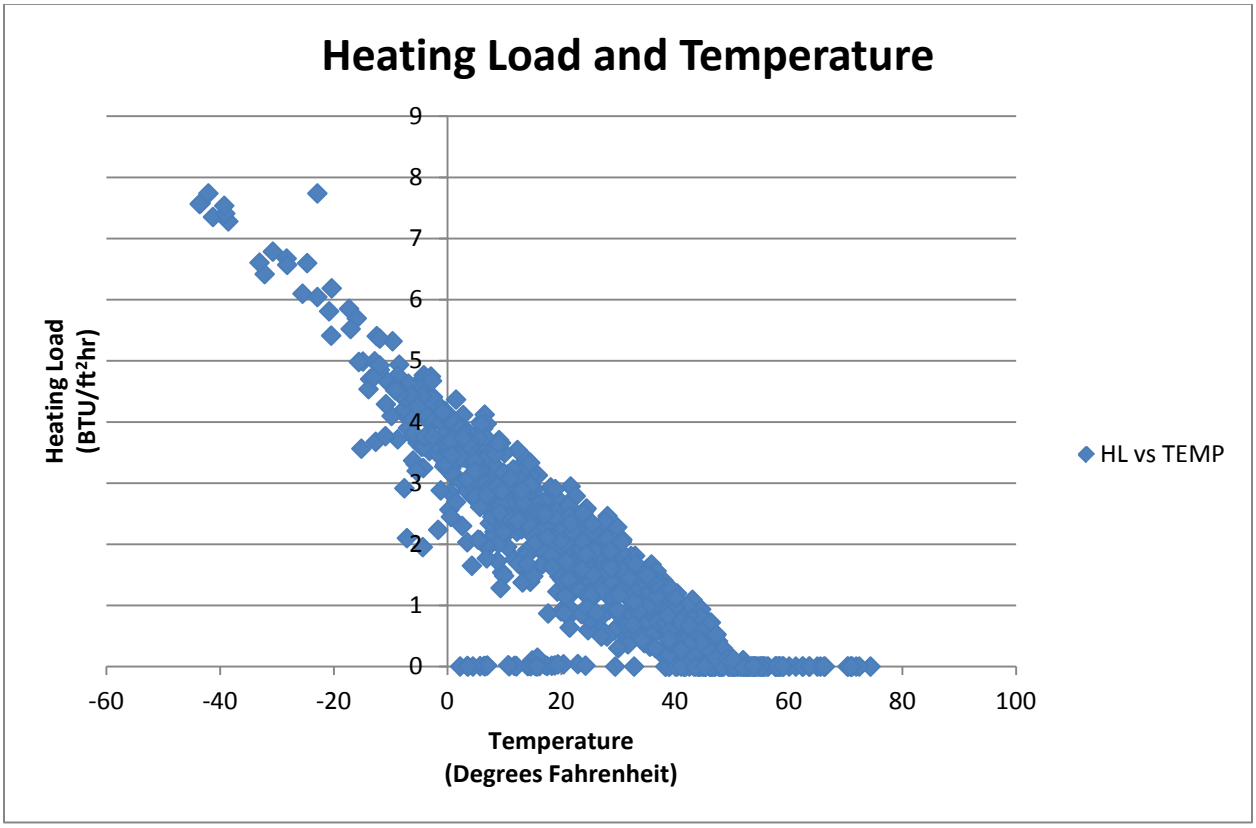


Figure 4.20 - Relationship between Heating Load and Temperature

The relationship between the Cooling Load and temperature as shown in Figure 4.21 also indicates a similar trend as seen between the previous graphs and analysis. As the temperature increases, the Cooling Load increases rapidly due to some of the causes mentioned earlier such as the small temperature differences between indoors and the exterior during the cooling season. Similar to the comparison between the Annual Heating Demand and Cooling Demand, the magnitude of the Cooling Load is not as great as that of the Heating Load.

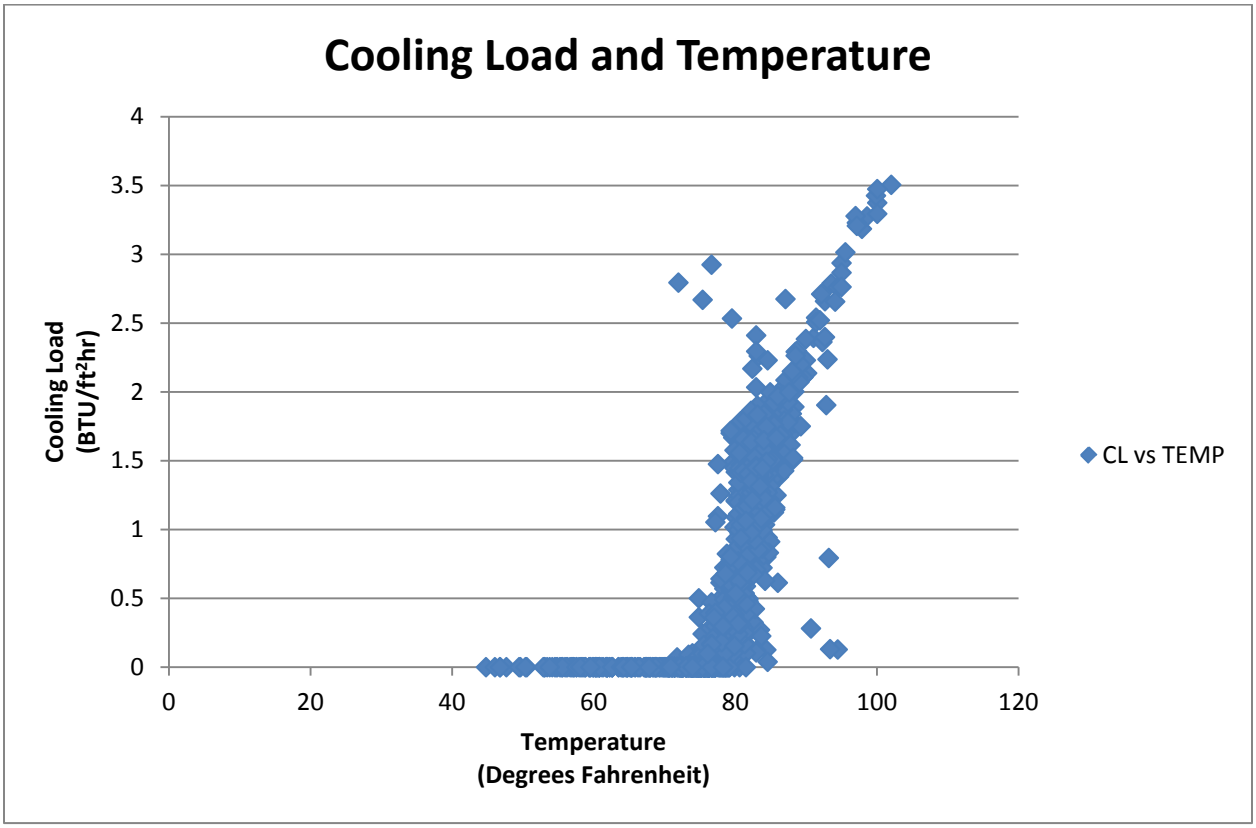


Figure 4.21 - Relationship between Cooling Load and Temperature

Figures 4.19-4.21, above, for the analysis between the various energy use graphs and temperature all show a strong correlation between the temperature and the energy use. In addition, all of the figures show trends that are to be expected, such as, when the temperature decreases, heating will increase. The figures that follow show climate characteristics other than

temperature, such as solar radiation. Within the climate set, radiation is determined for each cardinal direction as well as a global value. The following five figures show the relationship between the Annual Heat Demand and the different radiation climate characteristics.

Figure 4.22 shows that for the relationship between the Annual Heating Demand and Radiation North there is a visual correlation, but for the majority of climate data sets the radiation values are within a very small range. The amount of annual heating energy does not seem to depend strongly on the radiation from the North, which could be due to the fact that very little heat gain occurs from radiation through the north windows as compared to the other directions during the heating season. However, when looking at Figures 4.23-4.26, there is a very similar trend. There is a slight increase in Annual Heating Demand when the radiation is less and climates with extremely high radiation values do not have any heating energy use.

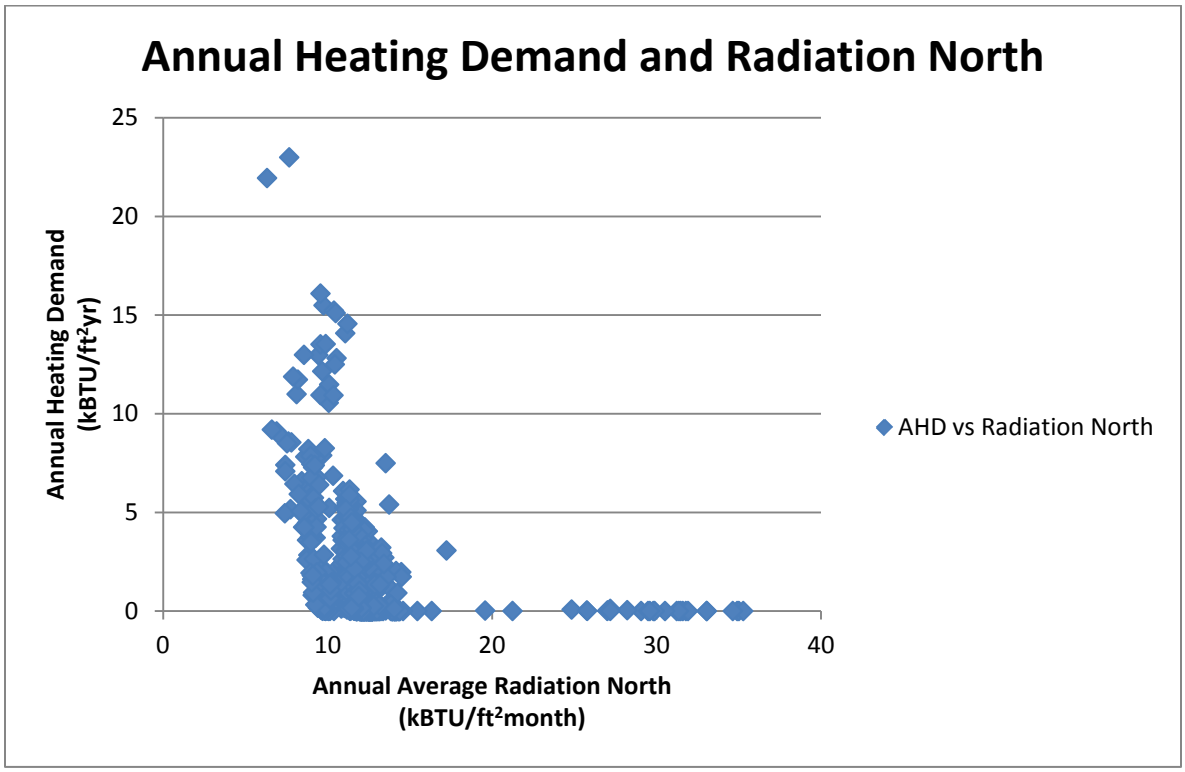


Figure 4.22 - Relationship between Annual Heat Demand and Radiation North

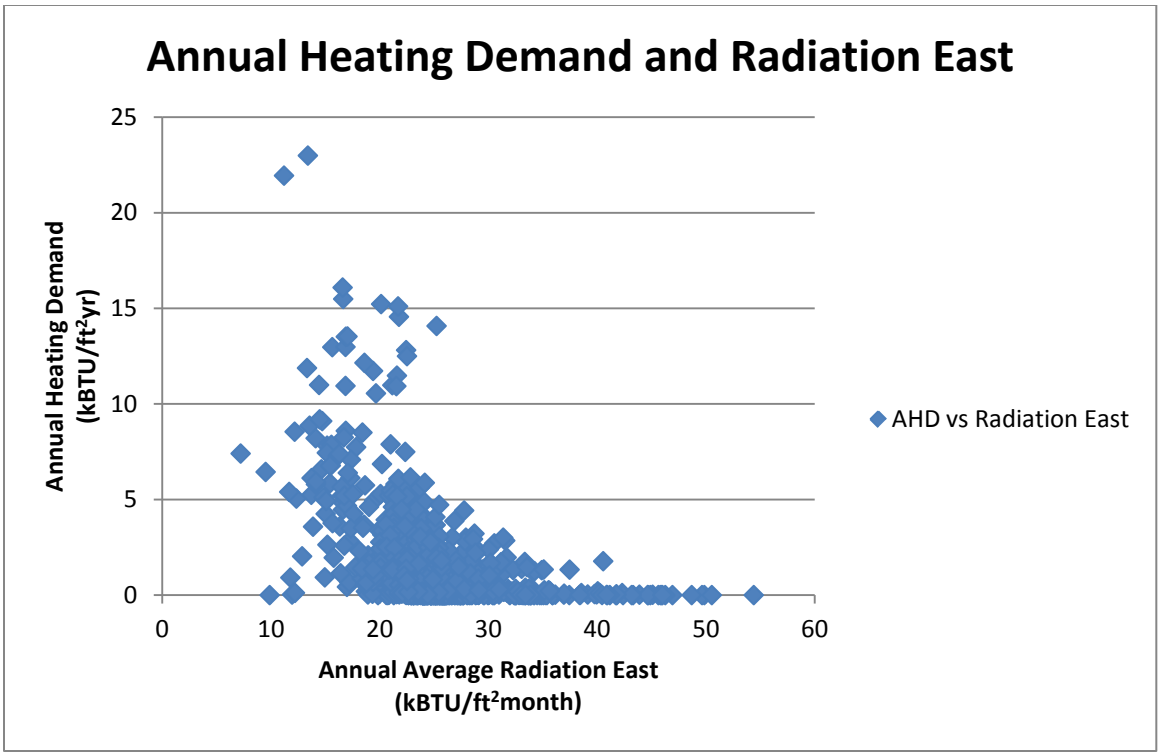


Figure 4.23 - Relationship between Annual Heat Demand and Radiation East

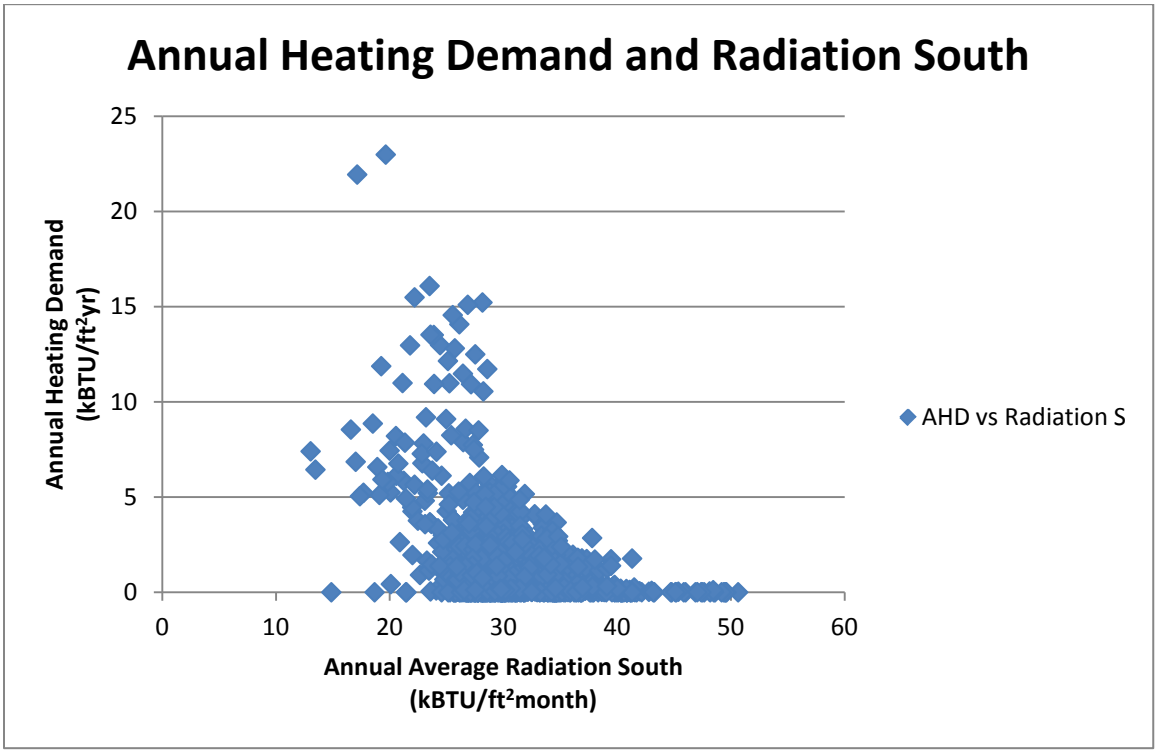


Figure 4.24 - Relationship between Annual Heat Demand and Radiation South

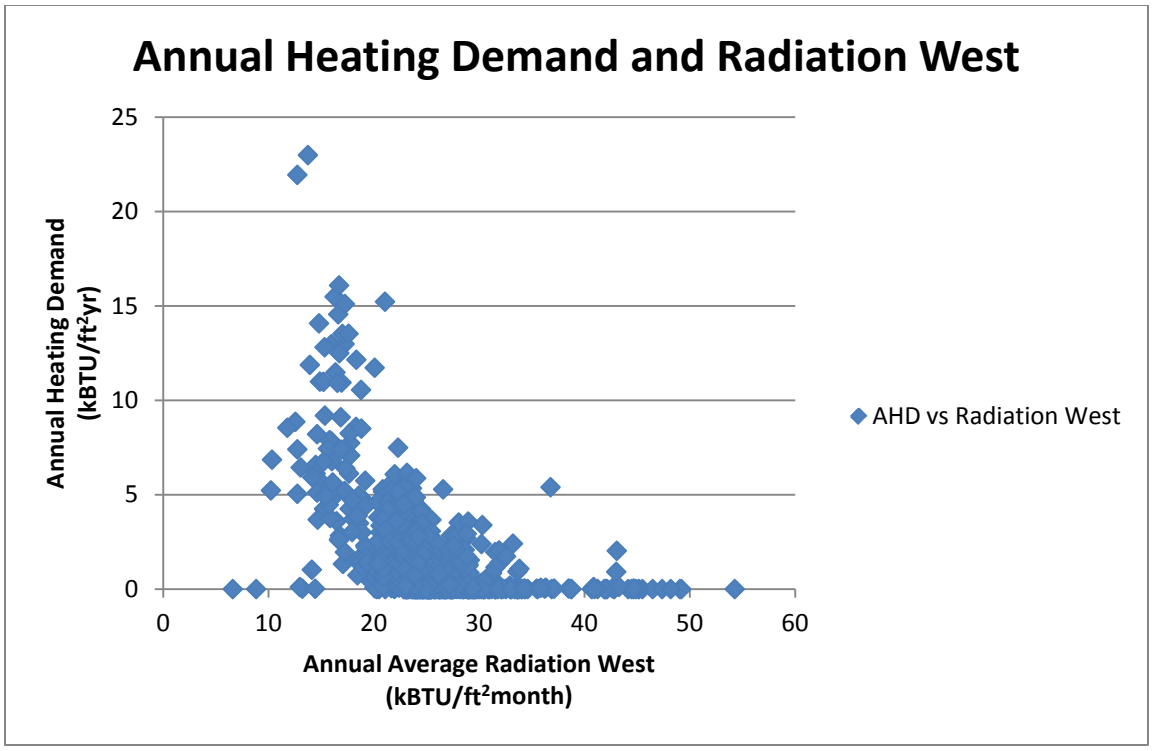


Figure 4.25 - Relationship between Annual Heat Demand and Radiation West

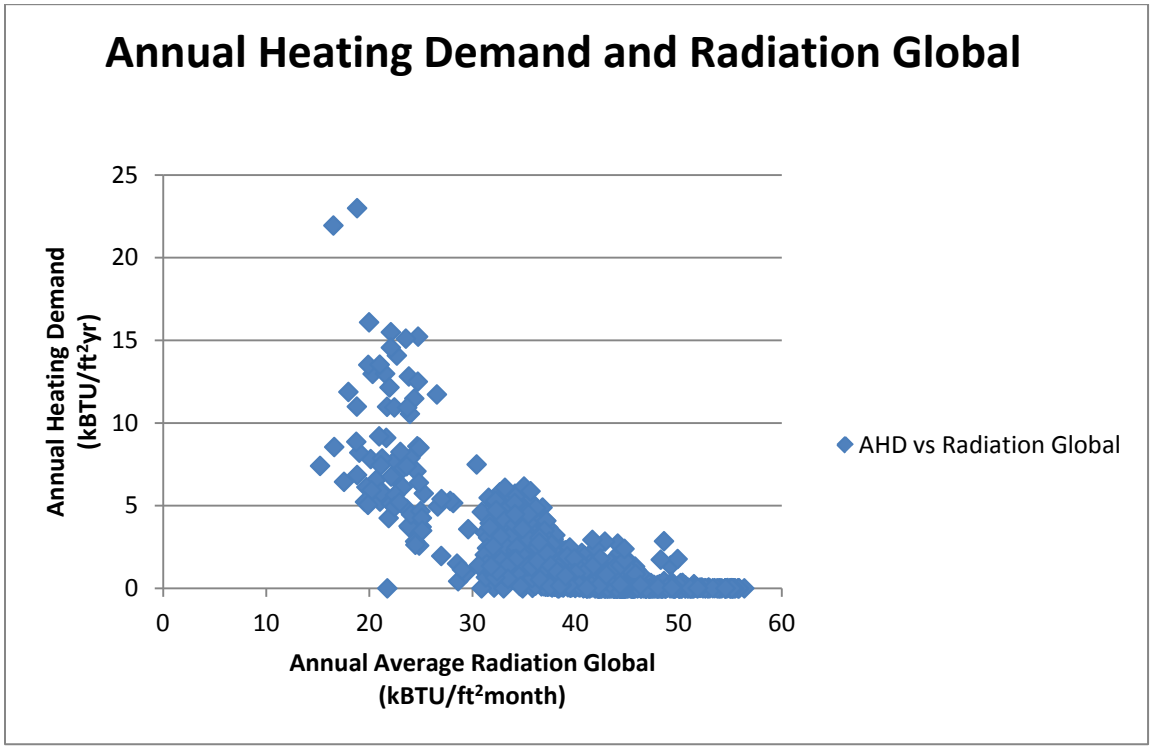


Figure 4.26 - Relationship between Annual Heat Demand and Radiation Global

Figures 4.27-4.31 illustrate the relationship between the Annual Cooling Demand and the five radiation values. For each graph, a similar grouping of points exists. Within a relatively narrow band of radiation values, the Annual Cooling Demand increases and decreases significantly. The climate locations with the least amount of radiation also have the least amount of cooling energy used. Through this observation, it can be reasoned that more radiation leads to higher cooling energy, but also that there are many factors that must have greater influence because changes in radiation only have a small effect. Therefore, based on the analysis thus far, it can be reasoned that the Annual Heating and Annual Cooling Demand are driven primarily by temperature, and to a lesser extent by the amount of radiation present. There are some outlier data points within this analysis. When researched, many of these points were in the state of Hawaii and are far removed from the typical climate conditions seen in the United States.

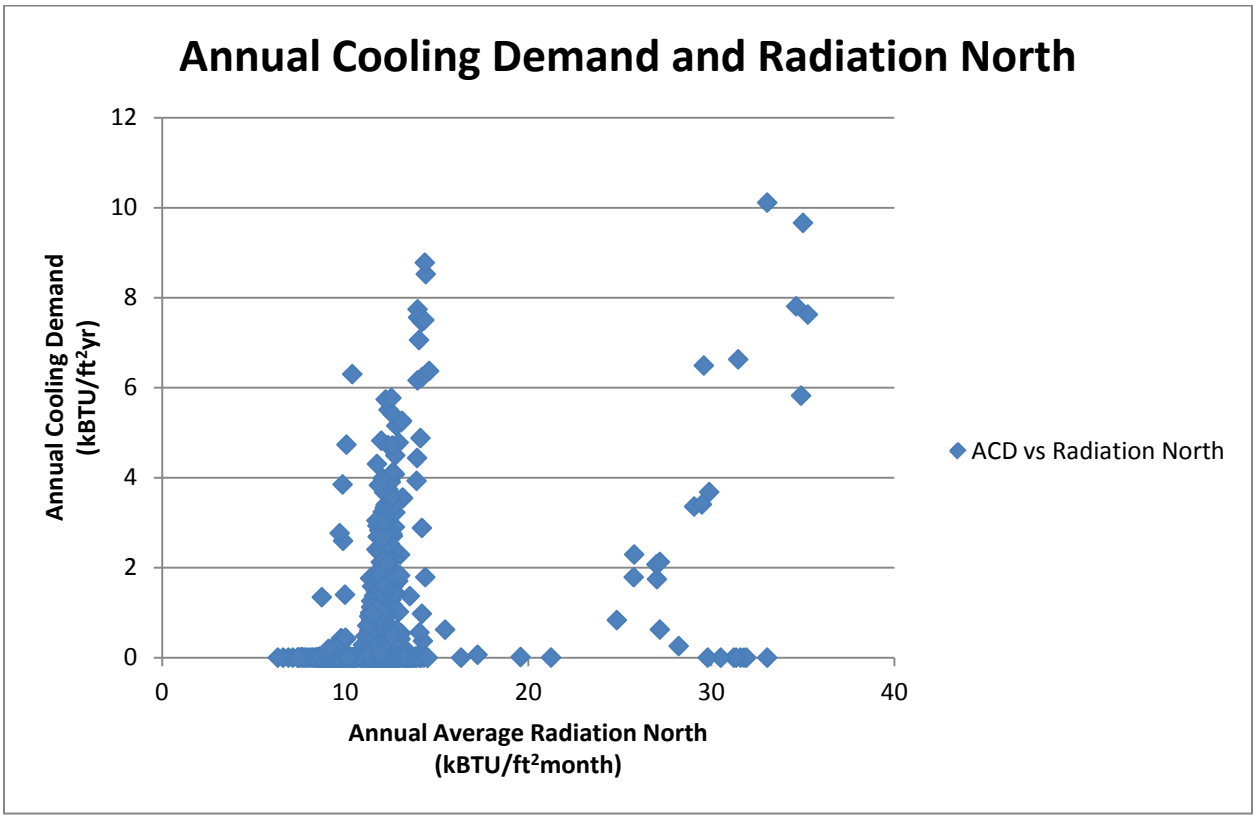


Figure 4.27 - Relationship between Annual Cooling Demand and Radiation North

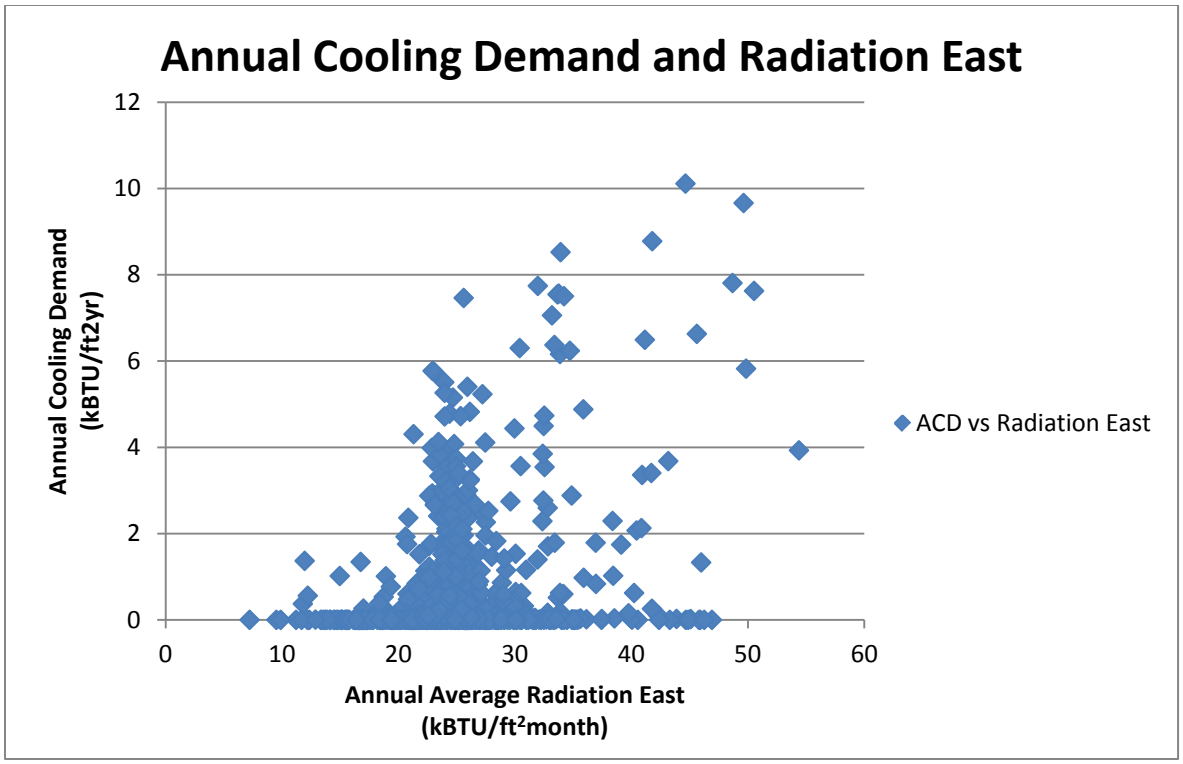


Figure 4.28 - Relationship between Annual Cooling Demand and Radiation East

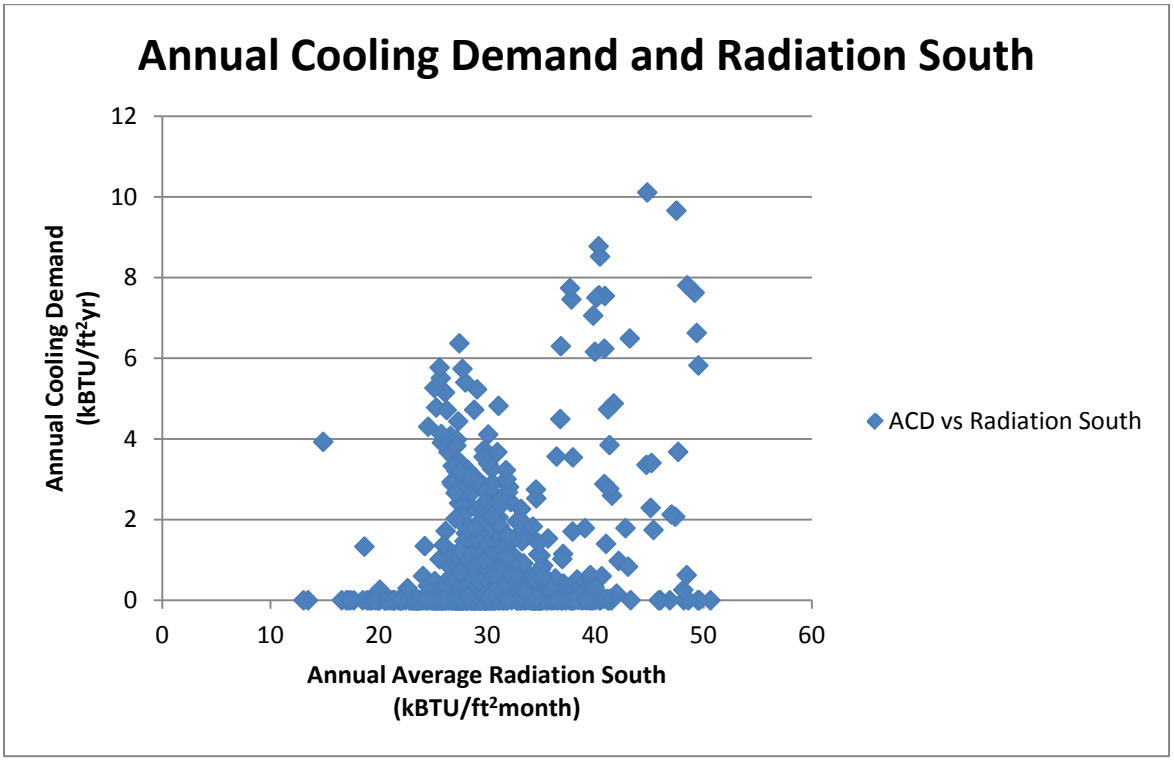


Figure 4.29 - Relationship between Annual Cooling Demand and Radiation South

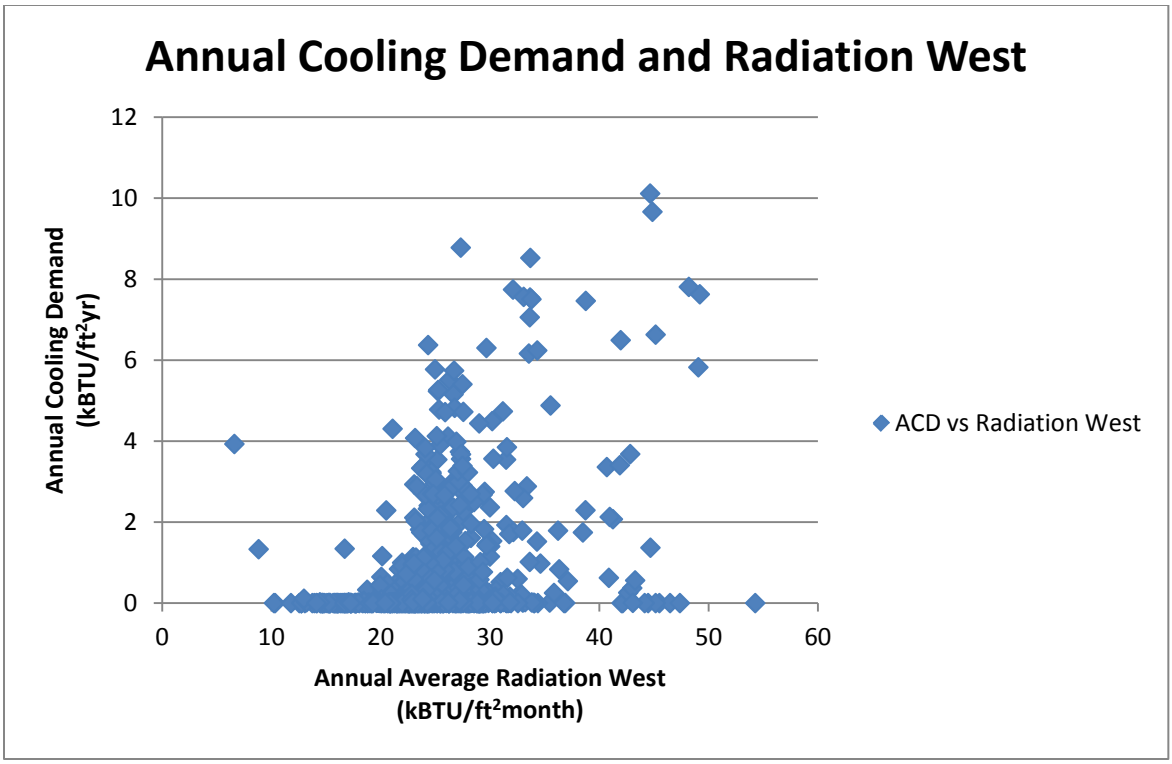


Figure 4.30 - Relationship between Annual Cooling Demand and Radiation West

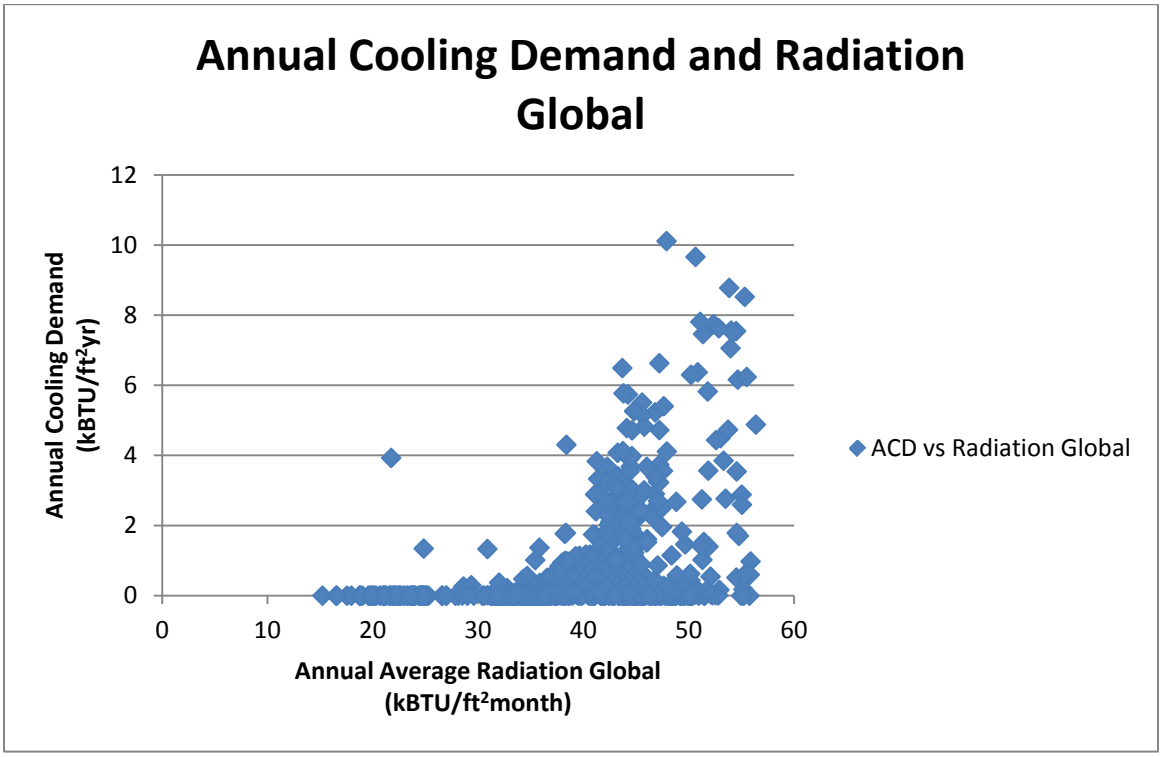


Figure 4.31 - Relationship between Annual Cooling Demand and Radiation Global

The relationships between the Heating / Cooling Load and radiation are similar to that of the energy demand and radiation as seen in the figures above. Figures 4.32-4.37, below, show the relationship between the Heating Load and each of the radiation characteristics. Figures 4.38-4.43, further below, illustrate the relationship the Cooling Load has to the radiation characteristics. In general, as the radiation decreases, the Heating Load increases. This trend occurs most strongly in climates that have very high Heating Loads, and seems to have less of an impact in climates with smaller loads. However, as the amount of radiation increases, the Cooling Load does not seem to follow a logical trend. The Cooling Load seems to function rather independently of the radiation. This is especially true for all of the values except the global value, which shows an extremely weak trend that would be expected based on the generalized trend in which cooling energy use increases when there is a larger amount of gain driven by solar radiation. The lack of a relationship between the Cooling Demand and the radiation values is curious because when analyzing a building, shading the building from radiation does have an impact on the cooling and overheating, but these graphs show it is not the case for the Cooling Load, it only holds true for the Cooling Demand.

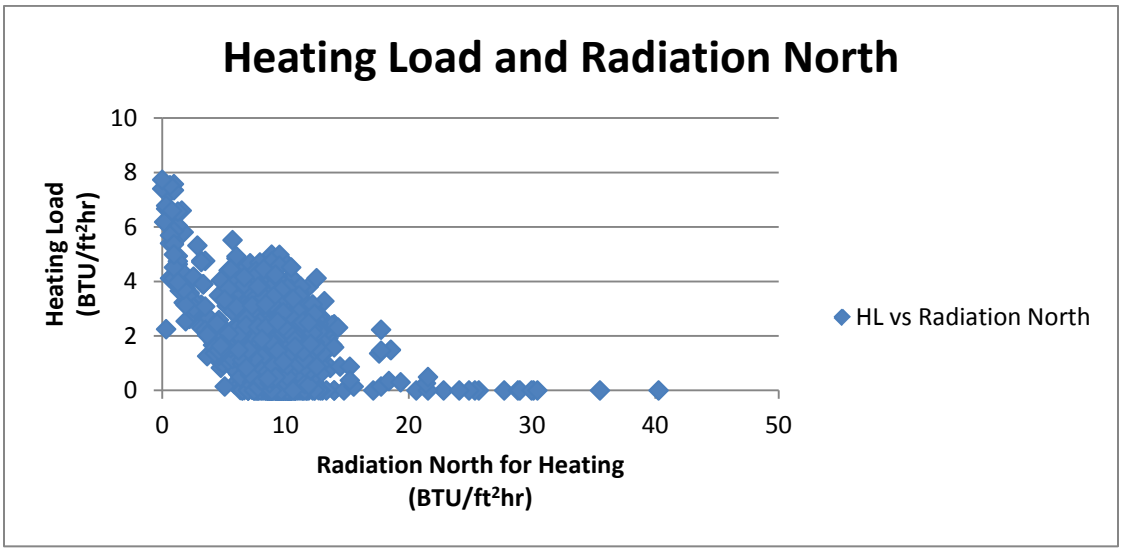


Figure 4.32 - Relationship between Heating Load and Radiation North

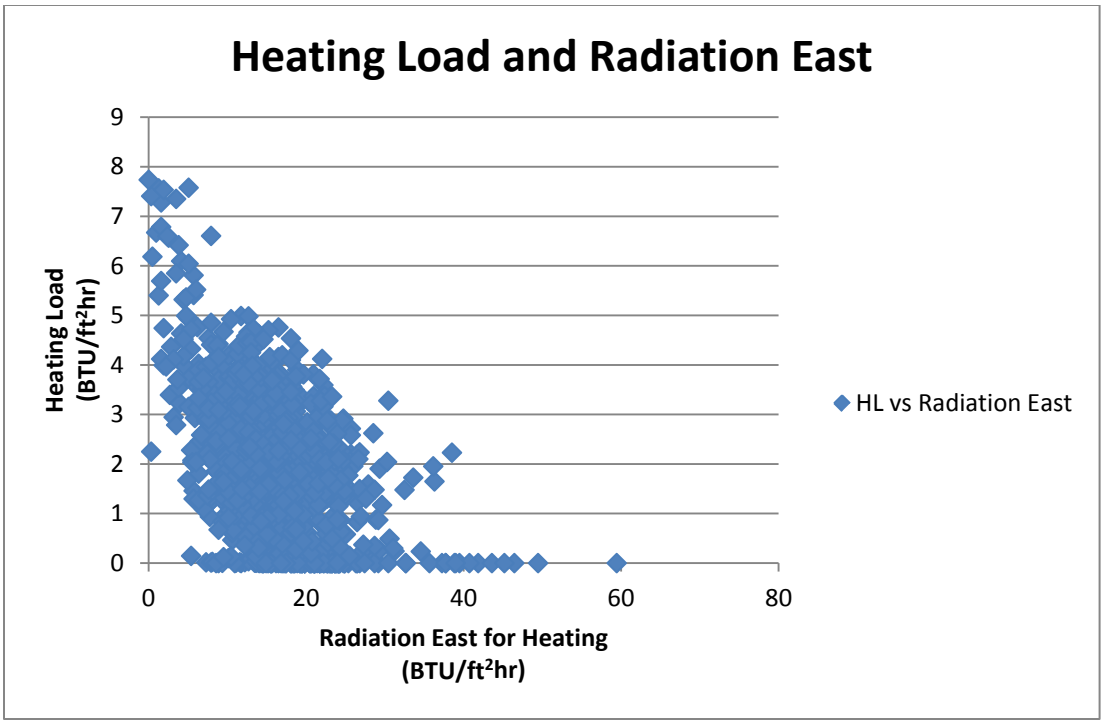


Figure 4.33 - Relationship between Heating Load and Radiation East

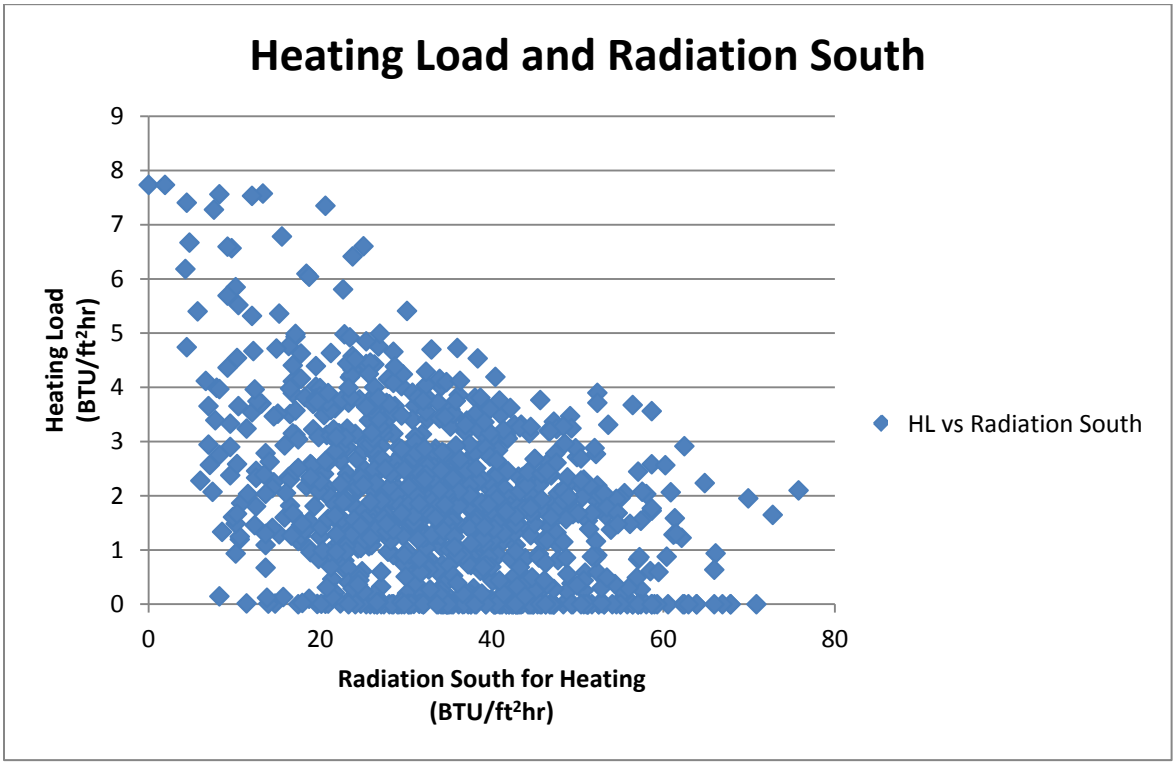


Figure 4.34 - Relationship between Heating Load and Radiation South

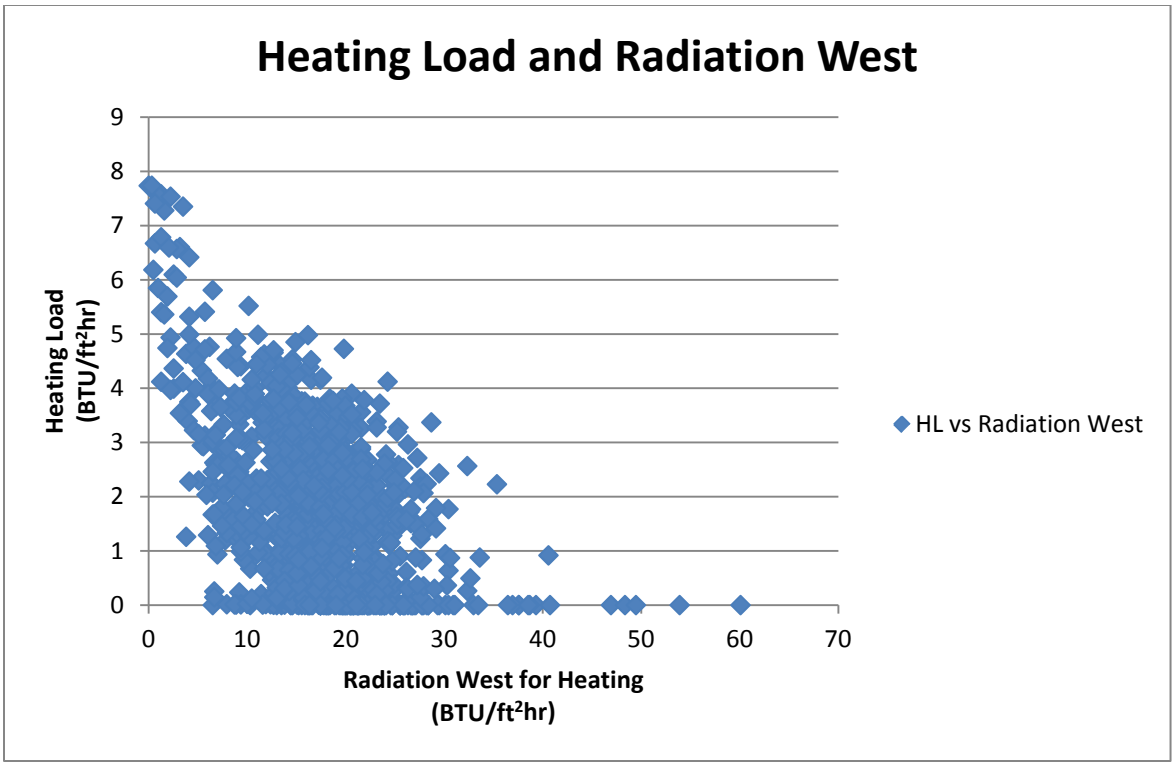


Figure 4.35 - Relationship between Heating Load and Radiation West

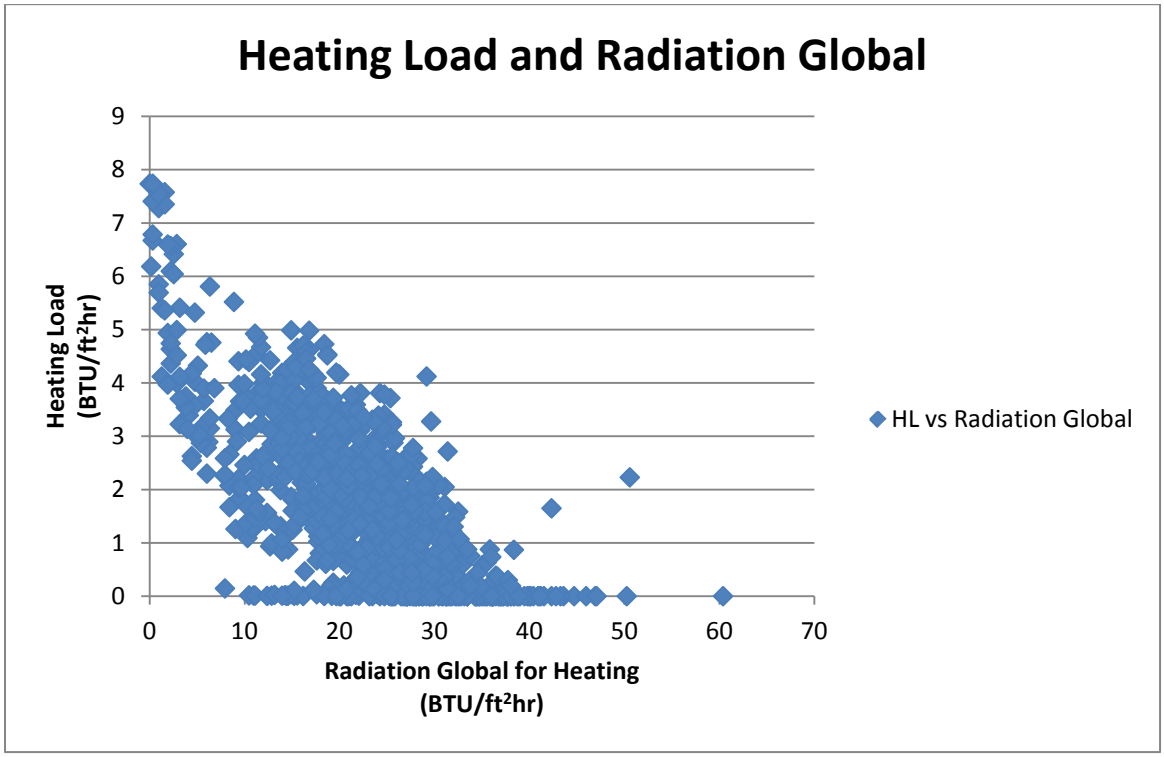


Figure 4.36 - Relationship between Heating Load and Radiation Global

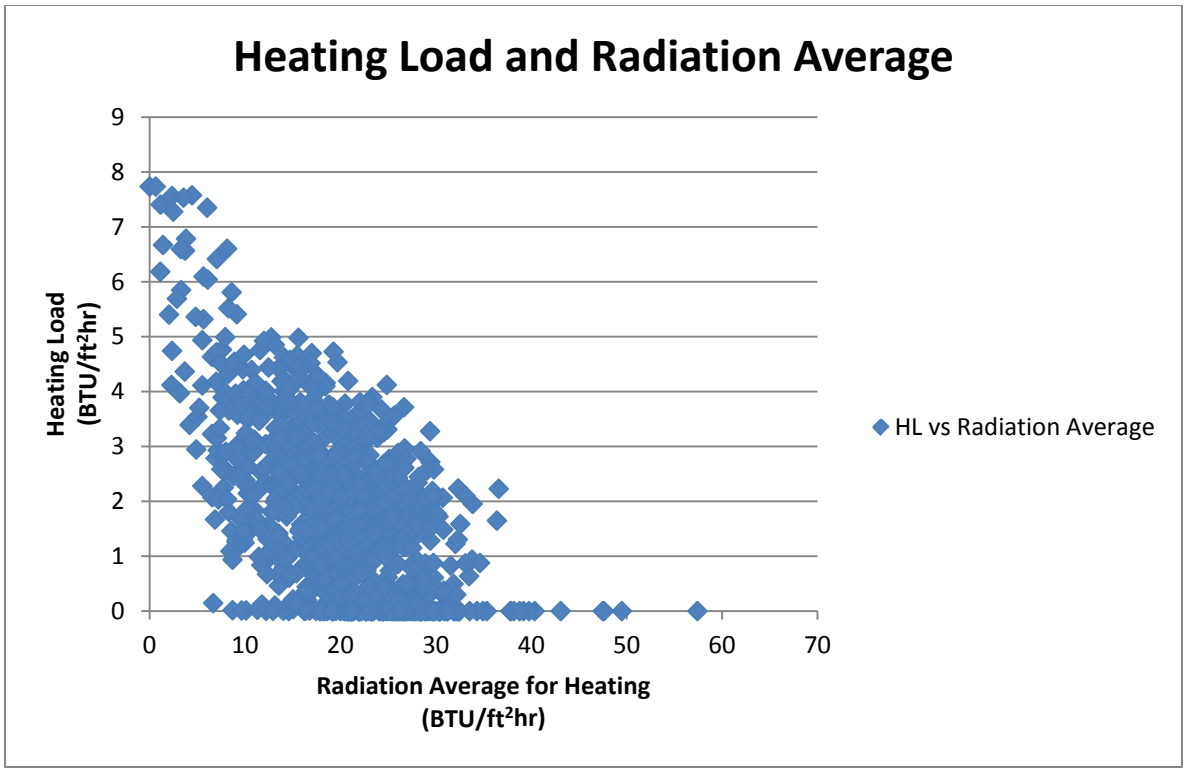


Figure 4.37 - Relationship between Heating Load and Radiation Average

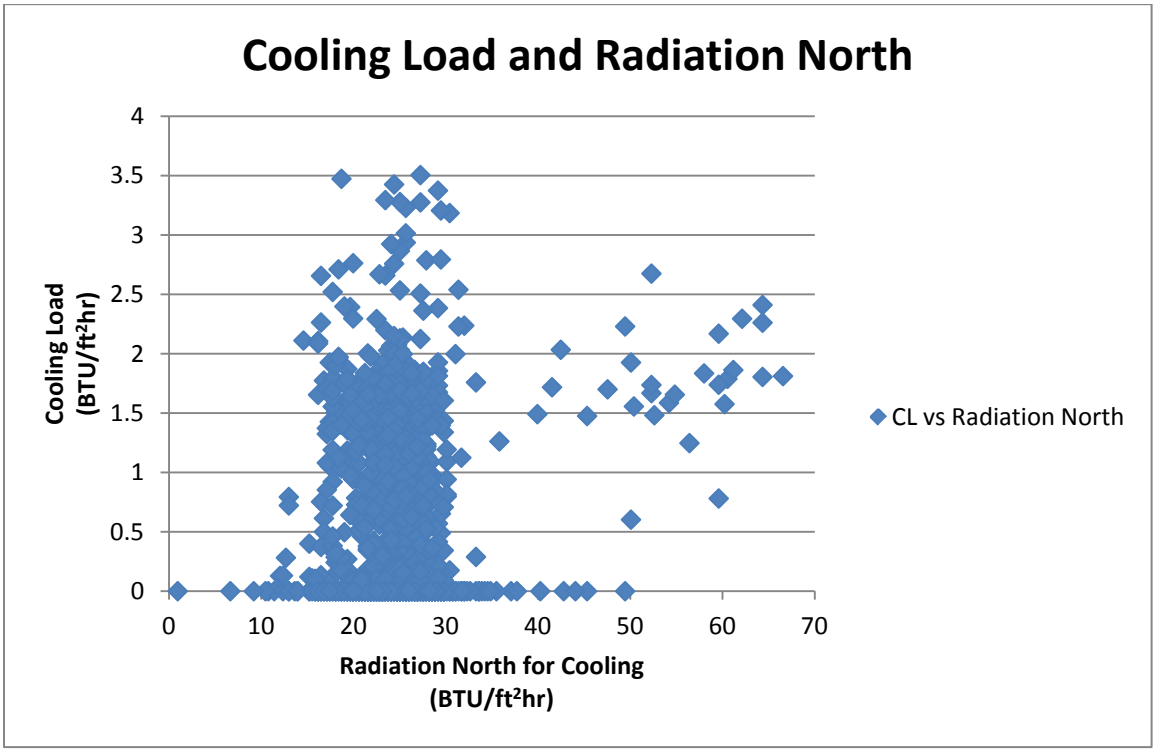


Figure 4.38 - Relationship between Cooling Load and Radiation North

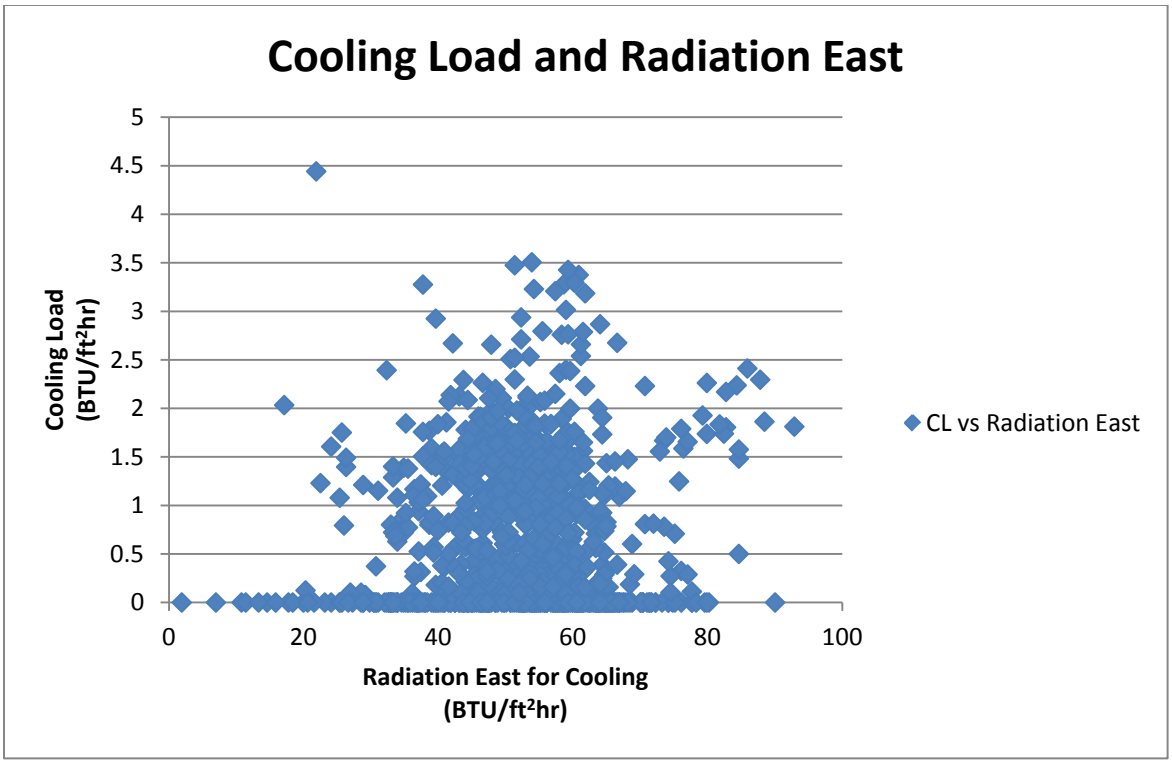


Figure 4.39 - Relationship between Cooling Load and Radiation East

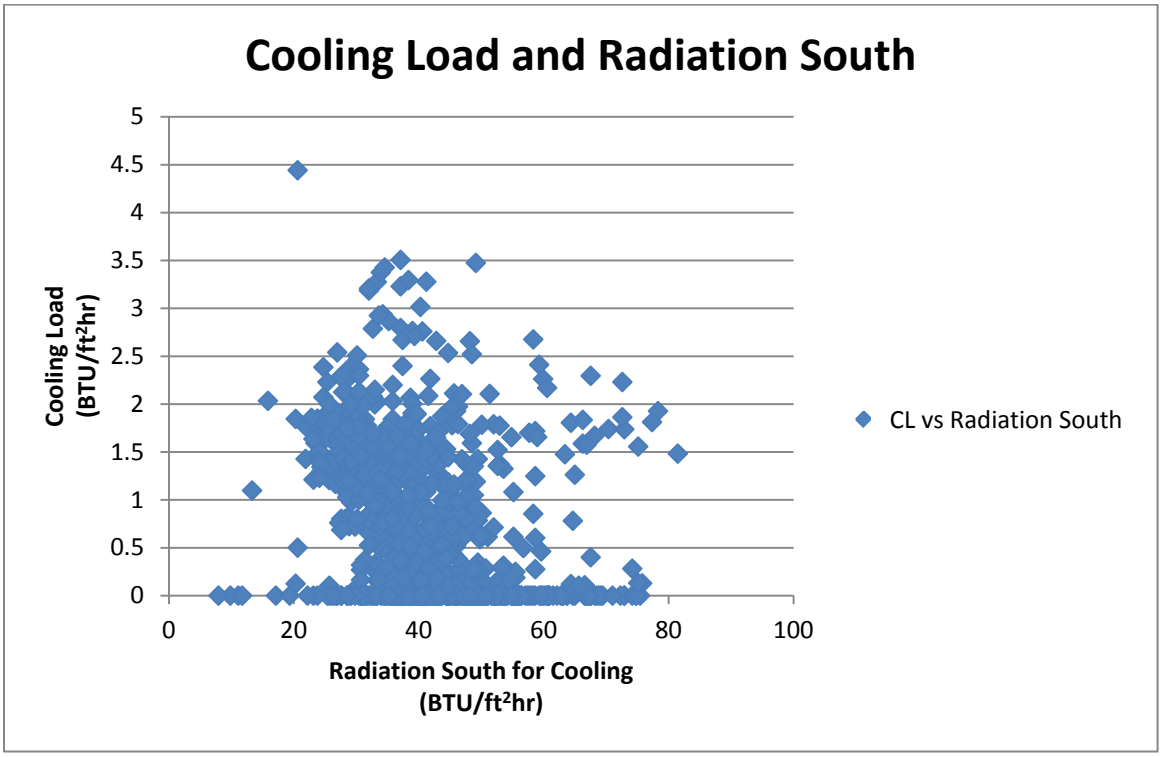


Figure 4.40 - Relationship between Cooling Load and Radiation South

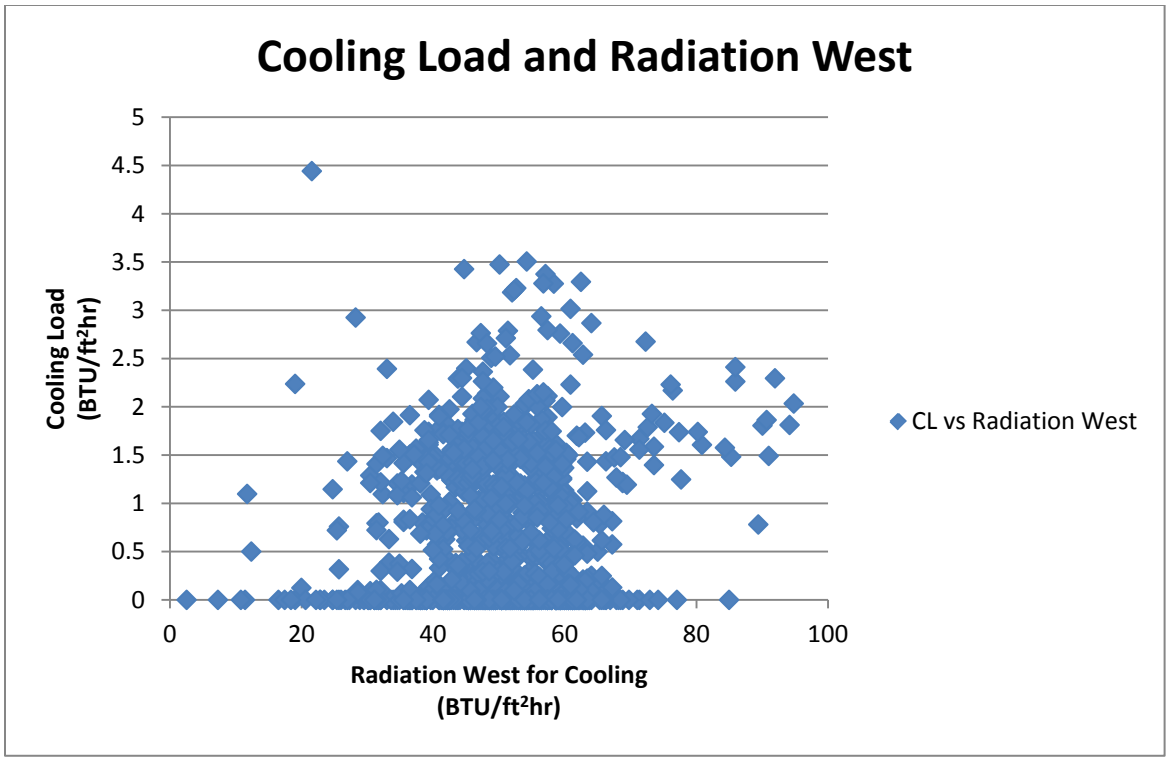


Figure 4.41 - Relationship between Cooling Load and Radiation West

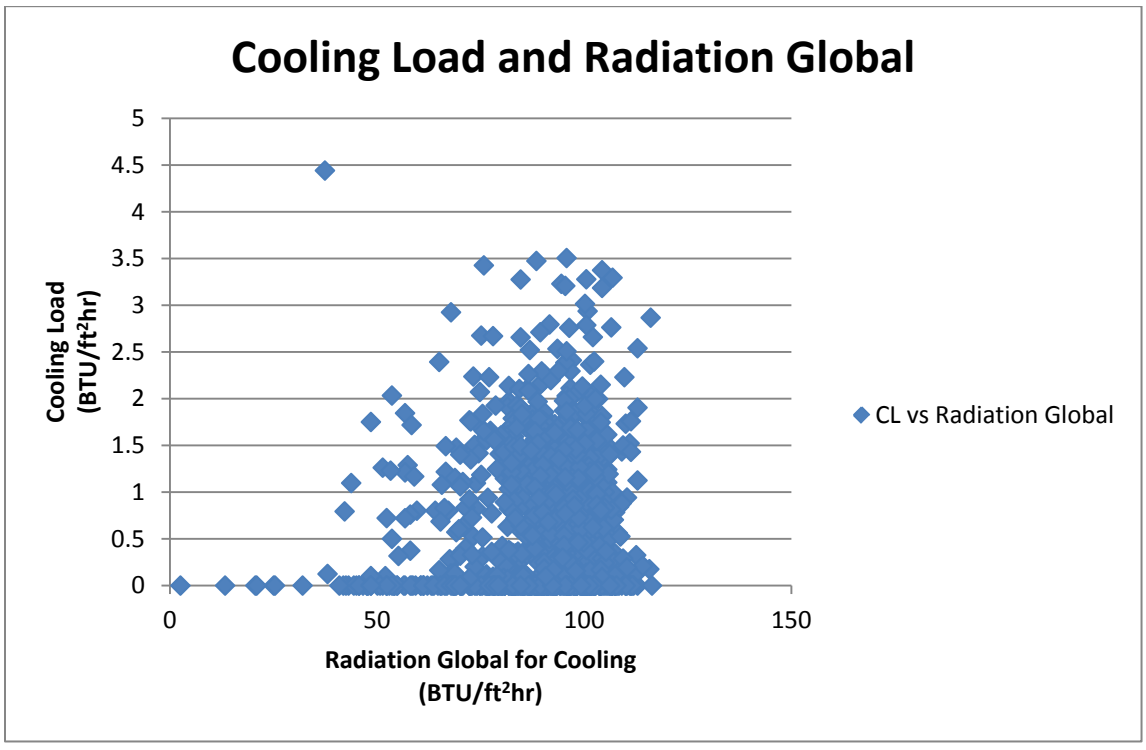


Figure 4.42 - Relationship between Cooling Load and Radiation Global

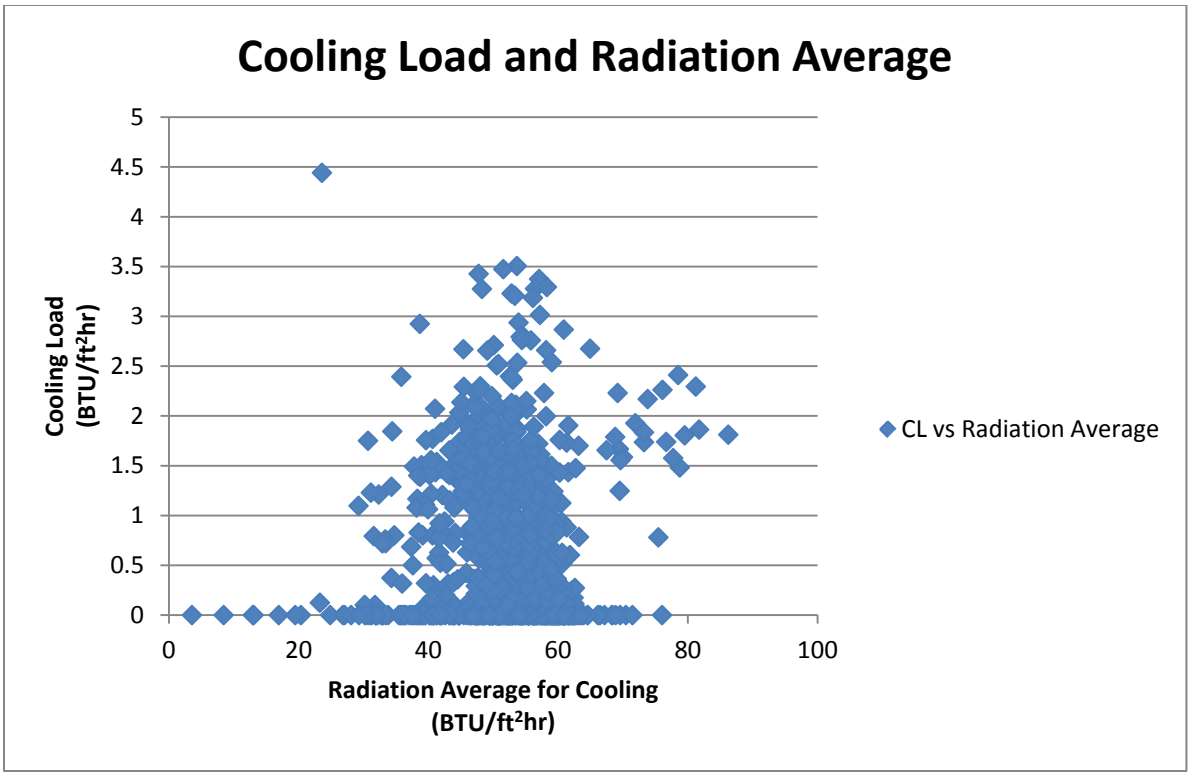


Figure 4.43 - Relationship between Cooling Load and Radiation Average

The climate data sets also contains two additional temperature entries, the Dew Point Temperature and the Sky Temperature, for the calculation of the Annual Heating Demand and Annual Cooling Demand. The analysis again shows a correlation between the energy demand and the temperature. These temperatures are less of an overall issue since the temperature used to make any adjustment to the standard should be the average exterior temperature, because it controls the amount of transmission losses which need to be offset by space conditioning. The dew point temperature and sky temperature are specifically included in the climate data for specific purposes. For instance, the dew point is used to determine latent energy information. However, the dew point and sky temperature correlate with the average exterior temperature well enough that the analysis based on those three factors are relatively similar in their trends.

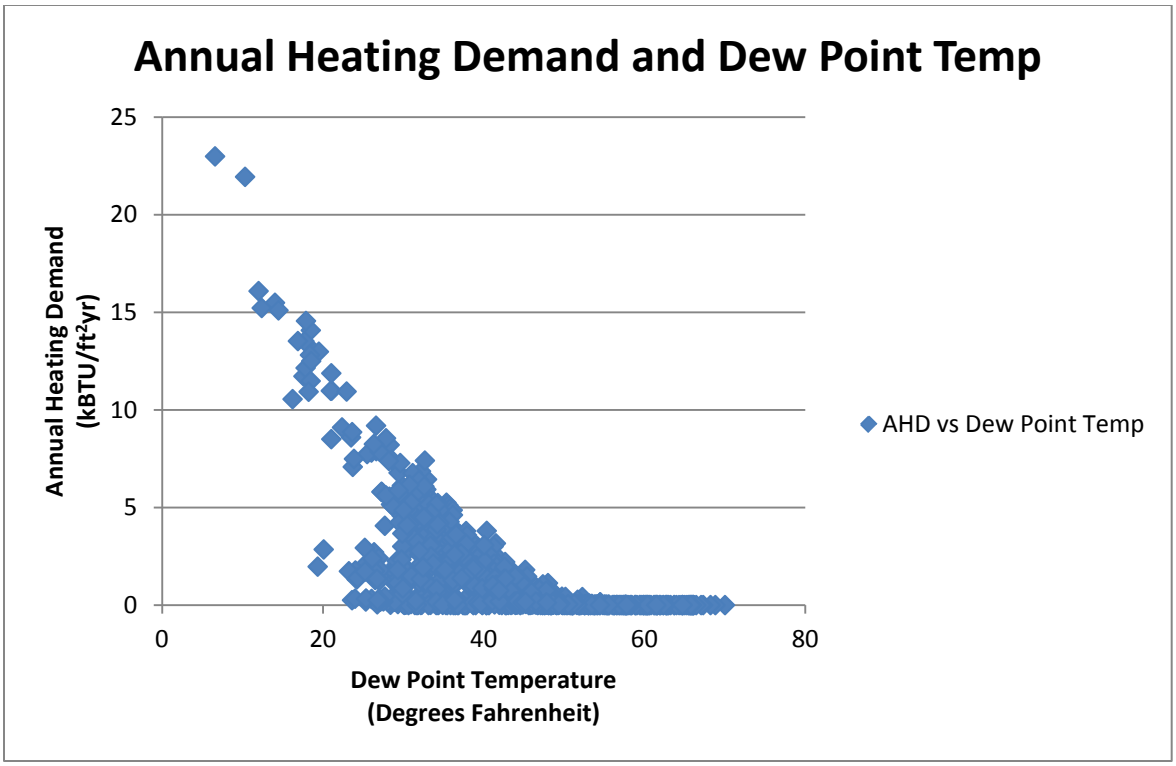


Figure 4.44 - Relationship between Annual Heat Demand and Dew Point Temperature

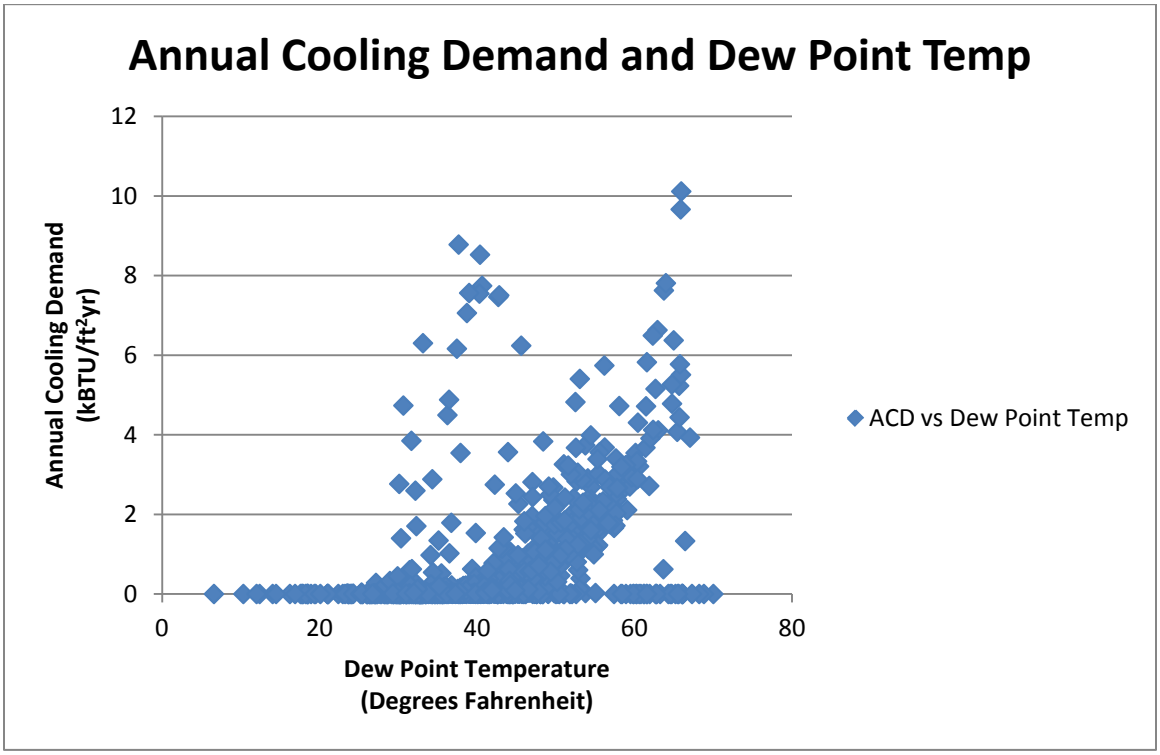


Figure 4.45 - Relationship between Annual Cooling Demand and Dew Point Temperature

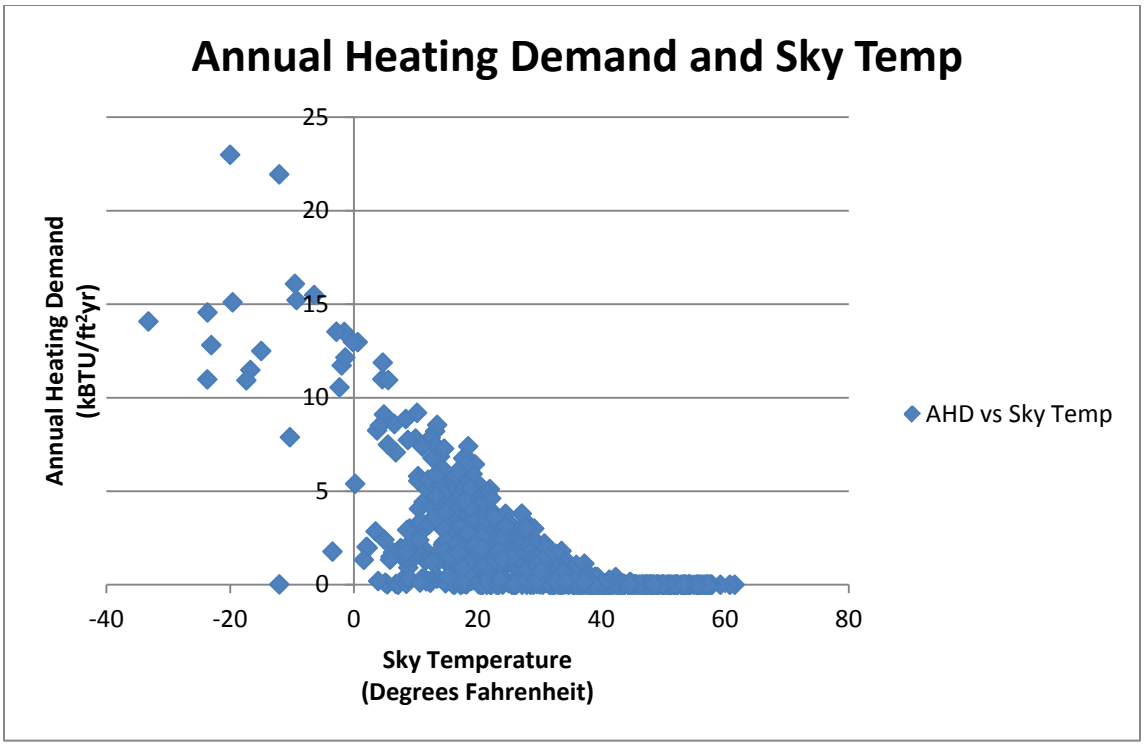


Figure 4.46 - Relationship between Annual Heat Demand and Sky Temperature

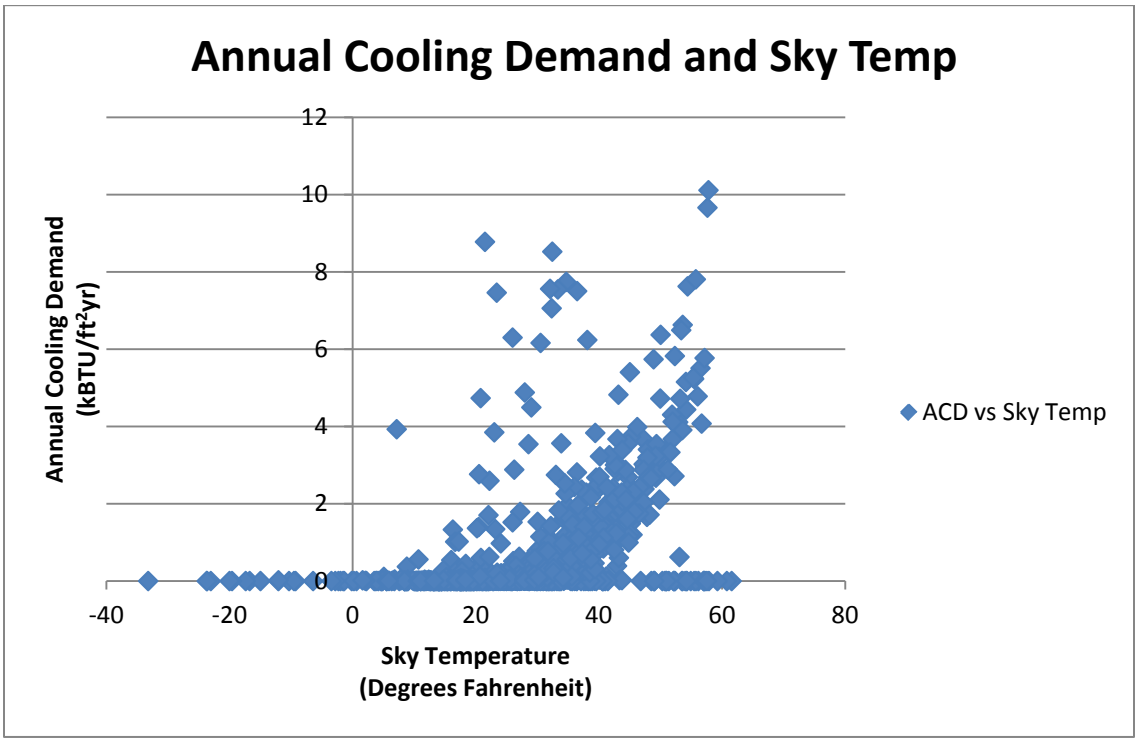


Figure 4.47 - Relationship between Annual Cooling Demand and Sky Temperature

There are opportunities present to find trends in the data that may be helpful in providing feedback for any adjustment to the Passive House Standard's criteria. The most important are latitude, longitude, and elevation. These three pieces of information pinpoint an exact location on Earth. Figures 4.48-4.51, shows a strong relationship between latitude and energy use. This can be attributed to the correlation between temperatures decreasing the further North the location is for climate data locations in the Northern Hemisphere. Figures 4.52-4.55, does not show such a relationship between longitude and energy use. Moving horizontally across the United States seems to have no notable influence and suggests that other factors have a much greater influence on energy use.

The most interesting analysis of these three factors was the analysis of the relationship of elevation and energy use. Like latitude, it is generally understood that the higher the elevation, the cooler the temperature becomes and therefore, it would be expected that the correlation would look similar to the relationship between energy use and temperature. Figures 4.56-4.59 illustrate the relationship between elevation and energy use. The location with the highest Annual Heating Demand had one of the lowest elevations and the location with the highest elevation had a very low Annual Heating Demand. For cooling, the trend reinforces the logical assumption that high elevation leads to low cooling energy. The location with the highest elevation had an Annual Cooling Demand of zero, while many of the climates with the lowest elevations had very high Annual Cooling Demands. However, the Annual Cooling Demands of zero occur not just at high elevations. In fact, they occur even more frequently at low elevations. It can be assumed that the weak relationships that exists for some of the resulting data is again the product of the relationship between temperature and elevation, but that overall that relationship is weak when compared to the other interactions discussed thus far.

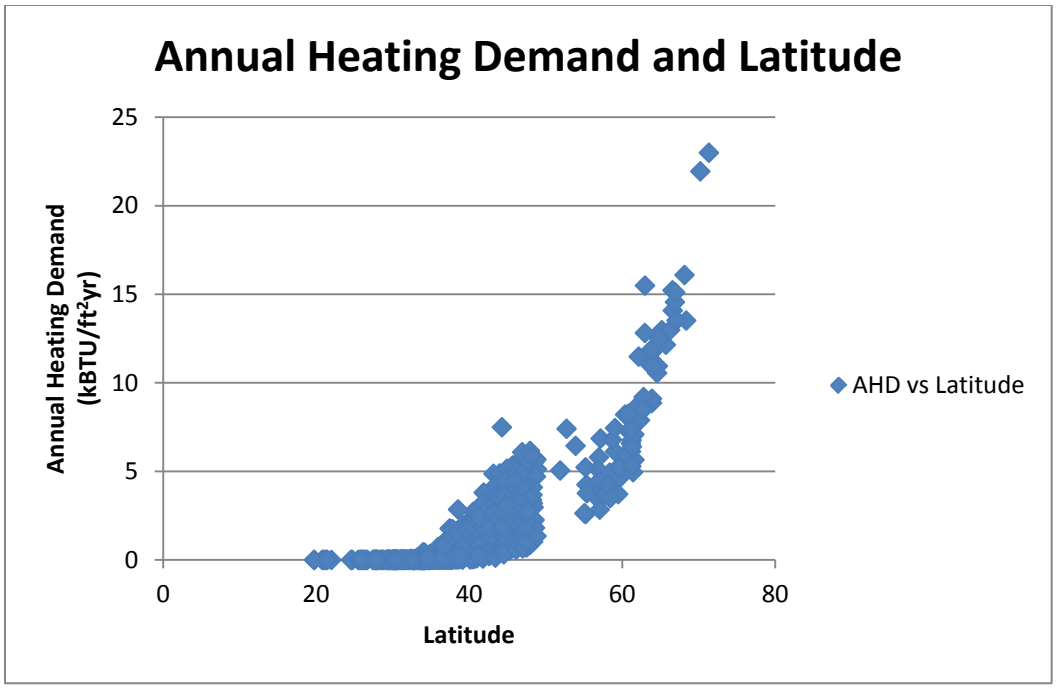


Figure 4.48 - Relationship between Annual Heating Demand and Latitude

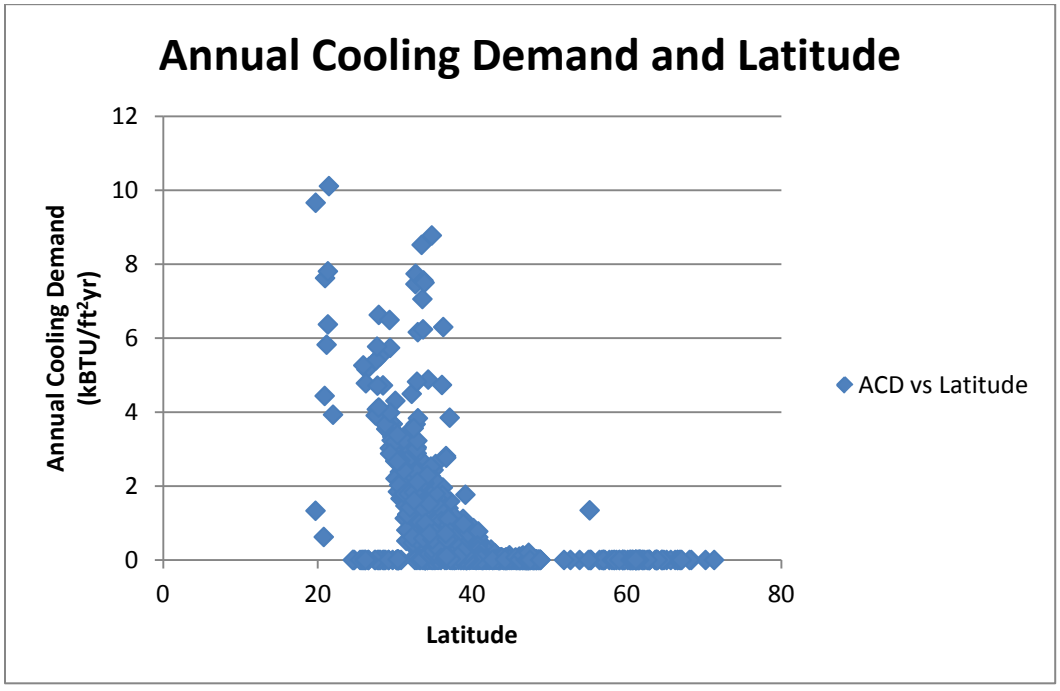


Figure 4.49 - Relationship between Annual Cooling Demand and Latitude

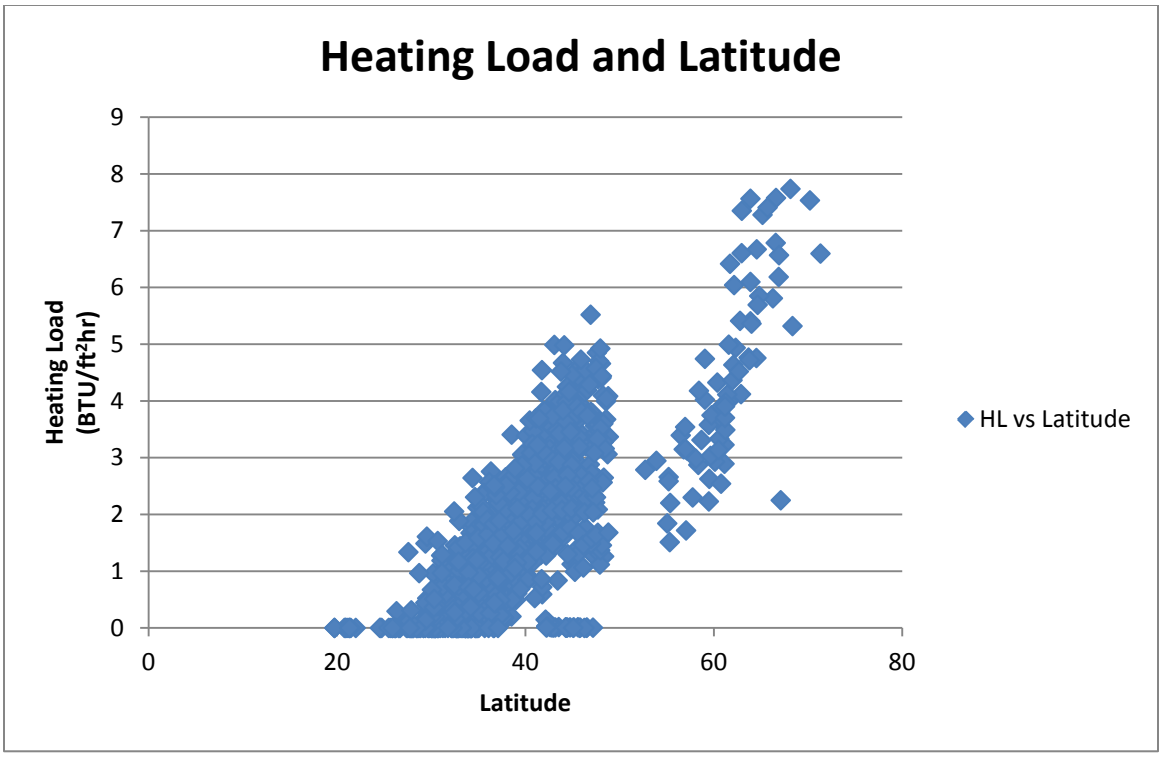


Figure 4.50 - Relationship between Heating Load and Latitude

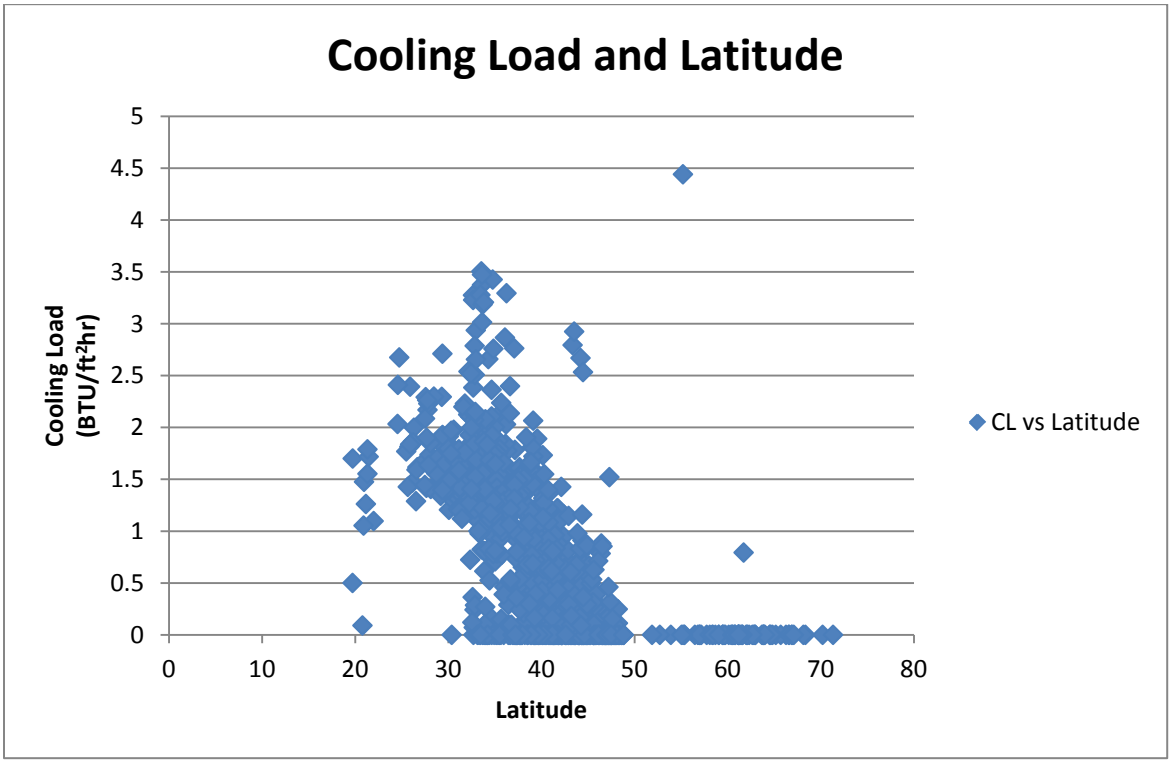


Figure 4.51 - Relationship between Cooling Load and Latitude

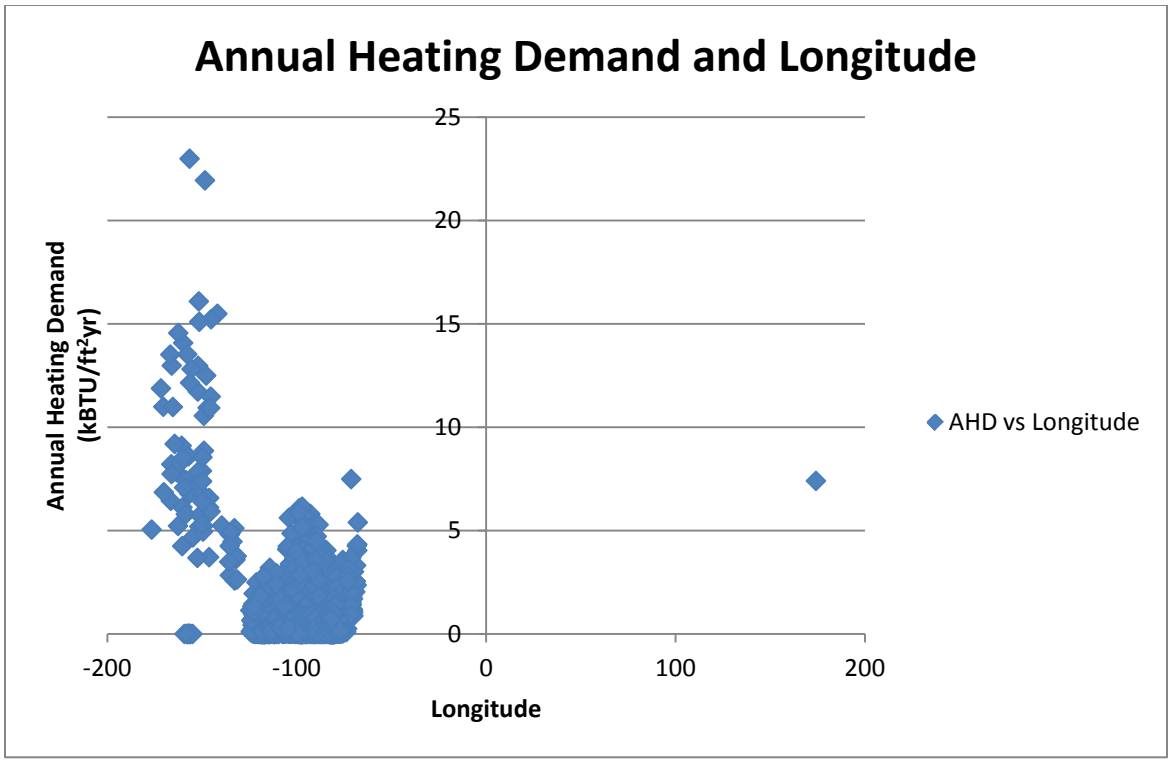


Figure 4.52 - Relationship between Annual Heating Demand and Longitude

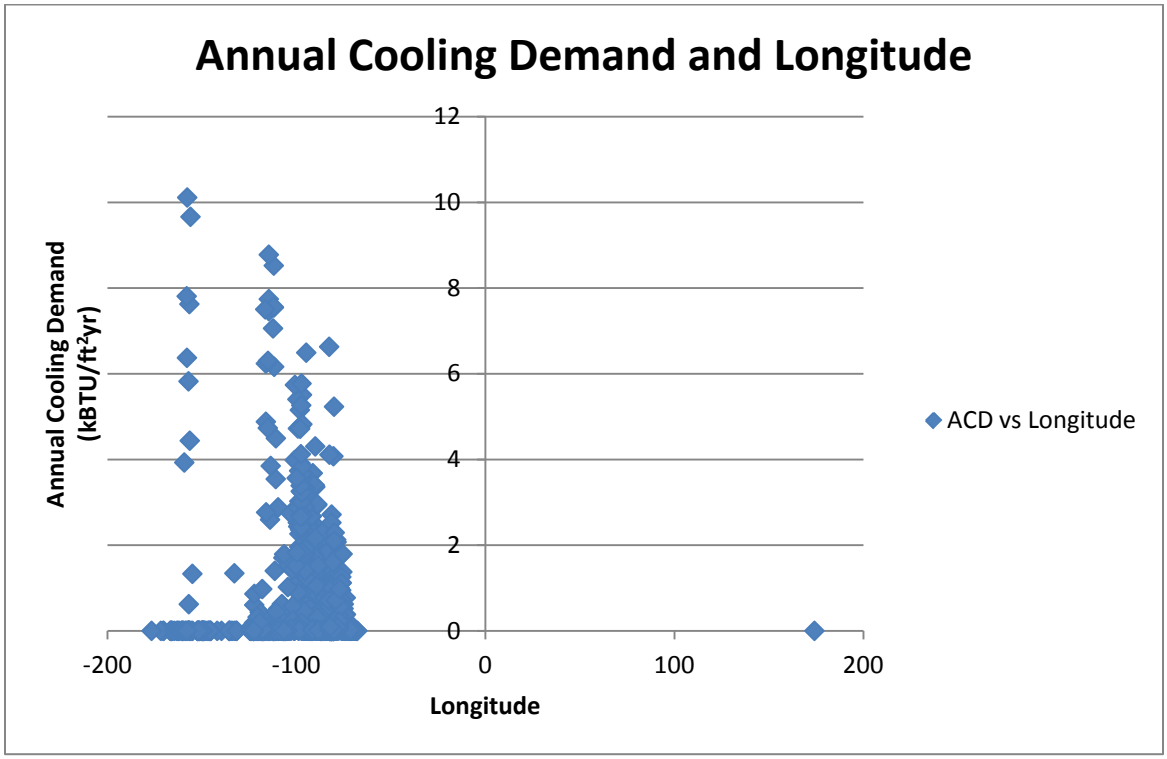


Figure 4.53 - Relationship between Annual Cooling Demand and Longitude

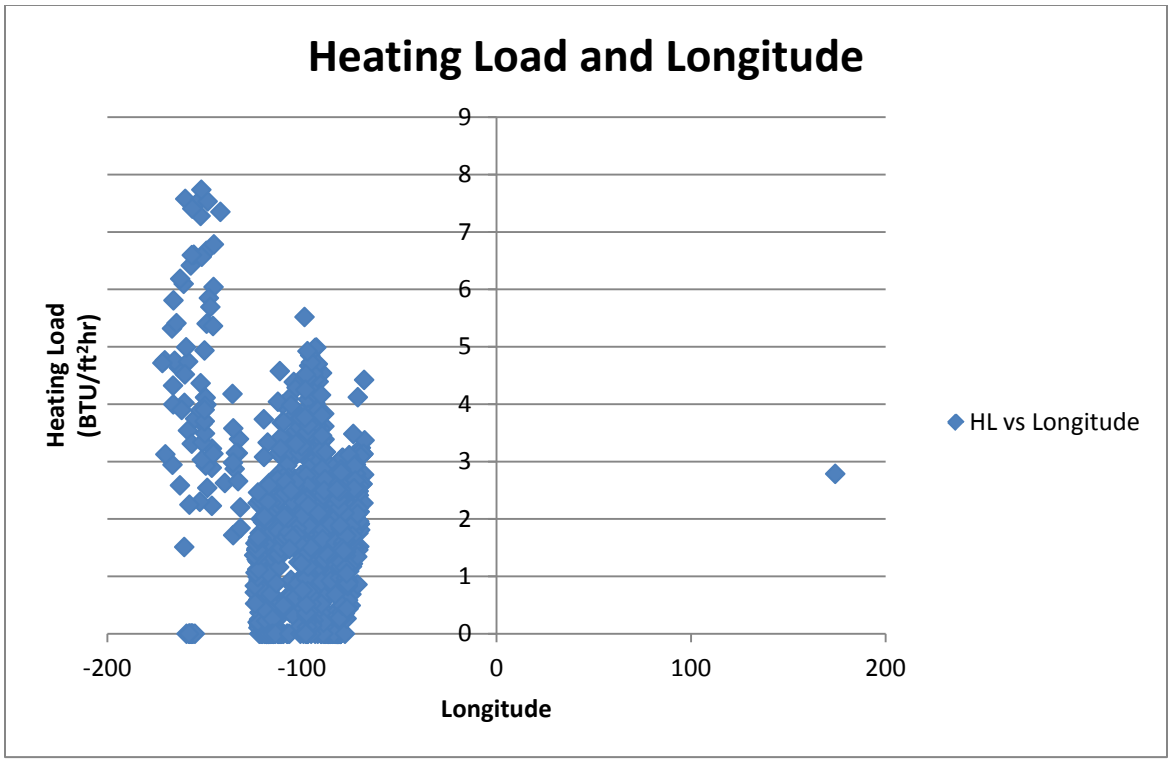


Figure 4.54 - Relationship between Heating Load and Longitude

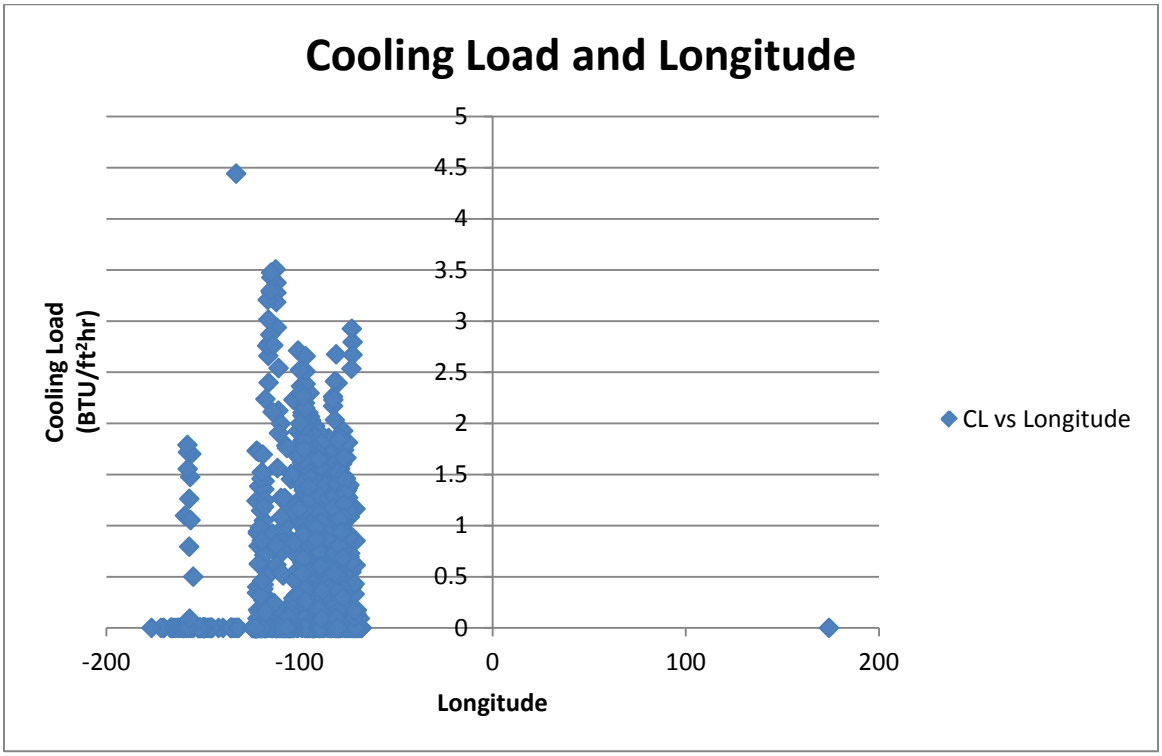


Figure 4.55 - Relationship between Cooling Load and Longitude

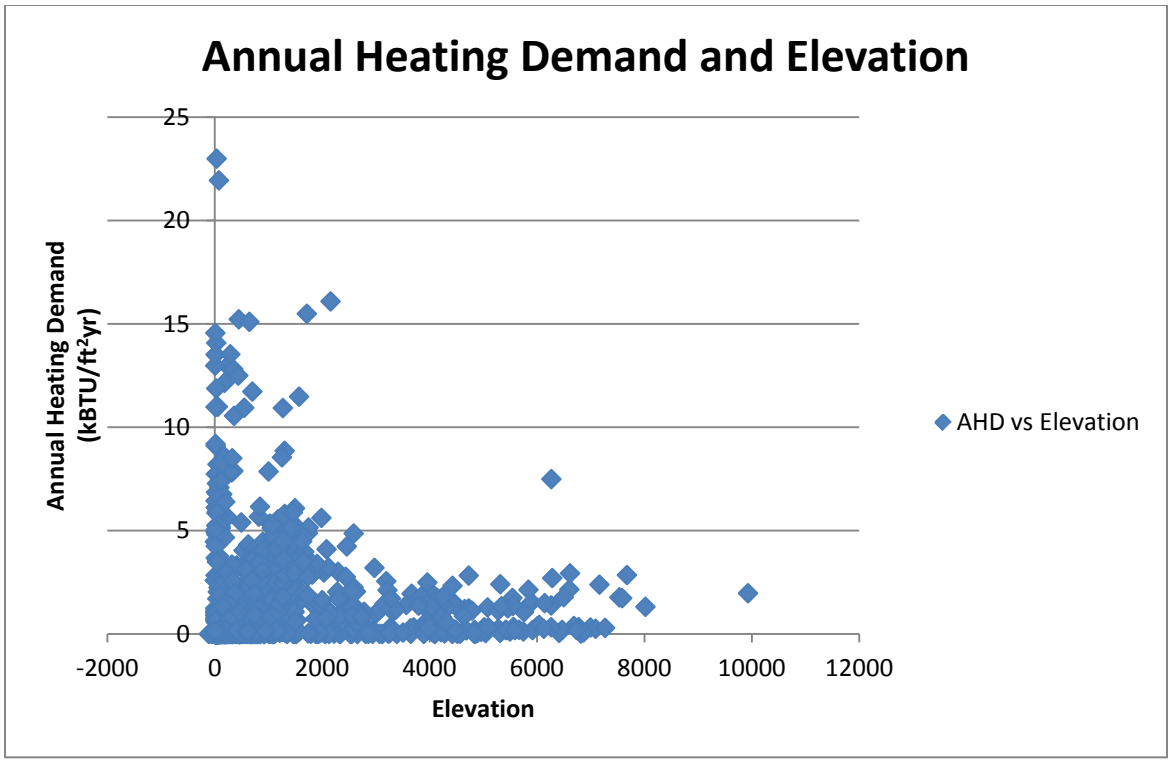


Figure 4.56 - Relationship between Annual Heating Demand and Elevation

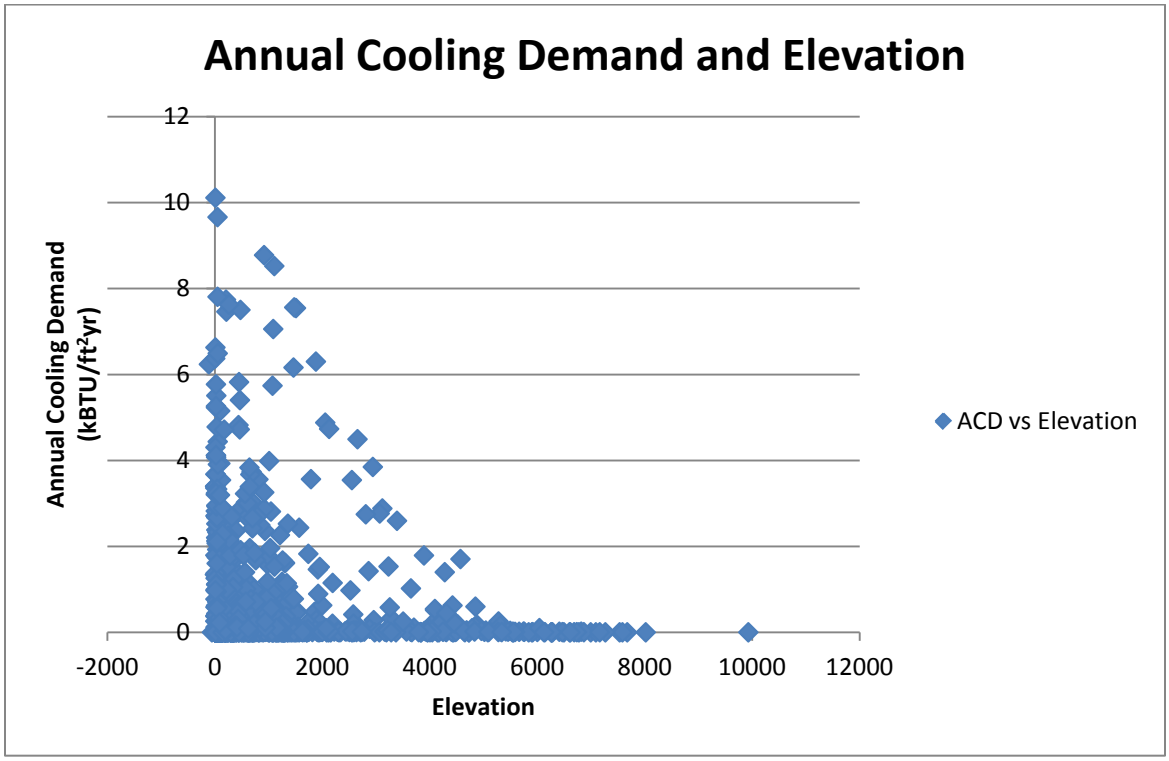


Figure 4.57 - Relationship between Annual Cooling Demand and Elevation

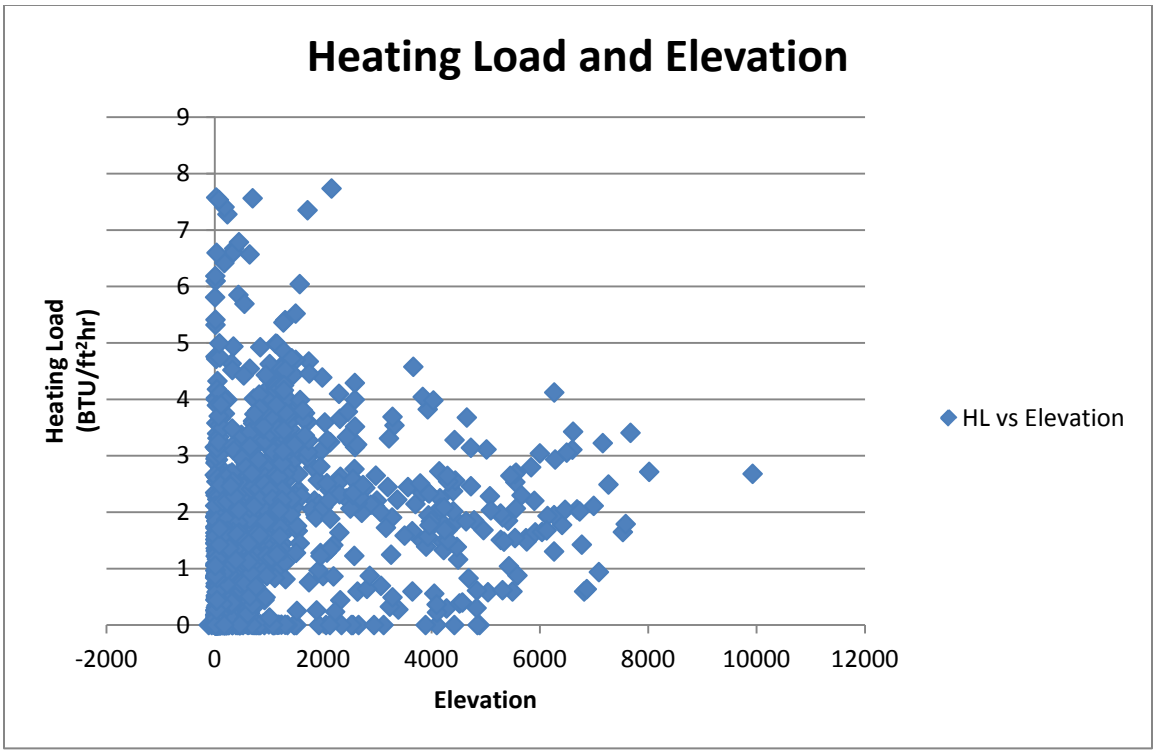


Figure 4.58 - Relationship between Heating Load and Elevation

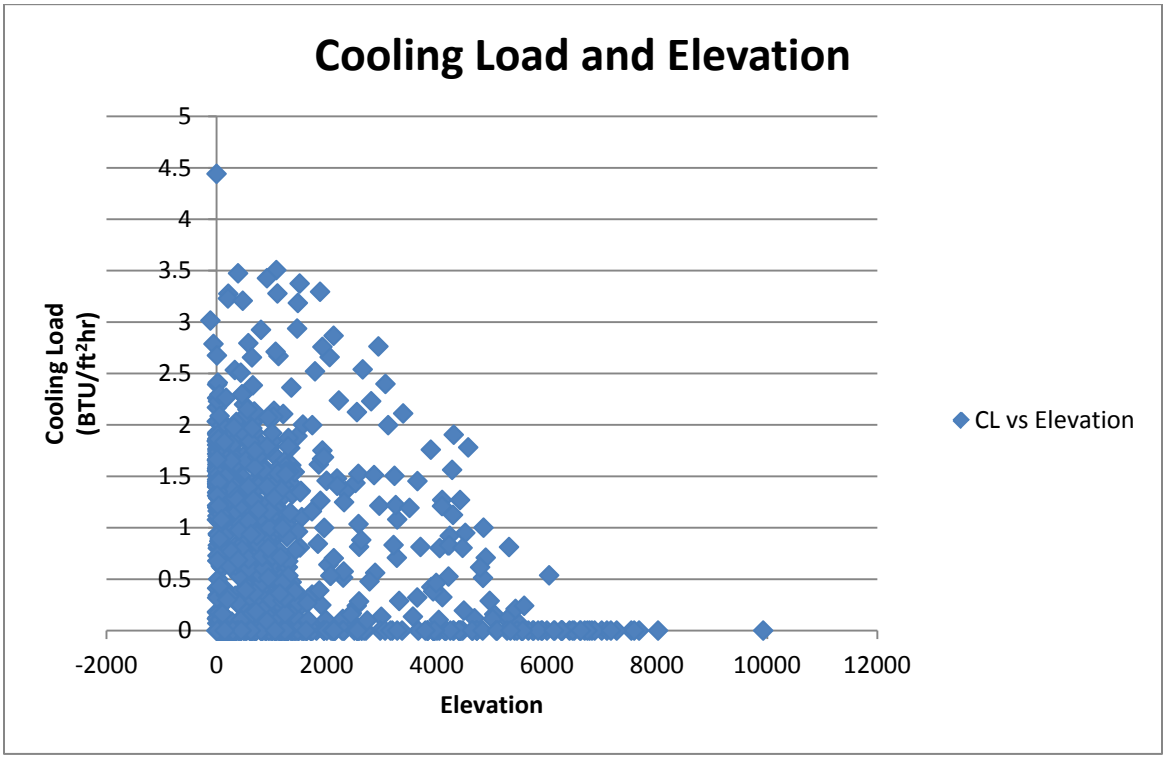


Figure 4.59 - Relationship between Cooling Load and Elevation

Another analysis was completed based on the concept of the functional definition of a passive house as a building that can supply its entire Heating Load through the ventilation supply air stream. At each climate location, the results from the case that was closest to 3.17 BTU/ft^{2}hr without going over were chosen and plotted against the climate characteristics analyzed above. Figure 4.60 shows the effect of the Annual Heating Demand due to a change in average temperature. When compared to Figure 4.18, the correlation between the Annual Heating Demand and temperature was not as strong. The upper end of the range remains the same. At these points, the climate was cold enough that the Heating Load was unable to be below 3.17 BTU/ft^{2}hr. In this case, the Annual Heating Demand chosen corresponded to the case with the lowest Heating Load.

In Figure 4.18, many of the cases had Annual Heating Demands plotted that corresponded to Heating Load values below 3.17 BTU/ ft^{2}hr. When the heat load was increased to 3.17 BTU/ft^{2}hr the Annual Heating Demand rose as well because the overall envelope performance of the cases decreased. This accounts for the cases with temperatures between 45 and 65 degrees having significantly higher Annual Heating Demand. Figure 4.61 shows the various Heating Loads that were used. The largest portion of cases were held right at 3.17 BTU/ ft^{2}hr, but there were cases above that, below that, and at zero. The cases above were in cold climates where it was not possible to have a Heating Load below the threshold while the cases that were at zero were hot climates where there was not a Heating Load. The cases between zero and 3.17 BTU/ft^{2}hr were for climate locations that experienced some heating, but not enough to have any cases above the threshold of 3.17 BTU/ft^{2}hr. In these instances, the case with the highest Heating Load was chosen to represent the adjusted values.

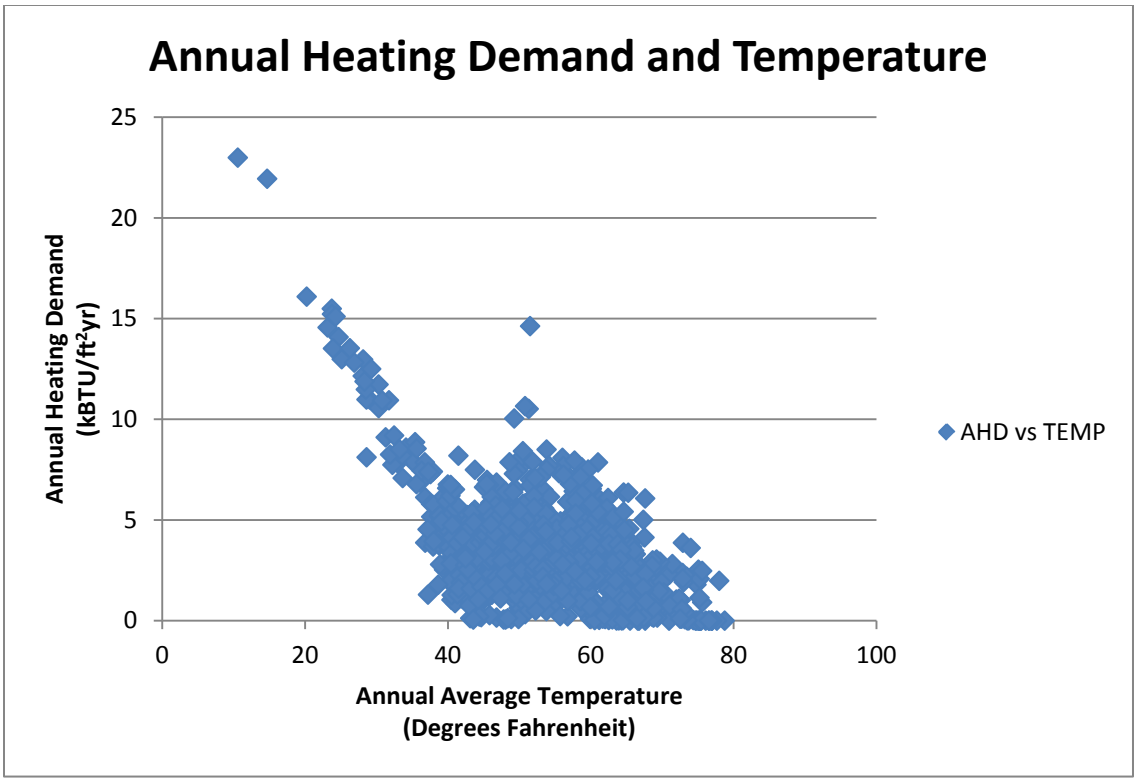


Figure 4.60 - Relationship between Annual Heating Demand and Temperature

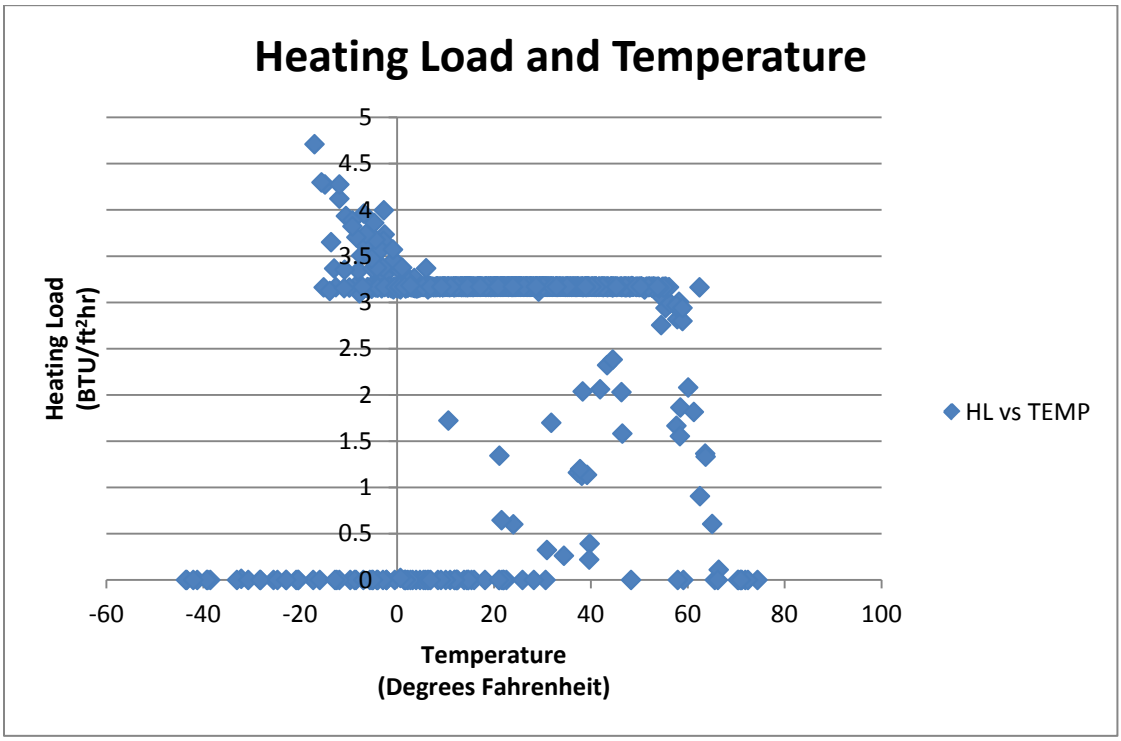


Figure 4.61 - Relationship between Heating Load and Temperature

Both the Annual Cooling Demand, Figure 4.63, and Heating Load, Figure 4.64, plotted against Temperature show similar correlations to their original graphs without the Heating Load being controlled. However, both Figures exhibit some spread or loosening of the data. Most interestingly, in Figure 4.63, the climates where the temperature is cold had very little, or not any, Annual Cooling Demand. In those climates, with the envelope relaxed to meet the Heating Load, not only did the Annual Heating Demand Increase, but so too did the Annual Cooling Demand. Like Figure 4.61, Figure 4.63 demonstrates that a slight relaxation occurred overall, which means many of the cases utilized were below the supply air heating threshold.

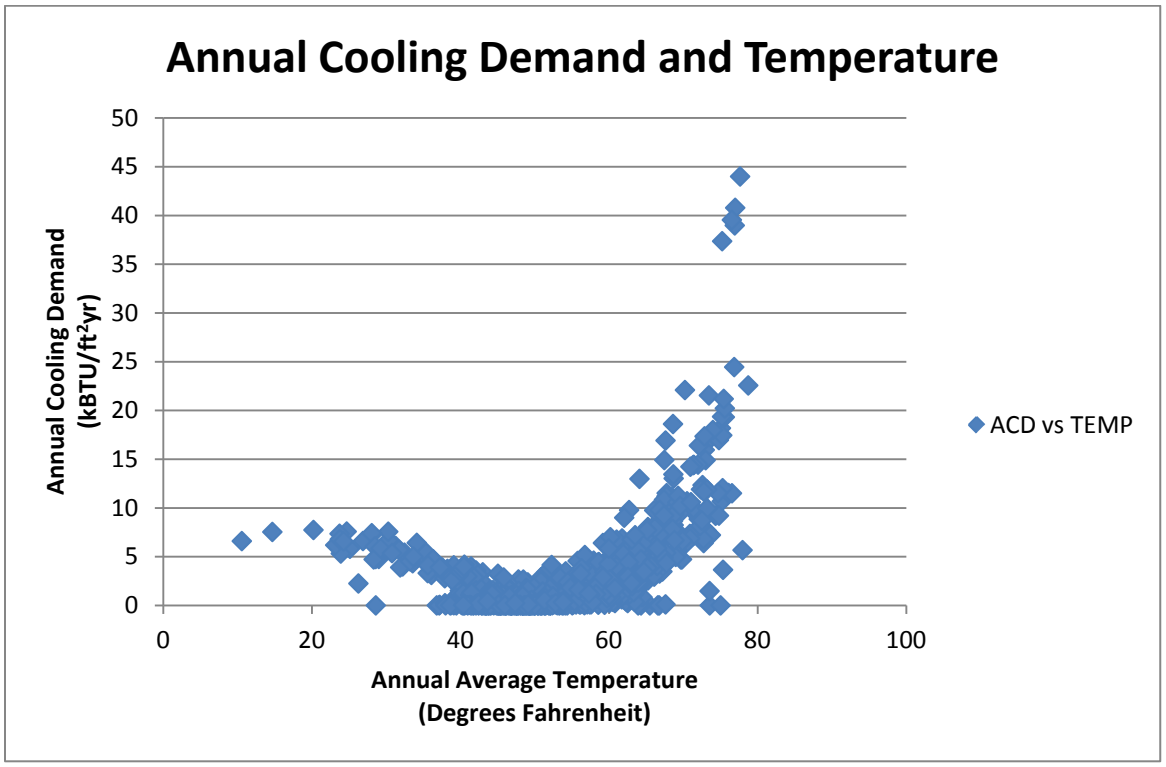


Figure 4.62 - Relationship between Annual Cooling Demand and Temperature

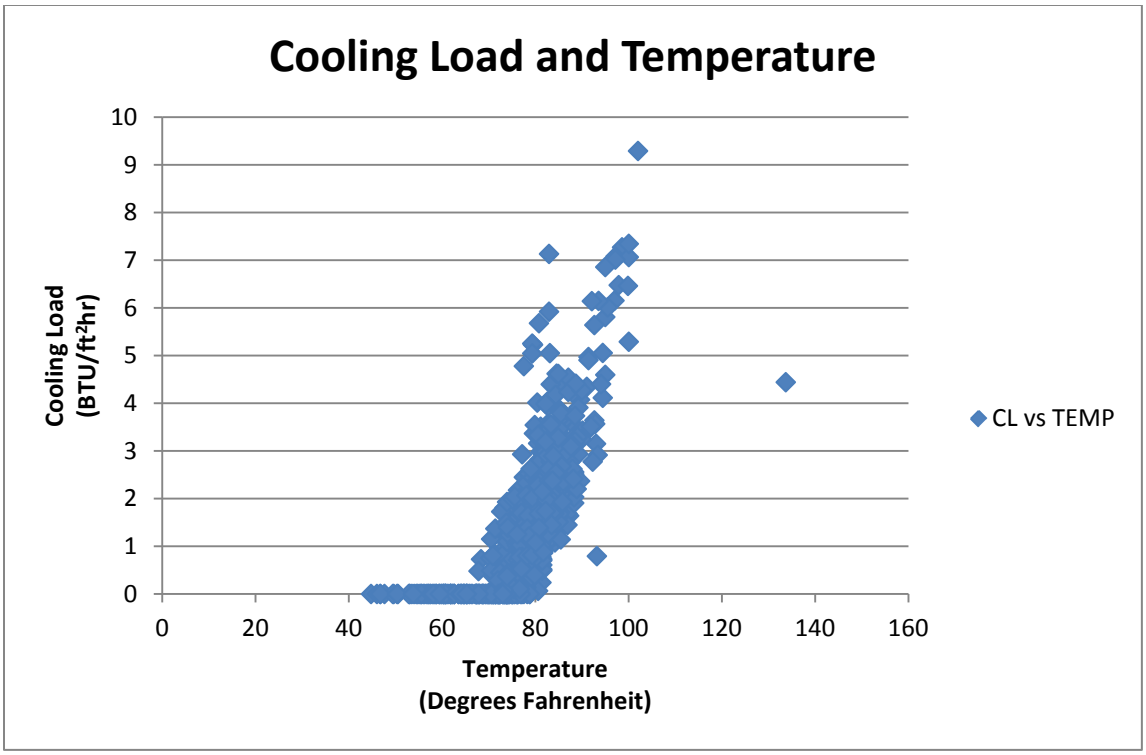


Figure 4.63 - Relationship between Cooling Load and Temperature

Similar to Figure 4.61, which showed the relationship between the Annual Heating Demand and temperature, Figure 4.64 below, demonstrates the relationship between the Annual Heating Demand and the Latitude. The same effect occurred. Those climates furthest north were relatively unaffected, while the mid-range climates were affected the most. The cases which were already surpassing the supply air heating threshold were relaxed slightly and this effect is also visible in the Annual Heating Demand.

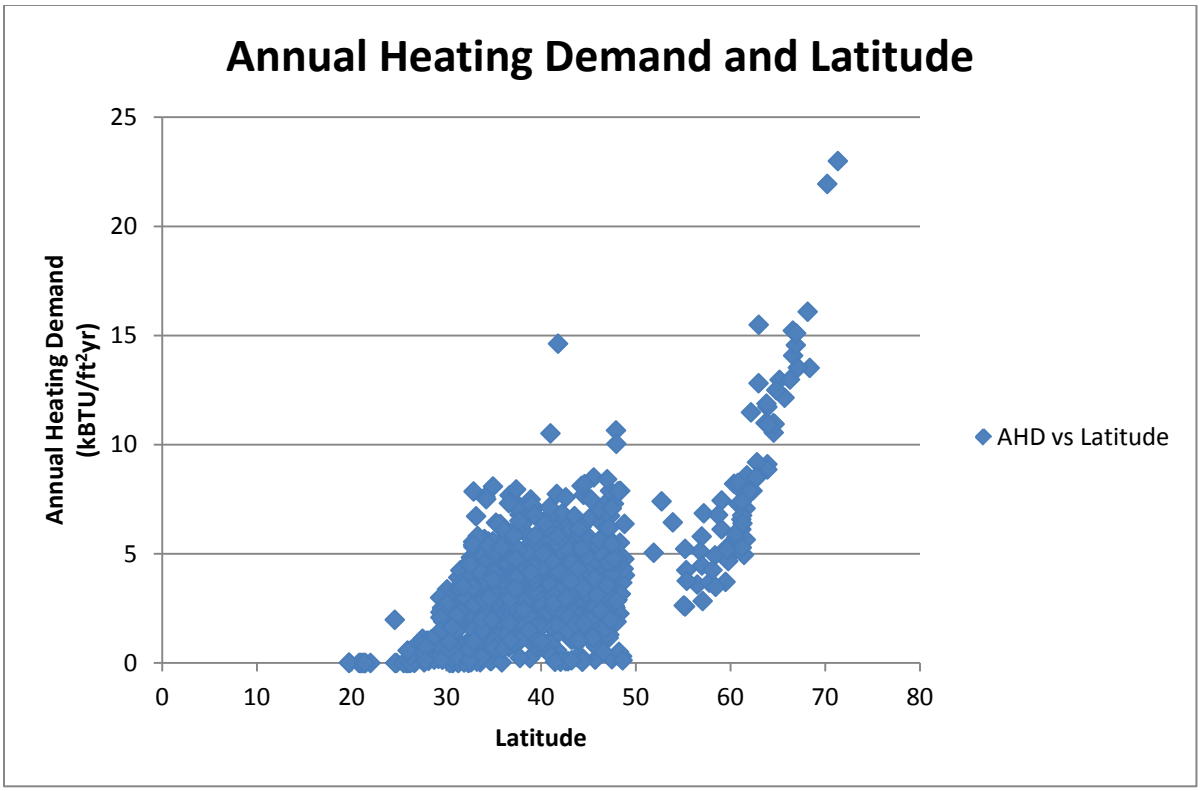


Figure 4.64 - Relationship between Annual Heating Demand and Latitude

Using the supply air heating as a limiting factor did have a large effect for many specific cases, but the overall correlation and trends were similar to those cases that were not limited by their ability to have the supply air provide all of the heating energy. It was also demonstrated, that there are a few locations where it is not possible given the extents and limitations of the experimental simulations to meet the Heating Load criteria to fulfill the functional definition of passive house. At the same time, it was demonstrated that a large majority of climates are able to meet the Heating Load according to the current Passive House Standard, but that there are locations that this is not possible. It was also demonstrated that the relationship between Annual Heat Demand and Heating Load is not linear nor a straight correlation, but is variable based on climactic factors and building design.

This unfiltered analysis of the data suggests a number of possible alterations to the Passive House Standard's certification criteria. These include adjustments, both loosening and tightening, to the Annual Heating Demand, Annual Cooling Demand, and the Heating Load based on climate. These will be discussed in greater detail in Chapter 6, but before discussing these, a filtered analysis of the data will be presented in the following chapter.

Chapter 5

Filtered Case Studies

This chapter takes an in-depth look at eight climate locations as specific case studies in an effort to understand what the full factorial simulation may mean for a given climate. The simulations for each climate location discussed in Chapter 4 were filtered to eliminate any cases that were not feasible as buildings in every climate location. The cases that were kept provide comfort and ecological benefit without placing a hardship on the project due to diminishing returns. The eight climate locations discussed are:

Miami, FL	Climate Zone 1A
Memphis, TN	Climate Zone 3A
San Francisco, CA	Climate Zone 3C
Seattle, WA	Climate Zone 4C
Chicago, IL	Climate Zone 5A
Burlington, VT	Climate Zone 6A
Duluth, MN	Climate Zone 7
Fairbanks, AK	Climate Zone 8

These climate locations were taken from a list of representative cities based on the ASHRAE climate zones based on NREL Report 43340 and as representative locations, they cover most climate conditions seen in the United States, including heating dominated, cooling dominated , and mixed climates. Each location above belongs to a specific climate zone. The filtering was begun by eliminating all of the cases that do not meet International Energy Conservation Code (IECC) requirements. The IECC sets the standards for energy efficiency as code. Many jurisdictions, especially small ones, use these requirements in lieu of any local code and most energy efficiency minimums are based on these requirements. Therefore, each

location's minimum requirements used the IECC requirements based on the climate zone in which they were located. Figure 5.1 shows the minimum R-Values and maximum SHGCs for all climate zones. For instance, the cases that have a wall R-Value of 10 are below code minimum everywhere and were eliminated. The cases in climate zones 6-8 that have a roof R-Value of 40 were also culled. Cases were filtered by glazing percentage, roof and wall R-Value, slab R-Value, window R-Value, and SHGC based on the IECC. Cases were also filtered by window R-Value and the diminishing returns from insulation.

Climate Zone	Window R-Value (SHGC)	Wall R-Value	Roof R-Value	Floor R-Value
1	.8333 (.30)	13	30	0
2	1.538 (.30)	13	30	0
3	2.00 (.30)	13	30	0
4 except Marine	2.857 (none)	13	38	10
5 and Marine 4	2.857 (none)	20	38	10
6	2.857 (none)	20	49	10
7 - 8	2.857 (none)	21	49	10

Figure 5.1 - 2012 IECC Major Prescriptive Requirements

Window R-Values were based on the interior surface temperature of the window necessary to maintain occupant comfort. The surface temperature is driven by the exterior temperature. The average of the two Heating Load temperatures was used to determine the target R-Value needed to maintain comfort. Any case with a window R-Value below that threshold was

filtered out of the results. The following list shows the temperature and corresponding R-Value required for each representative climate location.

Climate	Temperature (F)	R-Value (required)
Fairbanks, AK	-17.32	8.351429
Duluth, MN	-1.21	6.774524
Burlington, VT	19.31	4.765952
Chicago, IL	14.36	5.250476
Seattle, WA	32.09	3.515
San Francisco, CA	31.82	3.541429
Memphis, TN	51.98	1.568095
Miami, FL	65.03	0.290714

The last threshold for filtering was determined by the diminishing returns of insulation. As more insulation is added, it reduces heat transmission by a smaller percentage. The first inch of insulation is much more effective than the next inch of insulation. By the time the assembly is over a foot thick, the additional inch of insulation does not have the same effect on performance that the first inch had, despite the R per Inch of the material being the same. This is often an argument against superinsulated buildings and, by extension, passive houses. The diminishing returns are plotted in the figures below. The x-axis is the R-Value of the assembly while the y-axis is the transmission heat losses through the assembly. Figures 5.2, 5.3, and 5.4 show the roof, walls, and slab assemblies, respectively, for the cases in Fairbanks, AK.

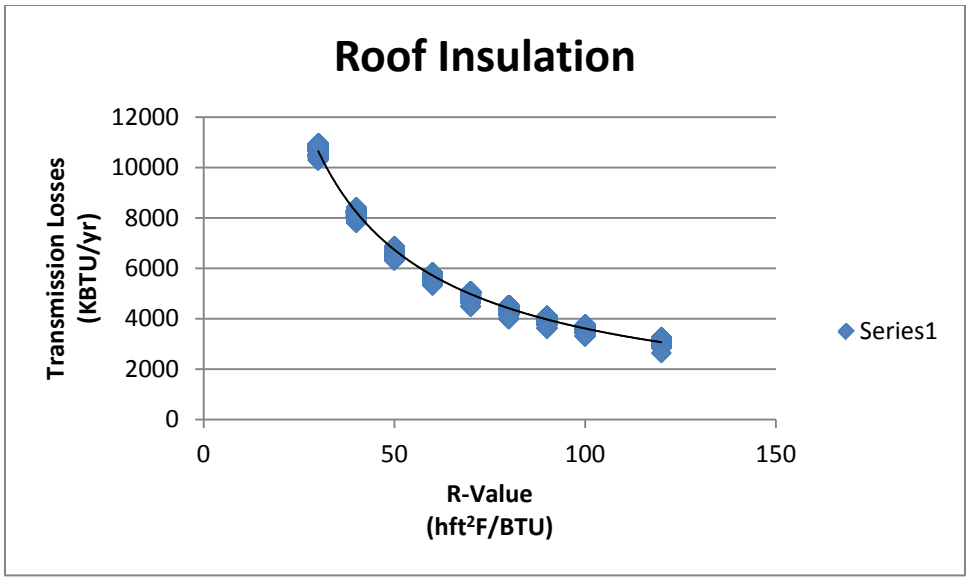


Figure 5.2 - Roof Insulation - Fairbanks - Diminishing Returns

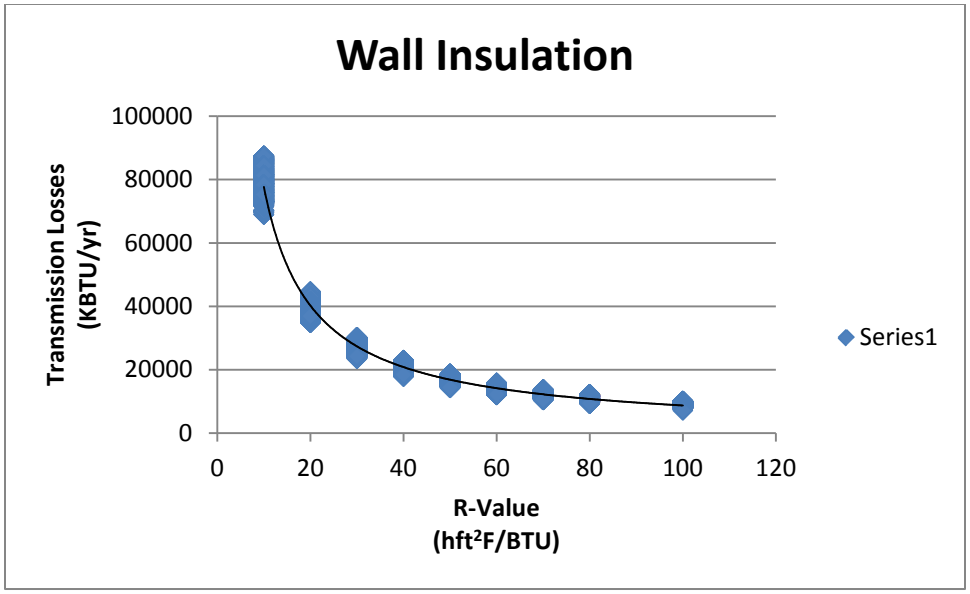


Figure 5.3 - Wall Insulation - Fairbanks - Diminishing Returns

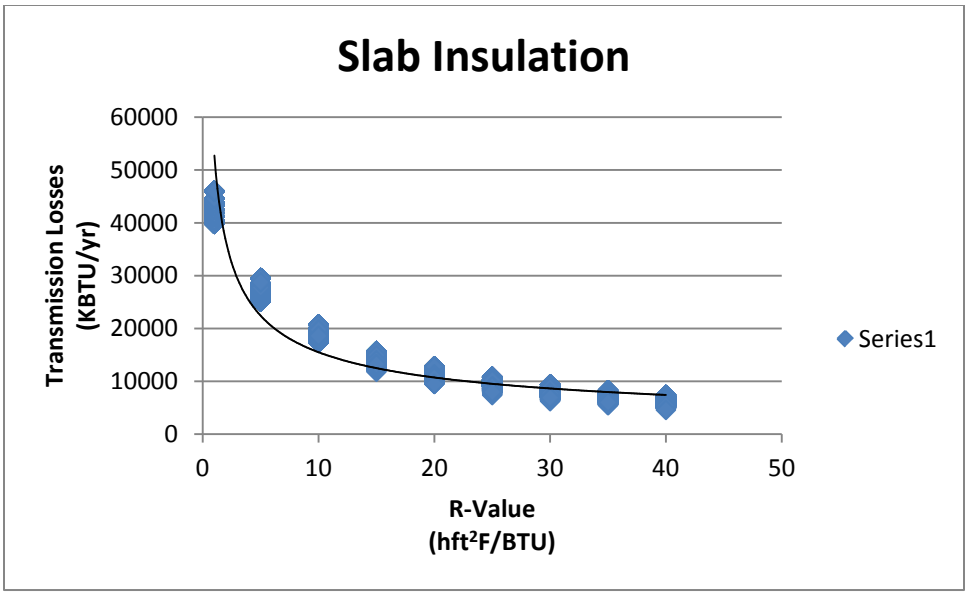


Figure 5.4 - Slab Insulation - Fairbanks - Diminishing Returns

All three figures exhibit the same characteristics when compared to each other. The cases with small amounts of insulation make a marginally larger difference than do the cases where insulation was added to an assembly that already contained large amounts of insulation. The question that must be answered is where the limit should be placed, or where is the point beyond which it no longer makes sense to add insulation because the benefit is negligible compared to the cost or the environmental impact.

Figures 5.5 - 5.11 show the roof, wall, and slab insulation R-Values, for Memphis, TN and Duluth, MN, plotted against the corresponding transmission heat loss from those assemblies. The trends between the two locations are remarkably similar. The shape of the curve is exponential and consistent throughout all sets; the only difference is the magnitude at which it occurs. For the eight locations studied in depth using this analysis, the roof insulation had the steepest curve in the high range of R-Values, leading to the conclusion that it may still be effective to insulate, or at least more effective to insulate the roof further as compared to the

walls or slab. The slab insulation curves were the shallowest. Even in the colder climates the curve flattened considerably beyond R-30. Adding significant amounts of insulation under the slab beyond that point, especially R-60 plus, is generally not advantageous based on this analysis.

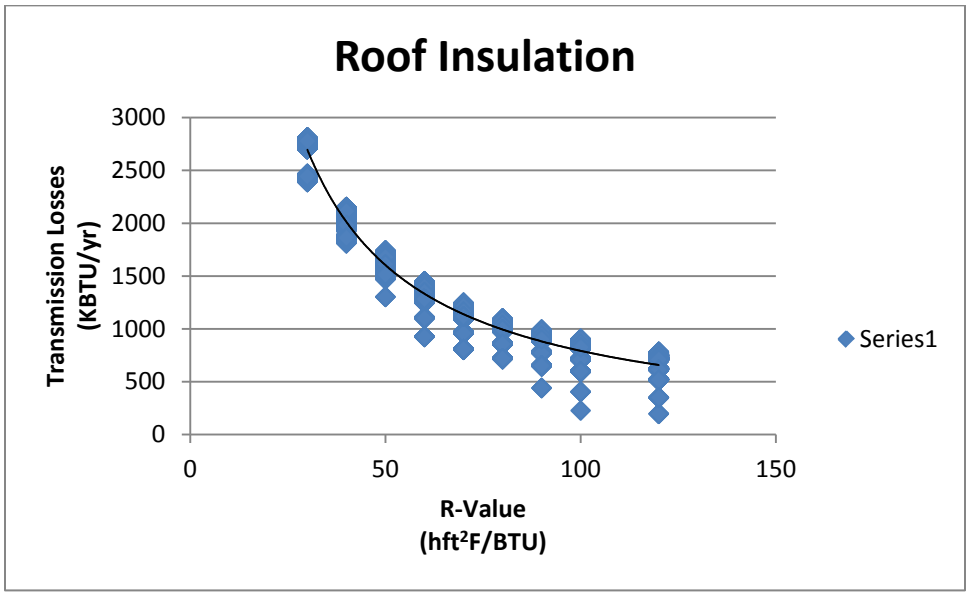


Figure 5.5 - Roof Insulation - Memphis - Diminishing Returns

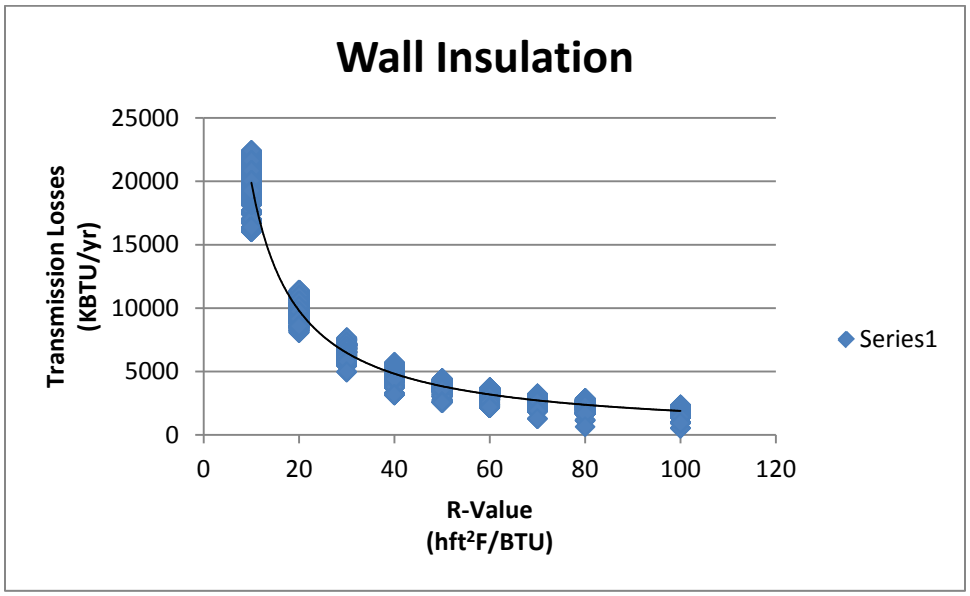


Figure 5.6 - Wall Insulation - Memphis - Diminishing Returns

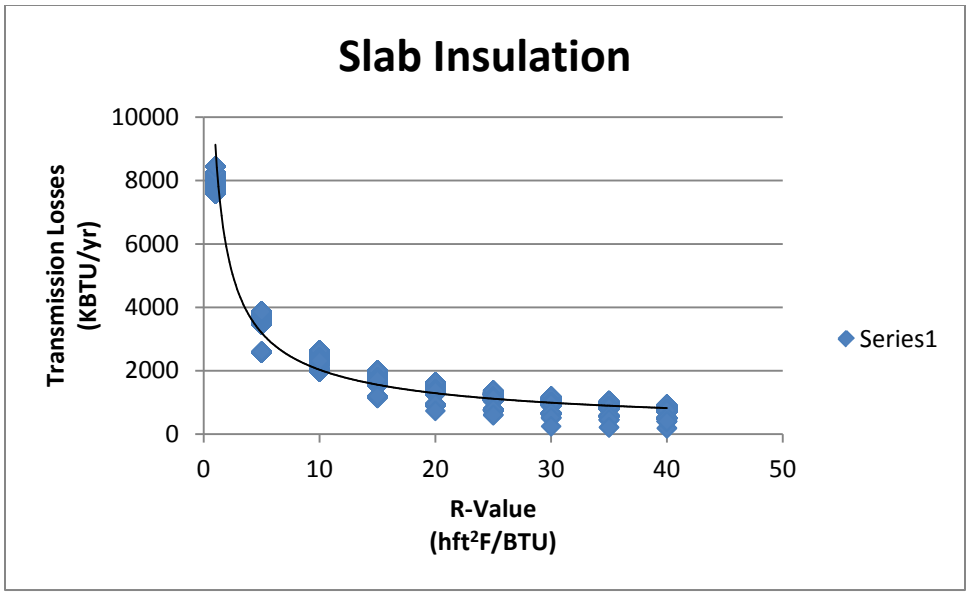


Figure 5.7 - Slab Insulation - Memphis - Diminishing Returns

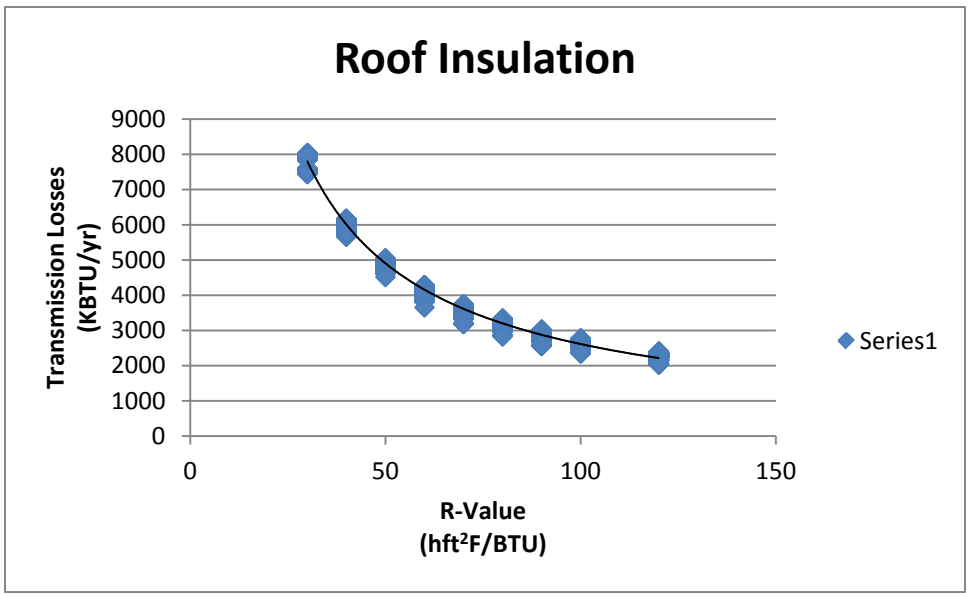


Figure 5.8 - Roof Insulation - Duluth - Diminishing Returns

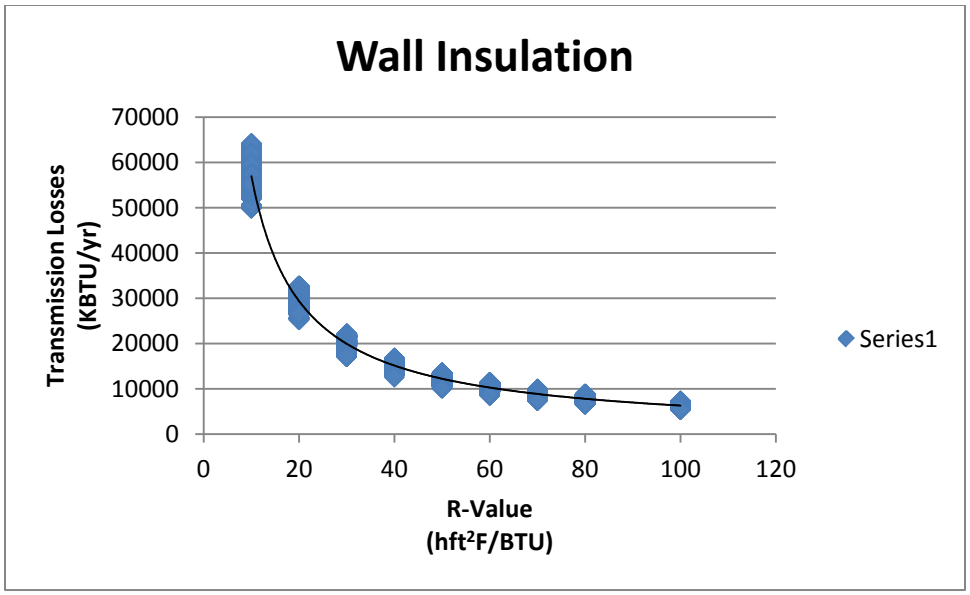


Figure 5.9 - Roof Insulation - Duluth - Diminishing Returns

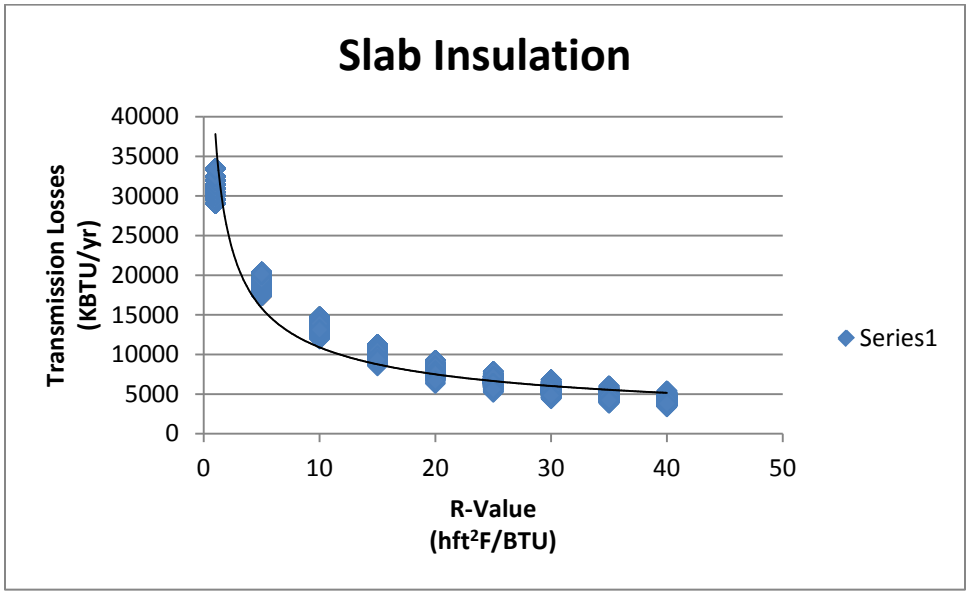


Figure 5.10 - Roof Insulation - Duluth - Diminishing Returns

When each location is plotted separately, the curve is nearly identical due to the scaling of the transmission heat losses along the y-axis, but a greater understanding can be achieved by

analyzing Figure 5.11. Figure 5.11 is a graph of every climate set, except Miami, showing the diminishing returns of the wall insulation. Miami was not shown because for heating, there were no transmission heat losses. The colder climates, such as Fairbanks, exhibit a greater amount of a savings when insulation is added. The milder climates, such as San Francisco, do not see the same amount of savings when the insulation is added. Because of this, an insulation increase from R-80 to R-100 in Fairbanks saves roughly the equivalent amount of energy as does the increase from R-40 to R-60 in San Francisco on a marginal, or return on investment, type of analysis as seen in Figure 5.11. To find a point where similar transmission losses occur, the R-10 wall in San Francisco is equivalent to the R-40 wall in Fairbanks and the R-20 wall in San Francisco is equivalent to the R-100 Wall in Fairbanks. According to this metric, projects in Fairbanks will need at least 4 times the insulation as compared to projects in San Francisco to achieve the same result.

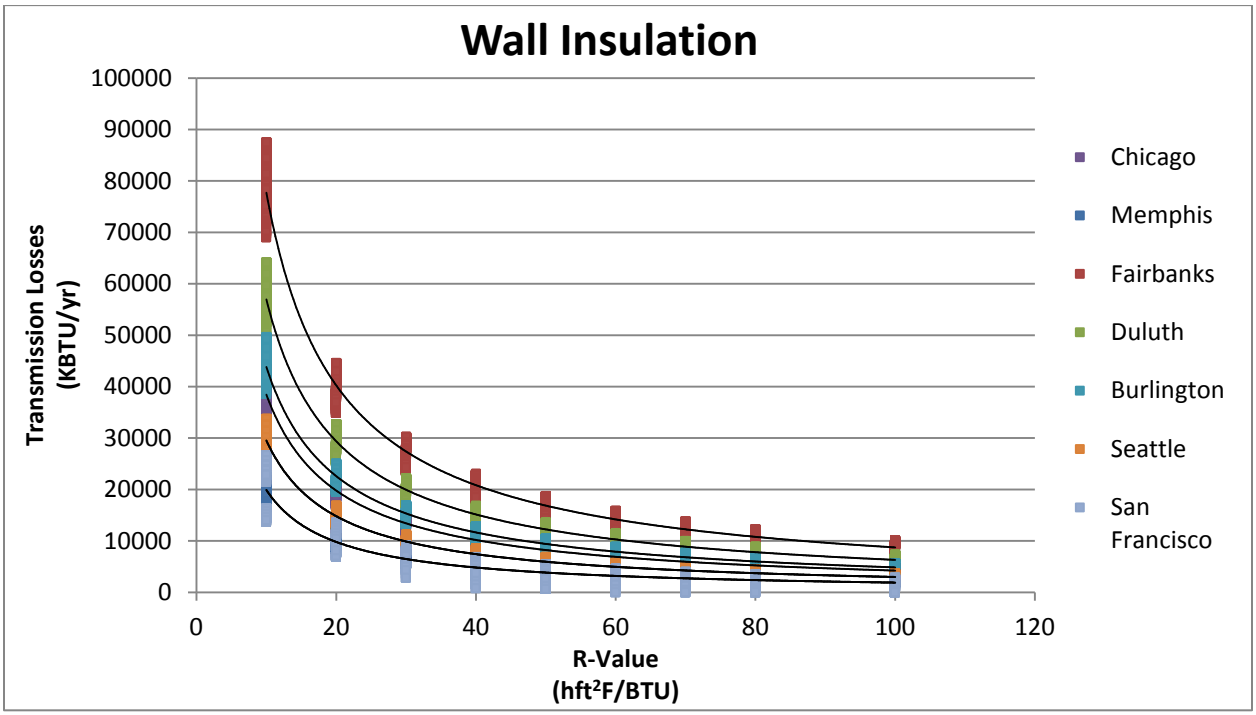


Figure 5.11 - Wall Insulation - Diminishing Returns

Based on this information alone, it is difficult to determine the point where diminishing returns becomes too great to overcome in a given climate zone. One way to find that point is to optimize the building's overall energy performance. If there are other factors besides the wall, roof and slab insulation, such as other insulation values, window outputs, and mechanical systems, that make a much larger difference, then the insulation amount may be optimal. Most likely, in Fairbanks, where there is a very large temperature difference, once the insulation begins to lose effectiveness, other strategies, such as an increased efficiency of a heat recovery ventilator may still hold great energy savings so that it does not make sense to insulate further. On the other hand, if increasing the efficiency of heat recovery does not provide significant energy savings either, more insulation may still be one of the best ways to limit energy use even if the last inches are less effective than the first. Without specific and detailed analysis, it is difficult to determine where the point is where insulation is no longer effective, because it is effective even for unrealistic thicknesses, but just less so. There is never a point where it is totally ineffective; therefore, finding the exact point to stop insulating is difficult without further analysis.

Cost is one of the most important factors driving construction in the United States today. Cost as defined primarily in monetary terms, but also in other costs such as environmental or social, including the effects of less energy and less carbon in and on the atmosphere. Monetary cost is very difficult to determine in a study such as this. Regional differences in materials, building styles, and preferences, not to mention standard of living or average wage, have a huge influence on costs within the United States. While there is software and some national databases available from which to draw this information an analysis of this data is beyond the scope of this thesis. Cost fluctuations can happen rapidly and dramatically or they can increase or decrease

slowly while some materials or technologies become cheaper and other become more expensive. Because of these difficulties, cost was not included in the analysis as a method to find the diminishing returns.

While analyzing the eight climates, the Primary Energy Demand of each was graphed. As mentioned earlier, primary energy is the total energy the building needs from the power plant and is dependent not just on the envelope, but also on the lighting, mechanical systems, internal heat gains, and other settings that make up a building. For all the simulations, these settings were set at default or approximate values for common systems, therefore, the major difference between the cases' Primary Energy Demand were the envelope losses and gains. Figures 5.12-5.19 show the Primary Energy Demand for each of the locations. The most striking finding in comparing these Primary Energy Demands is that nearly all the cases are below the threshold of 38 $kBTU/ft^2yr$ except for Fairbanks and Duluth, where the heating energy necessary in the poorly performing cases requires a large amount of Primary Energy input to maintain comfort. However, in the top twenty percent of cases, which include those needed for meeting the Passive House Standards for heating and cooling climates, the Primary Energy Demand criteria is achievable.

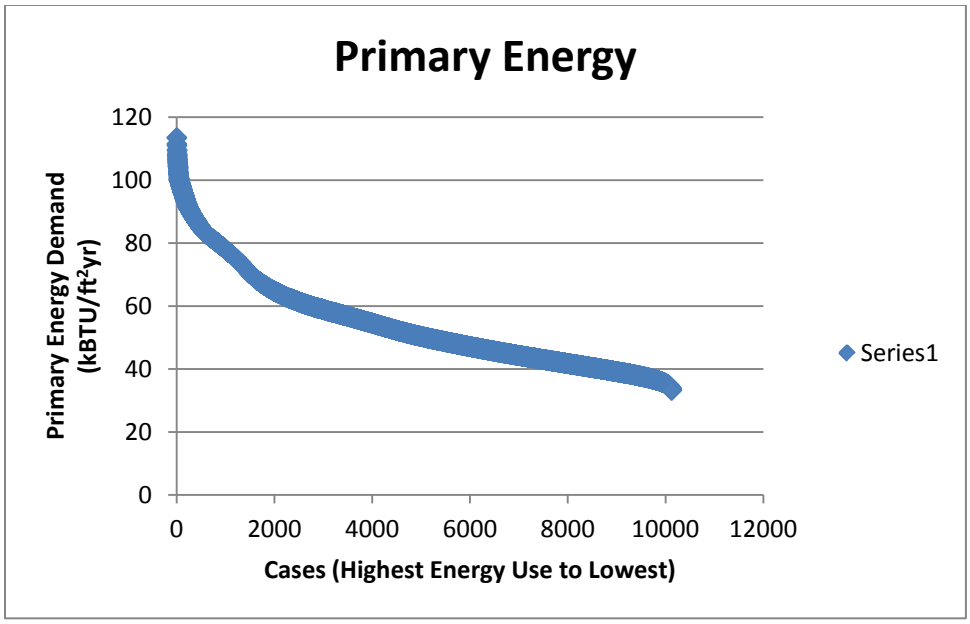


Figure 5.12 - Primary Energy - Fairbanks, AK

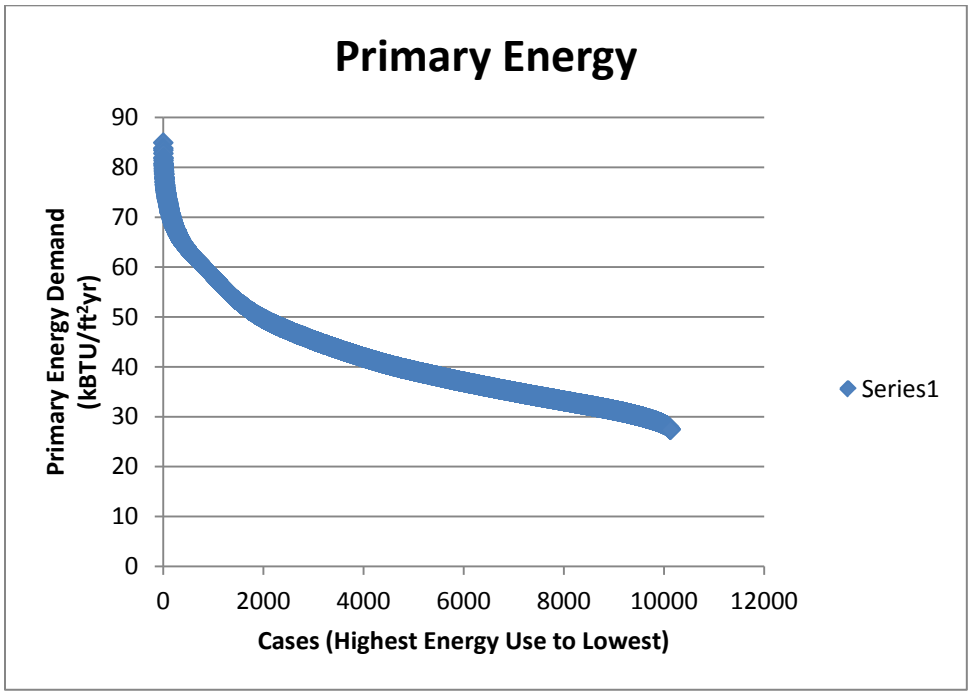


Figure 5.13 - Primary Energy - Duluth, MN

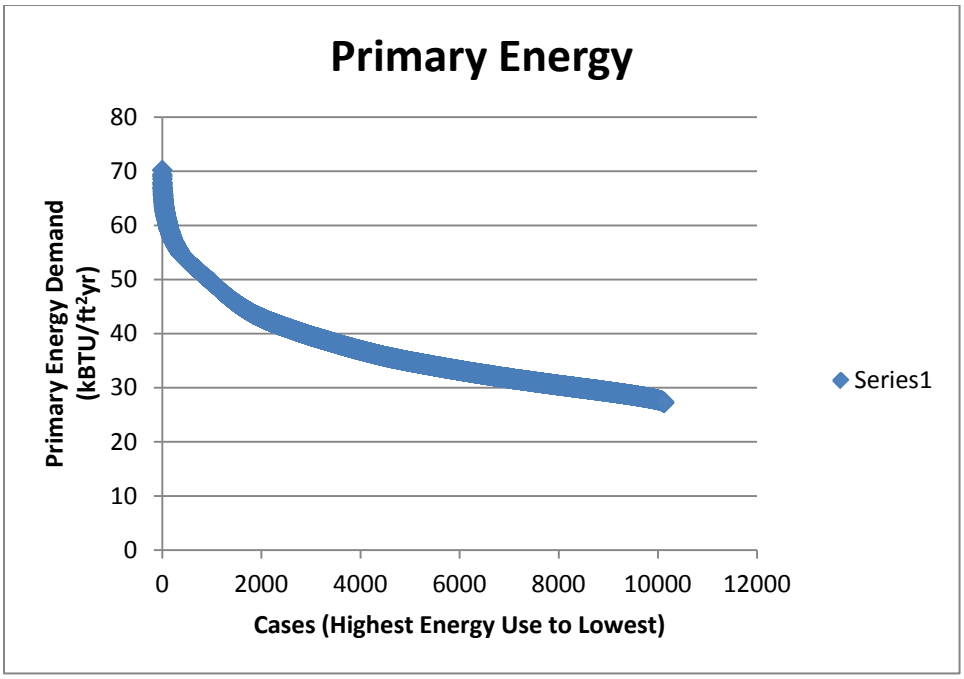


Figure 5.14 - Primary Energy - Burlington, VT

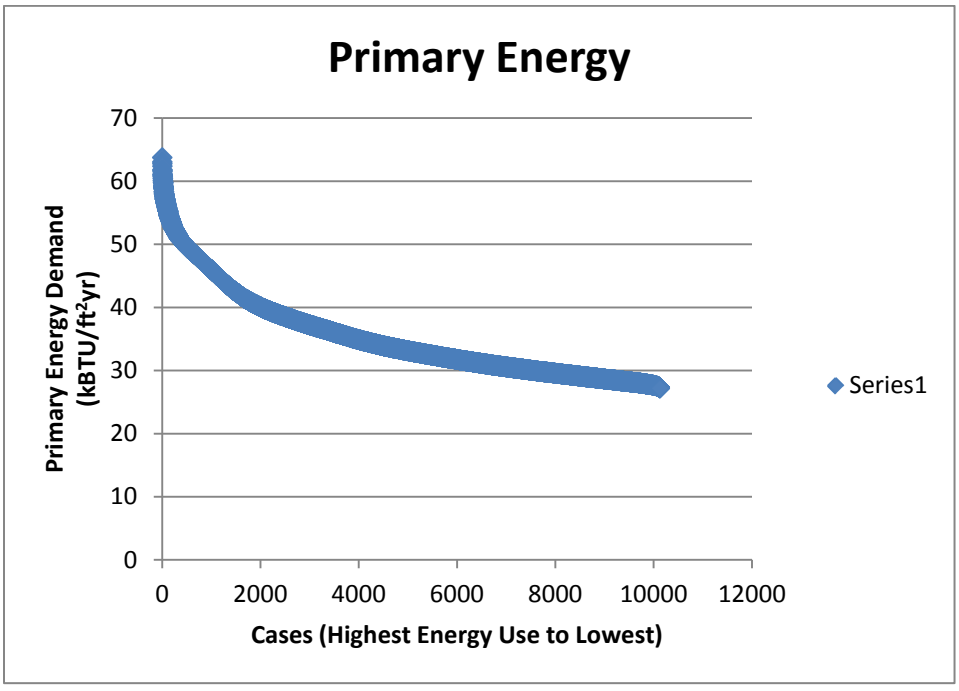


Figure 5.15 - Primary Energy - Chicago, IL

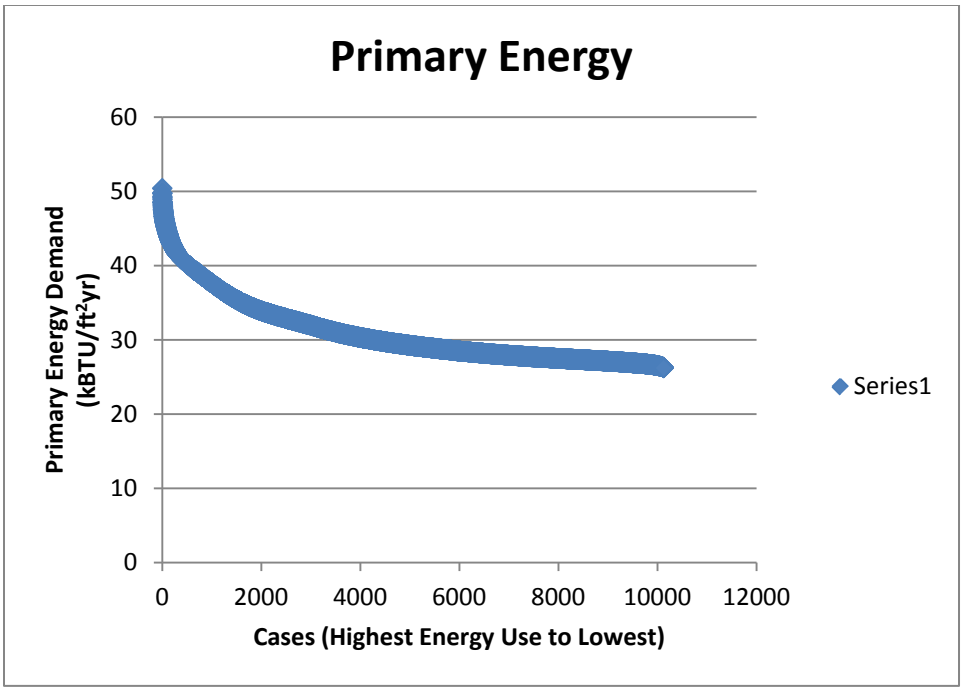


Figure 5.16 - Primary Energy - Seattle, WA

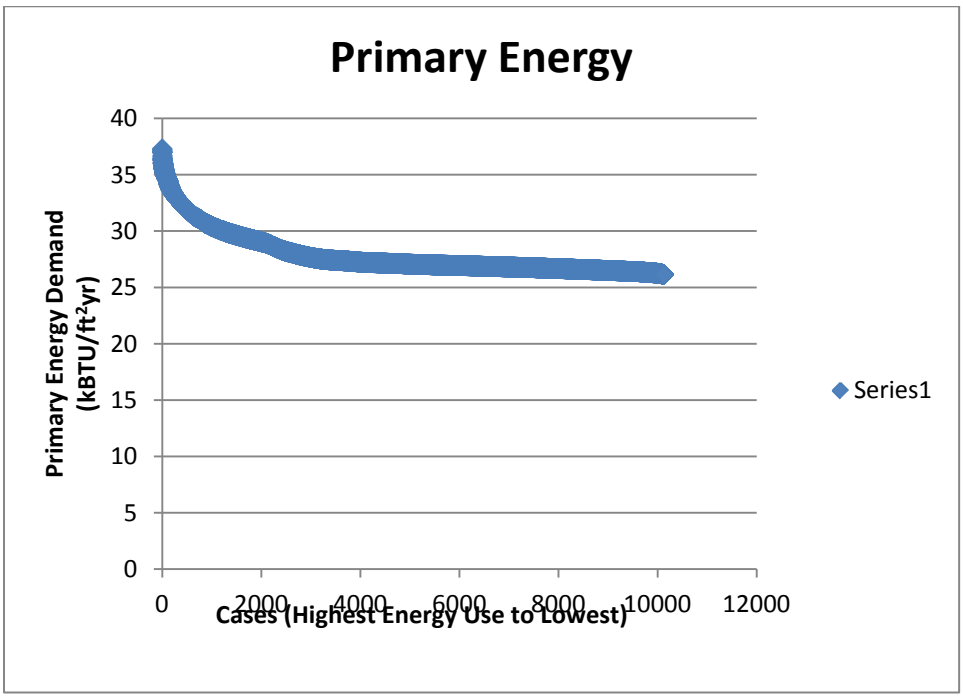


Figure 5.17 - Primary Energy - San Francisco, CA

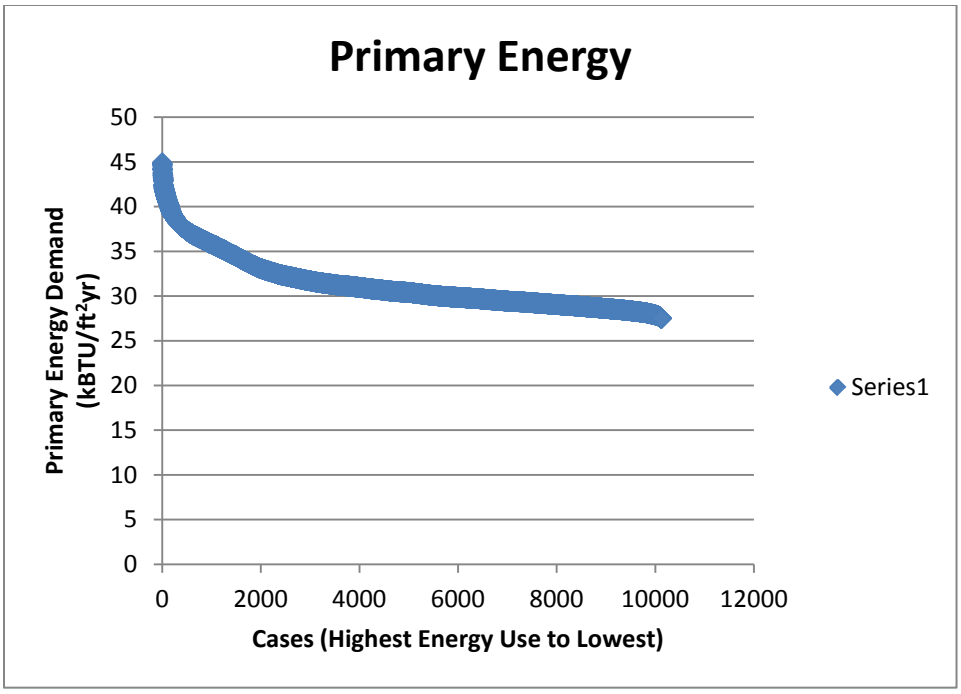


Figure 5.18 - Primary Energy - Memphis

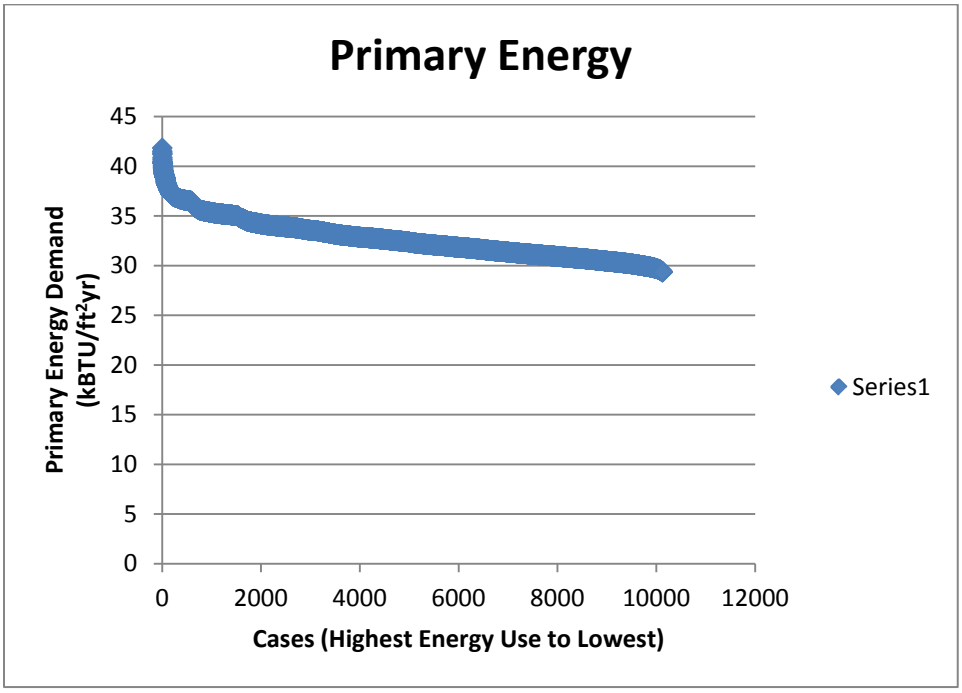


Figure 5.19 - Primary Energy - Miami, FL

Miami, FL

All of the eight cases are analyzed in climate zone order from low to high. The first filtering was climate zone 1, which was represented by Miami, FL. By filtering out the cases with a SHGC higher than .3 and the cases where the wall R-Value below R-10, only 3600 possible cases remained. The next criteria to filter was the daily temperature swing below 5.76 degrees F which did not remove any cases due to the high heat gain cases already being filtered and the glazing percentages used within the simulation limited to moderately glazed options. The cases that contained less than 10% South glazing percentage left were eliminated from the original 10,125 cases which left 2,880 cases that were simulated.

The Annual Heat Demand for Miami is zero. In this climate there is no heating necessary. Even in the event where the temperature may dip low enough to cause heat loss to the outside, the internal gains and the lag time created by superinsulation lead to a situation where there is no heating necessary. Therefore, there is also not a Heating Load for any of the viable cases. Unfiltered, the Annual Cooling Demand fluctuated between the best case of around 5.9 kBTU/hr*ft^2 to the worst case of 23.9 kBTU/hr*ft^2 with an average of 11.9 kBTU/hr*ft^2. Filtered, the Annual Cooling Demand fluctuated between the best case of around 6.6 kBTU/hr*ft^2 to the worst case of 16.1 kBTU/hr*ft^2 with an average of 9.88 kBTU/hr*ft^2.

The best performing cases consisted of the highest levels of insulation in the wall, roof and slab, with the roof and walls being slightly more important than the slab. The best cases were also the lowest glazed, to limit heat gain, and had the lowest SHGC and the highest window R-Values. For the windows, controlling the heat gains through the SHGC and the glazing percentage was more important than controlling the R-Value. The worst cases generally consisted of opposite characteristics from the best cases. They included the lowest levels of wall,

roof, and slab insulation and the windows with the lowest R-Values, highest SHGC, and highest glazing percentage. In Miami, it is not a problem to meet the Annual Heating Demand, but the current criteria for the Annual Cooling Demand is impossible to meet given the parameters of the study. In this case, other strategies or means need to be utilized, or the standard needs to be adjusted so that buildings in Miami can meet it.

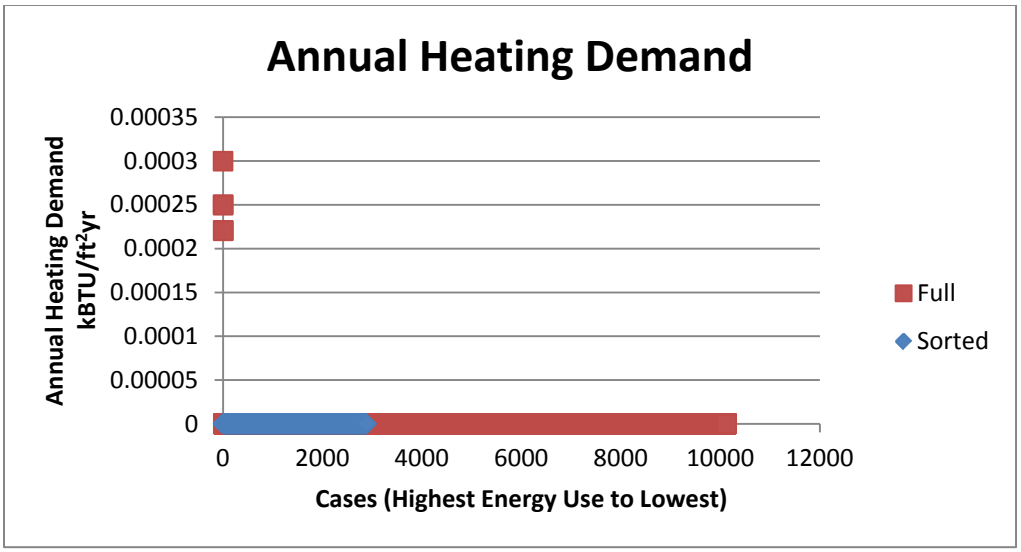


Figure 5.20 - Annual Heating Demand - Miami, FL

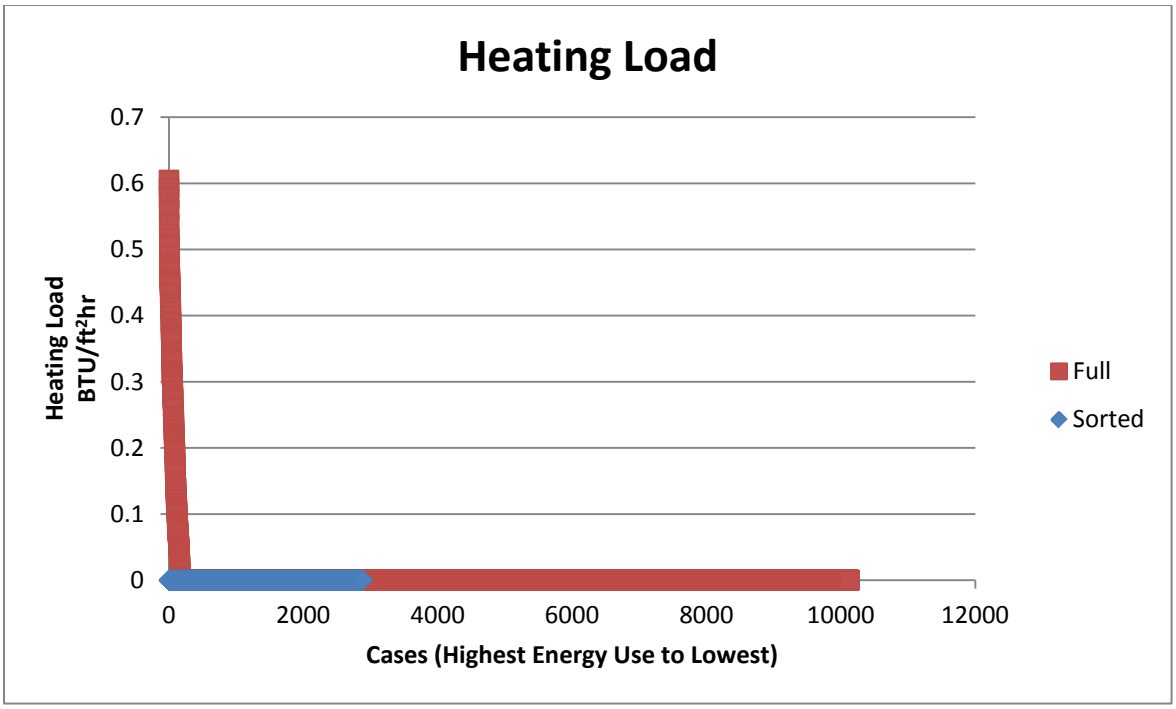


Figure 5.21 - Heating Load - Miami, FL

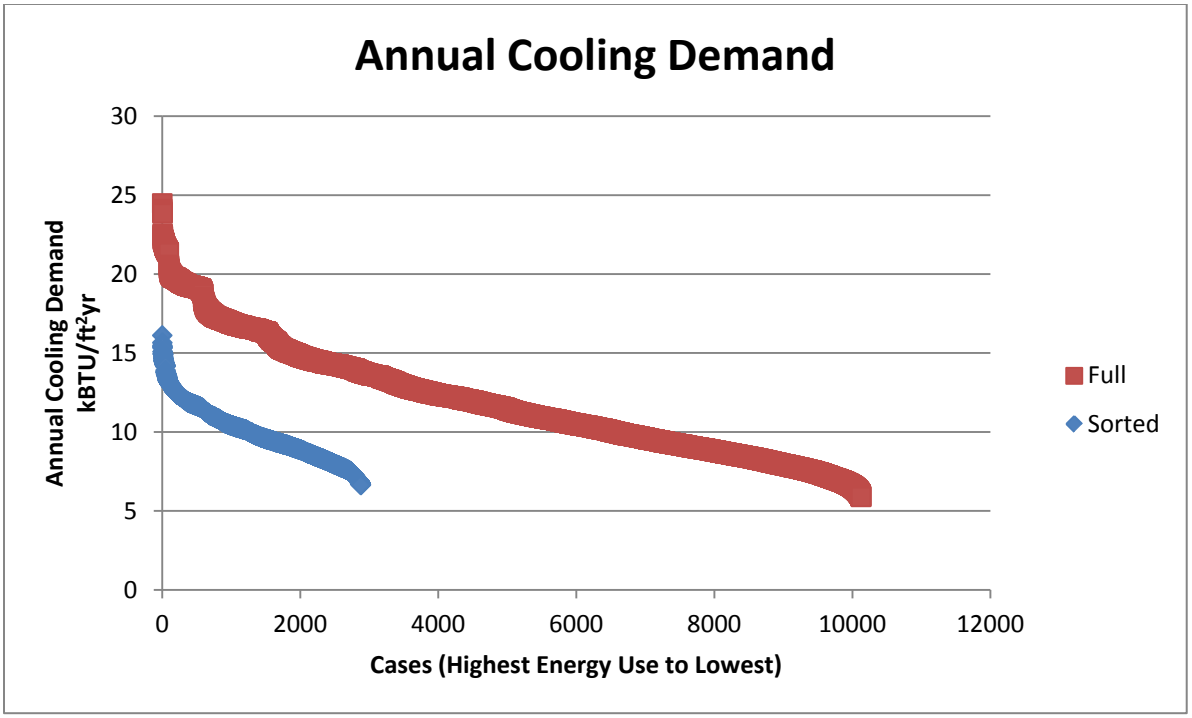


Figure 5.22 - Annual Cooling Demand - Miami, FL

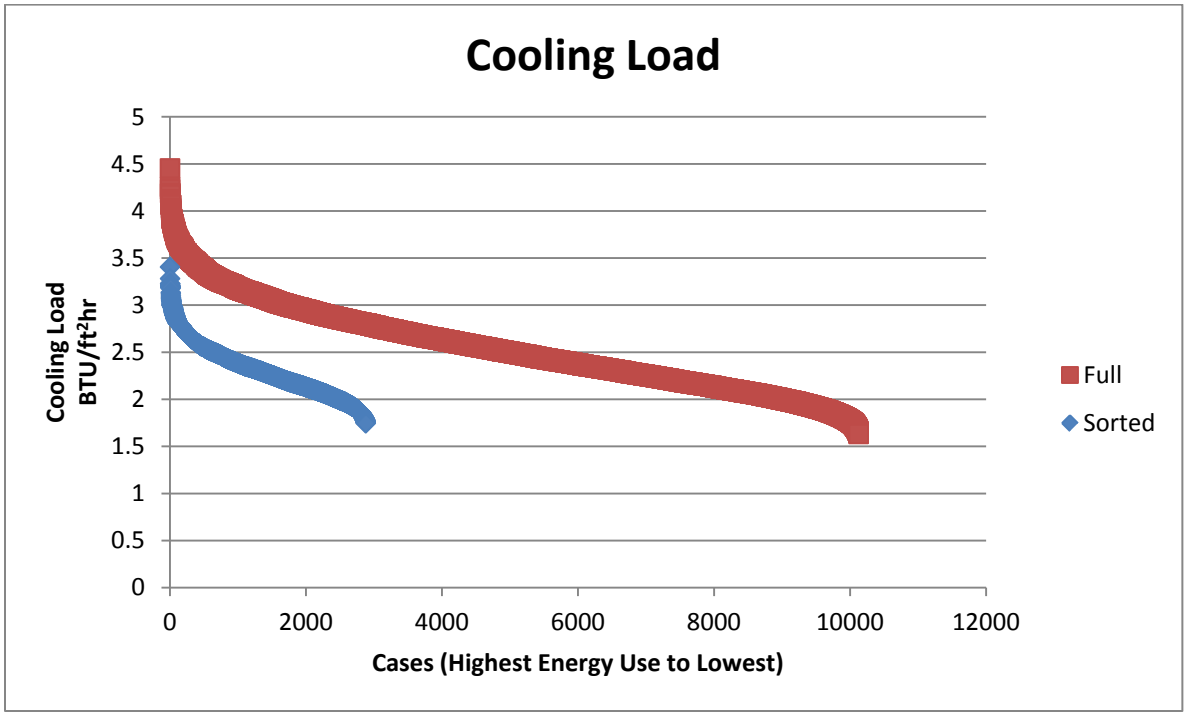


Figure 5.23 - Cooling Load - Miami, FL

Memphis, TN

The cases in Memphis were screened for the wall and roof R-Value and the SHGC. After the filtering, there were 2879 cases left. Memphis is a mixed climate where both heating and cooling need to be taken into account. It is also a climate where the best cases meet the current passive house criteria. Unfiltered, the Annual Heating Demand fluctuated between the best case of around 0.0 kBTU/hr*ft^2 to the worst case of 16.8 kBTU/hr*ft^2 with an average of 3.2 kBTU/hr*ft^2. Filtered, the Annual Heating Demand fluctuated between the best case of around .04 kBTU/hr*ft^2 to the worst case of 12.9 kBTU/hr*ft^2 with an average of 3.1 kBTU/hr*ft^2. Unfilterd, the Annual Cooling Demand fluctuated between the best case of around 1.7 kBTU/hr*ft^2 to the worst case of 12.1 kBTU/hr*ft^2 with an average of 4.7 kBTU/hr*ft^2. Filtered,

the Annual Cooling Demand fluctuated between the best case of around 2.0 kBTU/hr*ft^2 to the worst case of 7.6 kBTU/hr*ft^2 with an average of 3.7 kBTU/hr*ft^2.

For heating, the cases that performed best were those that consisted of the maximum insulation values for the wall, slab, and roof, with the roof and walls being the most important of the three. The best cases also were characterized by windows with the higher R-Value, highest SHGC, and the largest glazing area. The windows were more important than the assembly insulation values and the order, from most important to least, were the R-Value, the SHGC, and the glazing percentage. The cases that performed the worst were the cases with the least amount of insulation. Larger amounts of windows also contributed to poorer results, but only when the R-Value of the window and the SHGC were both poor.

The cases that performed the best were the most highly insulated cases for the wall and roof. The cases that had median amounts of slab insulation, between R-10 and R-20 also fared the best, however, highly insulated slabs did perform much better than slabs insulate to R-1 or R-5, which performed rather poorly. The best windows were ones with high R-Values and low SHGC's. The lowest percentage of glazing was also particularly common in the best cases. The cases that performed the worst were again the assemblies with the least amount of insulation, but also the cases that had the highest glazing percentage and highest SHGC's. The window R-Value did matter, but its effect was almost insignificant when compared to the effect of the glazing percentage and the SHGC.

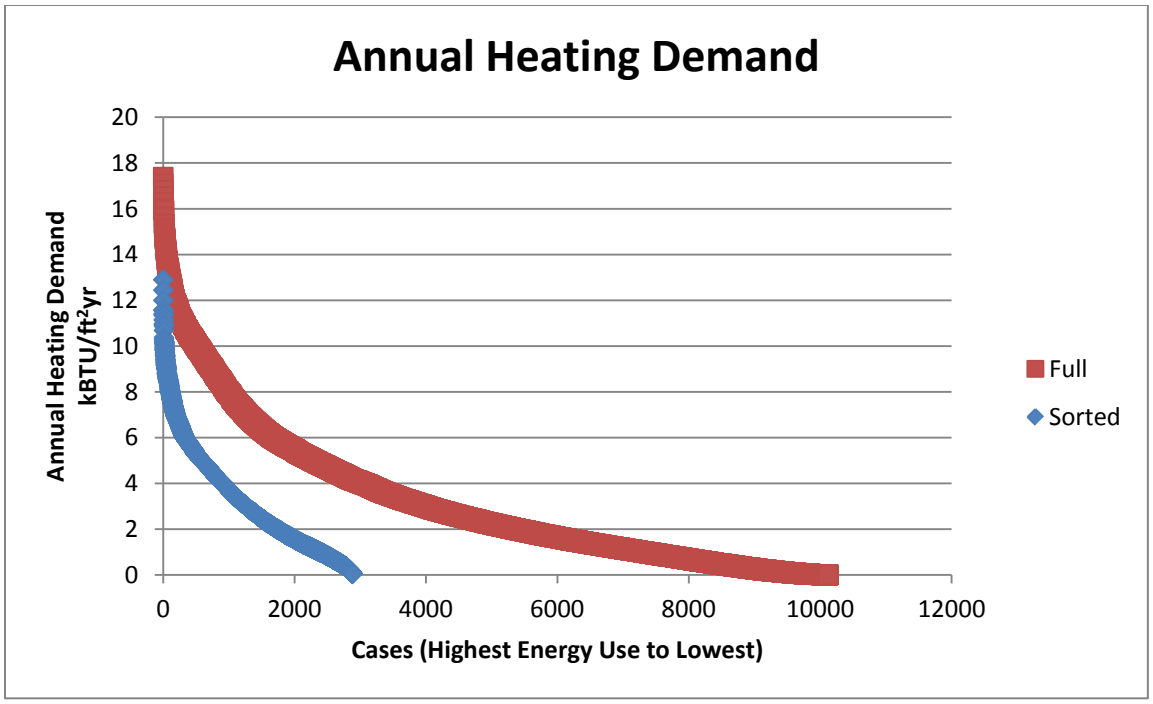


Figure 5.24 - Annual Heating Demand - Memphis, TN

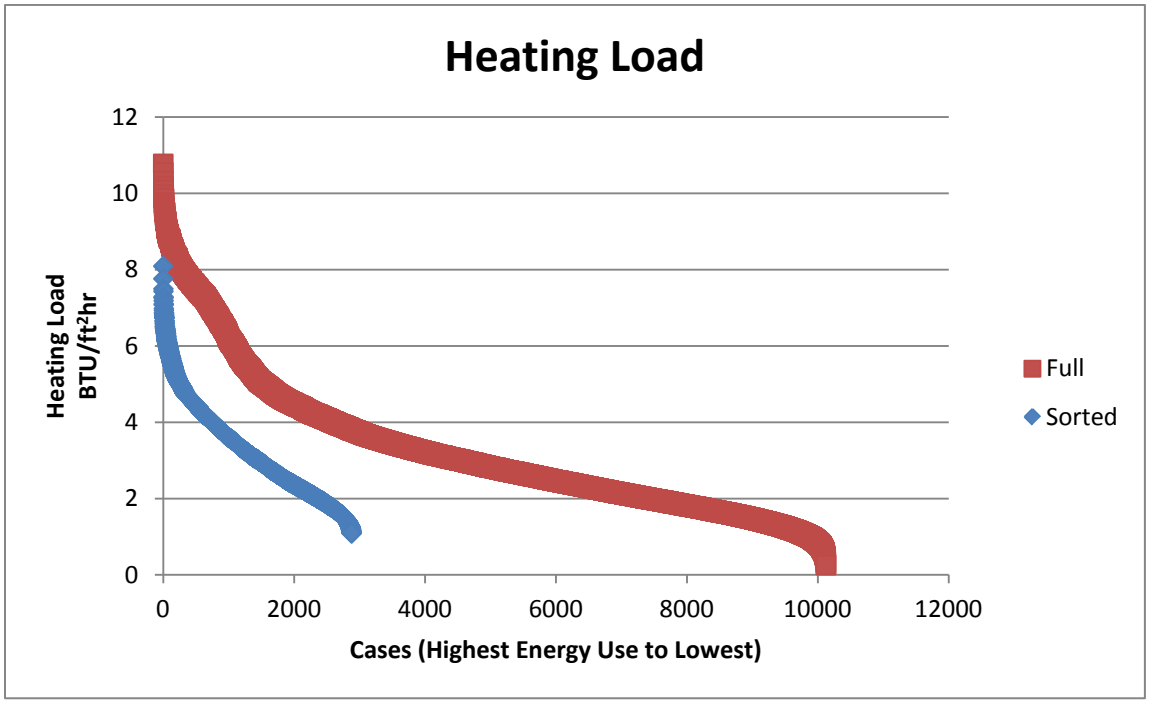


Figure 5.25 - Heating Load - Memphis, TN

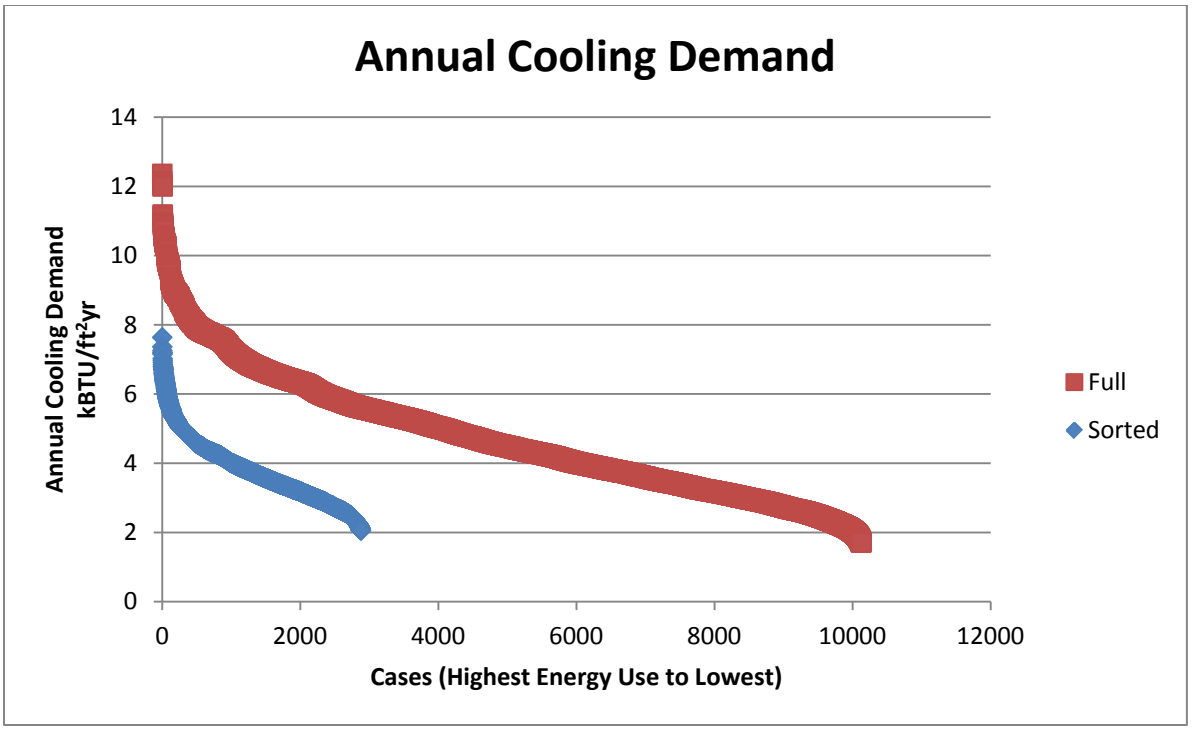


Figure 5.26 - Annual Cooling Demand - Memphis, TN

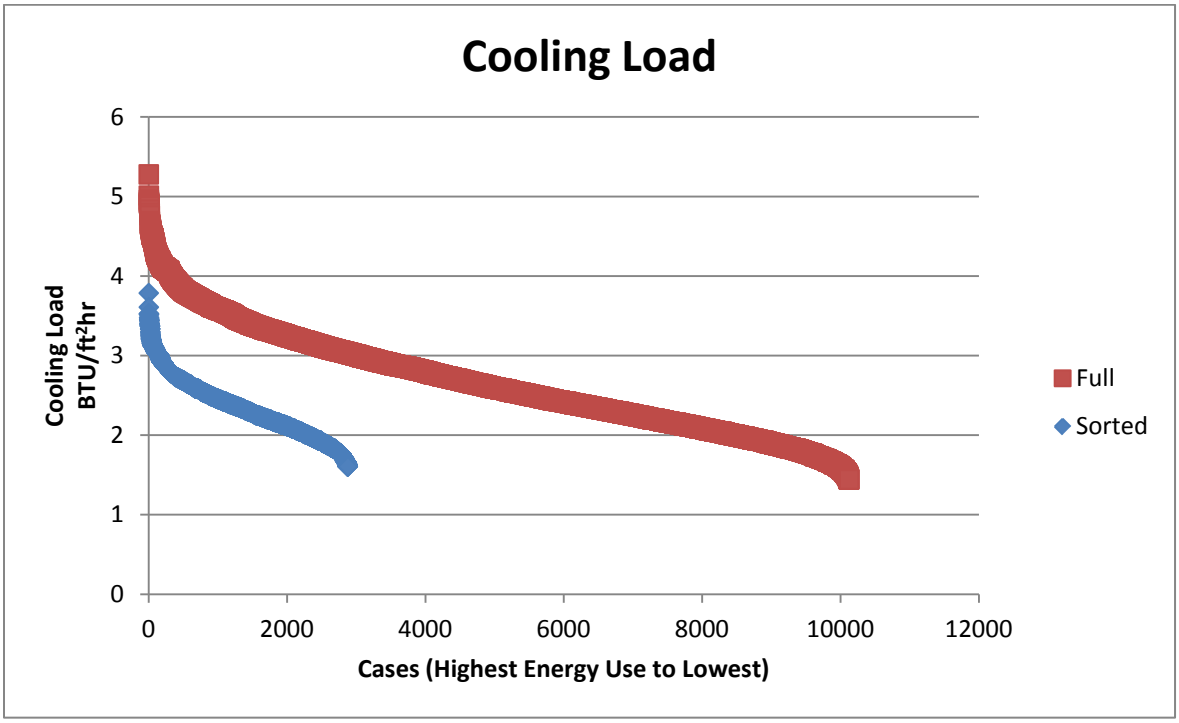


Figure 5.27 - Cooling Load - Memphis, TN

San Francisco, CA

The cases in San Francisco were filtered for the wall and roof R-Value and the SHGC as well as R-3 windows. After the filtering, there were 2304 cases left. San Francisco is a mild climate where both heating and cooling need to be taken into account, but also where neither is particularly difficult to meet. This is true for cooling, which can mostly be dealt with by natural ventilation in many cases. It is also a climate where the best cases easily meet the current passive house criteria. Unfiltered, the Annual Heating Demand fluctuated between the best case of around 0.0 kBTU/hr*ft^2 to the worst case of 12.7 kBTU/hr*ft^2 with an average of 1.8 kBTU/hr*ft^2. Filtered, the Annual Heating Demand fluctuated between the best case of around 0.001 kBTU/hr*ft^2 to the worst case of 12.58 kBTU/hr*ft^2 with an average of 1.3 kBTU/hr*ft^2. Unfiltered, the Annual Cooling Demand fluctuated between the best case of around 0.0 kBTU/hr*ft^2 to the worst case of 3.7 kBTU/hr*ft^2 with an average of 0.24 kBTU/hr*ft^2. Filtered, the Annual Cooling Demand fluctuated between the best case of around 0.0 kBTU/hr*ft^2 to the worst case of 1.3 kBTU/hr*ft^2 with an average of 0.1 kBTU/hr*ft^2.

For heating, the cases that performed the best were numerous as there were many cases with an Annual Heating Demand of zero. These cases had R-Values in the wall of over R-60 and in the roof of over R-80. The cases also had windows with R-9 or above with the higher solar heat gain coefficient. Despite the high heat gains and glazing percentage, the best heating cases were not the worst cooling cases and all of them had Annual Cooling Demands well below the average. The cases that performed the worst for heating were the ones that consisted of the lowest insulation values for all components including the windows. The lowest SHGC's were also very poor performers, but glazing percentage seemed to matter very little.

The best cases for cooling were those that had the highest levels of insulation for all building components, but were also the cases that limited heat gain. The best window configurations consisted of the lowest or second lowest glazing percentages and no SHGC's above .4. The worst cases for cooling were more interesting because they too consisted of the cases with the highest levels of wall and roof insulation. However, the windows in these cases all had the highest allowable SHGC and glazing percentage. This leads to the conclusion that because of the high insulation values, the high solar gains and the internal gains are unable to be lost through the envelope fast enough to dissipate the heat buildup. R-1 slap insulation was the worst performing variable and appeared in all of the worst case buildings. This was an interesting result because, designers are usually taught that the ground temperature will be cooler than the air temperature in a cooling situation and therefore, the ground acts as a heat sink. In San Francisco, this proves not to be the case and more insulation is needed under the slab. However, because all of the filtered cases met the Passive House Standard for Annual Cooling Demand, additional insulation has a low marginal benefit and is likely below the cost effective range.

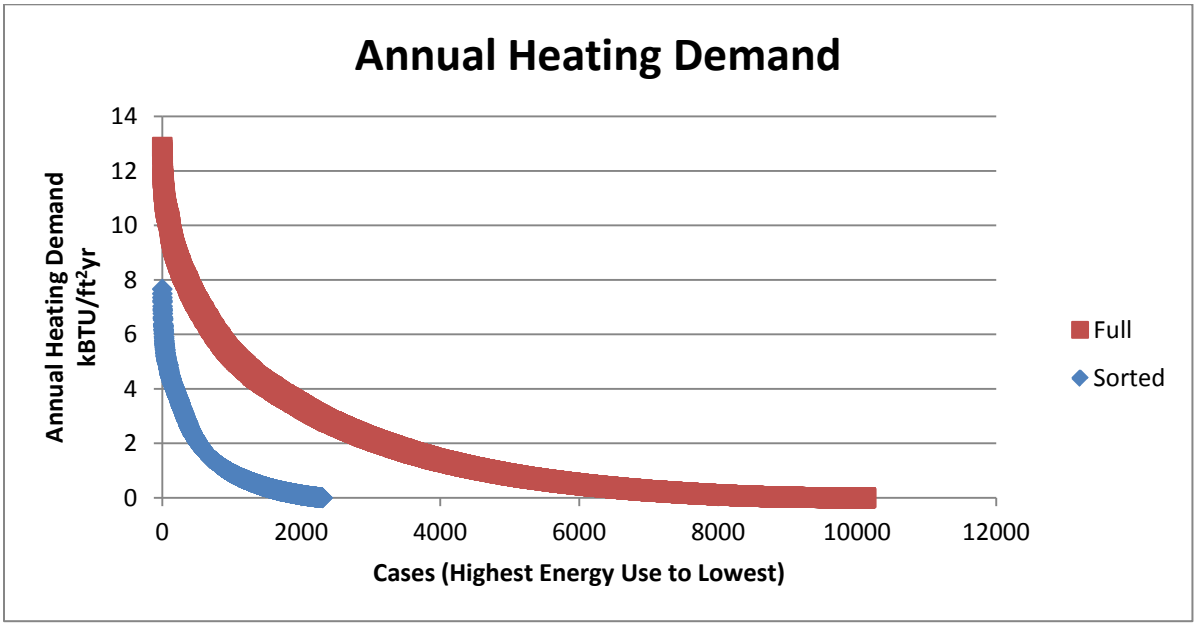


Figure 5.28 - Annual Heating Demand - San Francisco, CA

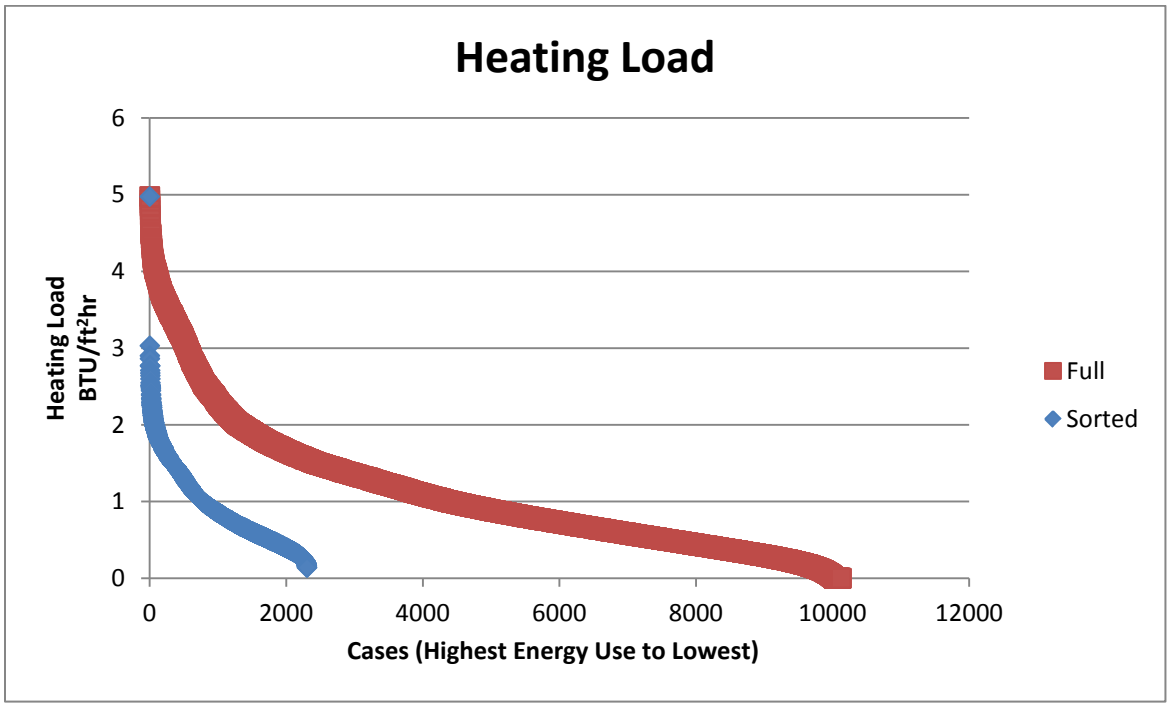


Figure 5.29 - Heating Load - San Francisco, CA

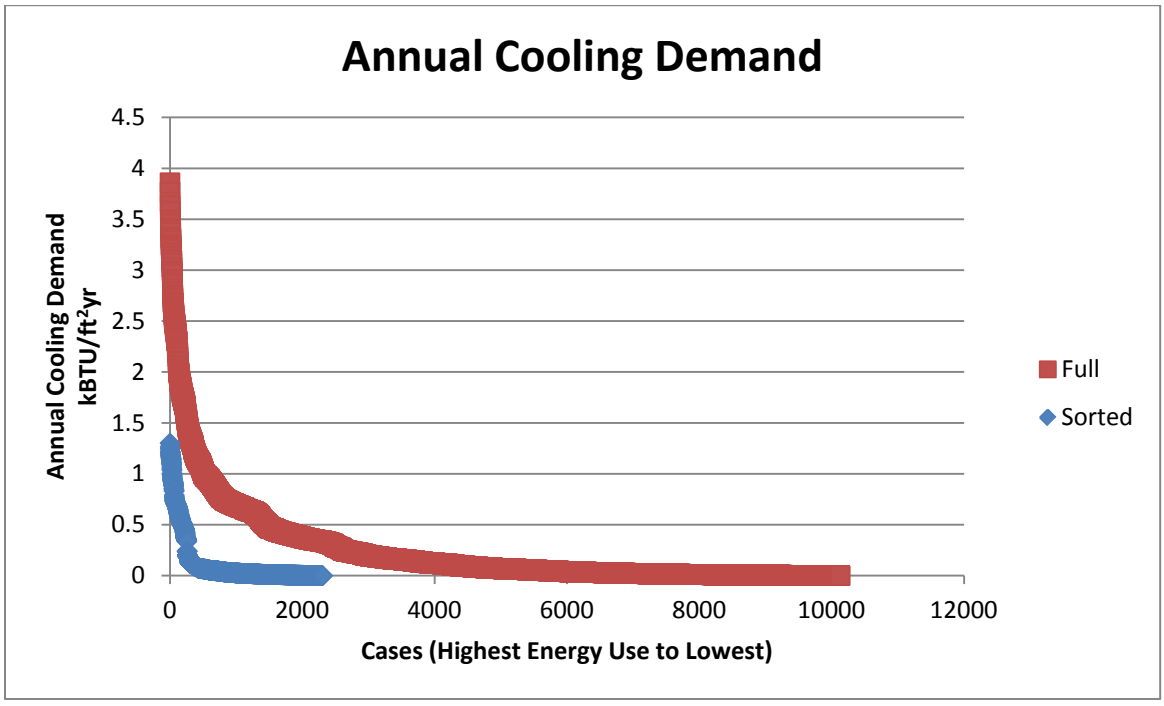


Figure 5.30 - Annual Cooling Demand - San Francisco, CA

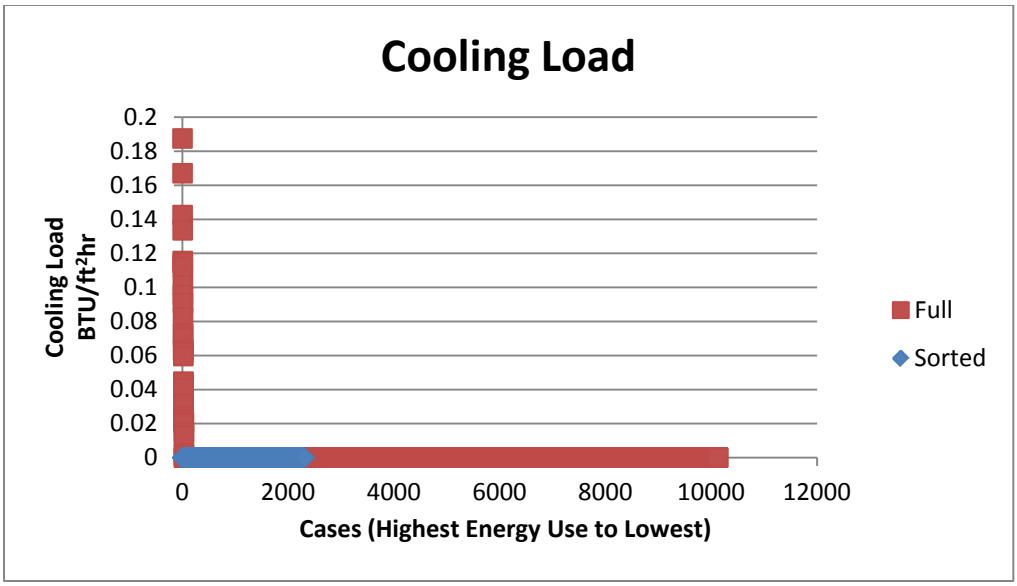


Figure 5.31 - Cooling Load - San Francisco, CA

Seattle, WA

The Seattle cases were filtered for the wall and roof R-Value and the slab R-Value as well as R-3 windows. For the first time during the sorting, the SHGC was not filtered because the IECC requirements do not specify a given maximum or minimum SHGC for this climate zone. After the filtering, there were 4480 cases left. Seattle is a mild climate where both heating and cooling need to be taken into account, but where the Annual Cooling Demand is rather easy to meet. It is also a climate where the best cases meet the current Passive House Standard's criteria with ease. Unfiltered, the Annual Heating Demand fluctuated between the best case of around .129 kBTU/hr*ft^2 to the worst case of 27.1 kBTU/hr*ft^2 with an average of 6.56 kBTU/hr*ft^2. Filtered, the Annual Heating Demand fluctuated between the best case of around 0.13 kBTU/hr*ft^2 to the worst case of 25.8 kBTU/hr*ft^2 with an average of 3.4 kBTU/hr*ft^2. Unfiltered, the Annual Cooling Demand fluctuated between the best case of around 0.0 kBTU/hr*ft^2 to the worst case of 2.9 kBTU/hr*ft^2 with an average of 0.25 kBTU/hr*ft^2. Filtered,

the Annual Cooling Demand fluctuated between the best case of around 0.0 kBTU/hr*ft^2 to the worst case of 1.1 kBTU/hr*ft^2 with an average of .18 kBTU/hr*ft^2.

For heating, the best cases were those with extremely high levels of insulation, a high SHGC, and high glazing percentages. This is the exact combination that works in a heating dominated climate to reduce the amount of heating energy needed by generating a large amount and losing very little. Similarly, the worst cases were those with the least insulation and the lowest SHGC. The glazing percentage was less important. The best cases for cooling were those that were highly insulated, but that had low SHGC's and very low glazing percentages. The worst cooling cases were those that had high glazing percentages and high SHGC's, while also being highly insulated. These results were similar to San Francisco and the same slab insulation phenomenon exists, which points to increased slab insulation. With further analysis, it can be shown that the amount of slab insulation and its impact on the building were very minor and in this climate there was not a strong reason or change between different slab insulation values for cooling.

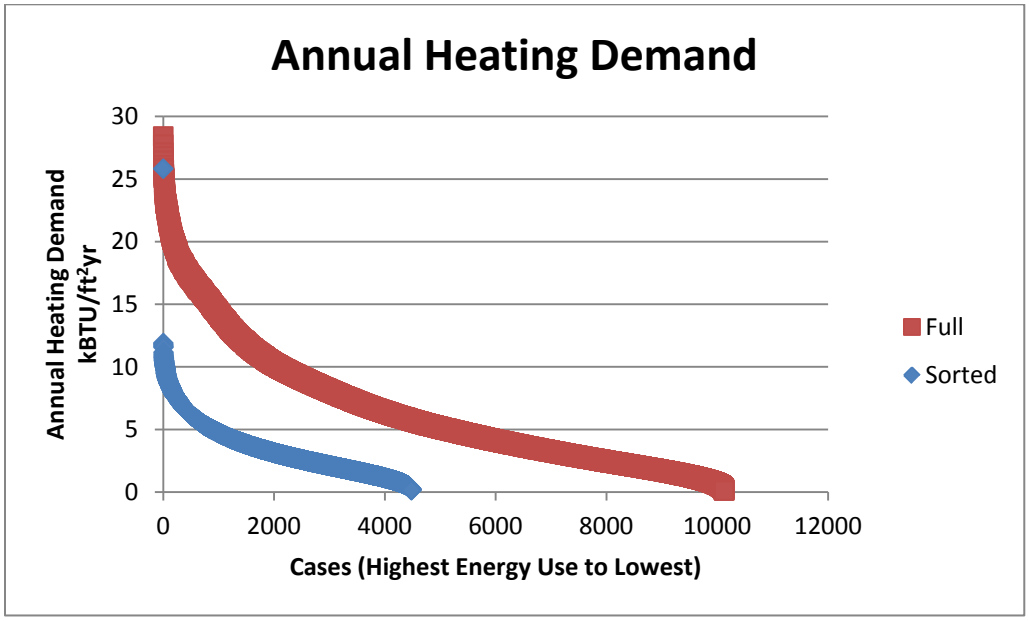


Figure 5.32 - Annual Heating Demand - Seattle, WA

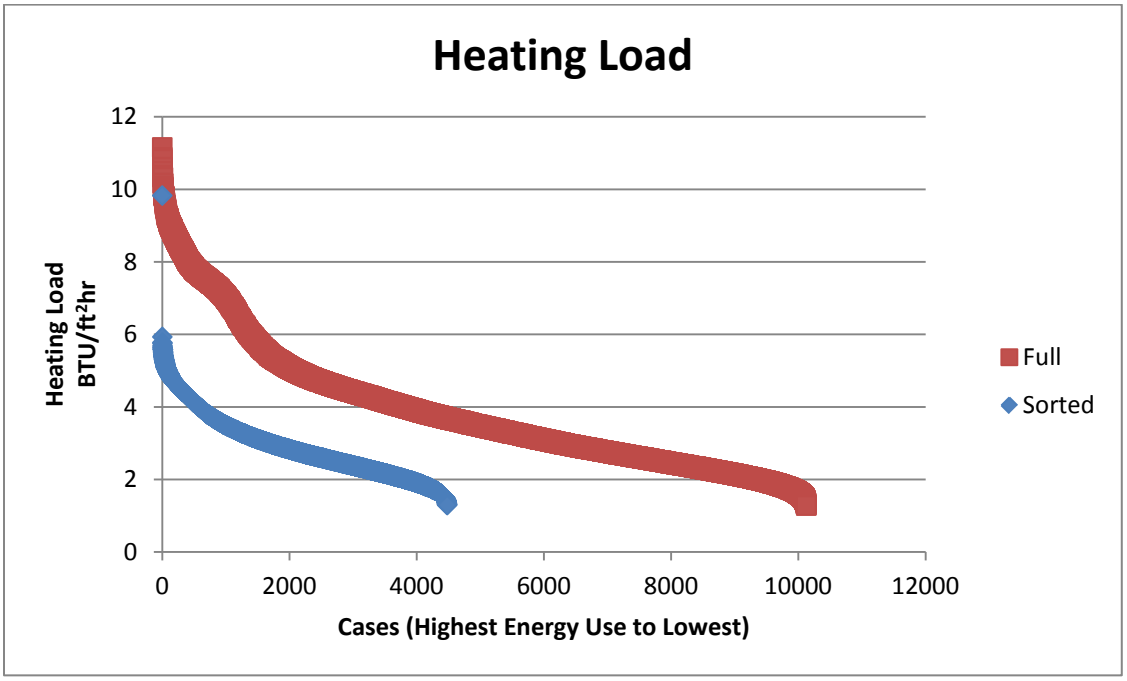


Figure 5.33 - Heating Load - Seattle, WA

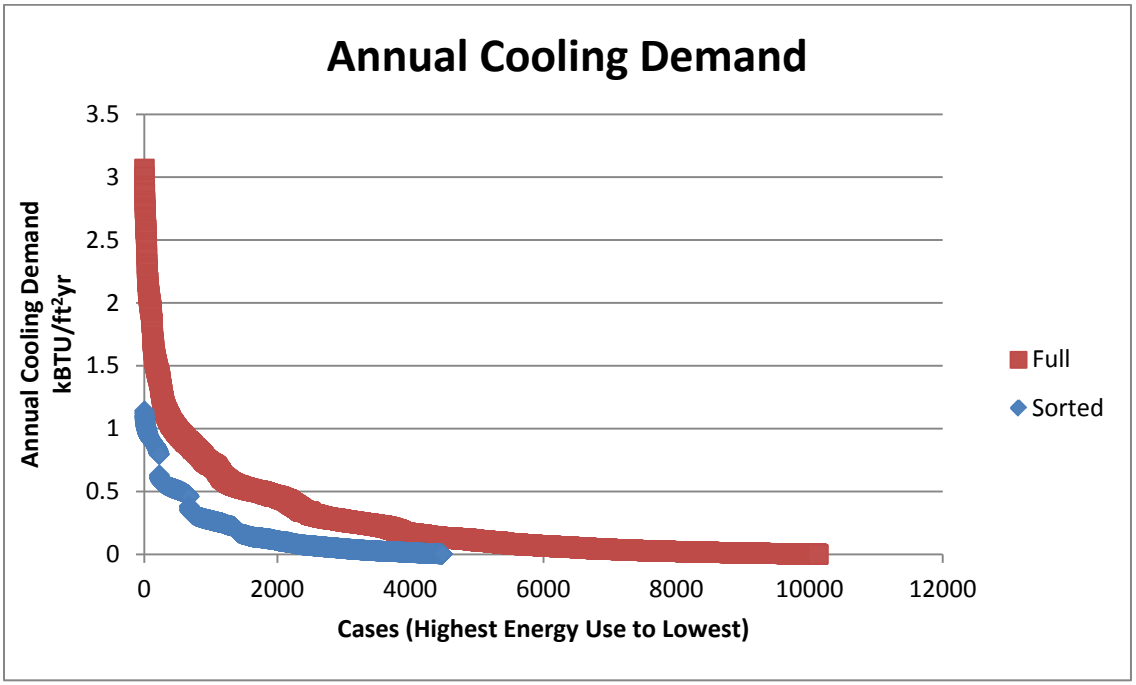


Figure 5.34 - Annual Cooling Demand - Seattle, WA

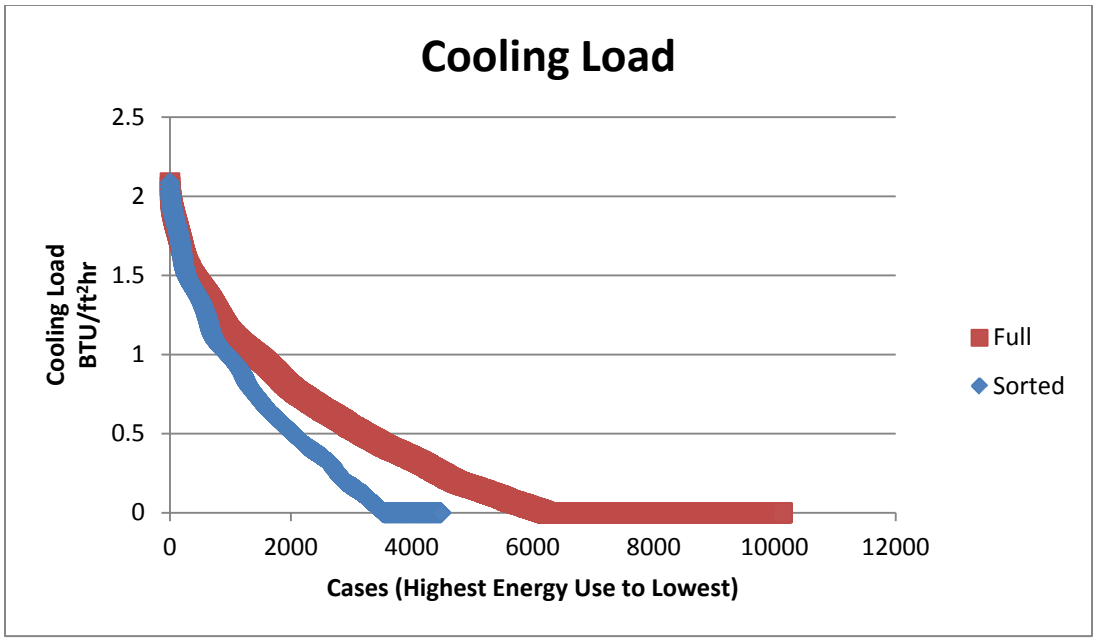


Figure 5.35 - Cooling Load - Seattle, WA

Chicago, IL

The cases for Chicago were filtered for the wall, roof and slab R-Values as well as R-3 and R-5 windows. After the filtering, there were 2940 cases left. Chicago is the first climate that is strongly heating dominated. It is a climate where the best cases meet the current passive house criteria, but the worst cases fail by a wide margin under the Annual Heating Demand. Cooling is generally utilized, but its use is minimal and it is fairly easy to meet the certification criteria for cooling. Unfiltered, the Annual Heating Demand fluctuated between the best case of around 0.1 kBTU/hr*ft^2 to the worst case of 40.4 kBTU/hr*ft^2 with an average of 11.1 kBTU/hr*ft^2. Filtered, the Annual Heating Demand fluctuated between the best case of around 0.13 kBTU/hr*ft^2 to the worst case of 38.5 kBTU/hr*ft^2 with an average of 4.8 kBTU/hr*ft^2. Unfiltered, the Annual Cooling Demand fluctuated between the best case of around 0.03 kBTU/hr*ft^2 to the worst case of 4.3 kBTU/hr*ft^2 with an average of 0.73 kBTU/hr*ft^2. Filtered,

the Annual Cooling Demand fluctuated between the best case of around 0.05 kBTU/hr*ft^2 to the worst case of 2.2 kBTU/hr*ft^2 with an average of 0.62 kBTU/hr*ft^2.

The best cases for heating were products of the very highest insulation levels and window R-Values. The highest SHGC and the largest glazing percentage were also featured in the best cases. The factor that mattered the least was the slab insulation followed by the wall and roof insulation. High glazing percentages and SHGCs were mandatory for the best cases. The worst cases were characterized by low insulation values including the wall, roof, slab, and windows. Cases with low SHGCs were among the worst cases regardless of the glazing percentage. Therefore, to increase performance, if glass is present, it needs to have a high SHGC. For cooling, the best cases were those with high levels of wall and roof insulation and minimal windows with very low SHGCs. The slab R-Values were best at medium levels between R-15 and R20. The R-Value of the window mattered little when compared to the SHGC and glazing percentage. The worst cases were highly glazed buildings with high SHGCs. For cooling, the slab insulation levels seem to matter less, but like the other cases before, low ground insulation values again are present.

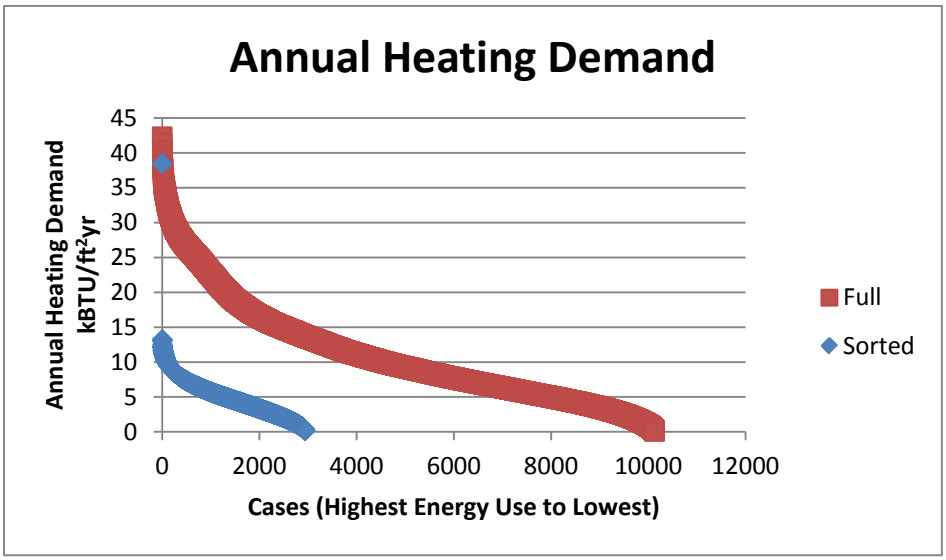


Figure 5.36 - Annual Heating Demand - Chicago, IL

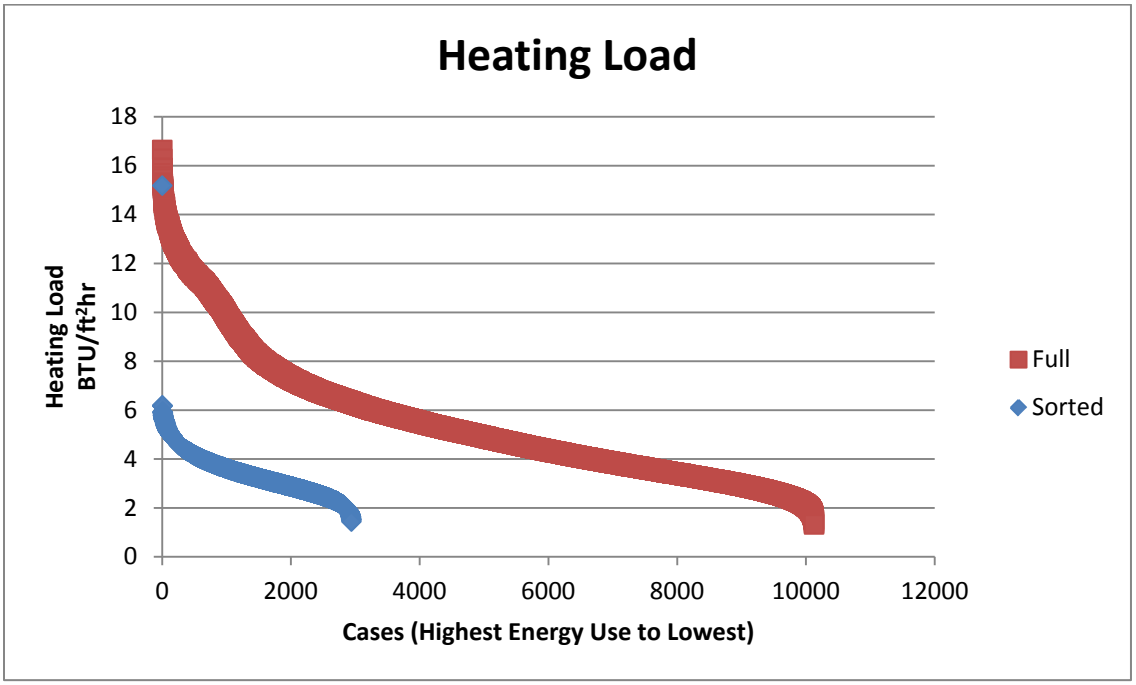


Figure 5.37 - Heating Load - Chicago, IL

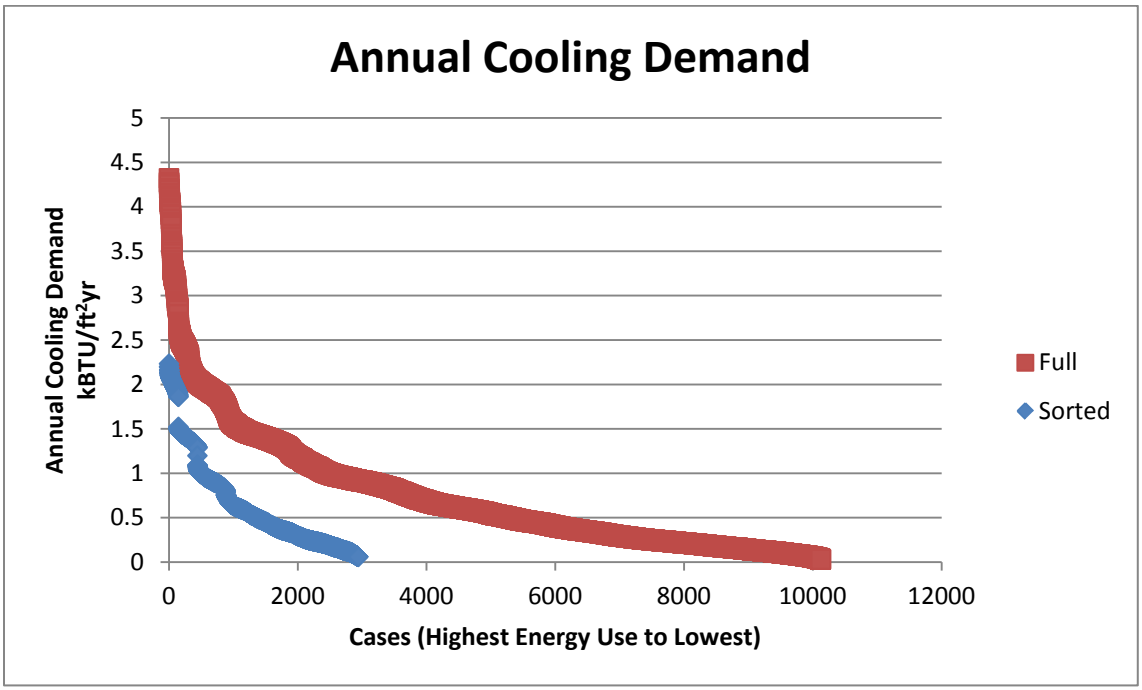


Figure 5.38 - Annual Cooling Demand - Chicago, IL

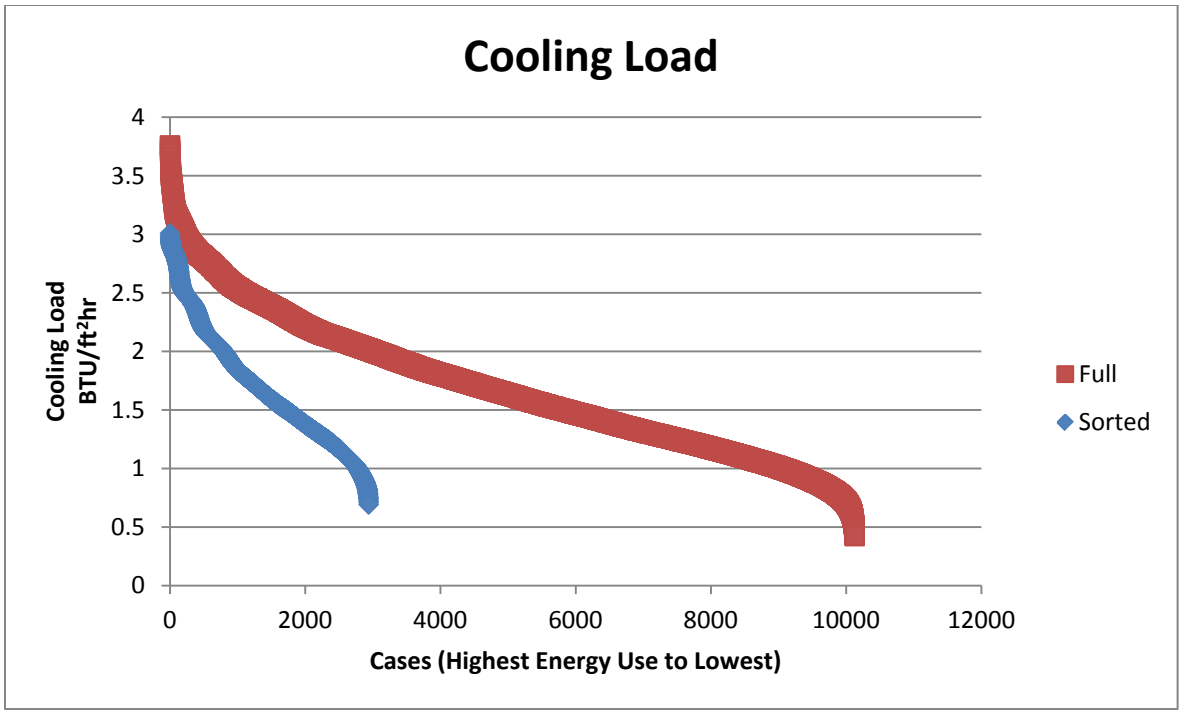


Figure 5.39 - Cooling Load - Chicago, IL

Burlington, VT

The cases for Burlington were filtered for the wall, roof and slab R-Values as well as R-3 windows. After the filtering, there were 3920 cases left. Burlington is a heating dominated climate and a climate where there are existing passive houses. For heating, it is a climate where the best cases meet the current passive house criteria, but the worst cases fail by large margins. It is fairly easy to meet the certification criteria for cooling. Unfiltered, the Annual Heating Demand fluctuated between the best case of around 0.1 kBTU/hr*ft^2 to the worst case of 40.4 kBTU/hr*ft^2 with an average of 11.1 kBTU/hr*ft^2. Filtered, the Annual Heating Demand fluctuated between the best case of around 0.33 kBTU/hr*ft^2 to the worst case of 45.1 kBTU/hr*ft^2 with an average of 6.95 kBTU/hr*ft^2. Unfiltered, the Annual Cooling Demand fluctuated between the best case of around 0.03 kBTU/hr*ft^2 to the worst case of 4.3

kBTU/hr*ft^2 with an average of 0.73 kBTU/hr*ft^2. Filtered, the Annual Cooling Demand fluctuated between the best case of around 0.008 kBTU/hr*ft^2 to the worst case of 1.02 kBTU/hr*ft^2 with an average of 0.21 kBTU/hr*ft^2.

For heating, the best cases were characterized by the highest insulation levels and a high SHGC with high percentages of glazing. The best cases were identical to the best cases in Chicago. The worst cases could be attributed to low levels of insulation, low SHGCs, and high glazing percentages. For cooling, the best cases were highly insulated, except the slab, for which median insulation levels worked the best, and had very low solar heat gains due to a low SHGC and a low glazing percentage. The worst cases were a mix of the extremes of insulation both low and high, but all cases had the highest SHGC and the highest glazing percentage in common.

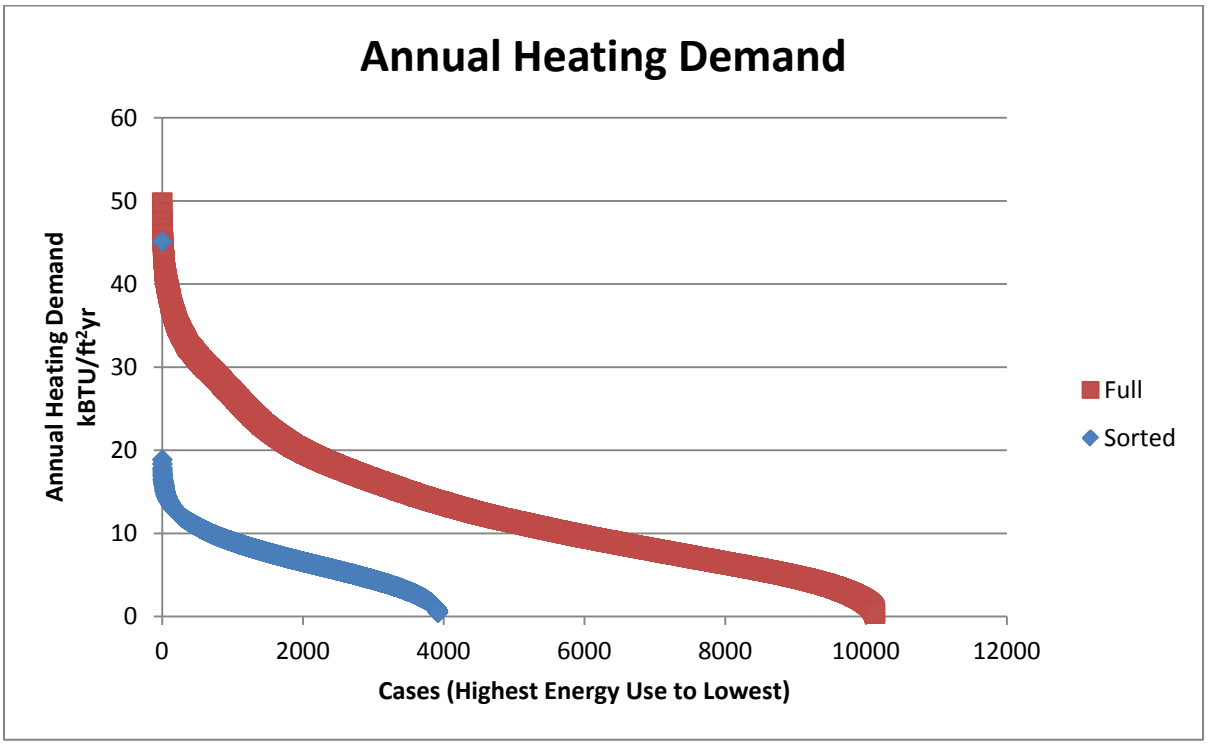


Figure 5.40 - Annual Heating Demand - Burlington, VT

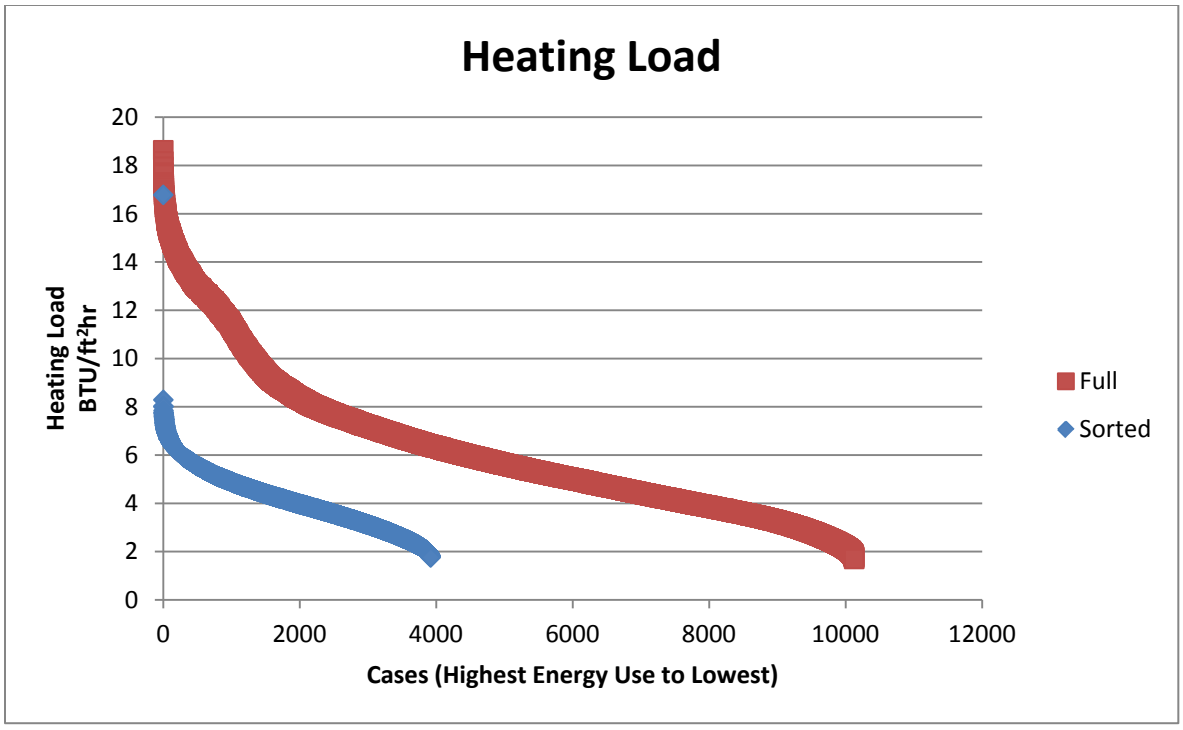


Figure 5.41 - Heating Load - Burlington, VT

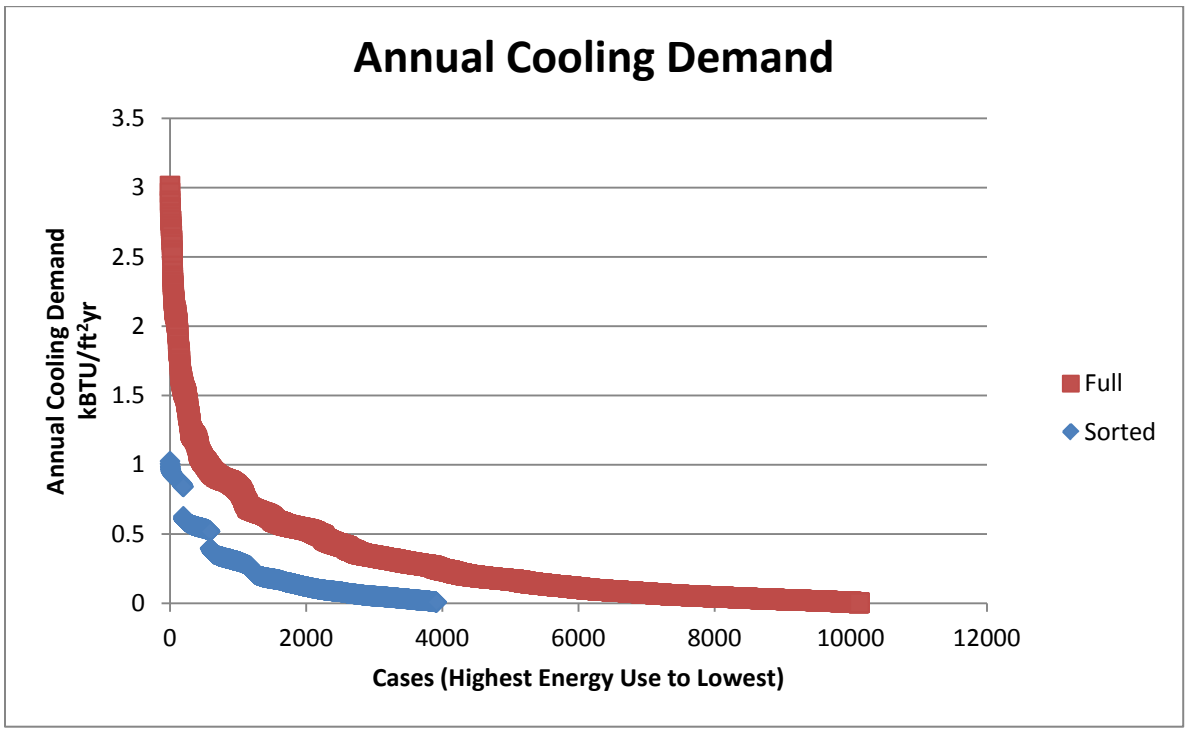


Figure 5.42 - Annual Cooling Demand - Burlington, VT

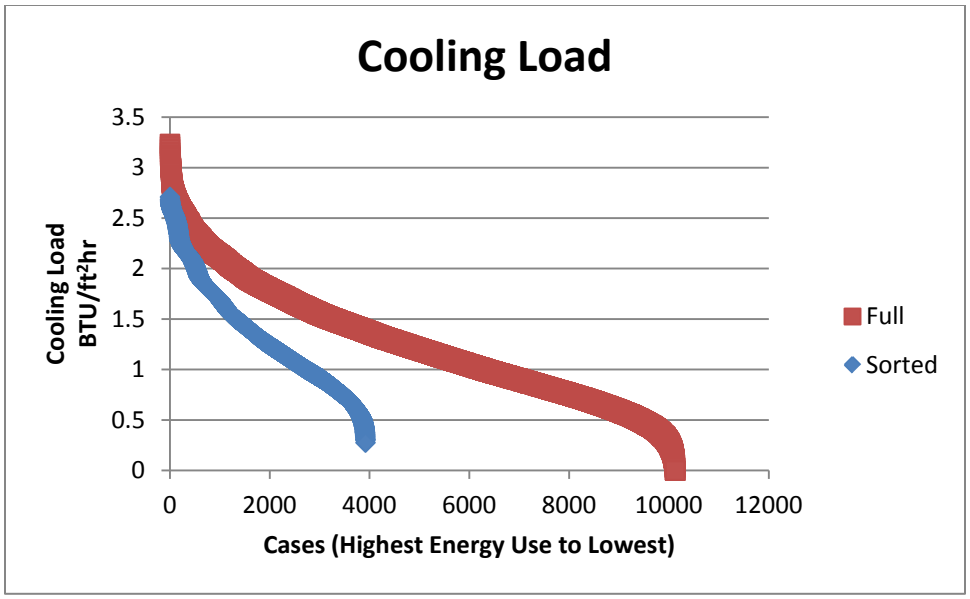


Figure 5.43 - Cooling Load - Burlington, VT

Duluth, MN

The cases for Duluth were filtered for the wall, roof and slab R-Values as well as R-3 and R-5 windows. After the filtering, there were 2940 cases left. Duluth is a heating dominated climate and a climate where cooling is not an issue. For heating, it is a climate where the best cases meet the current passive house criteria, but again, the worst cases fail by large margins. Unfiltered, the Annual Heating Demand fluctuated between the best case of around 0.834 kBTU/hr*ft^2 to the worst case of 63.1 kBTU/hr*ft^2 with an average of 18.8 kBTU/hr*ft^2. Filtered, the Annual Heating Demand fluctuated between the best case of around 0.834 kBTU/hr*ft^2 to the worst case of 59.7 kBTU/hr*ft^2 with an average of 9.21 kBTU/hr*ft^2. Unfiltered, the Annual Cooling Demand fluctuated between the best case of around 0.0 kBTU/hr*ft^2 to the worst case of 1.99 kBTU/hr*ft^2 with an average of 0.13 kBTU/hr*ft^2. Filtered, the Annual Cooling Demand fluctuated between the best case of around 0.0006 kBTU/hr*ft^2 to the worst case of .39 kBTU/hr*ft^2 with an average of 0.062 kBTU/hr*ft^2.

For heating, the best cases were highly insulated, had high SHGCs, and had high glazing percentages. These results were identical to the best cases in both Burlington and Chicago. The worst cases had very low levels of insulation and a low SHGC. The glazing percentage was not a large factor. For cooling, there is not a major difference between any of the cases. Even the worst cases allowed by code are only about one-tenth of the Passive House Standard's maximum energy use.

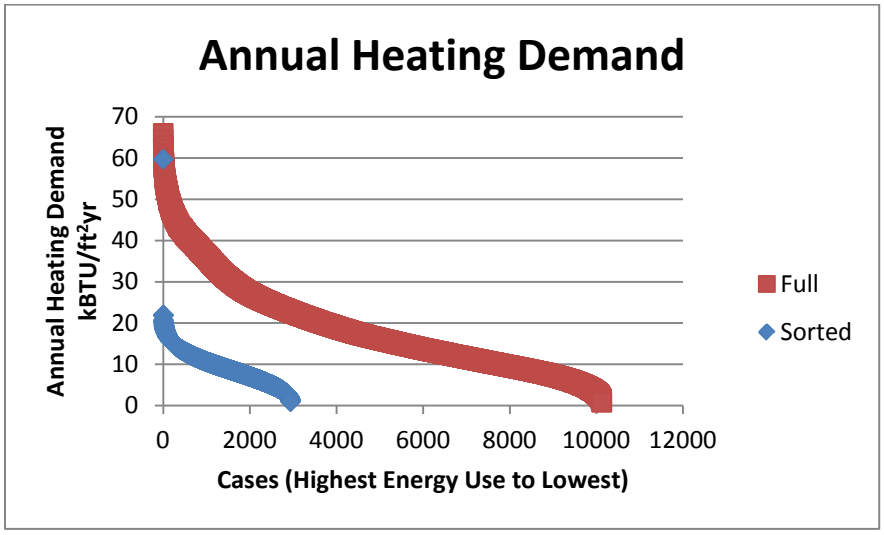


Figure 5.44 - Annual Heating Demand - Duluth, MN

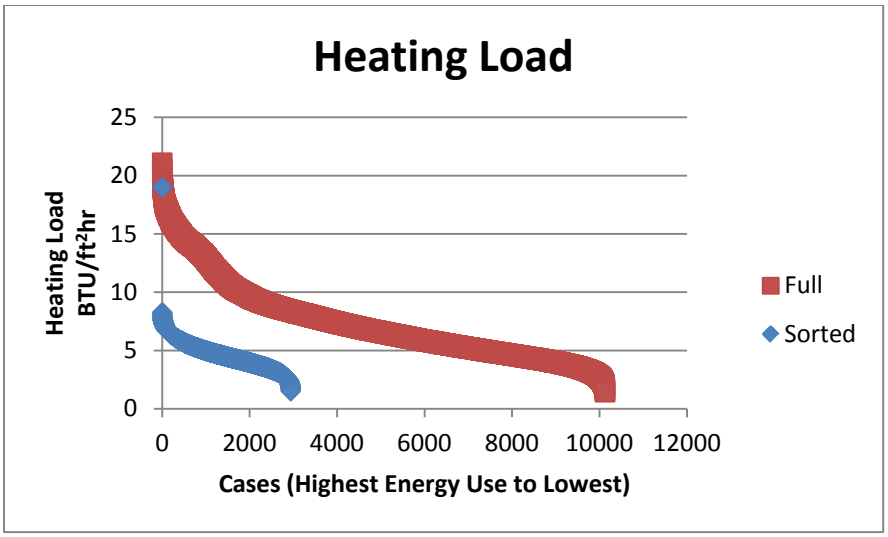


Figure 5.45 - Heating Load - Duluth, MN

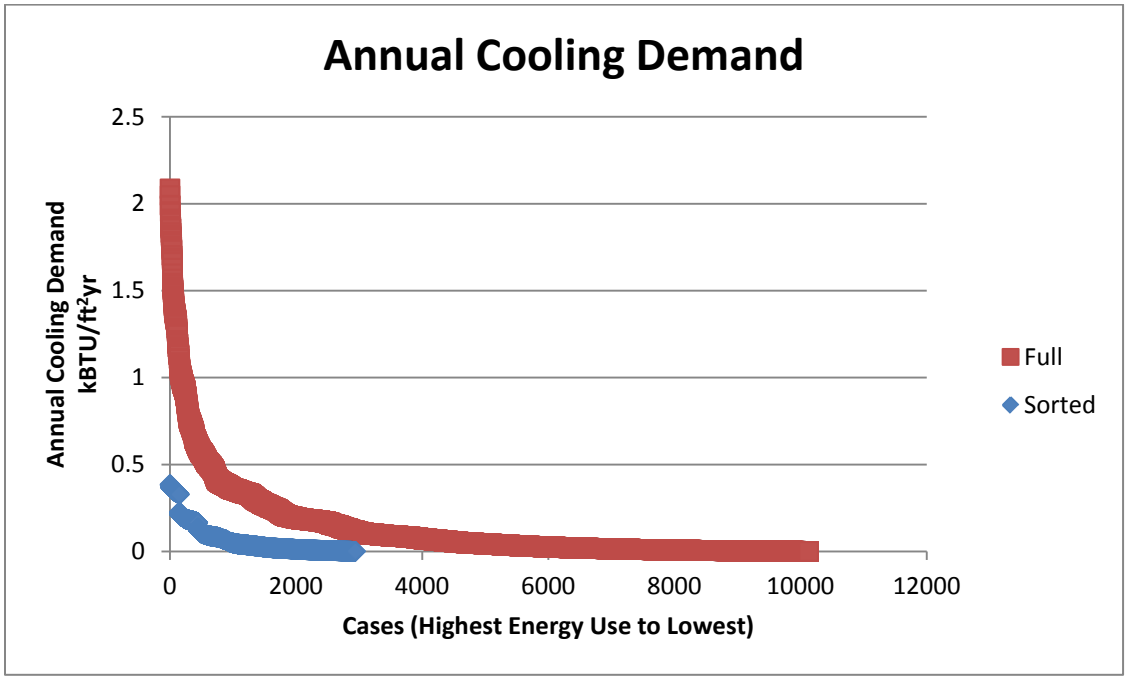


Figure 5.46 - Annual Cooling Demand - Duluth, MN

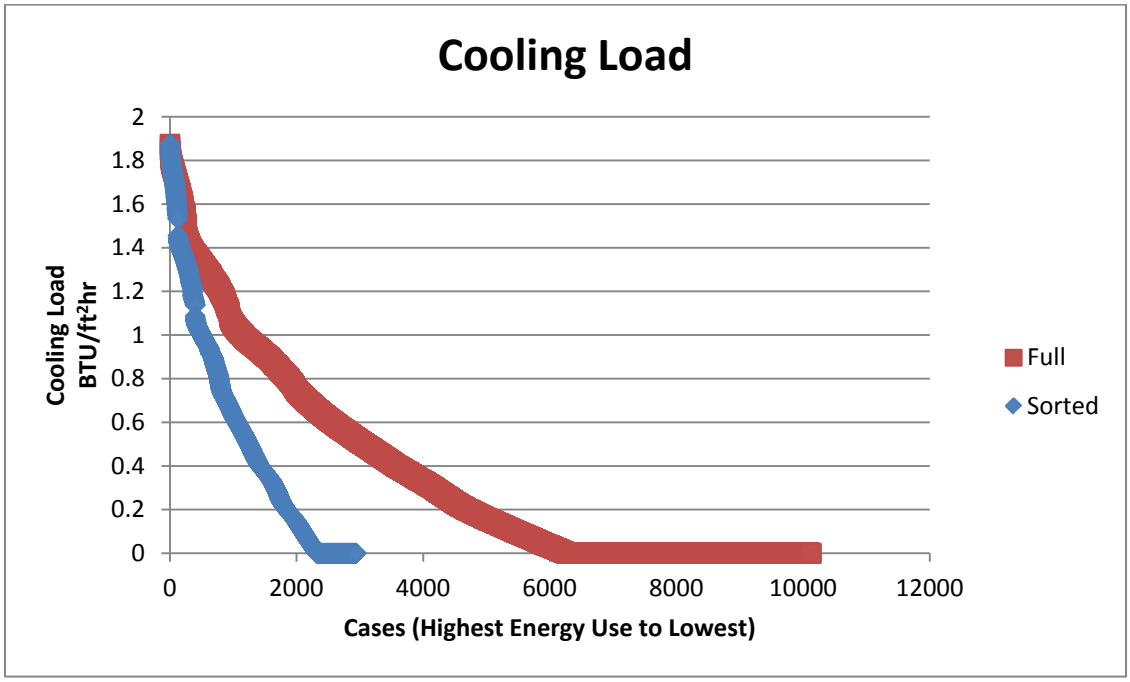


Figure 5.47 - Cooling Load - Duluth, MN

Fairbanks, AK

The cases for Fairbanks were filtered for the wall, roof and slab R-Values. Cases were also screened for R-3, R-5, and R-7 windows. After the filtering, there were 1960 cases left. Fairbanks is a heating dominated climate and a climate where cooling is not an issue. For heating, it is a climate where the best cases cannot meet the current Passive House Standard. This represents a significant difference from the other climate zones, which usually have a case that would meet the criteria. Unfiltered, the Annual Heating Demand fluctuated between the best case of around 9.39 kBTU/hr*ft^2 to the worst case of 94.6 kBTU/hr*ft^2 with an average of 32.0 kBTU/hr*ft^2. Filtered, the Annual Heating Demand fluctuated between the best case of around 9.39 kBTU/hr*ft^2 to the worst case of 86.86 kBTU/hr*ft^2 with an average of 18.1 kBTU/hr*ft^2. Unfiltered, the Annual Cooling Demand fluctuated between the best case of around 0.0 kBTU/hr*ft^2 to the worst case of 1.82 kBTU/hr*ft^2 with an average of 0.10 kBTU/hr*ft^2. Filtered, the Annual Cooling Demand fluctuated between the best case of around 0.0 kBTU/hr*ft^2 to the worst case of .35 kBTU/hr*ft^2 with an average of 0.042 kBTU/hr*ft^2.

The best cases were once again composed of high insulation values coupled with high SHGC. However, this time, the highest glazing percentage was not the best configuration. Instead, it seemed that the high end of moderate glazing percentages, .25-.45, were most effective. Another way to interpret the data is that the amount of windows did not make much of a difference as long as the other insulation values and the SHGC were at their highest possible levels. The worst cases were characterized by low insulation levels, a low SHGC, and a high glazing percentage. Having a large amount of poorly performing windows was the best way to have very high energy use in Fairbanks.

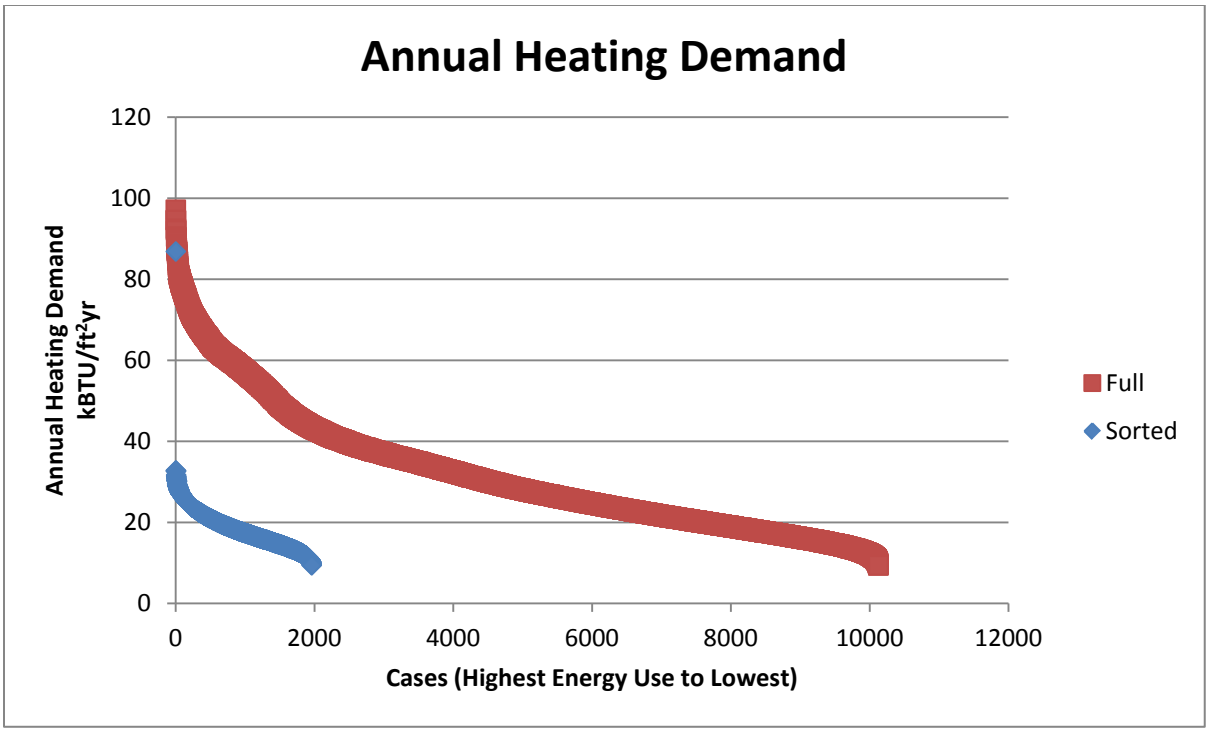


Figure 5.48 - Annual Heating Demand - Fairbanks, AK

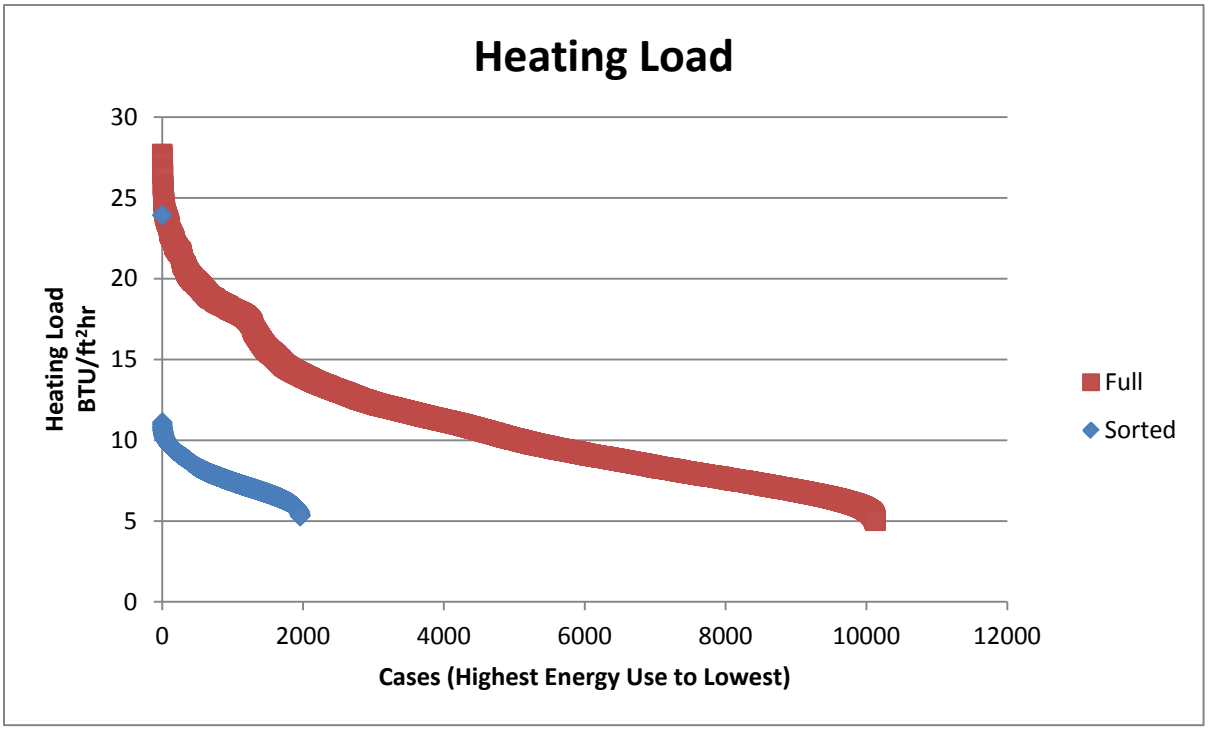


Figure 5.49 - Heating Load - Fairbanks, AK

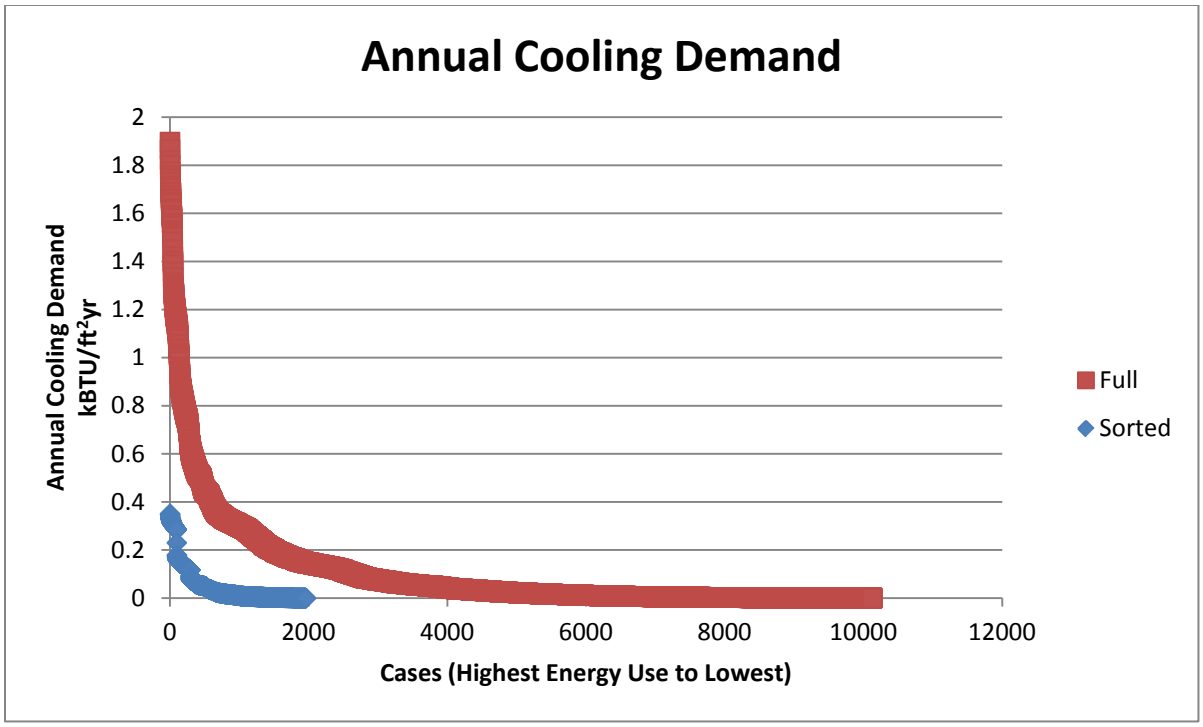


Figure 5.50 - Annual Cooling Demand - Fairbanks, AK

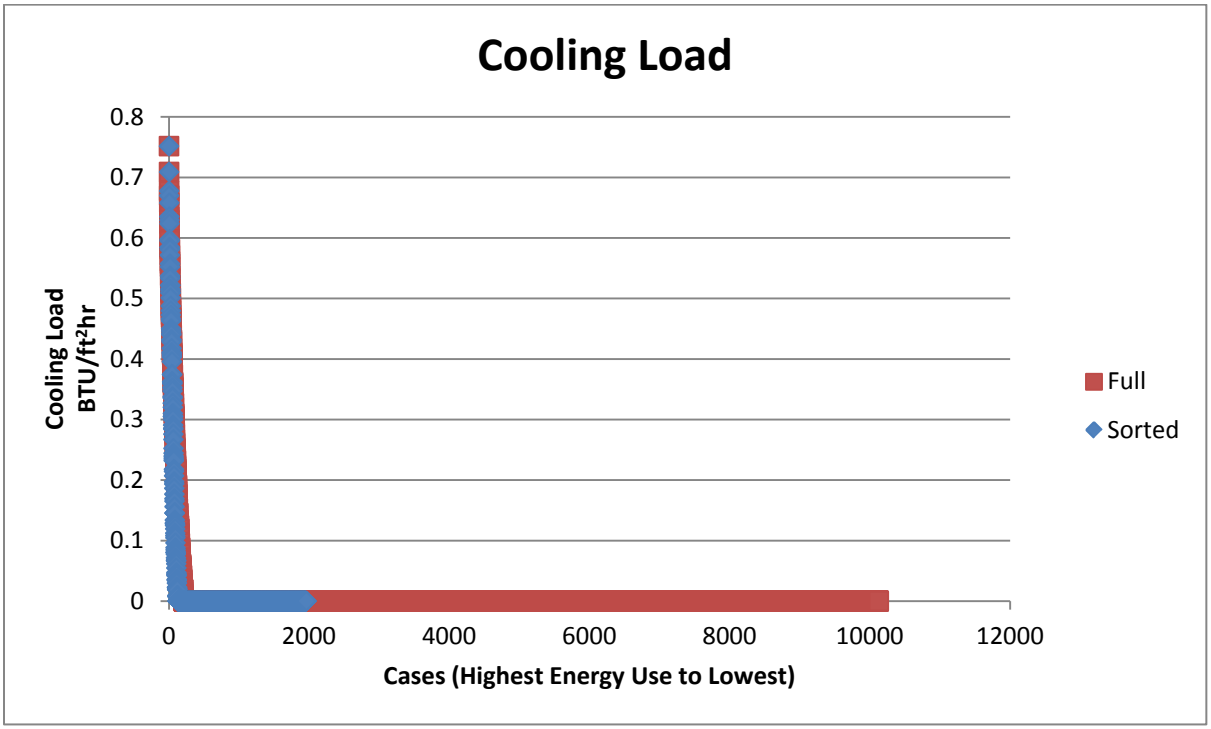


Figure 5.51 - Cooling Load - Fairbanks, AK

This filtered analysis showed that the filtered results performed better than the results that were not filtered. In climates that are heating dominate, such as Fairbanks, many combinations will meet the cooling energy use. The opposite is also true. In Miami, almost all of the case, and all of the filtered cases, meet the Annual Heating Demand and the Heating Load. It is apparent that the filtering process eliminated many of the worst cases, but did not allow the point of optimum envelope investment to be found. In the next chapter, the in-depth analysis by location, shown above, and the raw data analysis, shown in Chapter 4, will be expanded on to draw conclusions from the data and show the effect the findings could have on building design and the Passive House Standard.

Chapter 6

Conclusion

Though previous research has studied the issue of adjusting the Passive House Standard and it's applicability to different climates, this study is the first, that the author is aware of, that has utilized the Passive House Planning Package as its simulation engine. Furthermore, this is the first stud that specifically addresses locations in the United States using the PHPP. Certain findings were remarkable and surprising, while others were expected. These expectations followed from conventional building science and the author's previous experience with passive house and the PHPP. The results show both large-scale trends, which can lead policy changes for the adaption of the Passive House Standard for widespread applicability, and specific examples, such as the effect a given low energy building strategy can have in a particular climate. This chapter will discuss both the major trends and the interrelated effects the independent variables had on various climate conditions.

One of the most interesting findings that can be seen is the range of energy use values given for all climates. The most striking aspect of this finding is that in the majority of climates, meeting the standard is achievable. Meeting the Annual Cooling Demand seems to be the easiest criteria to meet followed by the Annual Heating Demand and Heating Load. The locations where meeting the standard is difficult or impossible are primarily narrow regions that are generally limited to climates far to the North, such as inland areas of Alaska, where temperatures plummet solar gain is limited, and the moderating effect of the ocean does not have an impact. The other region where it is difficult to meet the standard is near the southern most points in the United States where internal heat gains become difficult to overcome because they cause a constant

cooling load. The South in particular would have an even more difficult time meeting the standard if latent energy were accurately accounted for by the PHPP in this simulation.

As mentioned throughout the thesis, the functional definition of passive house relies on the building's ability to transport the entire Heating Load through the low flow ventilation system. It was shown that for this transport to be possible, the Heating Load must be limited to 3.17 BTU/ft^{2}hr. In central Europe, limiting the Heating Load so that it was transportable by the supply air ventilation system led to an equivalent Annual Heating Demand of 4.75 kBTU/ft^{2}yr. One of the expected results that is worth repeating is that the relationship between the Annual Heat Demand and the Heating Load is not linear nor constant. It is also readily apparent that the relationship between the two does not hold in all locations and that the relationship is extremely complex and relies on climate factors as well as many facets of the building's design. Because of this, it is very difficult to predict in a give climate that a given Heating Load will result in a certain Annual Heating Demand. Therefore, the Passive House Standard's criteria for the Annual Heating Demand being set based on a Heating Load to Annual Heating Demand relationship in one location, Germany, does not work well and at a minimum should be studied further.

In the United States, the Annual Heating Demand can be met in many locations, but the Heating Load required to meet the functional definition is more difficult to achieve. Based on the results from Chapter 4, the Heating Load can still be met in many locations, but the envelope investment to ensure this may be too high. In this study, the Heating Load results seem to be slightly more favorable toward meeting the Passive House Standard than the current built projects are finding. The windows, as discussed later in this chapter, have a large impact on energy use for space conditioning. The window values in the study favored high window R-Values and modest glazing areas. Both of these are favorable for energy use and are in contrast

to the typical window, which has a lower R-Value due to being lower cost, and typical contemporary design aesthetics, which tend towards large glazing area. This is also a reminder that real world phenomena can transcend the ability of such a limited, "broad brush" simulation to accurately portray real world results in every instance.

Both Chapters 4 and 5 presented graphs and data results that showed the effect of the various climate data characteristics on the energy use which is represented by the dependent variables. The effect of the independent variables, which were measures of envelope investment, on energy use was also presented. The Annual Heating Demand has a strong correlation with temperature for locations that require heating. However, there are many climate characteristics that do not have strong correlations. The amount of radiation influenced the results for all four criteria only minimally, which was an unexpected result. By filtering the data, it was apparent that the SHGC, which controls the amount of radiation allowed into the building, was an important factor and had a large effect on the energy use. However, radiation alone, without the control of temperature or other factors was only weakly correlated with energy use and in some cases, no correlation could be discerned.

The trends exhibited by the Annual Heating Demand for both temperature and radiation were similar to those of the Annual Cooling Demand. Temperature influenced cooling in a significant and predictable way while radiation had a lesser effect. Because the difference in temperatures, and to a lesser extent radiation values, between the inside and outside in the summer are not as large as they are in the winter. The overall distribution of points shows that a small increase in temperature or radiation has a proportionally larger effect on the Annual Cooling Demand and Cooling Load compared to the effect of the same small difference in temperature or radiation on the Annual Heating Demand and Heating Load.

Elevation, Longitude, and Latitude pinpoint an exact location on Earth. The effect of these on the energy use was unexpected. For instance, it is generally understood that as elevation increases, the temperature decreases and therefore, the heating energy needed also should increase. The data shows that no such effect existed on its own due to sea level locations in Alaska being much colder, therefore requiring more heating energy, than higher elevation locations in the Appalachian, Rocky, and Sierra Nevada Mountains of which large portions of those mountain ranges occur in milder climates such as Tennessee, New Mexico, and California respectively. Similar effects were shown for the cooling conditions. The largest difference was that the cases with the highest Annual Cooling Demand did not occur at high elevations and none of the higher elevation locations had an Annual Cooling Demand.

The belief that the higher latitude results in lower temperatures which in turn results in lower cooling energy use and higher heating energy use was confirmed by the analysis. In fact, the correlation between the latitude and the various Passive House Standard criteria was similar to the correlation between the temperature and the criteria. On the other hand, longitude had no correlation with energy use. This is to be expected, but it is an interesting result because the further west a location is in the United States, the more likely it is to have higher radiation values.

The values of the variables themselves also had impacts on the energy use as shown by the filtered results. In virtually all of the climates analyzed, increasing the R-Value of the wall and roof led to lower energy use for both heating and cooling. There are some unique circumstances where this does not occur. For instance, in a mild climate increasing the insulation could decrease heating energy use while increasing the cooling energy use. This is especially true in the cooling season, if the internal or solar gains are high and the outside temperature is

mild and cools significantly a night. In this case, the increased insulation is preventing the heat loss that previously dissipated the high heat gains. The R-Value of the window shows similar effects to the wall and roof. Generally as the R-Value increases, the energy use decreases. It is important to reiterate that increasing the R-Value is most effective when it is first added and less effective the higher it gets. This is no different with windows. However, because assembly insulation values can be increased above R-100 and window values are difficult to raise above R-11, the diminishing returns have a much larger impact on assemblies than they do on windows.

Both the Solar Heat Gain Coefficient of the window and the glazing percentage of the building have significant effects on a buildings energy use. In a superinsulated building, a window is, for all intents and purposes, a "hole" in the building envelope. Even the best windows insulate only 20-30% as well as the average passive house wall and roof. Because of this, windows are very important. When the glazing percentage is very high, energy losses are increased due to replacing a high R-Value wall with a low R-Value window. At the same time, the gains are increased because the glass area is larger. The increased gains and increased losses can balance the heat loss equation, or even work to lower the Annual Heating Demand. While this strategy is often employed in the United States, due to the relatively high radiation values compared to central Europe, it has drawbacks. The first is that the Heating Load often increases because in the worst-case condition, the losses outweigh the gains. The second is that this strategy effects the temperature swing so that the house is overly reliant on gains to raise the temperature during the day to offset the extra losses at night, which can have an impact on thermal comfort. Another major consideration is the cooling condition. In the summer, both the excess losses, which are now also gains because of the high outdoor temperature, and the heat

gains, which can be difficult to shade fully, now work in tandem to create a very high Annual Cooling Demand.

Like the glazing percentage, the window SHGC has similar influences without the need to change the window size. This fact is very important for a designer to remember, as changes do not require redesigning the building. Instead the glass package can be adjusted to tune the building based on a specific set of conditions. The SHGC values that are most effective are climate specific. In climates where only heating occurs, the best performing cases were the cases with the high solar heat gain coefficients. In climates where only cooling occurs, the best performing cases had the lowest solar heat gain coefficients. However, in climates where both heating and cooling are necessary, the decision becomes more difficult. In the majority of cases, the best strategy is using a high SHGC in the window, but to provide a superb shading solution to limit excess gain in the summer while allowing the maximum gain in the winter. There are also locations where using a median SHGC works well for both heating and cooling in mild climates. One commonly used strategy for glazing is tuning the window based on the building's orientation. Tuning is a method where the R-Value and SHGC of a window is varied based on orientation. For instance, a typical design will use low SHGC's on the East, West, and North and high SHGC's on the South. This was not simulated here, but could be a method to further reduce energy use.

One specific factor that must be emphasized is the large impact windows have on the energy use within a building. Using a R-11 window with a .6 SHGC allows many cold climate projects to meet the Passive House Standard that otherwise would not. When compared to the windows readily available and commonly used in the United States, due to construction cost restraints, this type of window represents a significant improvement. In fact, this window is

slightly better than the most efficient window on the commercial market. Additionally, modern design aesthetics, which trend towards large glazed openings are also in conflict with the studies findings. Based on the findings of this study, it can be reasoned that once technological advances allow windows with R-Values above ~R-15 to be commercially available at an economic price, meeting Passive House Standard would be achievable in all but the most extreme climates in the world. The conclusion reached when filtering the results is that the development of an affordable high R-Value window would be the most effective use of research resources on any type of building envelope research with regard to energy efficiency.

Complex interactions occur as shown by the fact that increasing certain values can increase some energy use in some areas while decreasing it in others. For example, increasing the wall/roof R-Value may help both the Annual Heating Demand and Annual Cooling Demand. In contrast, increasing the Solar Heat Gain Coefficient may lower the Annual Heat Demand, due to extra internal gains, but raise the Annual Cooling Demand for the same reason. Slab insulation is even more unpredictable in both the real world and in simulations. The energy lost through the slab relies on many factors including local soil type and conditions, lag effect between ambient and ground temperature, the building design, and other complex interactions that occur between the bottom of the slab and the ground. Increasing slab insulation can lower the Annual Heating Demand and reduce the Annual Cooling Demand, but since the ground is generally more moderate than the ambient temperature, this is not always the case. In some cases, increasing the slab insulation still reduces the Annual Heating Demand, but will increase the Annual Cooling Demand because heat loss to the cool ground is reduced. In some very hot climates, with high temperatures swings, increasing the slab insulation could actually raise the Annual Heating Demand instead of lowering it. In this case, the Annual Cooling Demand is often decreased

because the ground temperature is higher than the interior temperature. By analyzing the data, these trends and their complexities can be found for any location, even though the in-depth, filtered analysis was completed for only eight representative locations.

The figures below show the summarized results for the eight locations analyzed in Chapter 5. In Figures 6.1 - 6.8, the energy use values per climate characteristic for both the filtered and unfiltered cases are shown. For each case, the maximum value, the minimum value and the average value are plotted. Of the two identical locations on the x-axis, the unfiltered values have the highest maximum energy use while the lower of the two maximum energy uses for each climate location. By analyzing each pair, the effect of the filtering can be more easily seen. Overall trends based on climate can also be visualized based on the following figures. Generally, the trends seen in the demand graphs are also seen in the load graphs. This is especially true for heating. However, for cooling, it is far less predictable. In fact, the loads for cooling demonstrate a dip for San Francisco and Seattle. This is due to their mild climates. Even though the climate in Duluth is also cooler, the temperature swing to the summer high creates potential for higher cooling loads that do not occur in the climates moderated by the ocean and heavier cloud cover.

The comparison between the filtered and unfiltered results as seen in Figures 6.1-6.4 generally follows a trend where the filtering has removed the worst cases and therefore lowered the energy use of the average cases as well. This is because the lowest insulated cases were below the code levels in all climates. Due to the difficulty in determining the point at which envelope investment is not longer optimal, in almost all cases, the case with the minimum energy use was not affected by the filtering process. It is also worth noting the shape of the distributions and the trends correspond to the trends seen throughout Chapters 4 and 5. For instance, the

colder the climate is the higher the heating energy use and the warmer the climate is the higher the cooling energy use. Mild climates such as San Francisco have low energy use for all types of space conditioning. Because of this, the mild climates were less influenced less by filtering. The climates where extremes exist were influenced the most by the filtering process. Again, filtered or not, the best cases in all climates, except Fairbanks for heating and Miami for cooling, are able to meet the Passive House Standard's criteria.

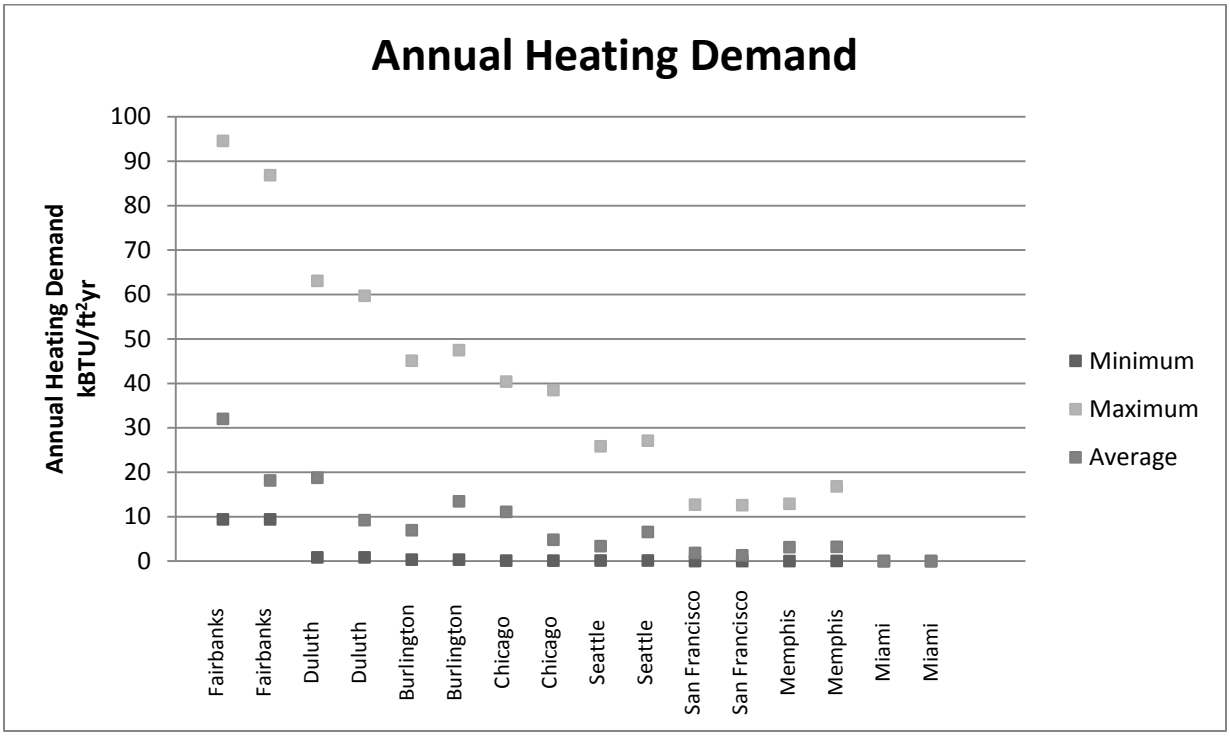


Figure 6.1 - Annual Heating Demand

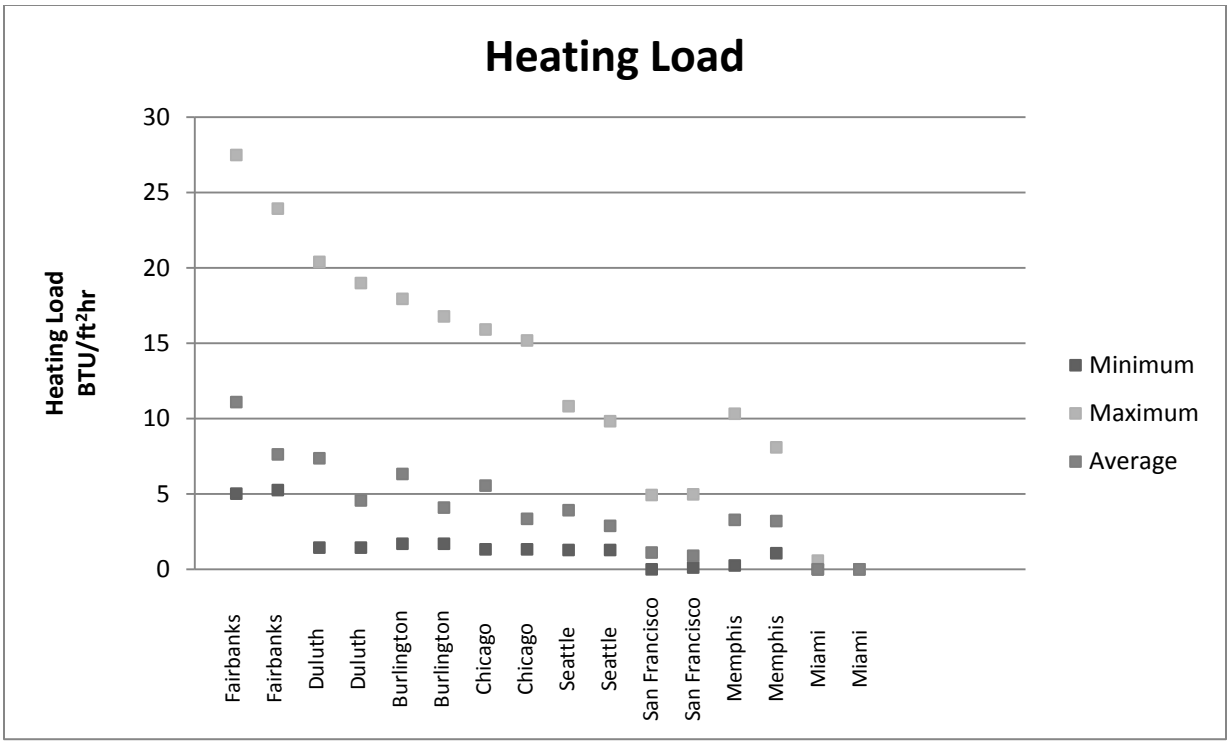


Figure 6.2 - Heating Load

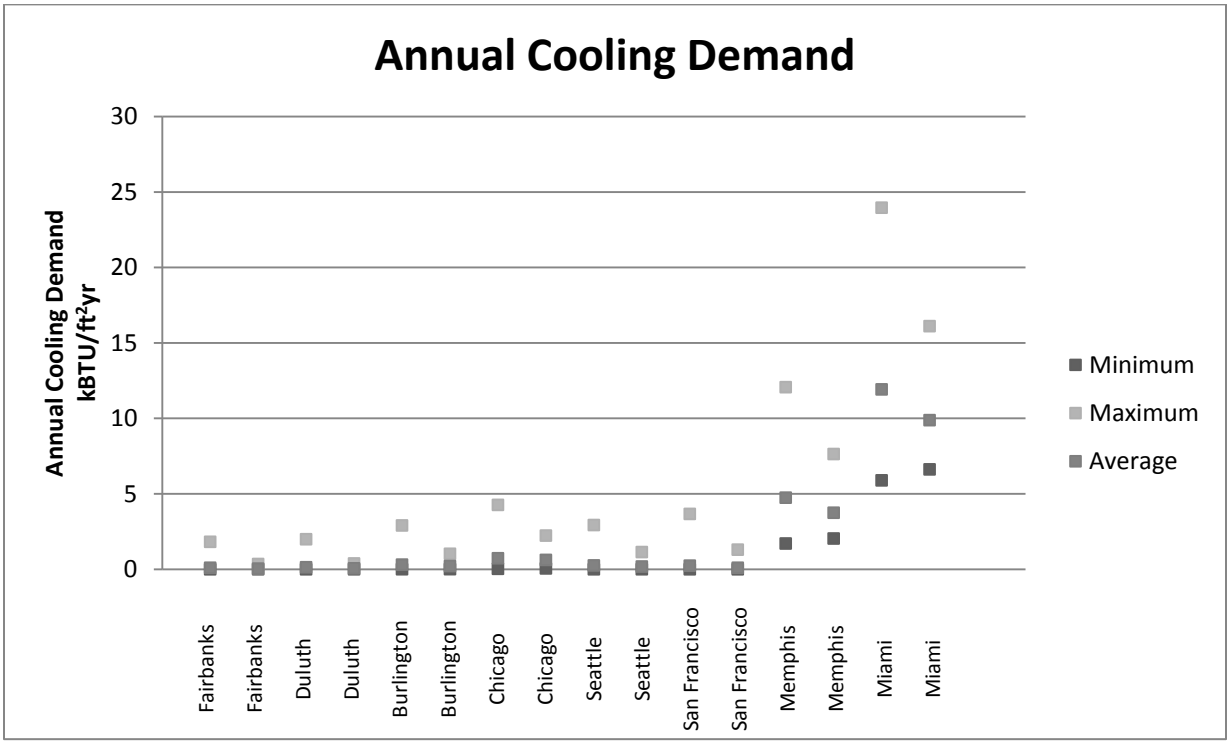


Figure 6.3 - Annual Cooling Demand

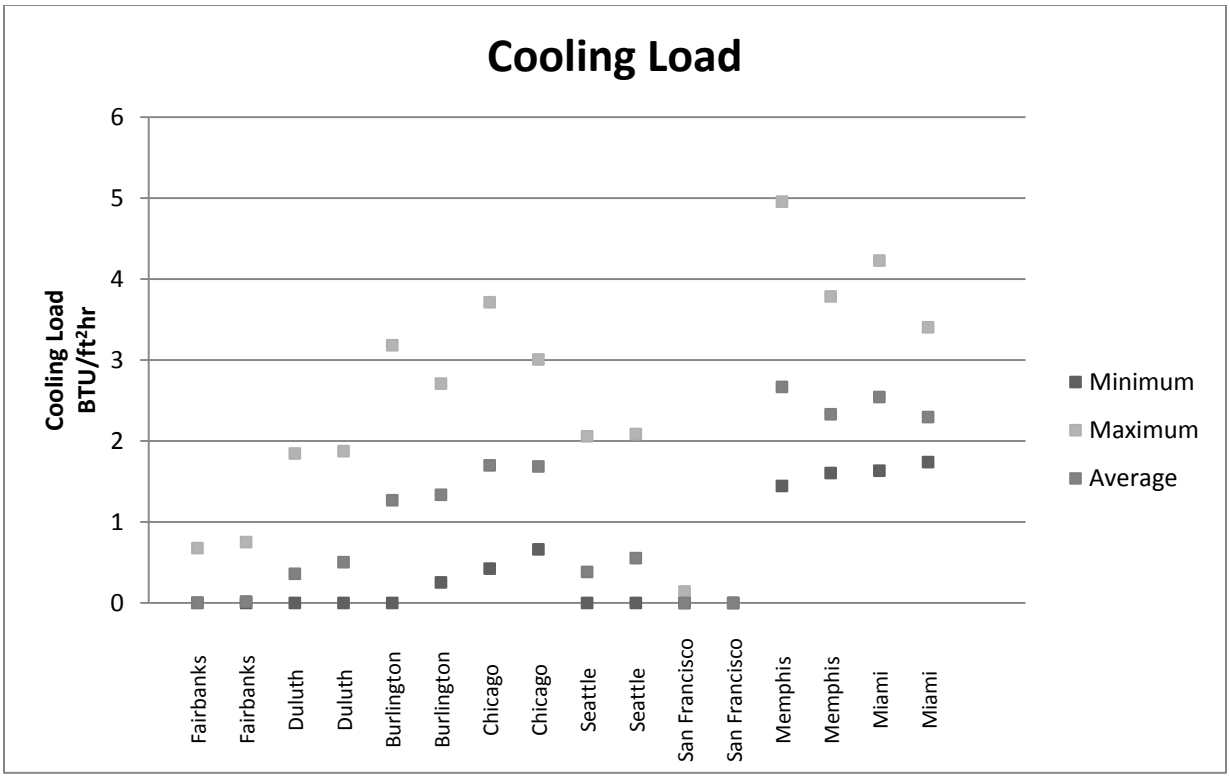


Figure 6.4 - Cooling Load

Figures 6.5 to 6.8, below, show the same eight climates, but this time show only the results after the sorting by the factors above took place. The overall trends and the shape of the lines look similar to the unfiltered results shown throughout the thesis and in the Appendix E, but the sorting removed many of the poorly performing cases. This should have left the shape of the curve with only two slopes in many cases instead of the most common three slope curve that occurred in the unsorted results. However, the movement at the extremes still existed even with the extremely poor performers removed. This shows that the sorting did not remove enough of the poor cases to get to a point where increases in performance are marginally more difficult to achieve. Instead, there was still significant room for improvement that was easily attainable by using techniques with a high marginal benefit.

The Annual Heating Demand in Figure 6.5 shows a distribution of the filtered cases for each climate location analyzed. All climates, except Fairbanks, can meet the Annual Heating Demand by using the strategies employed by the simulation. In fact, the best performing cases in each climate location only use half of the allotted amount of heating energy over the course of a year. The cases that appear on the graph were those that were not filtered. This means that they were found to meet code requirements and maintain the comfort criteria. However, the worst performing cases, except for Miami, which did not have an Annual Heating Demand, had much higher Annual Heating Demands than the Passive House Standard allows. Therefore, comfort and code requirements alone do not provide enough justification for setting new passive house criteria. Despite this, in most climate locations, there are over 1000 combinations of envelope investment that meet the current criteria, which means that the current Passive House Standard may be a realistic goal in much of the United States while being clearly unachievable in the extreme climates.

For the filtered cases, there is also a relationship between the Annual Heating Demand and the Heating Load. Large temperature differences and lower solar radiation during the heating period drive the Heating Load calculation. The overall shape of the curve is similar between the demand and load graphs when analyzing the heating energy use. As mentioned earlier in the chapter, it is generally marginally more difficult to meet the Heating Load than the Annual Heating Demand. However, the results show that every location is able to meet the Heating Load with the best cases and, like the Annual Heating Demand, the worst cases are much higher than the allowable limit. Again, in Fairbanks, it is impossible to come close to the Heating Load even in the very best case.

The Cooling Load, shown in Figure 6.9, is an interesting metric because the temperature difference during the cooling season is much smaller than in the heating season. In the summer, only a 20-25 degree Fahrenheit difference in temperature occurs compared to a large difference of upwards of 50 degrees Fahrenheit in winter. With a low temperature differential, the load at any given time cannot be very large. This is especially true if solar heat gain has been limited through shading, low SHGC's, or low glazing percentages. Therefore, assuming adequate building design, most locations have a low sensible Cooling Load even if they are considered extremely hot climates. Also, because most of the eight locations studied, get relatively warm during the summer, a Cooling Load exists and all locations exhibit similar values for the Cooling Load.

The comparison between the Annual Cooling Demand and the Cooling Load is similar to that between the Annual Heating Demand and Heating Load in that the relationship is complex, variable, and non linear. While Heating Loads are generally small, some climates, such as Miami and, to a lesser extent, Memphis, have extraordinarily high Annual Heat Demands. The high demand is caused by a low load over a long period of time. Miami has a small load, but since it occurs almost year round, the demand is large. Similarly, Memphis has a summer longer than the other climates analyzed and therefore has the second largest Annual Cooling Demand. Climates that are generally known for shorter summers do not have a problem meeting the Annual Heating Demand and the majority of climates as mentioned above, can meet the Heating Load.

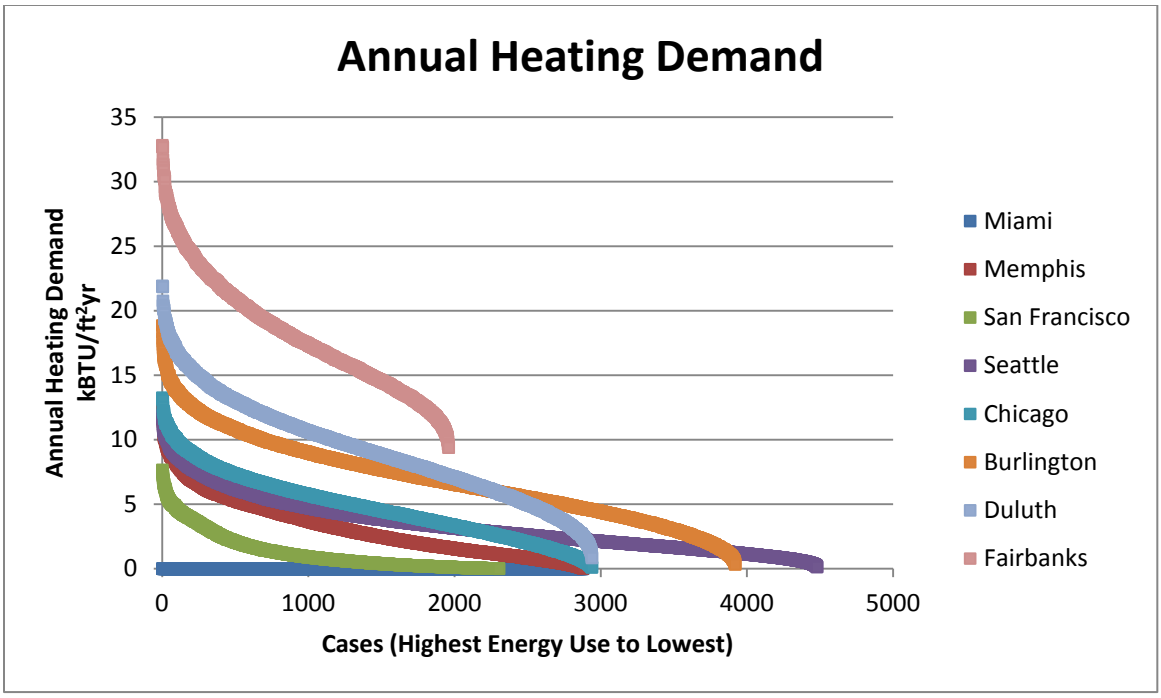


Figure 6.5 - Annual Heating Demand

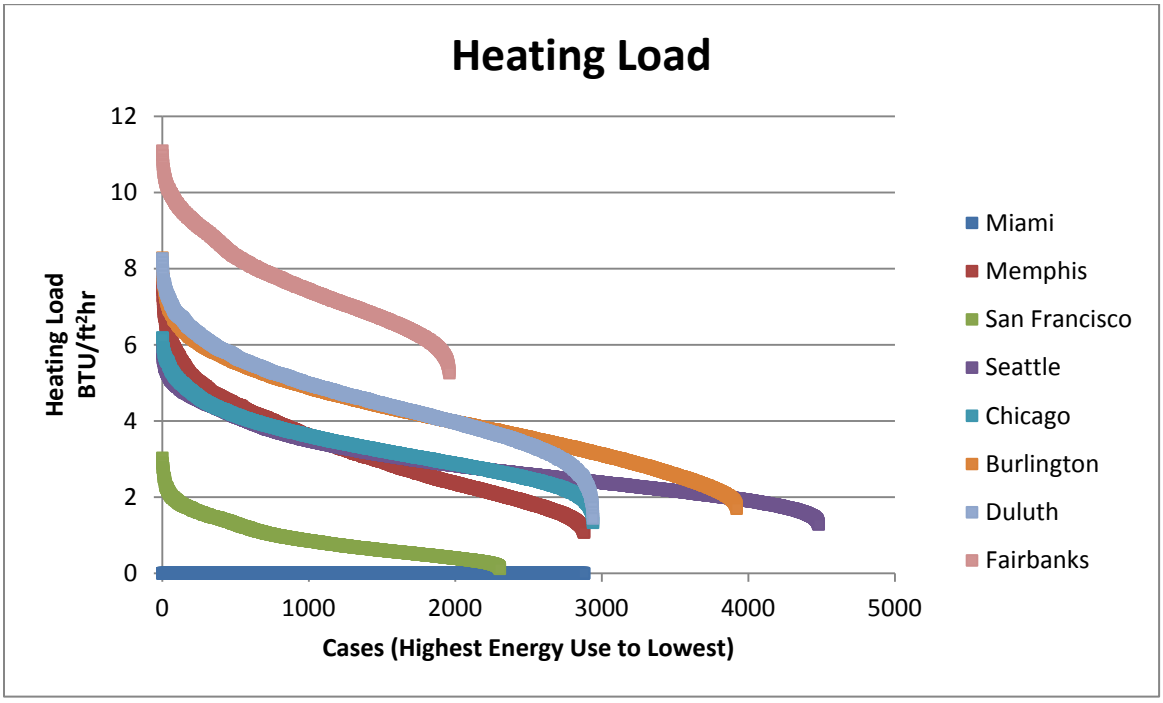


Figure 6.6 - Heating Load

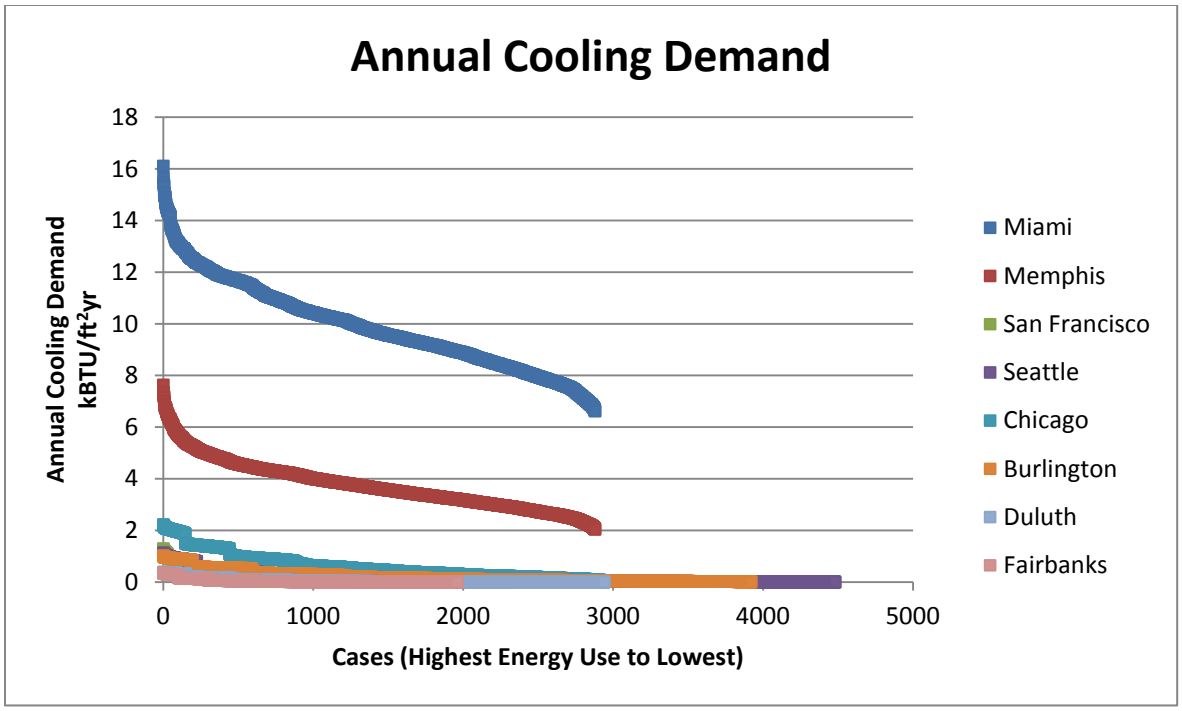


Figure 6.7 - Annual Cooling Demand

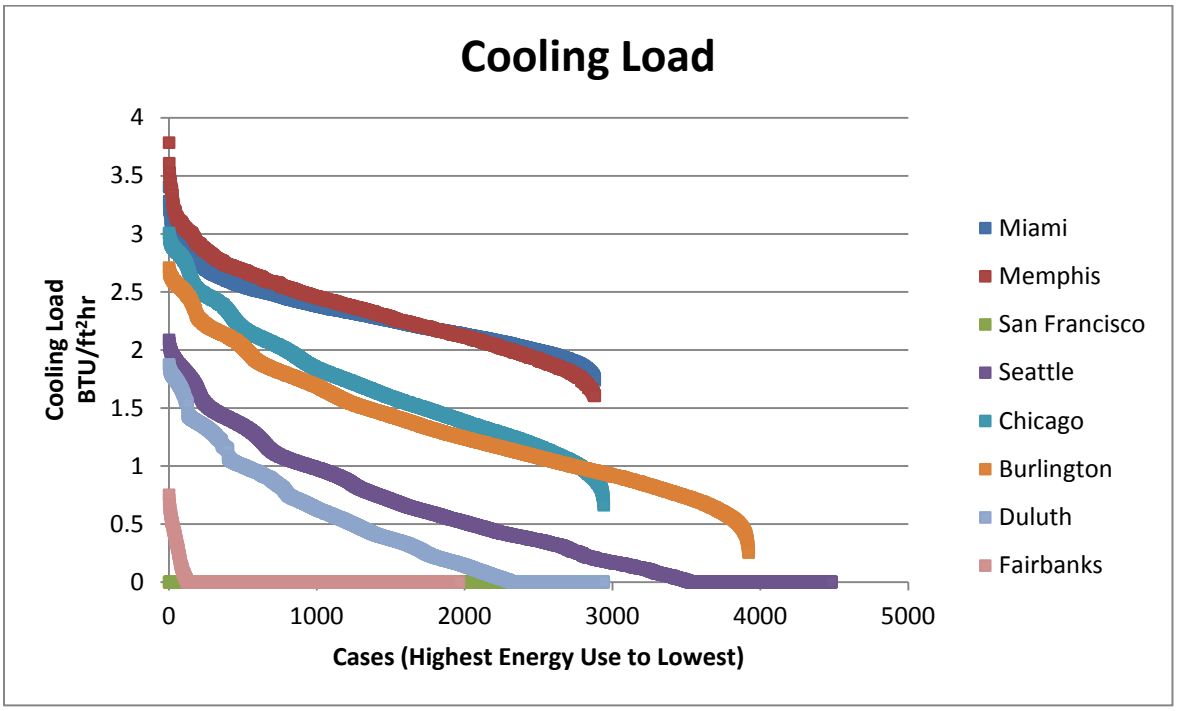


Figure 6.8 - Cooling Load

The eight climate locations that were analyzed in depth were chosen to be a representative sample of the United States. However, not every location or localized phenomena could be shown by these eight locations. Nevertheless, the locations do show how the results generated for the 10,125 cases could be sorted and adjusted for every location and then analyzed further. They also demonstrate the difficulty in finding the point where insulation and other building characteristics no longer provide value for their investment. Despite this, there was often a trend that occurred when filtering which was that the best cases were not filtered out. The code baselines generally filtered out the worst cases as they were designed. Filtering the best cases out to find something feasible is best left to the designer given the constraints of the study. The other major finding from this analysis is that the passive house criteria can be met in the majority of representative climates. Only the Annual Cooling Demand for Miami and the Annual Heating Demand for Fairbanks are absolutely unobtainable based on the variables used in the experiment.

As stated in Chapter 4, to set a recommendation for a an adjusted Passive House Standard set of criteria for the United States, the value chosen for each criteria must be achievable by more than the "perfect" project. Therefore, the very best case cannot be chosen as the new criteria. The criterion needs to be able to be surpassed to allow for imperfect conditions. For instance, if the site is not quite perfect in terms of solar access, certification would be unobtainable for the building if the best case was chosen as the criteria. Since the simulated building is rather compact, if the actual building differed slightly from the simulated building, in shape, size, or treated floor area, then certification would again be unobtainable. If the most effective strategy could not be used for some reason the best case would again be unobtainable. This is very important because the strategies that lowered energy use the most had the largest marginal

benefit. Therefore, the analysis attempted to find a point at which there was still room for improvement to allow for different building configurations and innovative strategies to be used to meet the adjusted Passive House Standard.

Both Chapter 4 and Chapter 5 demonstrate the need for adjustment of the current Passive House Standard; even if they do not fully derive what values should constitute a new standard. However, the method used, which showed the technical possibilities in a given climate and allowed filtering out the cases that were not feasible is a great strategy as a tool for future studies to use to determine the exact values of a new Passive House Standard. One major limitation the study encountered was data overload. The 10,125 cases were difficult to manage. However, through filtering, at least half the cases were removed from every location, with some locations removing eighty percent or more cases from the results. By adjusting the range of the independent variables and adding others, more strategies could be tested, potentially lowering the energy use further, while making the cases more accurate to the real world without significantly increasing the number of data points used in the study.

The simulation controls such as defaults for internal heat gains, thermal mass, ventilation efficiency and many more should be looked at in-depth before the values produced in this study are utilized. This is not to say that the defaults were incorrect, but many of them do have effects on energy and other building properties. For instance, the internal heat gains are commonly regarded as artificially low in the PHPP. This is caused by the emphasis of the tool for use in heating dominated climates, which allows it to be conservative. However, in practice in the United States, the internal heat gains could be anywhere from three to ten times larger. This type of increase would make the Annual Heating Demand significantly easier to meet, and at the same time, increase the Annual Cooling Demand. In Memphis, where the filtered results demonstrated

that it was relatively easy to meet the Passive House Standard, there would be overheating if the internal heat gains were increased. This type of effect would increase further if latent energy use were added to the Annual Cooling Demand. Any study attempting to analyze the standard using this method needs to confirm, using the latest data and best practices, that the defaults used work for all types of climates.

The results show cases that were still feasible after the filtering removed the poor performing cases that do not meet code and comfort requirements. The missing link to finding new values for the Passive House Standard is removing the cases where the envelope investment was well over, or under, the amount needed for a given climate. Without introducing cost, whether capital or lifecycle, finding that threshold is not easily discernible. If cost was never a concern, the building simulation would always point to more, or less, investment depending on climate because there is not an incentive to or a natural point at which to stop envelope investment. However, for the Passive House Standard to make an impact and become mainstream market force, it must be cost effective. Without using a cost variable as a filter, the cases were unable to be analyzed to find the point at which further insulation and envelope investment do not make sense. Without some way of finding this point, which both diminishing returns on insulation and the Primary Energy Criteria are unable to accomplish, any recommendation for adjusting the standard is difficult. While much work remains before a new Passive House Standard can be defined, this study has set a framework, began a discussion on the prominent factors, and displayed trends and insights into the existing Passive House Standard in varying climates zones within the United States as a first step toward this goal.

The complexity of the simulation, the analysis, and the relationship between both the building components and variables and climactic factors has been touched on previously and

cannot be understated. Because of this complexity, this study represents a starting point for further analysis of the Passive House Standard as it pertains toward its widespread adoption in the United States and throughout the world. This beginning has relied on previous work, of both the author and others, to get to this point. The author expects that additional research on the worldwide applicability of the Passive House Standard will occur and that this study does not proclaim to be the end of the need to analyze the Passive House Standard.

To be beneficial to future research, it is important to reflect on the this research in an effort to allow the potential weaknesses of the method and the possibility of adjustment to, or replacement of, the method to eliminate complexity while the goals of this study are preserved. Alternate research methods could involve using different factors or controls. BEopt is one method used to find the cost effective amount of envelope investment. However, more important than adjusting the method would be an additional statistical analysis of the results. A full factorial simulation can create complex interdependent reactions between the variables of the study. Additional statistic analysis looking into these relationships would further the work significantly. Analysis should be performed on the combined effects of various climate characteristics as well as for the relationship between the building's features, or the independent variables, on the test building.

As mentioned before, the number of climates became a limitation because the resulting data was too large to manage and an in-depth analysis of all 1000 locations would have been far too time and resource intensive. The overlaps between the plotted points on the various figures in Chapter 4 show that the same trends could be found using much fewer data points. These data points are representations of climate data locations and the climate characteristic studied at that location. Another method would be to chose a much smaller climate sample and perform a more

in-depth study into the building itself. This would allow for greater analysis of the buildings and its factors, but would limit the geographical proximity a real building would be to the simulated locations. If a study was conducted using less climate data sets, then additional variables could have been utilized. This would change the study from an analysis of the applicability of the Passive House Standard to a study to determine which strategies and techniques are most successful in a given area. This type of in-depth knowledge would be beneficial in developing new criteria for the Passive House Standard.

Additional variables means there is a greater potential to lower the simulated buildings energy use. For instance, if the additional variables of thermal mass, natural ventilation, and mechanical system efficiency were researched, the results may have looked different from the results that were found. In essence, more independent variables mean that there are greater chances of a combination of factors exist that lowers energy use even further. Additional variables also allow for the simulation to adapt to both the heating and cooling energy uses in variable climate. Giving the simulation more choices would allow the simulation to test more of the design combinations the designer has available, which in turn would allow greater accuracy in the simulation.

It is not apparent in some instances if the best combination of variables for cooling is also the best for heating. If it is not, it is difficult to determine which strategies produce the optimal energy results. One method of analysis that could have been used is a "space conditioning" analysis. In this analysis, the Annual Heating Demand and Annual Cooling Demand would combine by being summed together as one factor. However, combing these criteria leads to issues as well as solutions. For example, in another study on the Passive House Standard, BEopt was used as the simulation engine. That experiment was designed to find the cost optimum

building to use the lowest energy use for space conditioning (Kruger 2012). The results show that the optimum building in Baltimore, MD used more heating energy than the optimum building in Duluth, MN. This occurred because the Duluth building was over glazed to eliminate as much of the Annual Heating Demand as possible. At the same time, the large glazing areas allowed copious natural ventilation which eliminated almost all of the Annual Cooling Demand. However, it is this set of circumstances where the daily temperature swing could become uncomfortable, which would have been filtered by this thesis. Not combining the heating and cooling energy is also an analysis limitation in mixed climates because the building envelope, especially slab insulation, does not change over the course of a year while the climate does. Therefore, the building must be designed to handle both heating and cooling as the seasons change.

The most trying analysis problem occurred due to the interdependent relationships between multiple variables and multiple climactic factors. While it is easy to determine the effect a climate factor, such as temperature, has on a case's energy use, it is much more difficult to analyze the effect of two climate factors, such as temperature and radiation, on a case's energy use. Temperature and radiation can act on a building in varying ways. At some points in time, the temperature is causing losses, while at others, it is causing gains. Radiation does not generate significant losses, but the amount of gains are variable based on the time of year, cloud cover, and other factors. At times, these gains and losses work in tandem to increase the energy use, while at others, they work against one another so that the effect is not so severe. Predicating the magnitude at which each variable affects the results was not possible in the analysis.

Some of the trends throughout the study may not be caused by the characteristic they have been analyzed against. For instance, when analyzing the Annual Cooling demand against

the elevation, there is an effect. However, the elevation is a signifier, but not the cause, of the effect. Instead, the cause is most likely the decreasing temperature as elevation increases. However, without further analysis, it is not possible to determine which variable or climate characteristic is responsible for the trend. Similarly, longitude did not correlate with energy use. However, it is generally understood that radiation increases the further west the location is in the United States as referenced by Figure 1.17. The effect in the elevation can be seen while longitude cannot. This is due to the stronger correlation of temperature and energy demand than of radiation and energy demand. Since radiation had less of an effect on energy use than temperature, longitude had less of an effect on energy use than elevation. Determining the extent of these relationships is a weakness of the method and analysis techniques.

Despite these limitations, this thesis serves as an excellent first step in analyzing the Passive House Standard. The standard was found to be achievable in most of the climates in the United States, but was difficult to meet, using the variables in the study, in extreme cold climates and extreme hot climates. In mild climates, it was easy to meet the Passive House Standard. In some of the simulated locations, the energy use was so far below the standard, that building that meet the standard could still lower their energy use effectively. This look at the mild and the extreme climates leads to the conclusion that for realizing the combined goal of maximizing energy savings and widespread adoption, the Passive House Standard should be relaxed for the extreme climates and tightened for the mild climates.

Appendix A: List of Early Pioneering Passive Houses

MIT Solar I in Cambridge - 1939

Neil Hutcheon's Projects in Canada - 1953 to 1964

Arkansas Project in Arkansas - 1974

Lyngby House in Denmark - 1975

Provident House in Canada - 1976

Lo Cal House in Urbana, IL - 1976

Saskatchewan Conservation House in Canada- 1977

Leger House Pepperell, MA - 1977 to 1979

MIT Solar V in Cambridge - 1978

Balcomb House in Santa Fe, NM - 1979

Saskatoon Parade of Homes in Canada - 1980

R2000 Program in Canada - 1982

Buffalo Homes in Montana - 1985

Rocky Mountain Institute in Snowmass, Colorado - 1984

Dumont in Saskatoon, ON Canada - 1990

Darmstadt Passive House in Germany - 1991

Appendix B: PHPP Entries

Verification:

D23	1	Number of Units
I23	68	Interior Set Point Temperature
O18	Residential	Internal Gains Setting
O22	Dwelling	Utilization Pattern for Internal Gains
O23	Standard	Default Value for Internal Gains Used based on Utilization Pattern
O26	Verification	Determines Planned Number of Occupants
O30	Monthly	Calculation Using Monthly Climate Data

Areas:

Col. B	Varies	
Col. D	8,10,11	Designation for Exterior Wall, Ground, and Roof Respectively
Col. G-Y	Varies	Area Entry's (Exterior Dimensions - Based on Wall Thickness)
Col. AA	Varies	R-Value Assigned to Each Area
Col. AD	.7	Exterior Absorptivity
Col. AE	.9	Exterior Emissivity
Col. AF	0,90,180,270	Deviation from North (In Degrees)
Col. AG	0, 90	Angle from Horizontal (Roof-0, Walls-90)
Col. AH		Shading Reduction Factor

Ground:

G6	0.07	Thermal Resistance (R per Inch)
G8	2.0	Heat Capacity of the Ground
O13	0.0	Floor Slab R-Value
G14	Varies	Gross Floor Slab Area (Dependent on Wall Thickness)
G15	Varies	Gross Floor Slab Perimeter (Dependent on Wall Thickness)
D19	n/a	Heated Basement or Underground Floor Slab
D20	X	Slab on Grade
K19	n/a	Unheated Basement
K20	n/a	Suspended Floor
G23	n/a	Basement Depth
O23	n/a	R-Value Belowground Wall
G26	n/a	Air Change Unheated Basement
G27	n/a	Basement Volume
O25	n/a	Height Aboveground Wall
O26	n/a	R-Value Aboveground Wall
O27	n/a	R-Value Basement Floor Slab
G30	12.00	Perimeter Insulation Depth
G31	4.00	Perimeter Insulation Thickness
G32	4	Perimeter Insulation R-Value
G34	n/a	Location of the Perimeter Insulation (Horizontal)
G35	X	Location of the Perimeter Insulation (Vertical)

O30	n/a	R-Value Crawl Space
O31	n/a	Height of Crawl Space Wall
O32	n/a	R-Value Crawl Space Wall
O33	n/a	Area of Ventilation Openings
O34	n/a	Wind Velocity at 33 ft Height
O35	n/a	Wind Shield Factor
G38	n/a	Phase Shift
O38	0.000	Harmonic Fraction
G41	3.0	Depth of Groundwater Table
G42	0.16	Groundwater Flow Rate

Window Type:

C8	Variable	SHGC
D8	Variable	U-Value Glazing
C82	Variable	U-Value Frame
E82	3.500	Frame Dimensions - Width - Left
F82	3.500	Frame Dimensions - Width - Right
G82	3.500	Frame Dimensions - Width - Below
H82	3.500	Frame Dimensions - Width - Above
I82	0.000	Thermal Bridge
J82	0.000	Thermal Bridge

Shading:

Col. L	3	Window Jamb Reveal - Depth
Col. L	3.5	Window Jamb Reveal - Distance from Glazing to Shading Edge
Col. L	3	Window Overhang - Depth
Col. L	3.5	Window Overhang - Distance from Glazing to Shading Edge
Col. L	85%	Additional Shading Reduction Factor (100% Full Sun - 0% Full Shade)
N20,O20	24,18	Window Overhang Dimensions for 2nd Story South Glazing Units

Ventilation:

G14	18.00	Supply Air Requirement
G17	1	Kitchen Quantity
H17	2	Bathroom Quantity
I17	1	Half Bath Quantity
G21	94	Design Air Flow Rate (Max)
E27	n/a	Daily Operation Duration hr/day
E28	19.0	Daily Operation Duration hr/day
E29	n/a	Daily Operation Duration hr/day
E30	5.0	Daily Operation Duration hr/day
G27	1.00	Factors Referenced to Maximum
G28	0.77	Factors Referenced to Maximum
G29	0.54	Factors Referenced to Maximum
G30	0.40	Factors Referenced to Maximum

B32	X	Residential Building
G46	0.07	Wind Protection Coefficient (Coefficient e)
G47	15	Wind Protection Coefficient (Coefficient f)
G48	0.60	Air Change Rate - 50 Pascal Average Pressurization and Depressurization
A50	X	Balanced PH Ventilation
A51	n/a	Pure Extract Air
A56	X	Central unit within the thermal envelope
A57	n/a	Central unit outside of the thermal envelope
G60	10	Length Ambient Air Duct (ft)
G62	10	Length Exhaust Air Duct (ft)
G63	n/a	Temperature of Mechanical Services Room (F)
P57	6	Nominal Duct Width (in)
P58	4	Duct Insulation Thickness (in)
N61	n/a	Reflectivity of Duct Insulation
N62	X	Reflectivity of Duct Insulation
P63	4	Thermal Resistance (R/in) of Supply Duct
P83	6	Nominal Duct Width (in)
P84	4	Duct Insulation Thickness (in)
N87	n/a	Reflectivity of Duct Insulation
N88	X	Reflectivity of Duct Insulation
P89	4	Thermal Resistance (R/in) of Exhaust Duct
C77	-User defined-	Heat Recovery Unit
G77	85%	Heat Recovery (%)
H77	0.7	Electric Efficiency (W/cfm)
G69	60%	Subsoil Heat Exchanger Efficiency

Annual Heat Demand:

M33	8.2	Clear Room Height

Summer:

C6	13	Specific Heat Capacity (Thermal Mass)
C7	77	Overheating Limit (Summer Set Point Temperature)
M39	0.1	Air Change Rate by Natural or Exhaust-Only Mechanical Ventilation, Summer
E41	0.30	Mechanical Ventilation Summer (1/hr)
H41	n/a	Summer Bypass of Mechanical Ventilation System (blank if "yes")
D54	X	Window Night Ventilation, Manual
D55	n/a	Mechanical, Automatically Controlled Ventilation
O54	0.3	Corresponding Air Change Rate (1/hr)
O57	n/a	Minimum Acceptable Indoor Temperature (F)

Shading Summer:

Col. P	70%	Additional Shading Reduction Factor, Summer (%)

Col. Q	70%	Temporary Shading Reduction Factor, z (%)

Cooling Units:

K15	43%	Efficiency Humidity Recovery (Latent Transfer)
B26	n/a	Supply Air Cooling
I28	n/a	On/Off Mode (For Non Variable Speed Compressor)
I29	n/a	Minimum Temperature of Cooling Coil Surface (F)
B31	X	Recirculation Cooling
I33	n/a	On/Off Mode
I34	45	Minimum Temperature of Cooling Coil Surface (F)
I35	400	Volume Flow Rate (cfm)
B37	X	Additional Dehumidification
I39	0.012	Max. Humidity Ratio
I40	0.00041	Humidity Sources
I41	143	Humidity Capacity Building
I44	n/a	Panel Cooling

Domestic Hot Water - DHW:

Q4	n/a	Heat Loss Coefficient Calculator - Nominal Width (in)
Q5	n/a	Heat Loss Coefficient Calculator - Insulation Thickness (in)
O7	n/a	Heat Loss Coefficient Calculator - Yes
O8	n/a	Heat Loss Coefficient Calculator - No
Q9	n/a	Heat Loss Coefficient Calculator - Thermal Resistance (R/in)
H17-18	n/a	Hydronic Space Heat Distribution Values
H20	120	DHW Set Point Temperature
H21-22	n/a	Hydronic Space Heat Distribution Values
K34	6.6	Gallons of Hot Water Per Person Per Day
K35	50	Temperature of Incoming Cold Water
H41-42	n/a	DHW Circulation Loop Values
H44	120.0	DHW Set Point Temperature
H45	n/a	DHW Circulation Loop Values
H53	150.00	Length of Individual Pipes
H54	0.625	Exterior Diameter of Individual Pipes
H64	246.5	DHW Tank Storage Losses (BTU/hr)
S66	4.74	Storage Loss Calculator - Specific Heat Losses (Total)
S68	68	Storage Loss Calculator - Interior Room Temperature

Electricity:

AG7	n/a	Primary Energy Factor for Space Heating
AI7	n/a	Primary Energy Factor Space Heating/DHW
D11	1	Dishwashing
F11	1	Dishwashing
H11	1.20	Dishwashing
B12	DHW Con.	Dishwashing

D13	1	Clothes Washing
F13	1	Clothes Washing
H13	1.10	Clothes Washing
B14	DHW Con.	Clothes Washing
L13	1.00	Clothes Washing - Utilization Factor
F15	1	Clothes Drying
H15	3.50	Clothes Drying
B16	Clothesline	Clothes Drying
H16	n/a	Clothes Drying
J16	0.60	Clothes Drying - Residual dampness
D18	1	Refrigerator
H18	0.78	Refrigerator
D19	1	Freezer
F19	1	Freezer
H19	0.88	Freezer
D20	n/a	Combined Refrigerator / Freezer
H20	n/a	Combined Refrigerator / Freezer
H21	0.25	Range and Cooking Energy
J23	100%	Percentage CFLs
H24	80	Consumer Electronics
N24	0.55	Frequency Factor for Electronics - kh/(P*yr)
B28-H33	n/a	Other

Auxiliary Electricity:

Q8	n/a	Defrosting HX from (F)
D14	1	Winter Ventilation
F14	1	Winter Ventilation
D15	1	Summer Ventilation
F15	1	Summer Ventilation
D16	0	Defroster HX
F16	0	Defroster HX
H18	n/a	Enter the Rated Power of the Pump
K18	1	Controlled/Uncontrolled (1/0)
D19	0	Circulation Pump
F19	0	Circulation Pump
H20	n/a	Boiler Electricity Consumption at 30% Load
F21	0	Aux. Energy- Heat Boiler
H23	n/a	Enter Average Power Consumption of Pump
F24	0	Circulation Pump
H25	n/a	Enter the Rated Power of the Pump
D26	0	Storage Load Pump DHW
F26	0	Storage Load Pump DHW
H27	n/a	Enter Electricity Consumption at 100% Load
F28	0	DHW Boiler Aux. Energy
H29	n/a	Enter the Rated Power of the Solar DHW Pump

F30	0	Solar Aux Electricity
D32-34	0	Misc. Aux. Electricity
F32-34	0	Misc. Aux. Electricity
H32-34	30	Misc. Aux. Electricity

PE Value:

F11	n/a	Electricity Demand- Covered Fraction of Space Heat Demand (Final Energy)
F12	0%	Electricity Demand - Covered Fraction of DHW Demand (Final Energy)
F23	100%	Heat Pump- Covered Fraction of Space Heat Demand (Final Energy)
F24	0%	Heat Pump- Covered Fraction of DHW Demand (Final Energy)
F26	Electricity	Heat Pump- Energy Carrier- Supplementary Heating
G26	2.7	Heat Pump- Energy Carrier- Supplementary Heating (Primary Energy)
H26	.44	Heat Pump- Energy Carrier- Supplementary Heating (Emissions)
F27	2.85	Annual Coefficient of Performance- Heat Pump
F28	0.35	Heat Pump- Total System Performance Ratio of Heat Generator
F35	n/a	Compact Heat Pump Unit- Covered Fraction of Space Heat Demand
F36	n/a	Compact Heat Pump Unit- Covered Fraction of DHW Demand
F38	n/a	Compact Heat Pump Unit- Energy Carrier- Supplementary Heating
G38	n/a	Compact Heat Pump Unit- Energy Carrier- Supplementary Heating
H38	n/a	Compact Heat Pump Unit- Energy Carrier- Supplementary Heating
F49	n/a	Boiler- Covered Fraction of Space Heat Demand
H50	n/a	Boiler- Covered Fraction of DHW Demand
F61	n/a	District Heat- Covered Fraction of Space Heat Demand
F62	n/a	District Heat- Covered Fraction of DHW Demand
F73	0%	Other- Covered Fraction of Space Heat Demand
F74	100%	Other- Covered Fraction of DHW Demand
G74	2.7	Other- Covered Fraction of DHW Demand
H74	.44	Other- Covered Fraction of DHW Demand
H76	Heat Pump	Other- Heat Source
H78	170%	Other- Utilization Factor Heat Generator
F91	5	Cooling with Electric Heat Pump- Annual Cooling COP
F109	n/a	Solar Electricity- Planned Annual Electricity Generation

Appendix C: List of Simulated Climate Data Locations

Alabama

- Alabama, Anniston Metro AP (722287)
- Alabama, Auburn-Opelika AP (722284)
- Alabama, Birmingham Muni AP (722280)
- Alabama, Dothan Muni AP (722268)
- Alabama, Fort Rucker-Cairns Field (722269)
- Alabama, Gadsen Muni AWOS (722285)
- Alabama, Huntsville Intl AP-Jones Field (723230)
- Alabama, Maxwell AFB (722265)
- Alabama, Mobile-Downtown AP (722235)
- Alabama, Mobile-Rgnl AP (722230)
- Alabama, Montgomery-Dannelly Field (722260)
- Alabama, Muscle Shoals Rgnl AP (723235)
- Alabama, Troy Air Field (722267)
- Alabama, Tuscaloosa Muni AP (722286)

Alaska

- Alaska, Adak NAS (704540)
- Alaska, Ambler (701718)
- Alaska, Anaktuvuk Pass (701625)
- Alaska, Anchorage Intl AP (702730)
- Alaska, Anchorage-Elmendorf AFB (702720)
- Alaska, Anchorage-Lake Hood Seaplane Base (702725)
- Alaska, Anchorage-Merrill Field (702735)
- Alaska, Aniak AP (702320)
- Alaska, Annette Island AP (703980)
- Alaska, Anvik (702075)
- Alaska, Barrow-W Post-W Rogers AP (700260)
- Alaska, Bethel AP (702190)
- Alaska, Bettles Field (701740)
- Alaska, Big Delta-Allen AAF (702670)
- Alaska, Big River Lake (702986)
- Alaska, Birchwood (702746)
- Alaska, Chulitna (702606)
- Alaska, Cold Bay AP (703160)
- Alaska, Cordova (702960)
- Alaska, Deadhorse (700637)
- Alaska, Dillingham AMOS (703210)
- Alaska, Eielson AFB (702650)
- Alaska, Emmonak (702084)
- Alaska, Fairbanks Intl AP (702610)

- Alaska, Fort Yukon (701940)
- Alaska, Gambell (702040)
- Alaska, Gulkana (702710)
- Alaska, Gustavus (703670)
- Alaska, Hayes River (702495)
- Alaska, Healy River AP (702647)
- Alaska, Homer AP (703410)
- Alaska, Hoonah (702607)
- Alaska, Hooper Bay (702186)
- Alaska, Huslia (702225)
- Alaska, Hydaburg Seaplane Base (703884)
- Alaska, Iliamna AP (703400)
- Alaska, Juneau Intl AP (703810)
- Alaska, Kake Seaplane Base (703855)
- Alaska, Kenai Muni AP (702590)
- Alaska, Ketchikan Intl AP (703950)
- Alaska, King Salmon AP (703260)
- Alaska, Kodiak AP (703500)
- Alaska, Kotzebue-Ralph Wein Mem AP (701330)
- Alaska, McGrath AP (702310)
- Alaska, Mekoryuk (702185)
- Alaska, Middleton Island (703430)
- Alaska, Minchumina (702460)
- Alaska, Nenana Muni AP (702740)
- Alaska, Nome Muni AP (702000)
- Alaska, Northway AP (702910)
- Alaska, Palmer Muni AP (702740)
- Alaska, Petersburg (703860)
- Alaska, Point Hope AWOS (701043)
- Alaska, Port Heiden (703330)
- Alaska, Saint Marys AWOS (702005)
- Alaska, Sand Point (703165)
- Alaska, Savoonga (702035)
- Alaska, Selawik (700197)
- Alaska, Seward (702770)
- Alaska, Shemya AFB (704140)
- Alaska, Shishmaref AWOS (701195)
- Alaska, Sitka-Japonski Island AP (703710)
- Alaska, Skagway AP (703620)
- Alaska, Sleetmute (703407)
- Alaska, Soldotna (702595)
- Alaska, St Paul Island AP (703080)
- Alaska, Talkeetna State AP (702510)
- Alaska, Tanana-Ralph Calhoun AP (701780)

- Alaska, Togiak Village AWOS (703606)
- Alaska, Unalakleet Field (702070)
- Alaska, Unalaska-Dutch Harbor Field (704890)
- Alaska, Valdez (702750)
- Alaska, Valdez-Pioneer Field (702756)
- Alaska, Whittier (702757)
- Alaska, Wrangell (703870)
- Alaska, Yakutat State AP (703610)

Arizona

- Arizona, Casa Grande AWOS (722748)
- Arizona, Davis-Monthan AFB (722745)
- Arizona, Douglas-Bisbee Douglas Intl AP (722735)
- Arizona, Flagstaff-Pulliam AP (723755)
- Arizona, Grand Canyon National Park AP (723783)
- Arizona, Kingman AWOS (723700)
- Arizona, Luke AFB (722785)
- Arizona, Page Muni AWOS (723710)
- Arizona, Phoenix-Deer Valley AP (722784)
- Arizona, Phoenix-Sky Harbor Intl AP (722780)
- Arizona, Prescott-Love Field (723723)
- Arizona, Safford AWOS (722747)
- Arizona, Scottsdale Muni AP (722789)
- Arizona, Show Low Muni AP (723747)
- Arizona, Tucson Intl AP (722740)
- Arizona, Winslow Muni AP (723740)
- Arizona, Yuma Intl AP (722800)
- Arizona, Yuma MCAS (699604)

Arkansas

- Arkansas, Batesville AWOS (723448)
- Arkansas, Bentonville AWOS (723444)
- Arkansas, El Dorado-Goodwin Field (723419)
- Arkansas, Fayetteville-Drake Field (723445)
- Arkansas, Flippin AWOS (723447)
- Arkansas, Fort Smith Rgnl AP (723440)
- Arkansas, Harrison AP (723446)
- Arkansas, Jonesboro Muni AP (723407)
- Arkansas, Little Rock AFB (723405)
- Arkansas, Little Rock-Adams Field (723403)
- Arkansas, Pine Bluff AP (723417)
- Arkansas, Rogers AWOS (723449)
- Arkansas, Siloam Spring AWOS (723443)

- Arkansas, Springdale Muni AP (723434)
- Arkansas, Stuttgart AWOS (723416)
- Arkansas, Texarkana-Webb Field (723418)
- Arkansas, Walnut Ridge AWOS (723406)

California

- California, Alturas (725958)
- California, Arcata AP (725945)
- California, Bakersfield-Meadows Field (723840)
- California, Barstow Daggett AP (723815)
- California, Beale AFB (724837)-
- California, Bishop AP (724800)
- California, Blue Canyon AP (725845)
- California, Blythe-Riverside County AP (747188)
- California, Burbank-Glendale-Passadena Bob Hope AP (722880)
- California, Camarillo AWOS (723926)
- California, Camp Pendleton MCAS (722926)
- California, Carlsbad (722927)
- California, China Lake NAF (746120)
- California, Chino AP (722899)
- California, Chula Vista-Brown Field Muni AP (722904)
- California, Concord Concord-Buchanan Field (724936)
- California, Crescent City-Jack McNamara Field (725946)
- California, Edwards AFB (723810)
- California, Fairfield-Travis AFB (745160)
- California, Fresno Air Terminal (723890)
- California, Fullerton Muni AP (722976)
- California, Hawthorne-Jack Northrop (722956)
- California, Hayward Air Terminal (724935)
- California, Imperial County AP (747185)
- California, Lancaster-Gen Wm Fox Field (723816)
- California, Lemoore NAS (747020)
- California, Livermore Muni AP (724927)
- California, Lompoc AWOS (722895)
- California, Long Beach-Daugherty Field (722970)
- California, Los Angeles Intl AP (722950)
- California, March AFB (722860)
- California, Merced-Macready Field (724815)
- California, Modesto Muni AP (724926)
- California, Montague-Siskiyou County AP (725955)
- California, Monterey NAF (724915)
- California, Mountain View-Moffett Field NAS (745090)
- California, Napa County AP (724955)

- California, Needles AP (723805)
- California, Oakland Intl AP (724930)
- California, Oxnard AP (723927)
- California, Palm Springs Intl AP (722868)
- California, Palm Springs Thermal AP (747187)
- California, Palmdale AP (723820)
- California, Paso Robles Muni AP (723965)
- California, Point Mugu NAS (723910)
- California, Porterville AWOS (723895)
- California, Red Bluff Muni AP (725910)
- California, Redding Muni AP (725920)
- California, Riverside Muni AP (722869)
- California, Sacramento Exec AP (724830)
- California, Sacramento Metro AP (724839)
- California, Salinas Muni AP (724917)
- California, San Diego - Lindbergh Field (722900)
- California, San Diego-Miramar NAS (722930)
- California, San Diego-Montgomery Field (722903)
- California, San Diego-North Island NAS (722906)
- California, San Francisco Intl AP (724940)
- California, San Jose Intl AP (724945)
- California, San Luis Obispo AP (722897)
- California, Sandberg (723830)
- California, Santa Ana-John Wayne AP (722977)
- California, Santa Barbara Muni AP (723925)
- California, Santa Maria Public AP (723940)
- California, Santa Monica Muni AP (722885)
- California, Santa Rosa AWOS (724957)
- California, South Lake Tahoe-Lake Tahoe AP (725847)
- California, Stockton Metro AP (724920)
- California, Truckee Tahoe AP (725846)
- California, Twentynine Palms (690150)
- California, Ukiah Muni AP (725905)
- California, Van Nuys AP (722886)
- California, Visalia Muni AWOS (723896)
- California, Yuba County AP (724838)

Colorado

- Colorado, Akron-Washington County AP (724698)
- Colorado, Alamosa Muni AP (724620)
- Colorado, Aspen-Pitkin County-Sardy Field (724676)
- Colorado, Aurora-Buckley Field ANGB (724695)
- Colorado, Boulder-Broomfield-Jefferson County AP (724699)

- Colorado, Colorado Springs-Peterson Field (724660)
- Colorado, Cortez-Montezuma County AP (724767)
- Colorado, Craig Moffat AP (725700)
- Colorado, Denver Intl AP (725650)
- Colorado, Durango-La Plata County AP (724625)
- Colorado, Eagle County Rgnl AP (724675)
- Colorado, Fort Collins AWOS (724769)
- Colorado, Golden-NREL (724666)
- Colorado, Grand Junction-Walker Field (724760)
- Colorado, Greeley-Weld County AWOS (724768)
- Colorado, Gunnison County AWOS (724677)
- Colorado, Hayden-Yampa AWOS (725715)
- Colorado, La Junta Muni AP (724635)
- Colorado, Lamar Muni AP (724636)
- Colorado, Leadville-Lake County AP (724673)
- Colorado, Limon Muni AP (724665)
- Colorado, Montrose County AP (724765)
- Colorado, Pueblo Mem AP (724640)
- Colorado, Rifle-Garfield County Rgnl AP (725717)
- Colorado, Trinidad-Las Animas County AP (724645)

Connecticut

- Connecticut, Bridgeport-Sikorsky Mem AP (725040)
- Connecticut, Danbury Muni AP (725086)
- Connecticut, Groton-New London AP (725046)
- Connecticut, Hartford-Bradley Intl AP (725080)
- Connecticut, Hartford-Brainard Field (725087)
- Connecticut, New Haven-Tweed AP (725045)
- Connecticut, Oxford AWOS (725029)

Delaware

- Delaware, Dover AFB (724088)
- Delaware, Wilmington-New Castle (724089)

Florida

- Florida, Crestview-Bob Sikes AP (722215)
- Florida, Daytona Beach Intl AP (722056)
- Florida, Fort Lauderdale Executive AP (722039)
- Florida, Fort Lauderdale Intl AP (722025)
- Florida, Fort Myers-Page Field (722106)
- Florida, Fort Pierce-St Lucie County AP (722103)
- Florida, Fort Walton Beach-Hurlburt Field (747770)
- Florida, Gainesville Rgnl AP (722146)

- Florida, Homestead AFB (722026)
- Florida, Jacksonville Intl AP (722060)
- Florida, Jacksonville NAS (722065)
- Florida, Jacksonville-Craig Field (722068)
- Florida, Key West Intl AP (722010)
- Florida, Key West NAS (722015)
- Florida, Lakeland Linder Rgnl AP (722119)
- Florida, MacDill AFB (747880)
- Florida, Marathon AP (722016)
- Florida, Mayport NS (722066)
- Florida, Melbourne Rgnl AP (722040)
- Florida, Miami Intl AP (722020)
- Florida, Miami-Kendall-Tamiami Executive AP (722029)
- Florida, Miami-Opa Locka AP (722024)
- Florida, NASA Shuttle Landing Facility (747946)
- Florida, Naples Muni AP (722038)
- Florida, Ocala Muni AWOS (722055)
- Florida, Orlando Executive AP (722053)
- Florida, Orlando Intl AP (722050)
- Florida, Orlando-Sanford AP (722057)
- Florida, Panama City-Bay County AP (722245)
- Florida, Pensacola Rgnl AP (722223)
- Florida, Pensacola-Forest Sherman NAS (722225)
- Florida, Sarasota-Bradenton Intl AP (722115)
- Florida, Southwest Florida Intl AP (722108)
- Florida, St Petersburg-Albert Whitted Station (722104)
- Florida, St Petersburg-Clearwater Intl AP (722116)
- Florida, Tallahassee Rgnl AP (722140)
- Florida, Tampa Intl AP (722110)
- Florida, Tyndall AFB (747750)
- Florida, Valparaiso-Elgin AFB (722210)
- Florida, Vero Beach Muni AP (722045)
- Florida, West Palm Beach Intl AP (722030)
- Florida, Whiting Field NAS (722226)

Georgia

- Georgia, Albany-Dougherty County AP (722160)
- Georgia, Alma-Bacon County AP (722135)
- Georgia, Athens-Ben Epps AP (723110)
- Georgia, Atlanta-Hartsfield-Jackson Intl AP (722190)
- Georgia, Augusta-Bush-Field (722180)
- Georgia, Brunswick-Golden Isles AP (722136)
- Georgia, Brunswick-Malcolm McKinnon AP (722137)

- Georgia, Columbus Metro AP (722255)
- Georgia, Dekalb Peachtree AP (722196)
- Georgia, Fort Benning-Lawson Field (722250)
- Georgia, Fulton County AP (722195)
- Georgia, Macon-Middle Georgia Rgnl AP (722170)
- Georgia, Marietta-Dobbins AFB (722270)
- Georgia, Rome-Richard B Russell AP (723200)
- Georgia, Savannah Intl AP (722070)
- Georgia, Savannah-Hunter AAF (747804)
- Georgia, Valdosta Rgnl AP (722166)
- Georgia, Valdosta-Moody AFB (747810)
- Georgia, Warner Robins AFB (722175)

Hawaii

- Hawaii, Barbers Point NAS (911780)
- Hawaii, Hilo Intl AP (912850)
- Hawaii, Honolulu Intl AP (911820)
- Hawaii, Kahului AP (911900)
- Hawaii, Kailua-Kaneohe Bay MCAS (911760)
- Hawaii, Kapalua-West Maui AP (911904)
- Hawaii, Keahole-Kona Intl AP (911975)
- Hawaii, Lanai AP (911905)
- Hawaii, Lihue AP (911650)
- Hawaii, Molokai AWOS (911860)

Idaho

- Idaho, Boise Air Terminal (726810)
- Idaho, Burley Muni AP (725867)
- Idaho, Caldwell AWOS (726813)
- Idaho, Coeur dAlene AWOS (727834)
- Idaho, Hailey-Sun Valley AP (725865)
- Idaho, Idaho Falls-Fanning Field (725785)
- Idaho, Lewiston-Nez Perce County AP (727830)
- Idaho, Malad City AP (725786)
- Idaho, Mountain Home AFB (726815)
- Idaho, Pocatello Muni AP (725780)
- Idaho, Salmon-Lemhi AWOS (726865)
- Idaho, Soda Springs-Tigert AP (725868)
- Idaho, Twin Falls - Magic Valley Rgnl AP - Joslin Field (725866)

Illinois

- Illinois, Aurora Muni AP (744655)
- Illinois, Belleville-Scott AFB (724338)

- Illinois, Bloomington Normal - Central Illinois Rgnl AP (724397)
- Illinois, Cahokia AP (725314)
- Illinois, Carbondale-Southern Illinois AP (724336)
- Illinois, Chicago-Midway AP (725340)
- Illinois, Chicago-OHare Intl AP (725300)
- Illinois, Decatur AP (725316)
- Illinois, Du Page AP (725305)
- Illinois, Marion-Williamson County Rgnl AP (724339)
- Illinois, Moline-Quad City Intl AP (725440)
- Illinois, Mount Vernon AWOS (724335)
- Illinois, Peoria-Greater Peoria AP (725320)
- Illinois, Quincy Muni AP (724396)
- Illinois, Rockford-Greater Rockford AP (725430)
- Illinois, Springfield-Capital AP (724390)
- Illinois, Sterling - Rock Falls - Whiteside County AP (725326)
- Illinois, University of Illinois - Willard AP (725315)
- Illinois, Waukegan Rgnl AP (725347)

Indiana

- Indiana, Delaware County - Johnson Field (725336)
- Indiana, Evansville Rgnl AP (724320)
- Indiana, Fort Wayne Intl AP (725330)
- Indiana, Grissom AFB (725335)
- Indiana, Huntingburg Muni AP (724365)
- Indiana, Indianapolis Intl AP (724380)
- Indiana, Lafayette-Purdue University AP (724386)
- Indiana, Monroe County AP (724375)
- Indiana, South Bend - Michiana Rgnl AP (725350)
- Indiana, Terre Haute - Hulman Rgnl AP (724373)

Iowa

- Iowa, Algona Muni AP (725457)
- Iowa, Atlantic Muni AP (725453)
- Iowa, Boone Muni AP (725486)
- Iowa, Burlington Muni AP (725455)
- Iowa, Carroll Muni AP (725468)
- Iowa, Cedar Rapids Muni AP (725450)
- Iowa, Chariton Muni AP (725469)
- Iowa, Charles City Muni AP (725463)
- Iowa, Clarinda Muni AP (725479)
- Iowa, Clinton Muni AWOS (725473)
- Iowa, Council Bluffs Muni AP (725497)
- Iowa, Creston Muni AP (725474)

- Iowa, Decorah Muni AP (725476)
- Iowa, Denison Muni AP (725477)
- Iowa, Des Moines Intl AP (725460)
- Iowa, Dubuque Rgnl AP (725470)
- Iowa, Estherville Muni AP (726499)
- Iowa, Fairfield Muni AP (726498)
- Iowa, Fort Dodge AWOS (725490)
- Iowa, Fort Madison Muni AP (725483)
- Iowa, Keokuk Muni AP (725456)
- Iowa, Knoxville Muni AP (725493)
- Iowa, Le Mars Muni AP (725484)
- Iowa, Mason City Muni AP (725485)
- Iowa, Monticello Muni AP (725475)
- Iowa, Muscatine Muni AP (725487)
- Iowa, Newton Muni AP (725464)
- Iowa, Oelwein Muni AP (725488)
- Iowa, Orange City Muni AP (725489)
- Iowa, Ottumwa Industriali AP (725465)
- Iowa, Red Oak Muni AP (725494)
- Iowa, Sheldon Muni AP (725495)
- Iowa, Shenandoah Muni AP (725467)
- Iowa, Sioux City-Sioux Gateway AP (725570)
- Iowa, Spencer Muni AP (726500)
- Iowa, Storm Lake Muni AP (725496)
- Iowa, Washington Muni AP (725454)
- Iowa, Waterloo Muni AP (725480)
- Iowa, Webster City Muni AP (725478)

Kansas

- Kansas, Chanute - Martin Johnson AP (724507)
- Kansas, Concordia-Blosser Muni AP (724580)
- Kansas, Dodge City Rgnl AP (724510)
- Kansas, Emporia Muni AP (724556)
- Kansas, Fort Riley-Marshall AAF (724550)
- Kansas, Garden City Muni AP (724515)
- Kansas, Goodland-Renner Field (724650)
- Kansas, Great Bend AWOS (724517)
- Kansas, Hays Muni AWOS (724518)
- Kansas, Hill City Muni AP (724655)
- Kansas, Hutchinson Muni AP (724506)
- Kansas, Liberal Muni AP (724516)
- Kansas, Manhattan Rgnl AP (724555)
- Kansas, Newton AWOS (724509)

- Kansas, Olathe-Johnson County Executive AP (724468)
- Kansas, Olathe-Johnson County Industrial AP (724475)
- Kansas, Russell Muni AP (724585)
- Kansas, Salina Muni AP (724586)
- Kansas, Topeka-Forbes AFB (724565)
- Kansas, Topeka-Phillip Billard Muni AP (724560)
- Kansas, Wichita-Col Jabara Field (724504)
- Kansas, Wichita-McConnell AFB (724505)
- Kansas, Wichita-Mid Continent AP (724500)

Kentucky

- Kentucky, Bowling Green-Warren County AP (746716)
- Kentucky, Cincinnati-Northern Kentucky AP (724210)
- Kentucky, Fort Campbell AAF (746710)
- Kentucky, Fort Knox-Godman AAF (724240)
- Kentucky, Henderson City County AP (724238)
- Kentucky, Jackson-Julian Carroll AP (724236)
- Kentucky, Lexington-Bluegrass AP (724220)
- Kentucky, London-Corbin-Magee Field (724243)
- Kentucky, Louisville-Bowman Field (724235)
- Kentucky, Louisville-Standiford Field (724230)
- Kentucky, Paducah-Barkley Rgnl AP (724350)
- Kentucky, Somerset-Pulaski County AWOS (724354)

Louisiana

- Louisiana, Alexandria-England AFB (747540)
- Louisiana, Alexandria-Esler Rgnl AP (722487)
- Louisiana, Barksdale AFB (722485)
- Louisiana, Baton Rouge-Ryan AP (722317)
- Louisiana, Fort Polk (722390)
- Louisiana, Houma-Terrebonne AP (722406)
- Louisiana, Lafayette Rgnl AP (722405)
- Louisiana, Lake Charles AP (722404)
- Louisiana, Lake Charles Rgnl AP (722400)
- Louisiana, Monroe Rgnl AP (722486)
- Louisiana, New Iberia (722314)
- Louisiana, New Orleans Intl AP (722310)
- Louisiana, New Orleans-Alvin Callender Field (722316)
- Louisiana, New Orleans-Lakefront AP (722315)
- Louisiana, Patterson Mem AP (722329)
- Louisiana, Shreveport Downtown (722484)
- Louisiana, Shreveport Rgnl AP (722480)

Maine

- Maine, Auburn-Lewiston Muni AP (726184)
- Maine, Augusta AP (726185)
- Maine, Bangor Intl AP (726088)
- Maine, Bar Harbor AWOS (726077)
- Maine, Caribou Muni AP (727120)
- Maine, Edmundston - Northern Aroostook Rgnl AP (726083)
- Maine, Houlton Intl AP (727033)
- Maine, Millinocket Muni AP (726196)
- Maine, Portland Intl Jetport (726060)
- Maine, Presque Isle Muni AP (727130)
- Maine, Rockland-Knox AWOS (726079)
- Maine, Sanford Muni AWOS (726064)
- Maine, Waterville AWOS (726073)
- Maine, Wiscasset AP (727135)

Maryland

- Maryland, Andrews AFB (745940)
- Maryland, Baltimore-Washington Intl AP (724060)
- Maryland, Hagerstown-Washington County Rgnl AP (724066)
- Maryland, Patuxent River NAS (724040)
- Maryland, Salisbury-Wicomico County Rgnl AP (724045)

Massachusetts

- Massachusetts, Barnstable-Boardman Poland AP (725067)
- Massachusetts, Beverly Muni AP (725088)
- Massachusetts, Boston-Logan Intl AP (725090)
- Massachusetts, Chicopee Falls-Westover AFB (744910)
- Massachusetts, Lawrence Muni AP (744904)
- Massachusetts, Marthas Vineyard AP (725066)
- Massachusetts, Nantucket Mem AP (725063)
- Massachusetts, New Bedford Rgnl AP (725065)
- Massachusetts, North Adams AP (725075)
- Massachusetts, Norwood Mem AP (725098)
- Massachusetts, Otis ANGB (725060)
- Massachusetts, Plymouth Muni AP (725064)
- Massachusetts, Provincetown AWOS (725073)
- Massachusetts, Westfield-Barnes Muni AP (744915)
- Massachusetts, Worcester Rgnl AP (725095)

Michigan

- Michigan, Alpena County Rgnl AP (726390)
- Michigan, Ann Arbor Muni AP (725374)

- Michigan, Battle Creek - Kellogg AP (725396)
- Michigan, Benton Harbor - Ross Field - Twin Cities AP (726355)
- Michigan, Cadillac-Wexford County AP (726384)
- Michigan, Chippewa County Intl AP (727344)
- Michigan, Detroit Metro AP (725370)
- Michigan, Detroit-City AP (725375)
- Michigan, Detroit-Willow Run AP (725376)
- Michigan, Escanaba AWOS (726480)
- Michigan, Flint-Bishop Intl AP (726370)
- Michigan, Grand Rapids-Kent County Intl AP (726350)
- Michigan, Hancock-Houghton County AP (727440)
- Michigan, Houghton-Lake Roscommon County AP (726380)
- Michigan, Howell-Livingston County AP (725378)
- Michigan, Iron Mountain-Ford Field (727437)
- Michigan, Ironwood AWOS (727445)
- Michigan, Jackson-Reynolds Field (725395)
- Michigan, Kalamazoo-Battle Creek Intl AP (726357)
- Michigan, Lansing-Capital City AP (725390)
- Michigan, Manistee AWOS (726385)
- Michigan, Menominee AWOS (726487)
- Michigan, Mount Clemens-Selfridge ANGB (725377)
- Michigan, Muskegon County AP (726360)
- Michigan, Oakland County Intl AP (726375)
- Michigan, Oscoda-Wurtsmith AFB (726395)
- Michigan, Pellston-Emmet County AP (727347)
- Michigan, Saginaw-Tri City Intl AP (726379)
- Michigan, Sault Ste Marie-Sanderson Field (727340)
- Michigan, St Clair County Intl AP (725384)
- Michigan, Traverse City-Cherry Capital AP (726387)

Minnesota

- Minnesota, Aitkin AWOS (727504)
- Minnesota, Albert Lea AWOS (726589)
- Minnesota, Alexandria Muni AP (726557)
- Minnesota, Austin Muni AP (727566)
- Minnesota, Baudette Intl AP (727476)
- Minnesota, Bemidji Muni AP (727550)
- Minnesota, Benson Muni AP (727507)
- Minnesota, Brainerd-Crow Wing County AP (726555)
- Minnesota, Cambridge Muni AP (727503)
- Minnesota, Cloquet AWOS (726558)
- Minnesota, Crane Lake AWOS (727473)
- Minnesota, Crookston Muni Field (727452)

- Minnesota, Detroit Lakes AWOS (727457)
- Minnesota, Duluth Intl AP (727450)
- Minnesota, Edin Prairie-Flying Cloud AP (726579)
- Minnesota, Ely Muni AP (727459)
- Minnesota, Eveleth Muni AWOS (727474)
- Minnesota, Fairmont Muni AWOS (726586)
- Minnesota, Faribault Muni AWOS (726563)
- Minnesota, Fergus Falls AWOS (726560)
- Minnesota, Fosston AWOS (727505)
- Minnesota, Glenwood AWOS (726547)
- Minnesota, Grand Rapids AWOS (727458)
- Minnesota, Hallock (727478)
- Minnesota, Hibbing-Chisholm Hibbing AP (727455)
- Minnesota, Hutchinson AWOS (726569)
- Minnesota, International Falls Intl AP (727470)
- Minnesota, Litchfield Muni AP (726583)
- Minnesota, Little Falls AWOS (726578)
- Minnesota, Mankato AWOS (726585)
- Minnesota, Marshall Muni-Ryan Field AWOS (726559)
- Minnesota, Minneapolis-Crystal AP (726575)
- Minnesota, Minneapolis-St Paul Intl AP (726580)
- Minnesota, Mora Muni AWOS (727475)
- Minnesota, Morris Muni AWOS (726565)
- Minnesota, New Ulm Muni AWOS (726567)
- Minnesota, Orr Rgnl AP (726544)
- Minnesota, Owatonna AWOS (726568)
- Minnesota, Park Rapids Muni AP (727453)
- Minnesota, Pipestone AWOS (726566)
- Minnesota, Red Wing Muni AP (726564)
- Minnesota, Redwood Falls Muni AP (726556)
- Minnesota, Rochester Intl AP (726440)
- Minnesota, Roseau Muni AWOS (727477)
- Minnesota, Silver Bay Muni AP (727556)
- Minnesota, South St Paul Muni AP (726603)
- Minnesota, St Cloud Muni AP (726550)
- Minnesota, St Paul-Downtown AP (726584)
- Minnesota, Thief River AWOS (727555)
- Minnesota, Two Harbors Muni AP (727444)
- Minnesota, Wheaton AWOS (727533)
- Minnesota, Willmar Muni AP (726576)
- Minnesota, Winona Muni AWOS (726588)
- Minnesota, Worthington AWOS (726587)

Mississippi

- Mississippi, Biloxi-Keesler AFB (747686)
- Mississippi, Columbus AFB (723306)
- Mississippi, Golden Triangle Rgnl AWOS (723307)
- Mississippi, Greenville Muni AP (722356)
- Mississippi, Greenwood-Leflore AP (722359)
- Mississippi, Gulfport-Biloxi Intl AP (747685)
- Mississippi, Hattiesburg-Laurel AP (722348)
- Mississippi, Jackson Intl AP (722350)
- Mississippi, McComb-Pike Co AP (722358)
- Mississippi, Meridian NAS (722345)
- Mississippi, Meridian-Key Field (722340)
- Mississippi, Natchez-Hardy Anders Field (722357)
- Mississippi, Tupelo Muni-C D Lemons AP (723320)

Missouri

- Missouri, Cape Girardeau Muni AP (723489)
- Missouri, Columbia Rgnl AP (724450)
- Missouri, Farmington Rgnl AP (724454)
- Missouri, Jefferson City Mem AP (724458)
- Missouri, Joplin Muni AP (723495)
- Missouri, Kaiser-Lee Fine Mem AWOS (724459)
- Missouri, Kansas City Downtown AP (724463)
- Missouri, Kansas City Intl AP (724460)
- Missouri, Kirksville Muni AP (724455)
- Missouri, Poplar Bluff AWOS (723300)
- Missouri, Rolla National AP (724456)
- Missouri, Springfield Rgnl AP (724400)
- Missouri, St Joseph-Rosecrans Mem AP (724490)
- Missouri, St Louis-Lambert Intl AP (724340)
- Missouri, St Louis-Spirit of St Louis AP (724345)
- Missouri, Whiteman AFB (724467)

Montana

- Montana, Billings-Logan Intl AP (726770)
- Montana, Bozeman-Gallatin Field (726797)
- Montana, Butte-Bert Mooney AP (726785)
- Montana, Cut Bank Muni AP (727796)
- Montana, Glasgow Intl AP (727680)
- Montana, Glendive AWOS (726676)
- Montana, Great Falls Intl AP (727750)
- Montana, Havre City-County AP (727770)
- Montana, Helena Rgnl AP (727720)

- Montana, Kalispell-Glacier Park Intl AP (727790)
- Montana, Lewistown Muni AP (726776)
- Montana, Livingston-Mission Field (726798)
- Montana, Miles City Muni AP (742300)
- Montana, Missoula Intl AP (727730)
- Montana, Sidney-Richland Muni AP (727687)
- Montana, Wolf Point Intl AP (727686)

Nebraska

- Nebraska, Ainsworth Muni AP (725556)
- Nebraska, Alliance Muni AP (725635)
- Nebraska, Beatrice Muni AP (725515)
- Nebraska, Bellevue-Offutt AFB (725540)
- Nebraska, Broken Bow Muni AP (725555)
- Nebraska, Chadron Muni AP (725636)
- Nebraska, Columbus Muni AP (725565)
- Nebraska, Falls City-Brenner Field (725533)
- Nebraska, Fremont Muni AP (725564)
- Nebraska, Grand Island-Central Nebraska Rgnl AP (725520)
- Nebraska, Hastings Muni AP (725525)
- Nebraska, Holdrege-Brewster Field (725628)
- Nebraska, Imperial Muni AP (725626)
- Nebraska, Kearney Muni AWOS (725526)
- Nebraska, Lincoln Muni AP (725510)
- Nebraska, McCook Muni AP (725625)
- Nebraska, Norfolk-Karl Stefan Mem AP (725560)
- Nebraska, North Platte Rgnl AP (725620)
- Nebraska, ONeill-Baker Field (725566)
- Nebraska, Omaha WSFO (725530)
- Nebraska, Omaha-Eppley Airfield (725500)
- Nebraska, Ord-Sharp Field (725524)
- Nebraska, Scottsbluff-W B Heilig Field (725660)
- Nebraska, Sidney Muni AP (725610)
- Nebraska, Tekamah AWOS (725527)
- Nebraska, Valentine-Miller Field (725670)

Nevada

- Nevada, Elko Muni AP (725825)
- Nevada, Ely-Yelland Field (724860)
- Nevada, Fallon NAS (724885)
- Nevada, Las Vegas-McCarran Intl AP (723860)
- Nevada, Lovelock-Derby Field (725805)
- Nevada, Mercury-Desert Rock AP (723870)

- Nevada, Nellis AFB (723865)
- Nevada, Reno-Tahoe Intl AP (724880)
- Nevada, Tonopah AP (724855)
- Nevada, Winnemucca Muni AP (725830)

New Hampshire

- New Hampshire, Berlin Muni AP (726160)
- New Hampshire, Concord Muni AP (726050)
- New Hampshire, Keene-Dillant Hopkins AP (726165)
- New Hampshire, Laconia Muni AWOS (726155)
- New Hampshire, Lebanon Muni AP (726116)
- New Hampshire, Manchester Muni AP (743945)
- New Hampshire, Mount Washington (726130)
- New Hampshire, Pease Intl Tradeport (726055)

New Jersey

- New Jersey, Atlantic City Intl AP (724070)
- New Jersey, Belmar-Monmouth County AP (724084)
- New Jersey, Caldwell-Essex County AP (724094)
- New Jersey, Cape May County AP (745966)
- New Jersey, McGuire AFB (724096)
- New Jersey, Millville Muni AP (724075)
- New Jersey, Newark Intl AP (725020)
- New Jersey, Teterboro AP (725025)
- New Jersey, Trenton-Mercer County AP (724095)

New Mexico

- New Mexico, Albuquerque Intl AP (723650)
- New Mexico, Carlsbad Cavern City Air Terminal (722687)
- New Mexico, Clayton Muni AP (723600)
- New Mexico, Clovis Muni AWOS (722689)
- New Mexico, Clovis-Cannon AFB (722686)
- New Mexico, Deming Muni AP (722725)
- New Mexico, Farmington-Four Corners Rgnl AP (723658)
- New Mexico, Gallup-Sen Clarke Field (723627)
- New Mexico, Holloman AFB (747320)
- New Mexico, Las Cruces Intl AP (722695)
- New Mexico, Las Vegas-Muni AP (723677)
- New Mexico, Roswell Industrial Air Park (722680)
- New Mexico, Ruidoso-Sierra Blanca Rgnl AP (722683)
- New Mexico, Santa Fe County Muni AP (723656)
- New Mexico, Taos Muni AP (723663)
- New Mexico, Truth or Consequences Muni AP (722710)

- New Mexico, Tucumcari AP (723676)

New York

- New York, Albany County AP (725180)
- New York, Binghamton-Edwin A Link Field (725150)
- New York, Buffalo-Greater Buffalo Intl AP (725280)
- New York, Elmira Rgnl AP (725156)
- New York, Fort Drum-Wheeler Sack AAF (743700)
- New York, Glens Falls-Bennett Mem AP (725185)
- New York, Islip-Long Island MacArthur AP (725035)
- New York, Jamestown AWOS (725235)
- New York, Massena AP (726223)
- New York, Monticello AWOS (725145)
- New York, New York-Central Park (725033)
- New York, New York-J F Kennedy Intl AP (744860)
- New York, New York-LaGuardia AP (725030)
- New York, Newburgh-Stewart Intl AP (725038)
- New York, Niagara Falls Intl AP (725287)
- New York, Poughkeepsie-Dutchess County AP (725036)
- New York, Republic AP (744864)
- New York, Rochester-Greater Rochester Intl AP (725290)
- New York, Saranac Lake-Adirondack Rgnl AP (726228)
- New York, Syracuse-Hancock Intl AP (725190)
- New York, Utica-Oneida County AP (725197)
- New York, Watertown AP (726227)
- New York, Westhampton-Suffolk County AP (744865)
- New York, White Plains-Westchester County AP (725037)

North Carolina

- North Carolina, Asheville Rgnl AP (723150)
- North Carolina, Cape Hatteras (723040)
- North Carolina, Charlotte-Douglas Intl AP (723140)
- North Carolina, Cherry Point MCAS (723090)
- North Carolina, Elizabeth City CGAS (746943)
- North Carolina, Fayetteville Muni AP (723035)
- North Carolina, Fayetteville-Pope AFB (723030)
- North Carolina, Fort Bragg-Simmons AAF (746930)
- North Carolina, Goldsboro-Seymour Johnson AFB (723066)
- North Carolina, Greensboro-Piedmont Triad Intl AP (723170)
- North Carolina, Hickory Rgnl AP (723145)
- North Carolina, Jacksonville AWOS (723069)
- North Carolina, Kinston Stallings AFB (723067)
- North Carolina, Manteo-Dare County Rgnl AP (723046)

- North Carolina, New Bern-Craven County Rgnl AP (723095)
- North Carolina, New River MCAS (723096)
- North Carolina, Pitt Greenville AP (723065)
- North Carolina, Raleigh-Durham Intl AP (723060)
- North Carolina, Rocky Mount-Wilson AP (723068)
- North Carolina, Southern Pines-Moore County AP (723143)
- North Carolina, Wilimington Intl AP (723013)
- North Carolina, Winston Salem-Smith Reynolds AP (723193)

North Dakota

- North Dakota, Bismarck Muni AP (727640)
- North Dakota, Devils Lake AWOS (727573)
- North Dakota, Dickinson Muni AP (727645)
- North Dakota, Fargo-Hector Intl AP (727530)
- North Dakota, Grand Forks AFB (727575)
- North Dakota, Grand Forks Intl AP (727576)
- North Dakota, Jamestown Muni AP (727535)
- North Dakota, Minot AFB (727675)
- North Dakota, Minot Intl AP (727676)
- North Dakota, Williston-Sloulin Field Intl AP (727670)

Ohio

- Ohio, Akron Canton Rgnl AP (725210)
- Ohio, Cincinnati Muni AP-Lunken Field (724297)
- Ohio, Cleveland-Burke Lakefront AP (725245)
- Ohio, Cleveland-Hopkins Intl AP (725240)
- Ohio, Columbus-Port Columbus Intl AP (724280)
- Ohio, Dayton Intl AP (724290)
- Ohio, Findlay AP (725366)
- Ohio, Mansfield-Lahm Muni AP (725246)
- Ohio, Ohio State University AP (724288)
- Ohio, Toledo Express AP (725360)
- Ohio, Youngstown Rgnl AP (725250)
- Ohio, Zanesville Muni AP (724286)

Oklahoma

- Oklahoma, Altus AFB (723520)
- Oklahoma, Bartlesville-Phillips Field (723565)
- Oklahoma, Clinton Sherman AP (723526)
- Oklahoma, Fort Sill-Henry Post AAF (723550)
- Oklahoma, Gage AP (723527)
- Oklahoma, Hobart Muni AP (723525)
- Oklahoma, Lawton Muni AP (723575)

- Oklahoma, McAlester Rgnl AP (723566)
- Oklahoma, Oklahoma City-Tinker AFB (723540)
- Oklahoma, Oklahoma City-Wiley Post Field (723544)
- Oklahoma, Oklahoma City-Will Rogers World AP (723530)
- Oklahoma, Ponca City Muni AP (723546)
- Oklahoma, Stillwater Rgnl AP (723545)
- Oklahoma, Tulsa Intl AP (723560)
- Oklahoma, Vance AFB (723535)

Oregon

- Oregon, Astoria Rgnl AP (727910)
- Oregon, Aurora State AP (726959)
- Oregon, Baker Muni AP (726886)
- Oregon, Burns Muni AP (726830)
- Oregon, Corvallis Muni AP (726945)
- Oregon, Eugene-Mahlon Sweet AP (726930)
- Oregon, Klamath Falls Intl AP (725895)
- Oregon, La Grande Muni AP (726884)
- Oregon, Lakeview AWOS (725976)
- Oregon, Medford-Rogue Valley Intl AP (725970)
- Oregon, North Bend Muni AP (726917)
- Oregon, Pendleton-Eastern Oregon Rgnl AP (726880)
- Oregon, Portland Intl AP (726980)
- Oregon, Portland-Hillsboro AP (726986)
- Oregon, Portland-Troutdale AP (726985)
- Oregon, Redmond-Roberts Field (726835)
- Oregon, Roseburg Rgnl AP (726904)
- Oregon, Salem-McNary Field (726940)
- Oregon, Sexton Summit (725975)

Pennsylvania

- Pennsylvania, Allentown-Lehigh Valley Intl AP (725170)
- Pennsylvania, Altoona-Blair County AP (725126)
- Pennsylvania, Bradford Rgnl AP (725266)
- Pennsylvania, Butler County AWOS (725124)
- Pennsylvania, DuBois-Jefferson County AP (725125)
- Pennsylvania, Erie Intl AP (725260)
- Pennsylvania, Franklin-Chess Lemberton AP (725267)
- Pennsylvania, Harrisburg Intl AP (725115)
- Pennsylvania, Harrisburg-Capital City AP (725118)
- Pennsylvania, Johnstown-Cambria County AP (725127)
- Pennsylvania, Lancaster AP (725116)
- Pennsylvania, Philadelphia Intl AP (724080)

- Pennsylvania, Philadelphia-NE Philadelphia AP (724085)
- Pennsylvania, Pittsburgh Intl AP (725200)
- Pennsylvania, Pittsburgh-Allegheny County AP (725205)
- Pennsylvania, Reading Mem AP-Spaatz Field (725103)
- Pennsylvania, State College-Penn State University (725128)
- Pennsylvania, Washington AWOS (725117)
- Pennsylvania, Wilkes-Barre-Scranton Intl AP (725130)
- Pennsylvania, Williamsport Rgnl AP (725140)
- Pennsylvania, Willow Grove NAS (724086)

Rhode Island

- Rhode Island, Block Island State AP (725058)
- Rhode Island, Pawtucket AWOS (725054)
- Rhode Island, Providence-T F Green State AP (725070)

South Carolina

- South Carolina, Anderson County AP (723125)
- South Carolina, Beaufort MCAS (722085)
- South Carolina, Charleston Intl AP (722080)
- South Carolina, Columbia Metro AP (723100)
- South Carolina, Florence Rgnl AP (723106)
- South Carolina, Greenville-Downtown AP (723119)
- South Carolina, Greer Greenville-Spartanburg AP (723120)
- South Carolina, Myrtle Beach AFB (747910)
- South Carolina, North Myrtle Beach-Grand Strand Field (747915)
- South Carolina, Shaw AFB (747900)

South Dakota

- South Dakota, Aberdeen Rgnl AP (726590)
- South Dakota, Brookings AWOS (726515)
- South Dakota, Ellsworth AFB (726625)
- South Dakota, Huron Rgnl AP (726540)
- South Dakota, Mitchell AWOS (726545)
- South Dakota, Mobridge Muni AP (726685)
- South Dakota, Pierre Muni AP (726686)
- South Dakota, Rapid City Rgnl AP (726620)
- South Dakota, Sioux Falls-Foss Field (726510)
- South Dakota, Watertown Muni AP (726546)
- South Dakota, Yankton-Chan Gurney Muni AP (726525)

Tennessee

- Tennessee, Bristol-TriCities Rgnl AP (723183)

- Tennessee, Chattanooga-Lovell Field AP (723240)
- Tennessee, Crossville Mem AP (723265)
- Tennessee, Dyersburg Muni AP (723347)
- Tennessee, Jackson-McKellar Sipes Rgnl AP (723346)
- Tennessee, Knoxville-McGhee Tyson AP (723260)
- Tennessee, Memphis Intl AP (723340)
- Tennessee, Nashville Intl AP (723270)

Texas

- Texas, Abilene Rgnl AP (722660)
- Texas, Abilene-Dyess AFB (690190)
- Texas, Alice Intl AP (722517)
- Texas, Amarillo Intl AP (723630)
- Texas, Austin-Camp Mabry (722544)
- Texas, Austin-Mueller Muni AP (722540)
- Texas, Brownsville-South Padre Island AP (722500)
- Texas, Childress Muni AP (723604)
- Texas, College Station-Easterwood Field (722445)
- Texas, Corpus Christi Intl AP (722510)
- Texas, Corpus Christi NAS (722515)
- Texas, Cotulla AP (722526)
- Texas, Cox Field (722587)
- Texas, Dalhart Muni AP (722636)
- Texas, Dallas-Addison AP (722598)
- Texas, Dallas-Fort Worth Intl AP (722590)
- Texas, Dallas-Love Field (722583)
- Texas, Dallas-Redbird AP (722599)
- Texas, Del Rio (722610)
- Texas, Del Rio-Laughlin AFB (722615)
- Texas, Draughon-Miller Central Texas AP (722577)
- Texas, El Paso Intl AP (722700)
- Texas, Fort Hood (722570)
- Texas, Fort Worth NAS (722595)
- Texas, Fort Worth-Alliance AP (722594)
- Texas, Fort Worth-Meacham AP (722596)
- Texas, Galveston (722420)
- Texas, Georgetown AWOS (722547)
- Texas, Greenville Muni AP (722588)
- Texas, Harlingen-Valley Intl AP (722505) -
- Texas, Hondo Muni AP (722533)
- Texas, Houston-Bush Intercontinental AP (722430)
- Texas, Houston-D W Hooks AP (722429)
- Texas, Houston-Ellington AFB (722436)

- Texas, Houston-William P Hobby AP (722435)
- Texas, Killeen Muni AWOS (722575)
- Texas, Kingsville (722516)
- Texas, Laredo Intl AP (722520)
- Texas, Longview-Gregg County AP (722470)
- Texas, Lubbock Intl AP (722670)
- Texas, Lufkin-Angelina Co AP (722446)
- Texas, Marfa AP (722640)
- Texas, McAllen-Miller Intl AP (722506)
- Texas, McGregor AWOS (722563)
- Texas, Midland Intl AP (722650)
- Texas, Mineral Wells Muni AP (722597)
- Texas, Nacogdoches AWOS (722499)
- Texas, Palacios Muni AP (722555)
- Texas, Port Arthur-Jefferson Co AP (722410)
- Texas, Randolph AFB (722536)
- Texas, Rockport-Aransas Co AP (722524)
- Texas, San Angelo-Mathis AP (722630)
- Texas, San Antonio Intl AP (722530)
- Texas, San Antonio-Kelly AFB (722535)
- Texas, San Antonio-Stinson AP (722523)
- Texas, Tyler-Pounds Field (722448)
- Texas, Victoria Rgnl AP (722550)
- Texas, Waco Rgnl AP (722560)
- Texas, Wichita Falls Muni AP (723510)
- Texas, Wink-Winkler County AP (722656)

Utah

- Utah, Blanding Muni AP (724723)
- Utah, Bryce Canyon AP (724756)
- Utah, Cedar City Muni AP (724755)
- Utah, Delta Muni AP (724795)
- Utah, Hanksville AP (724735)
- Utah, Moab-Canyonlands Field (724776)
- Utah, Ogden-Hill AFB (725755)
- Utah, Ogden-Hinkley AP (725750)
- Utah, Provo Muni AWOS (725724)
- Utah, Saint George AWOS (724754)
- Utah, Salt Lake City Intl AP (725720)
- Utah, Vernal AP (725705)
- Utah, Wendover USAF Auxiliary Field (725810)

Vermont

- Vermont, Burlington Intl AP (726170)
- Vermont, Montpelier AP (726145)
- Vermont, Rutland State AP (725165)
- Vermont, Springfield-Hartnes State AP (726115)

Virginia

- Virginia, Abingdon-Virginia Highlands AP (724058)
- Virginia, Arlington-Ronald Reagan Washington Natl AP (724050)
- Virginia, Blacksburg-Virginia Tech AP (724113)
- Virginia, Charlottesville-Albemarle County AP (724016)
- Virginia, Danville Rgnl AP (724106)
- Virginia, Davison AAF (724037)
- Virginia, Farmville Muni AP (724017)
- Virginia, Franklin Muni AP (723083)
- Virginia, Fredericksburg-Shannon AP (724033)
- Virginia, Hillsville-Twin County AP (724107)
- Virginia, Hot Springs-Ingalls Field (724115)
- Virginia, Langley AFB (745980)
- Virginia, Leesburg Muni AP-Godfrey Field (724055)
- Virginia, Lynchburg Rgnl AP-Preston Glen Field (724100)
- Virginia, Manassas Muni AWOS (724036)
- Virginia, Marion-Wytheville-Mountain Empire AP (724056)
- Virginia, Martinsville-Blue Ridge AP (745985)
- Virginia, Melfa-Accomack County AP (724026)
- Virginia, Newport News (723086)
- Virginia, Norfolk Intl AP (723080)
- Virginia, Norfolk NAS (723085)
- Virginia, Oceana NAS (723075)
- Virginia, Pulaski-New River Valley AP (724116)
- Virginia, Quantico MCAS (724035)
- Virginia, Richmond Intl AP (724010)
- Virginia, Roanoke Rgnl AP-Woodrum Field (724110)
- Virginia, Staunton-Shenandoah Valley Rgnl AP (724105)
- Virginia, Sterling-Washington Dulles Intl AP (724030)
- Virginia, Winchester Rgnl AP (724053)
- Virginia, Wise-Lonesome Pine AP (724117)

Washington

- Washington, Bellingham Intl AP (727976)
- Washington, Bremerton National AP (727928)
- Washington, Ephrata Muni AP (727826)
- Washington, Fairchild AFB (727855)
- Washington, Fort Lewis-Gray AAF (742070)

- Washington, Hanford (727840)
- Washington, Hoquiam AP (727923)
- Washington, Kelso AP (727924)
- Washington, Moses Lake-Grant County AP (727827)
- Washington, Olympia AP (727920)
- Washington, Pasco-Tri Cities AP (727845)
- Washington, Port Angeles-William R Fairchild Intl AP (727885)
- Washington, Pullman-Moscow Rgnl AP (727857)
- Washington, Quillayute State AP (727970)
- Washington, Renton Muni AP (727934)
- Washington, Seattle-Boeing Field (727935)
- Washington, Seattle-Tacoma Intl AP (727930)
- Washington, Snohomish County AP (727937)
- Washington, Spokane Intl AP (727850)
- Washington, Spokane-Felts Field (727856)
- Washington, Stampede Pass (727815)
- Washington, Tacoma Narrows AP (727938)
- Washington, Tacoma-McChord AFB (742060)
- Washington, The Dalles Muni AP (726988)
- Washington, Toledo-Winlock-Ed Carlson Mem AP (727926)
- Washington, Walla Walla City-County AP (727846)
- Washington, Wenatchee-Pangborn Mem AP (727825)
- Washington, Whidbey Island NAS (690230)
- Washington, Yakima Air Terminal-McAllister Field (727810)

West Virginia

- West Virginia, Beckley-Raleigh County Mem AP (724120)
- West Virginia, Bluefield-Mercer County AP (724125)
- West Virginia, Charleston-Yeager AP (724140)
- West Virginia, Clarksburg-Harrison Marion Rgnl AP (724175)
- West Virginia, Elkins-Randolph County AP (724170)
- West Virginia, Huntington-Tri State Walker Long Field (724250)
- West Virginia, Lewisburg-Greenbrier Valley AP (724127)
- West Virginia, Martinsburg-Eastern WV Rgnl AP (724177)
- West Virginia, Morgantown Muni-Hart Field (724176)
- West Virginia, Parkersburg-Wood County-Gill Robb Wilson AP (724273)
- West Virginia, Wheeling-Ohio County AP (724275)

Wisconsin

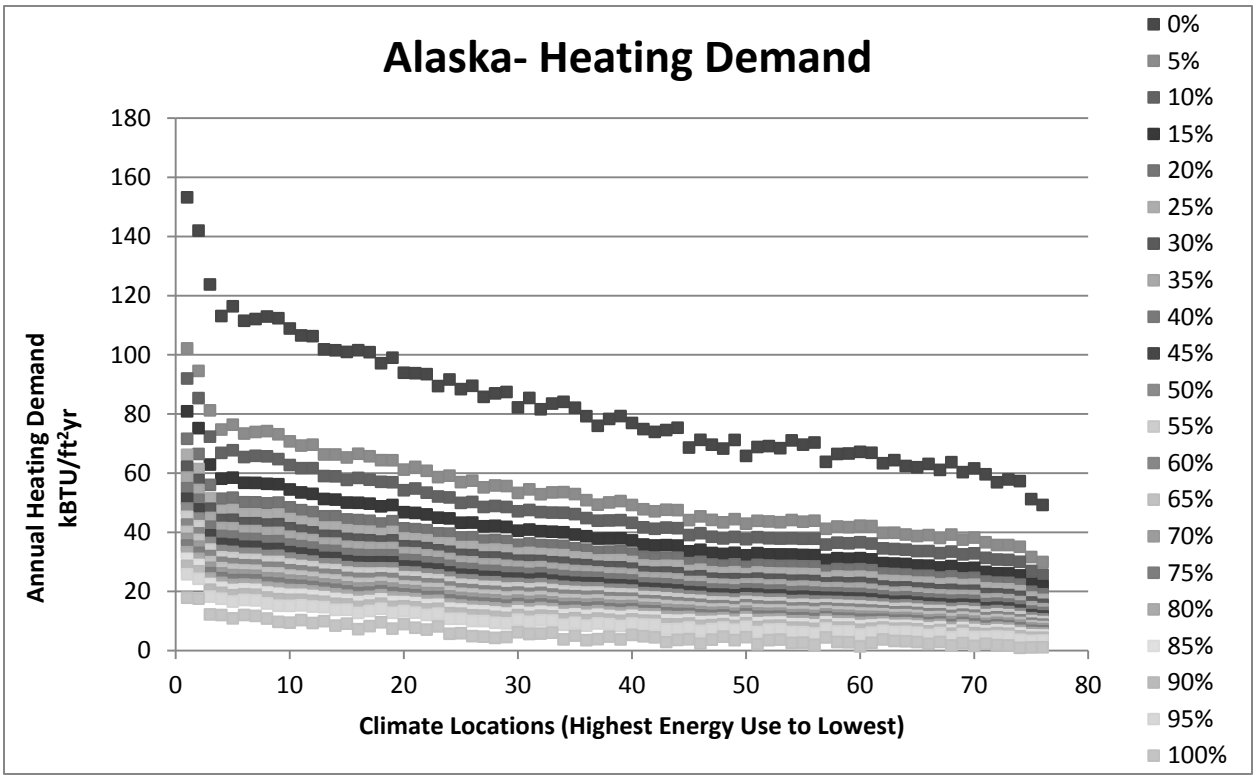
- Wisconsin, Appleton-Outagamie County AP (726457)
- Wisconsin, Eau Claire County AP (726435)
- Wisconsin, Green Bay-Austin Straubel Intl AP (726450)
- Wisconsin, Janesville-Rock County AP (726415)

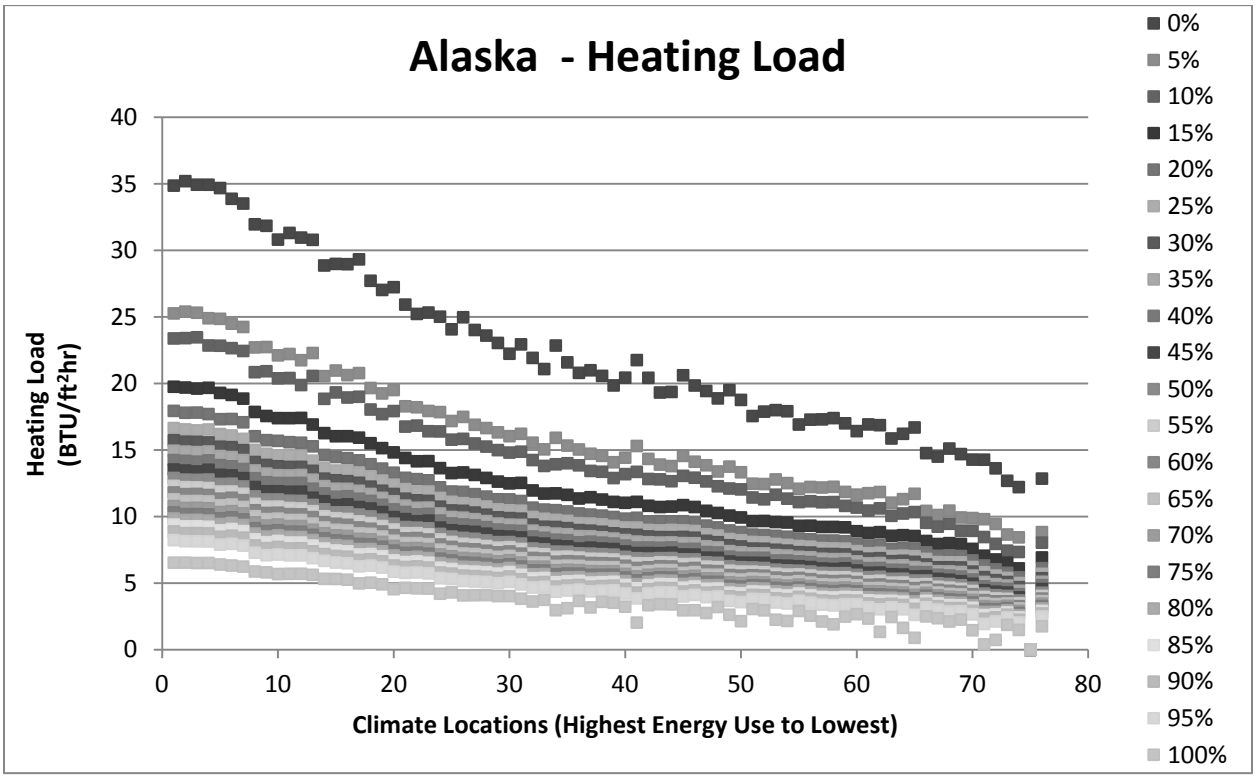
- Wisconsin, La Crosse Muni AP (726430)
- Wisconsin, Lone Rock AP (726416)
- Wisconsin, Madison-Dane County Rgnl AP (726410)
- Wisconsin, Manitowac Muni AWOS (726455)
- Wisconsin, Marshfield Muni AP (726574)
- Wisconsin, Milwaukee-Mitchell Intl AP (726400)
- Wisconsin, Minocqua-Woodruff-Lee Field (726404)
- Wisconsin, Mosinee-Central Wisconsin AP (726465)
- Wisconsin, Phillips-Price County AP (726468)
- Wisconsin, Rhinelander-Oneida County AP (727415)
- Wisconsin, Rice Lake Muni AP (726467)
- Wisconsin, Sturgeon Bay-Door County AP (726458)
- Wisconsin, Watertown Muni AP (726464)
- Wisconsin, Wausau Muni AP (726463)
- Wisconsin, Wittman Rgnl AP (726456)

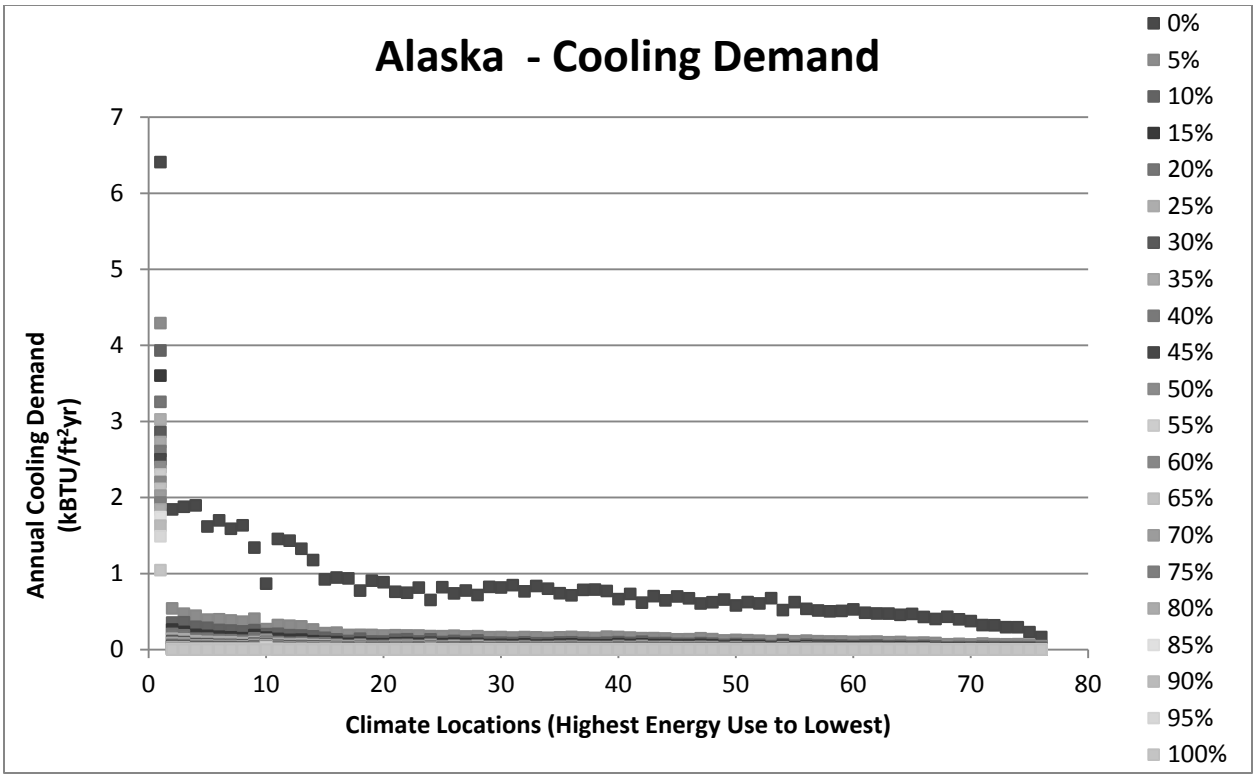
Wyoming

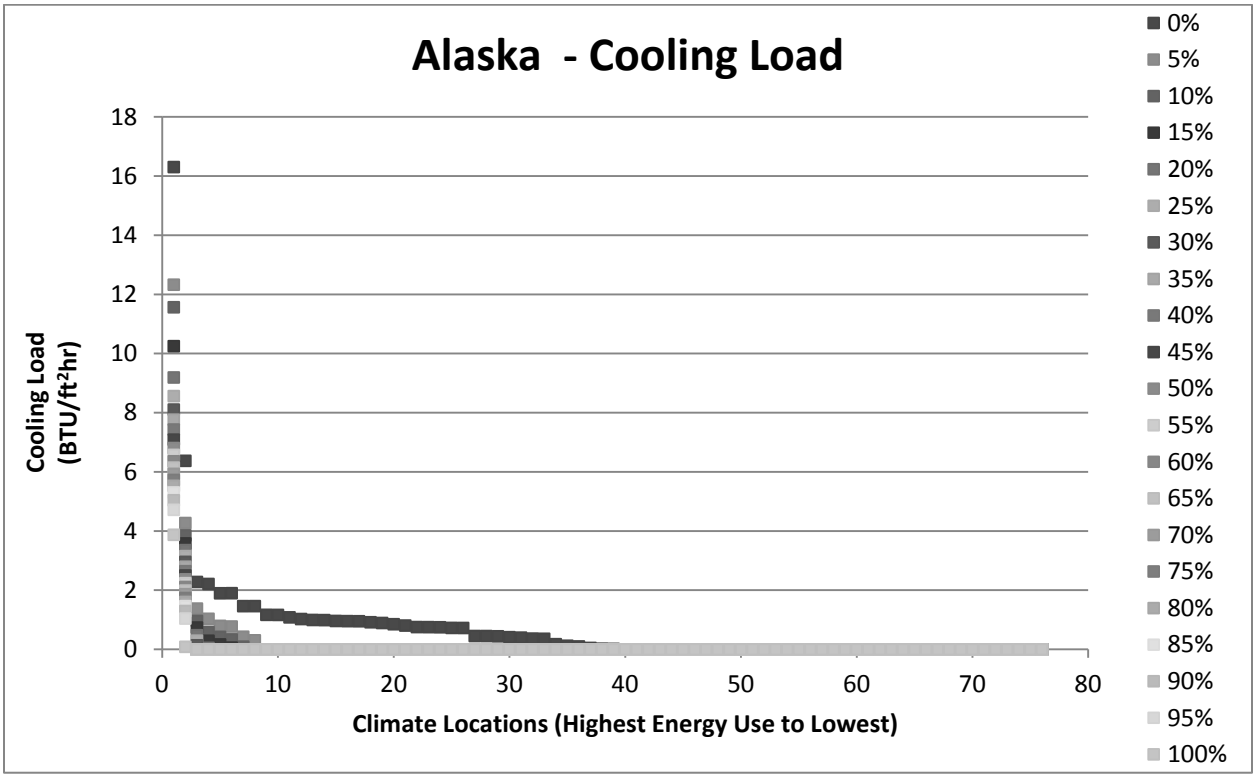
- Wyoming, Casper-Natrona County Intl AP (725690)
- Wyoming, Cheyenne Muni AP (725640)
- Wyoming, Cody Muni AWOS (726700)
- Wyoming, Evanston-Uinta County AP-Burns Field (725775)
- Wyoming, Gillette-Gillette County AP (726650)
- Wyoming, Green River-Greater Green River Intergalactic Spaceport (725744)
- Wyoming, Jackson Hole AP (725776)
- Wyoming, Lander-Hunt Field (725760)
- Wyoming, Laramie-General Brees Field (725645)
- Wyoming, Rawlins Muni AP (725745)
- Wyoming, Riverton Rgnl AP (725765)
- Wyoming, Sheridan County AP (726660)
- Wyoming, Worland Muni AP (726665)

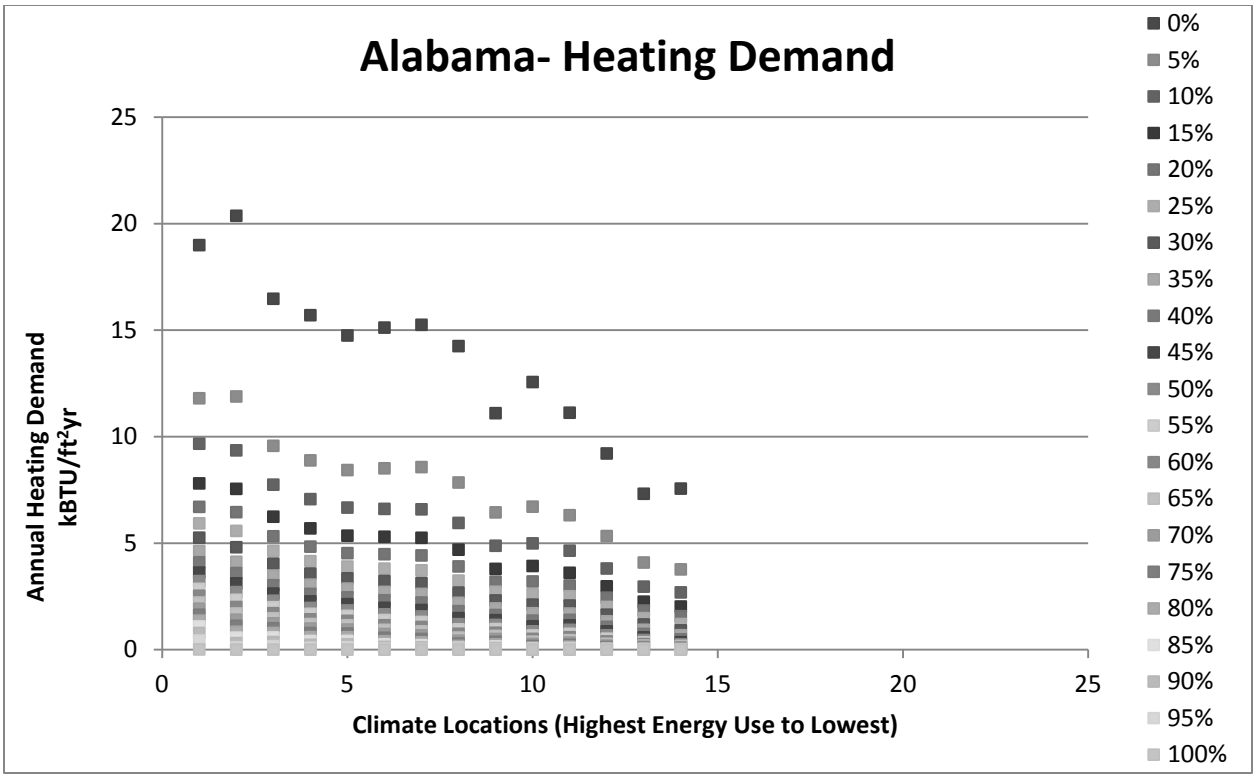
Appendix D: Figures (Every Five Percent)

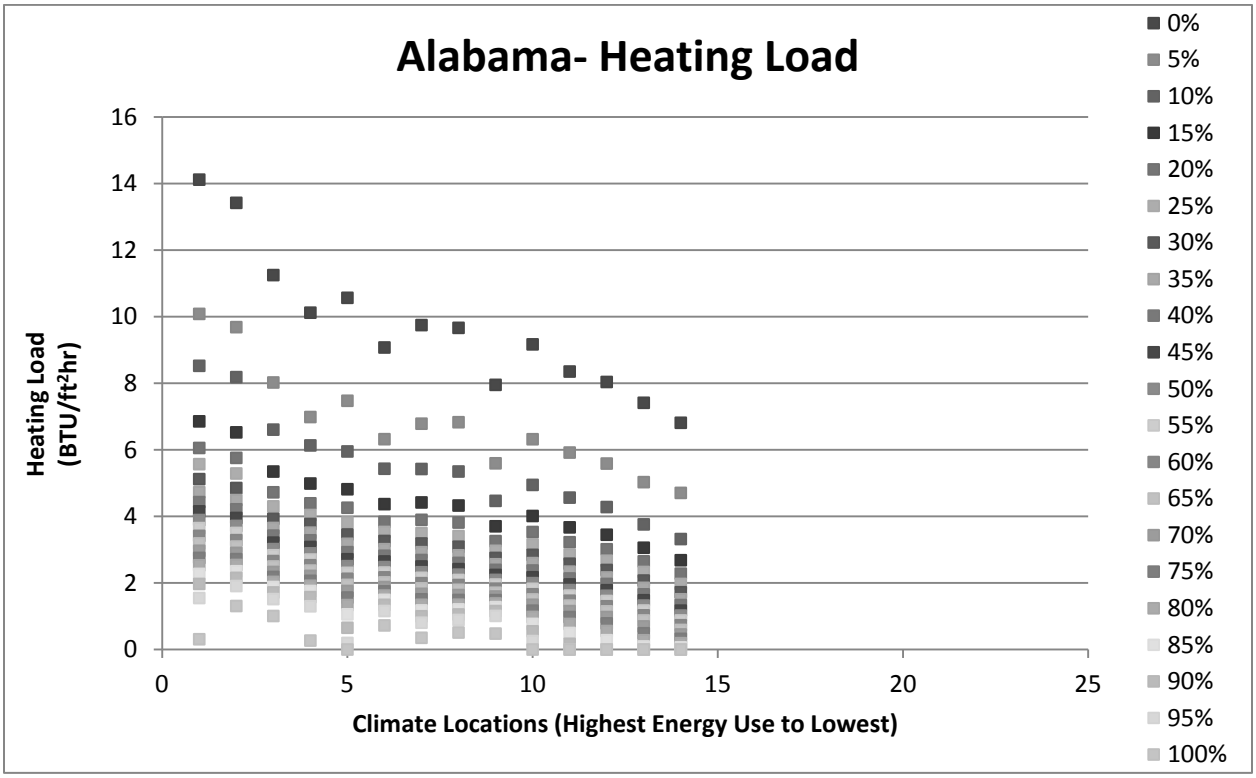


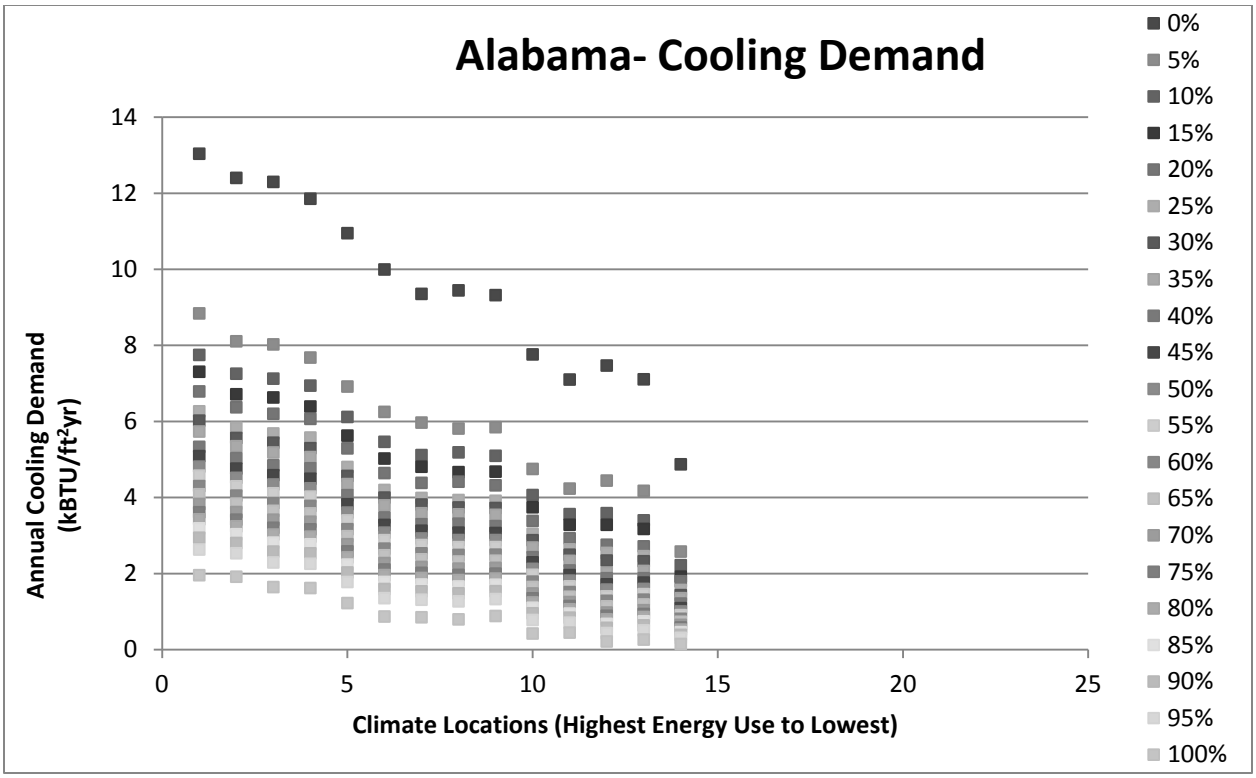


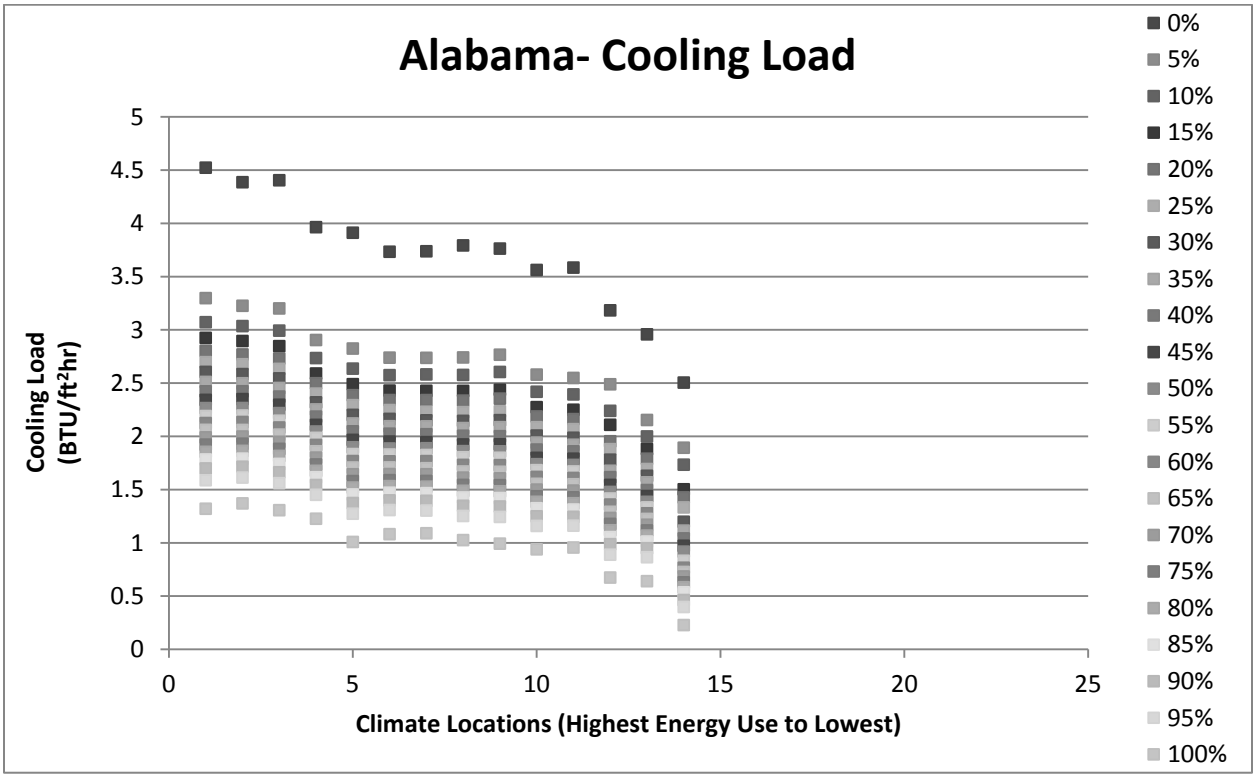

Alaska - Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
0
1
2
3
4
5
6
7
0
10
20
30
40
50
60
70
80
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

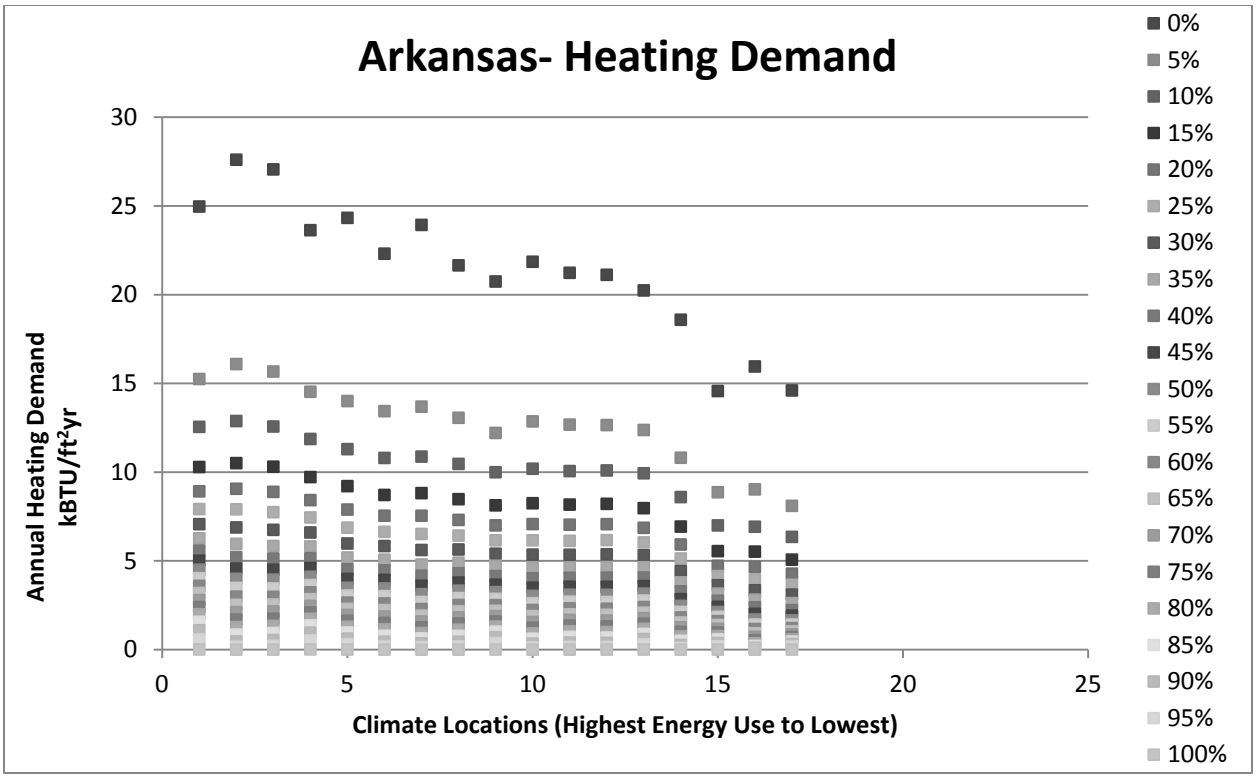

Alaska - Cooling Load
Cooling Load (BTU/ft²hr)
0
2
4
6
8
10
12
14
16
18
0
10
20
30
40
50
60
70
80
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

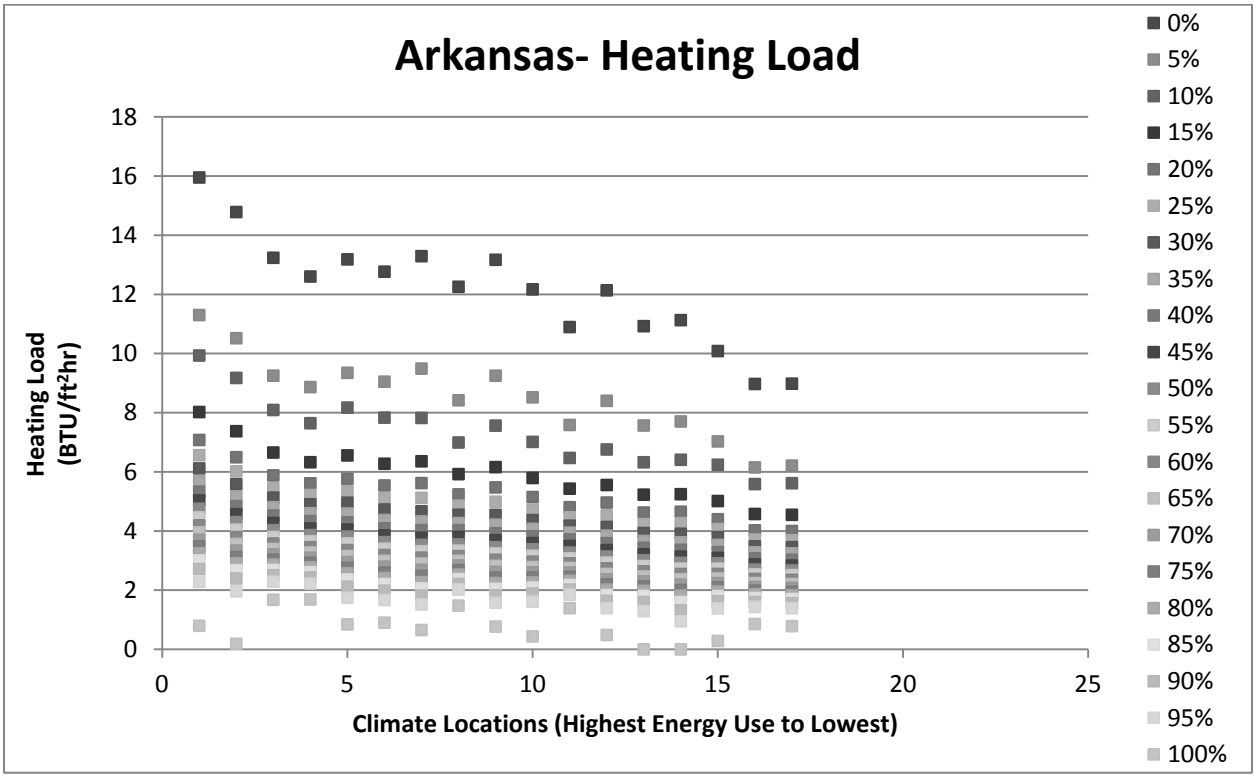

Alabama- Heating Demand
Annual Heating Demand kBTU/ft²yr
Climate Locations (Highest Energy Use to Lowest)
0
5
10
15
20
25
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

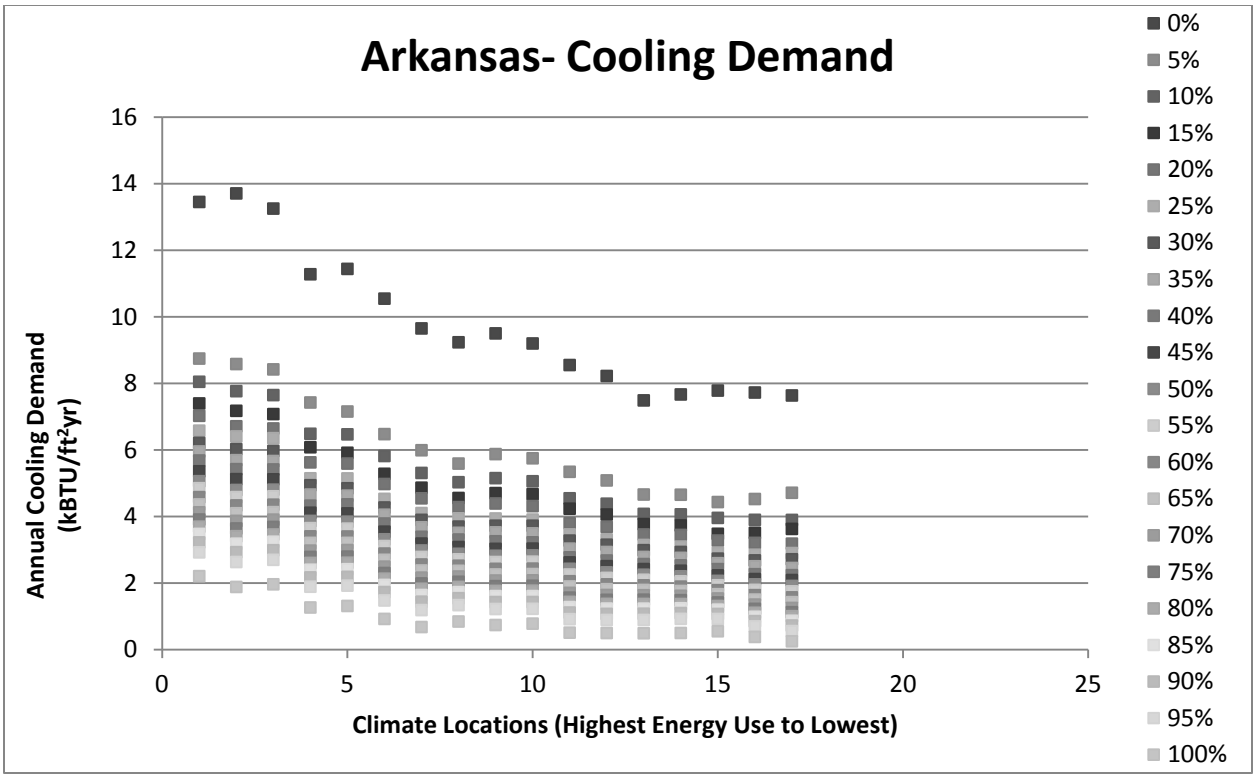

Alabama- Heating Load
Heating Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0
2
4
6
8
10
12
14
16
0
5
10
15
20
25
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%


Alabama- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%


Alabama- Cooling Load
Cooling Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%


Arkansas- Heating Demand
Annual Heating Demand kBTU/ft²yr
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%


Arkansas- Heating Load
Heating Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%


Arkansas- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
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75%
80%
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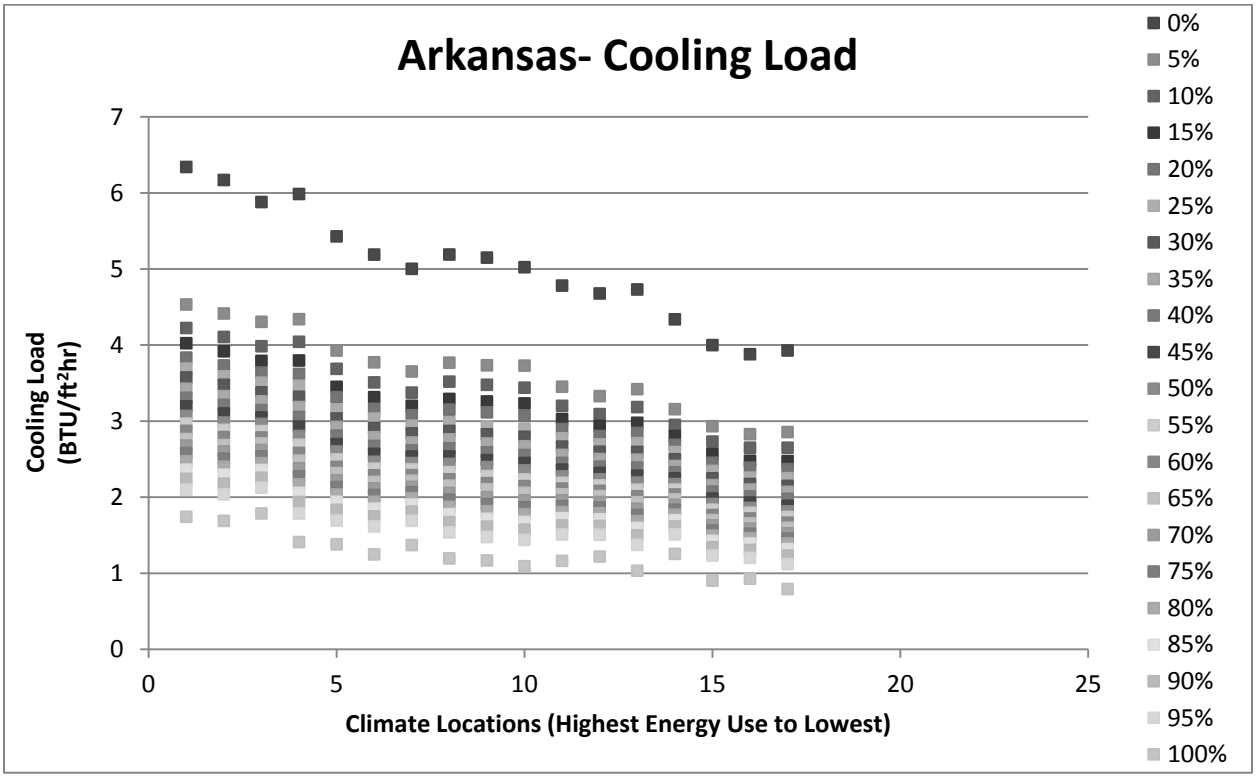
Arkansas- Cooling Load
Cooling Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
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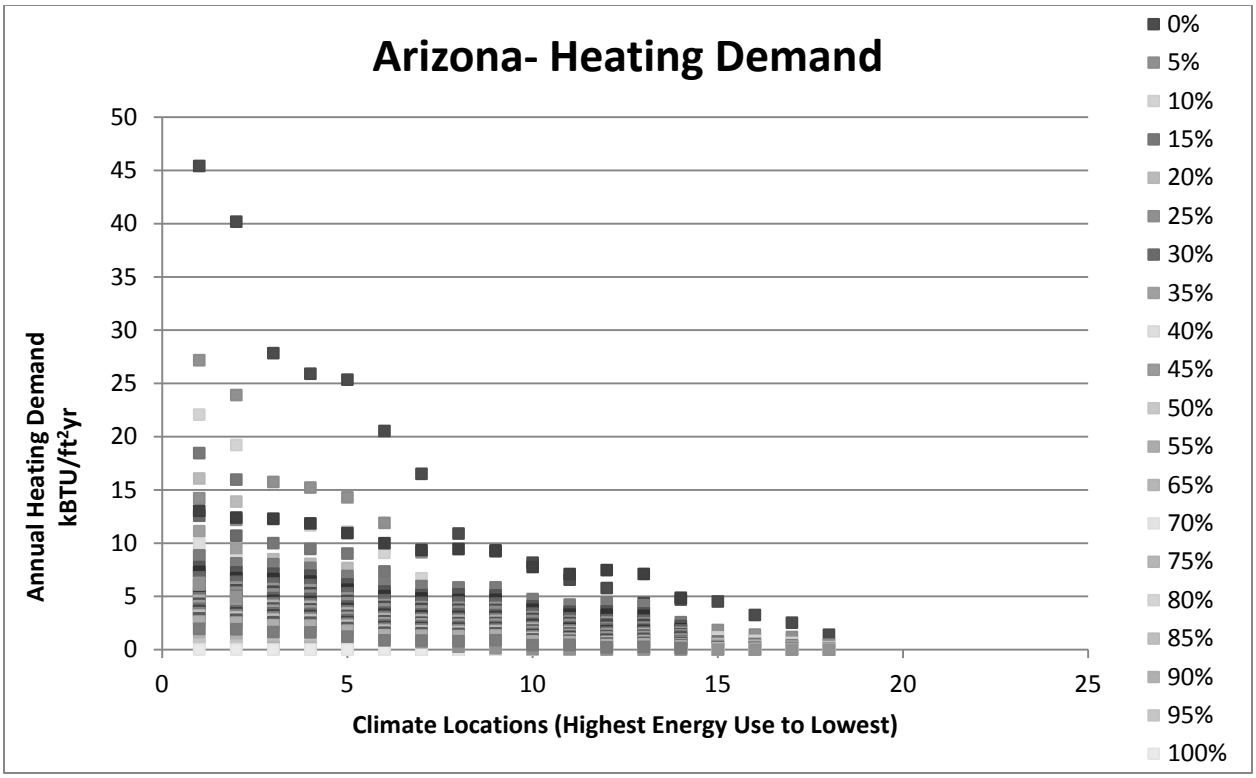
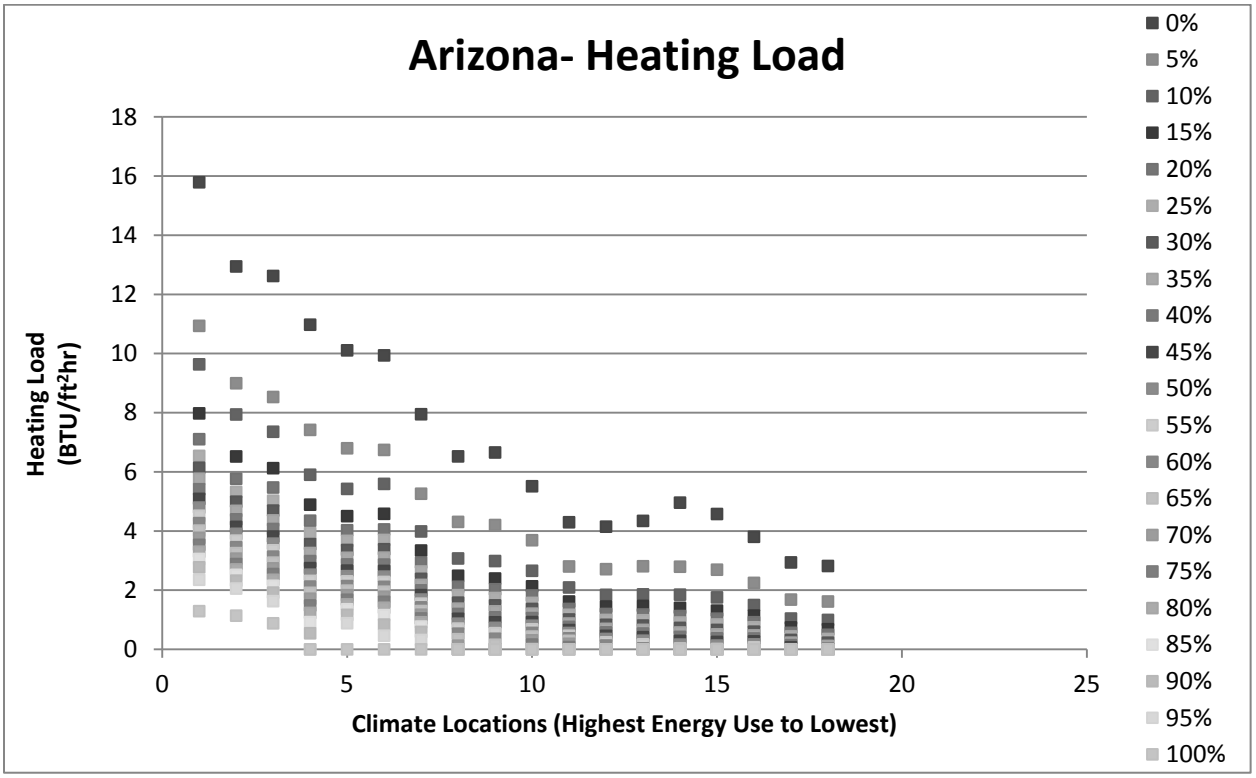
95%
100%


Arizona- Heating Demand
Annual Heating Demand kBTU/ft²yr
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
65%
70%
75%
80%
85%
90%
95%
100%


Arizona- Heating Load
Heating Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
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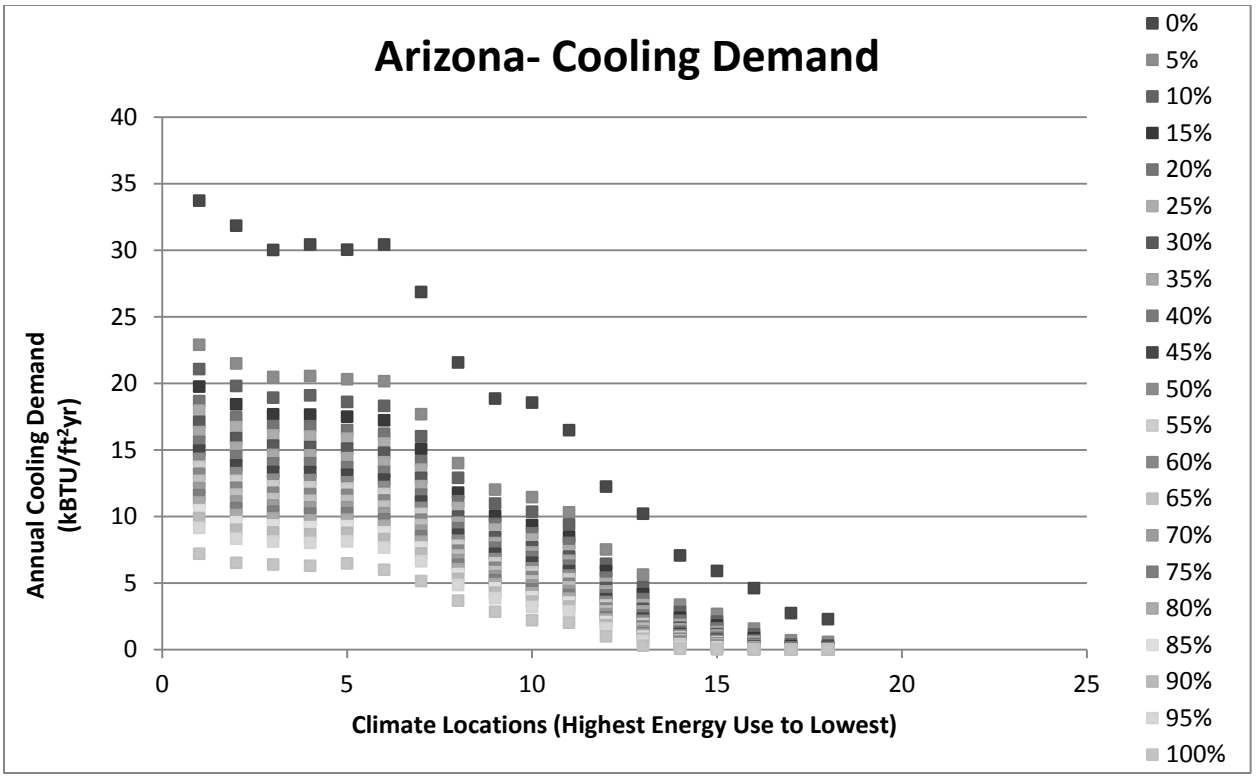
100%


Arizona- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
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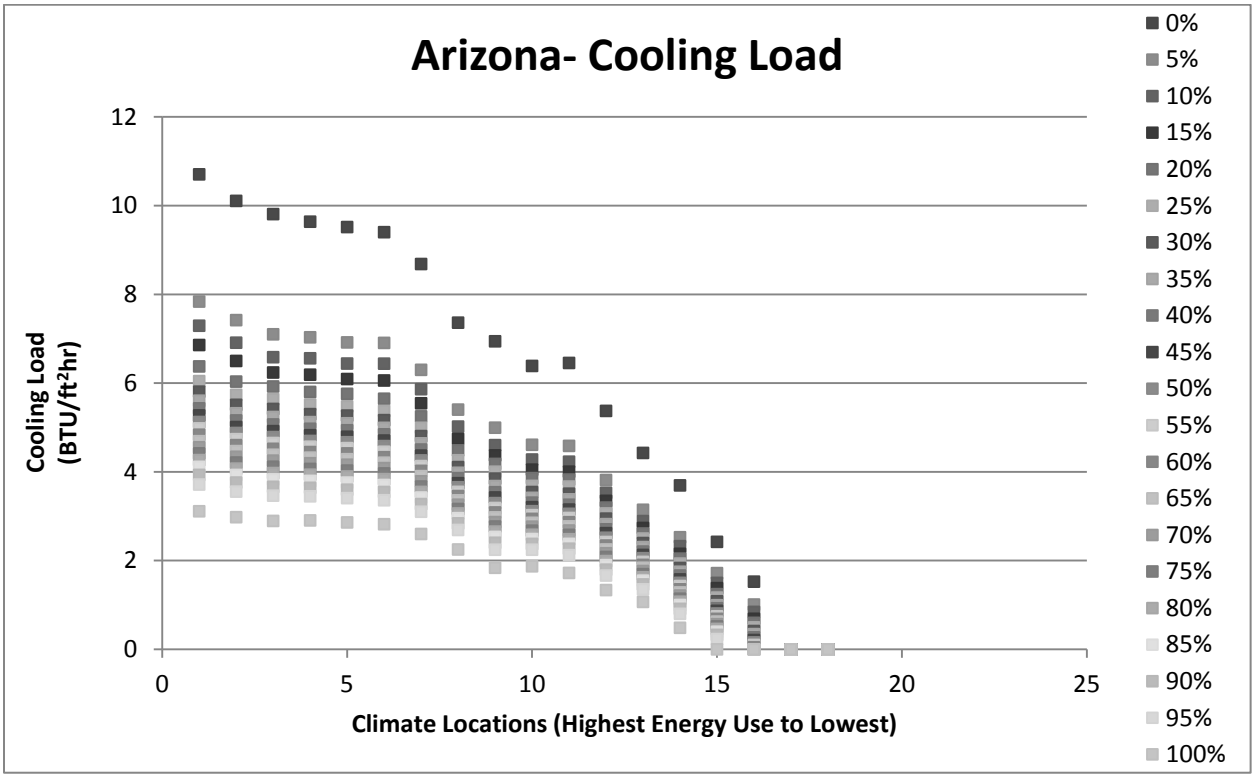
Arizona- Cooling Load
Cooling Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
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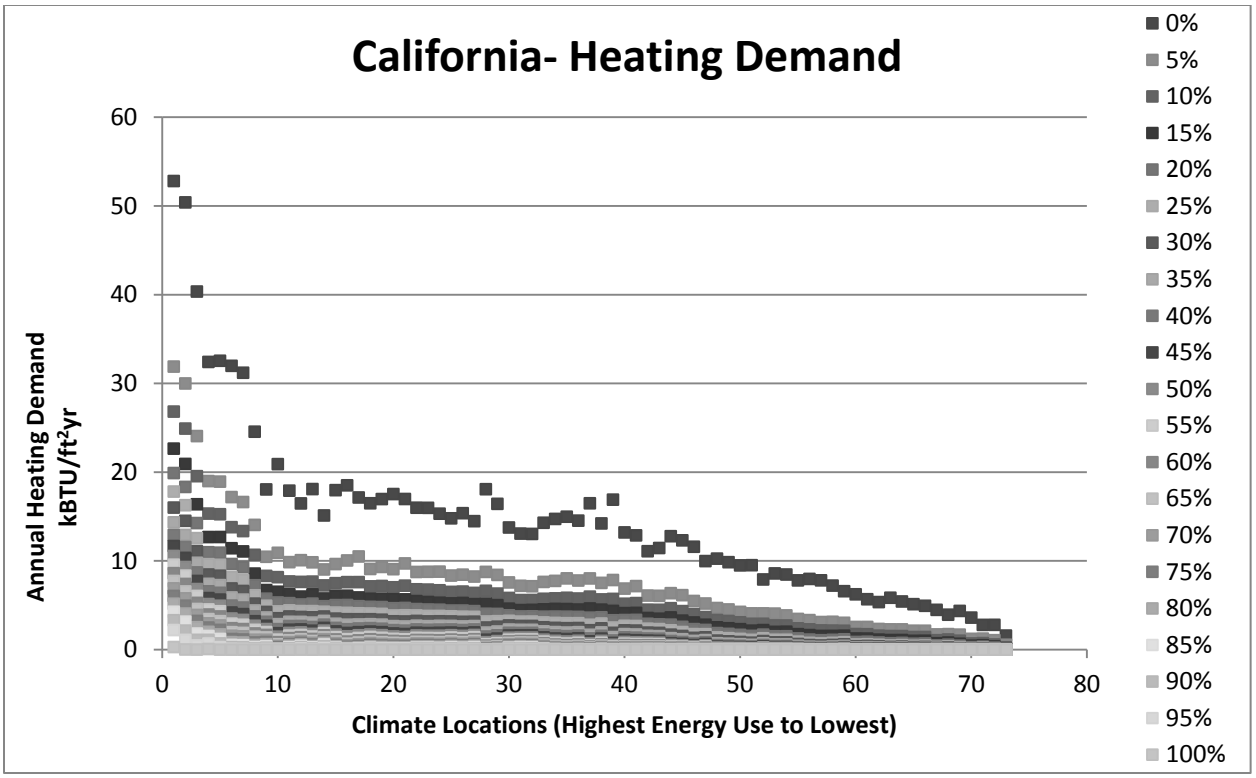
California- Heating Demand
Annual Heating Demand kBTU/ft²yr
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
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20%
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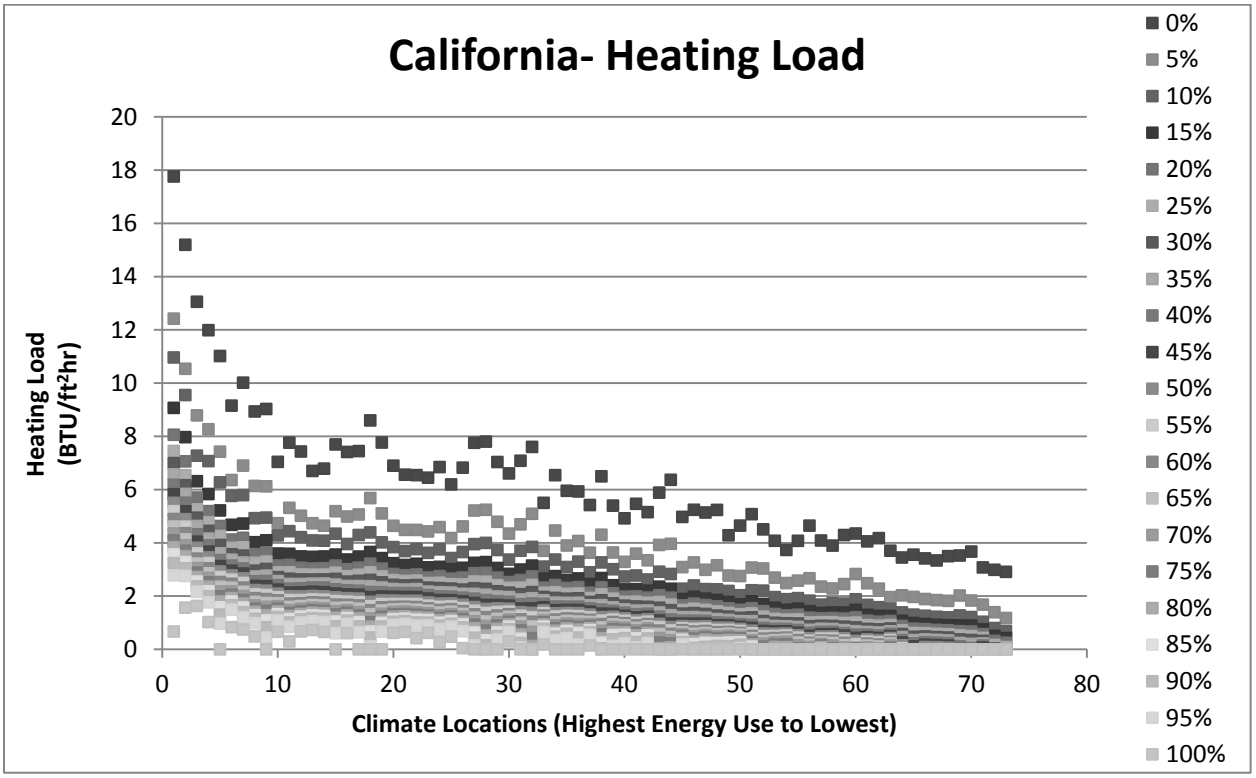
California- Heating Load
Heating Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
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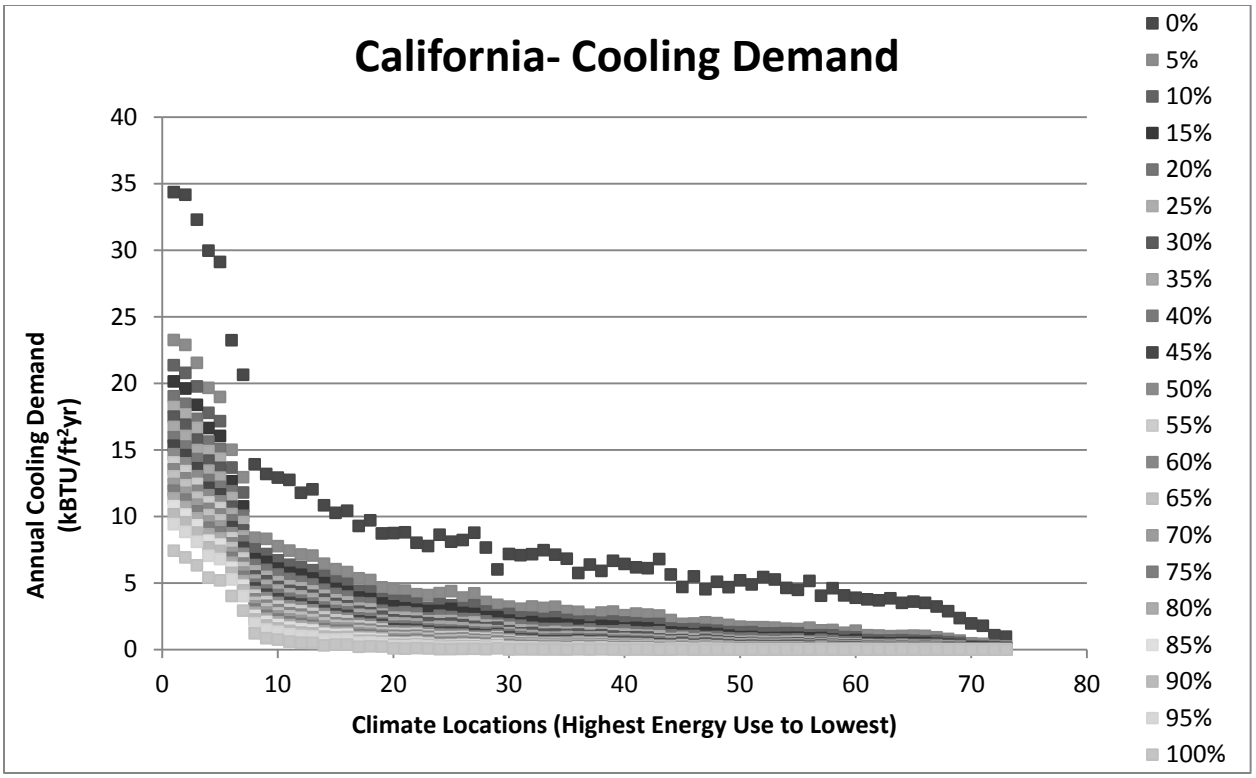
California- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
Climate Locations (Highest Energy Use to Lowest)
0%
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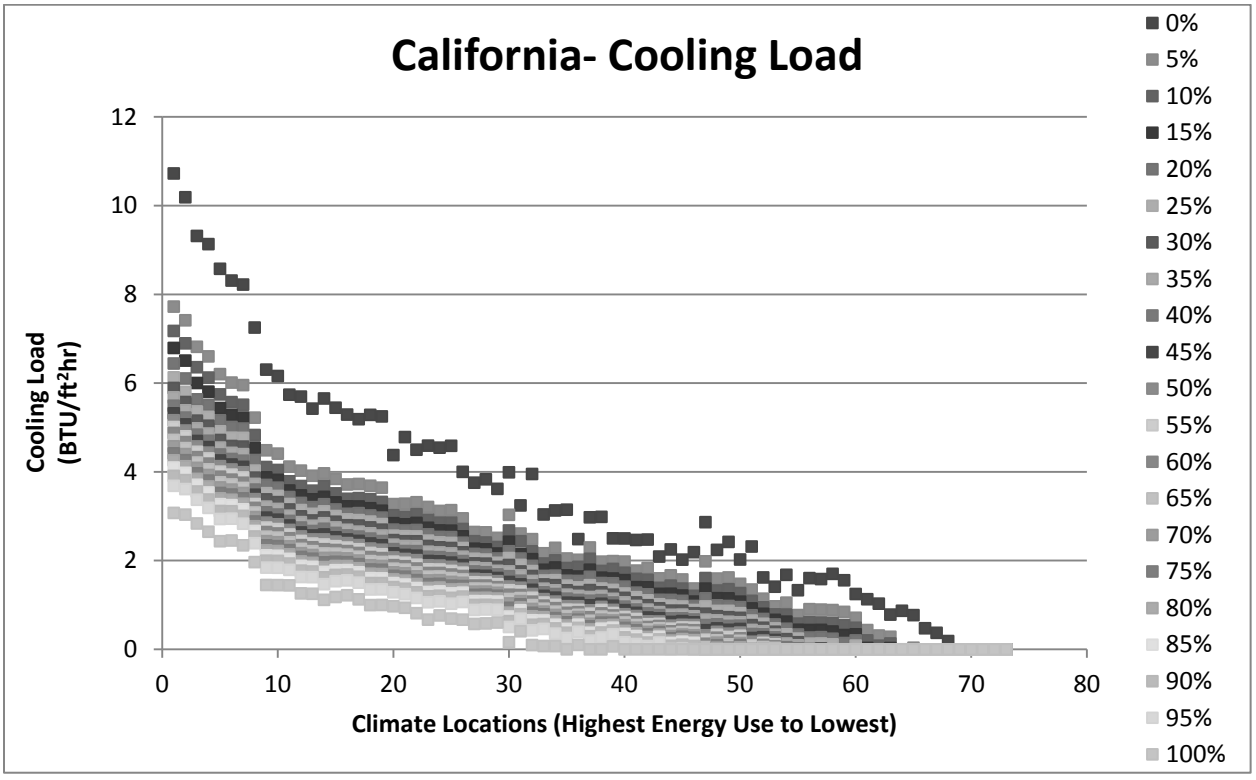
California- Cooling Load
Cooling Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
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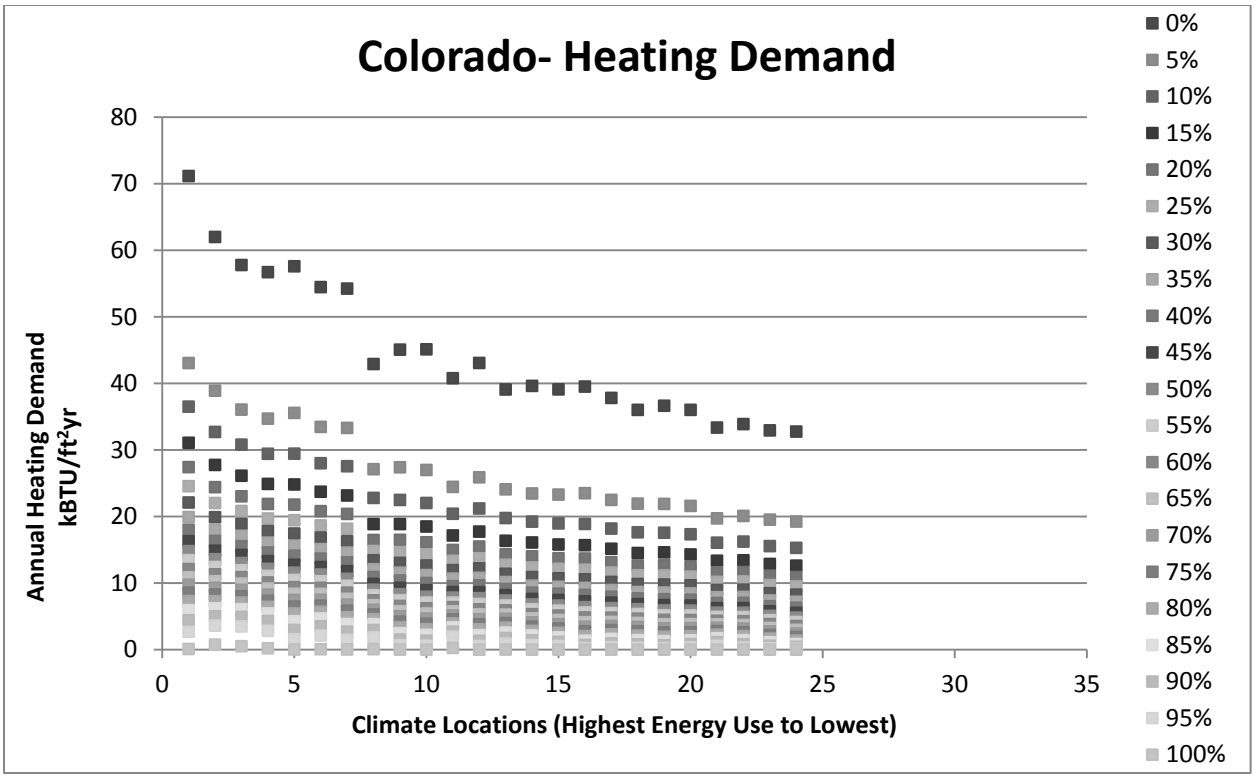
Colorado- Heating Demand
Annual Heating Demand kBTU/ft²yr
0
10
20
30
40
50
60
70
80
0
5
10
15
20
25
30
35
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
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55%
60%
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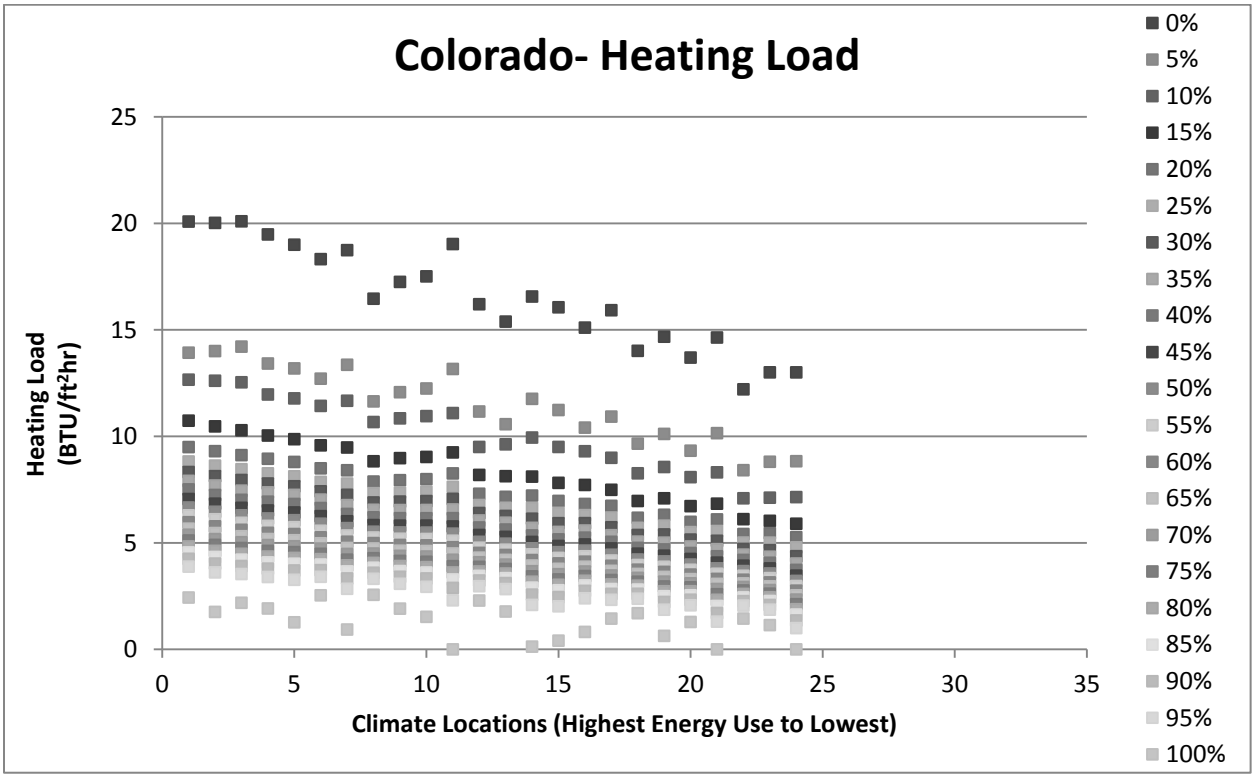
Colorado- Heating Load
Heating Load (BTU/ft²hr)
0
5
10
15
20
25
0
5
10
15
20
25
30
35
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
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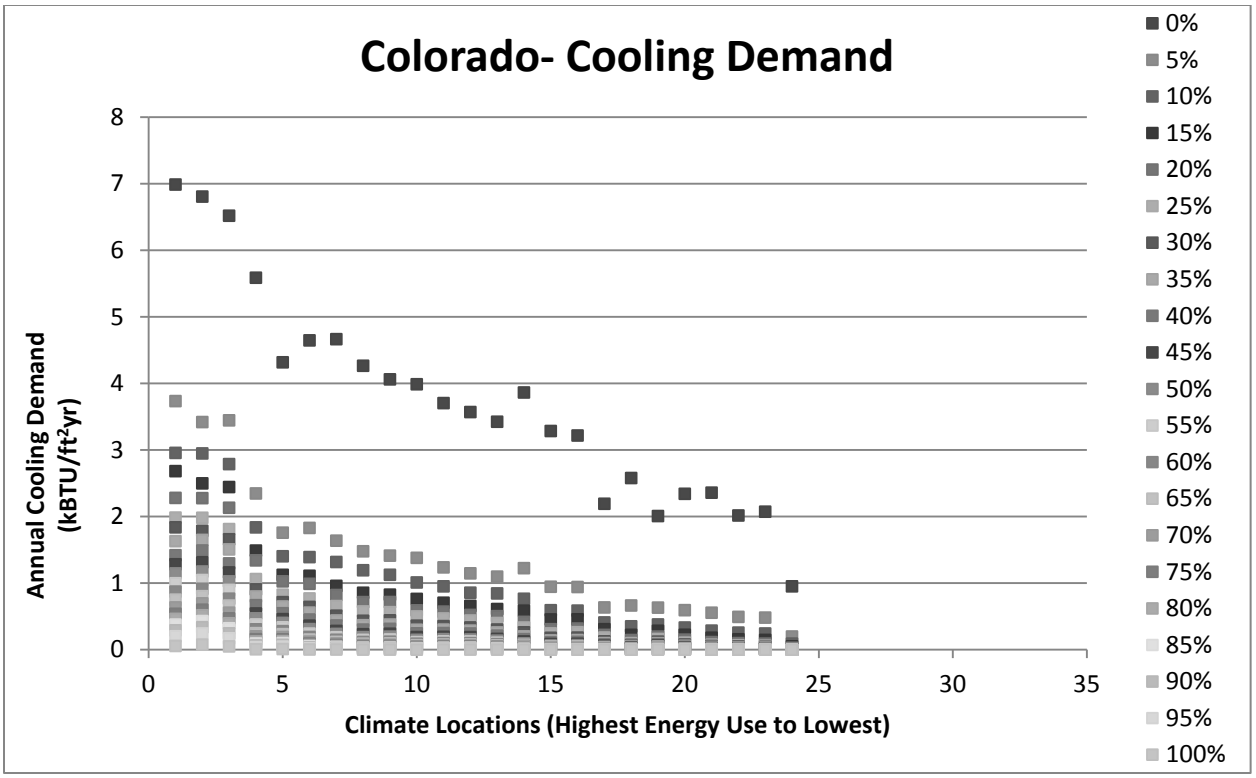
Colorado- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
Climate Locations (Highest Energy Use to Lowest)
0%
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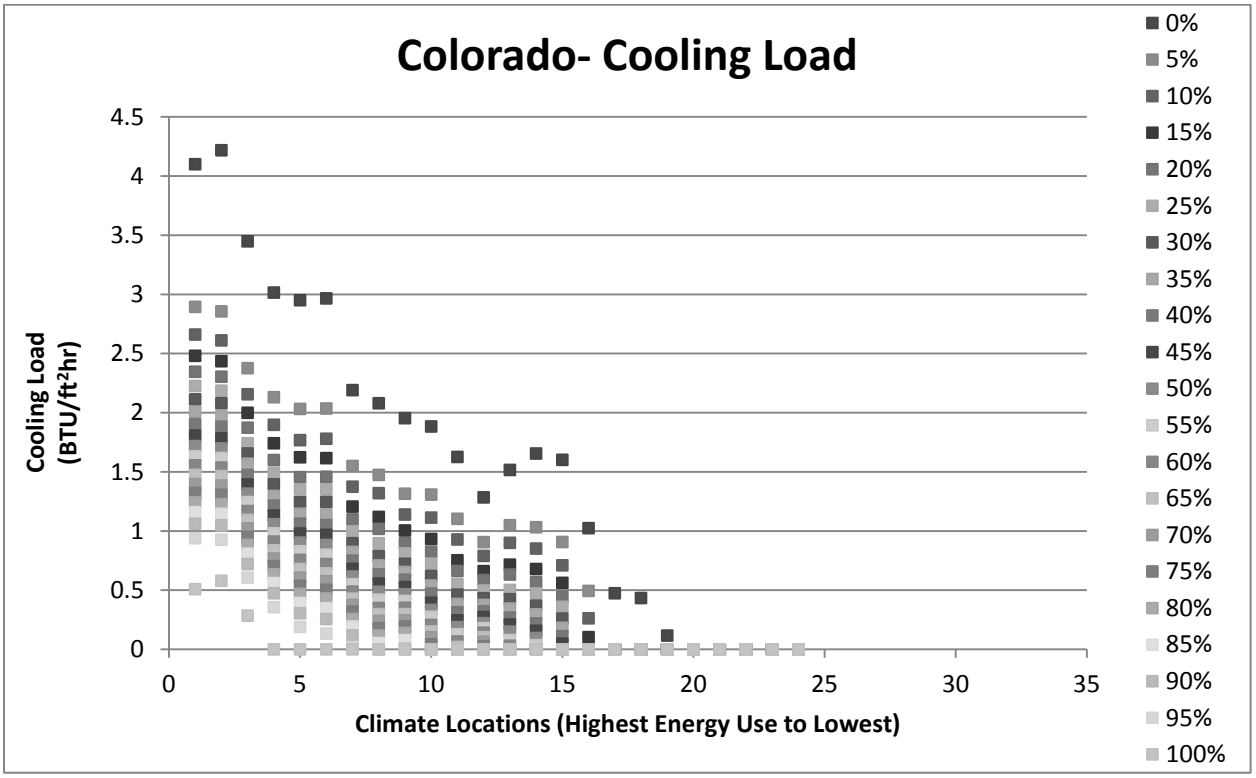
Colorado- Cooling Load
Cooling Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
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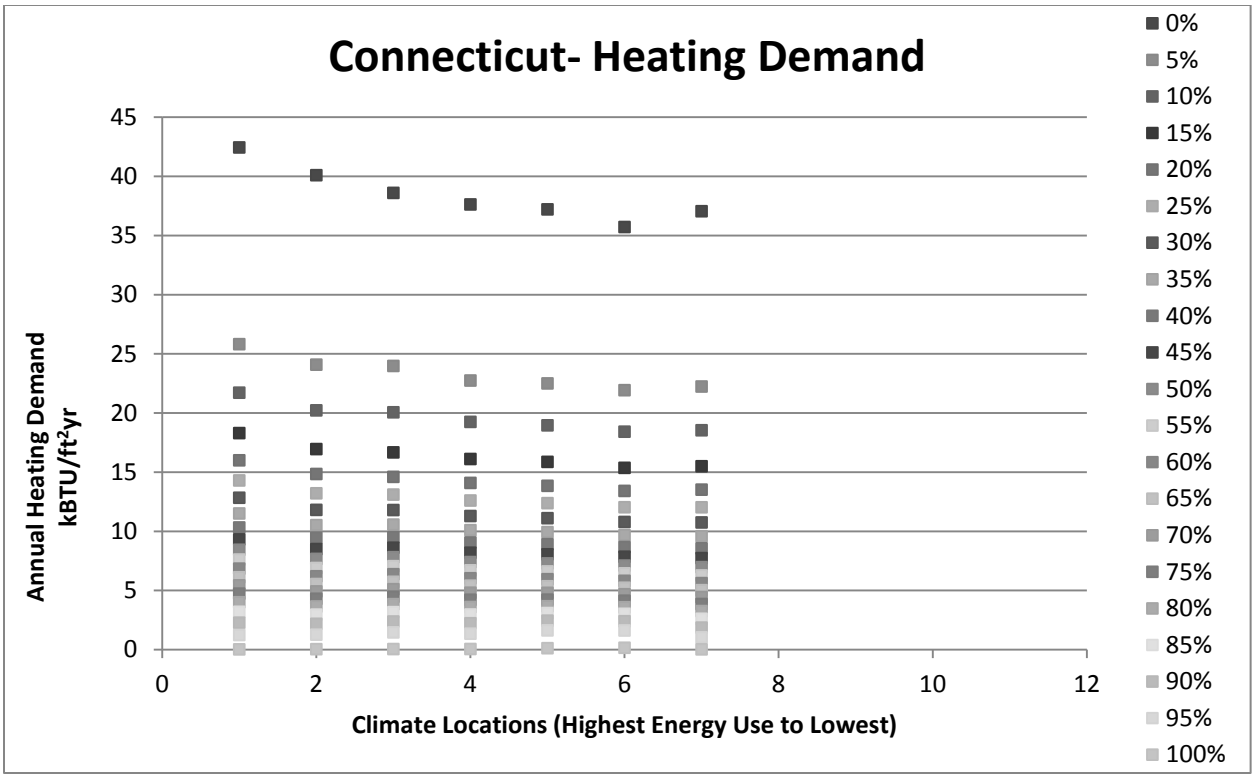
Connecticut- Heating Demand
Annual Heating Demand kBTU/ft²yr
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
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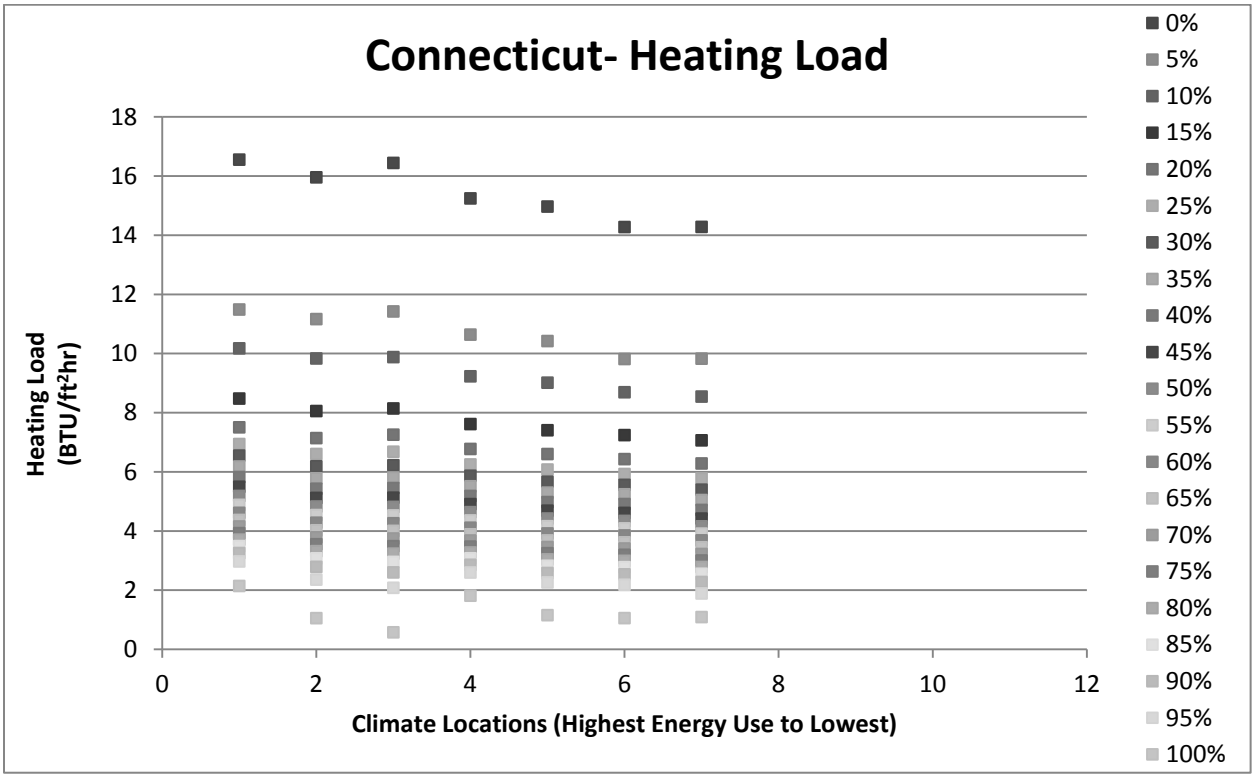
Connecticut- Heating Load
Heating Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
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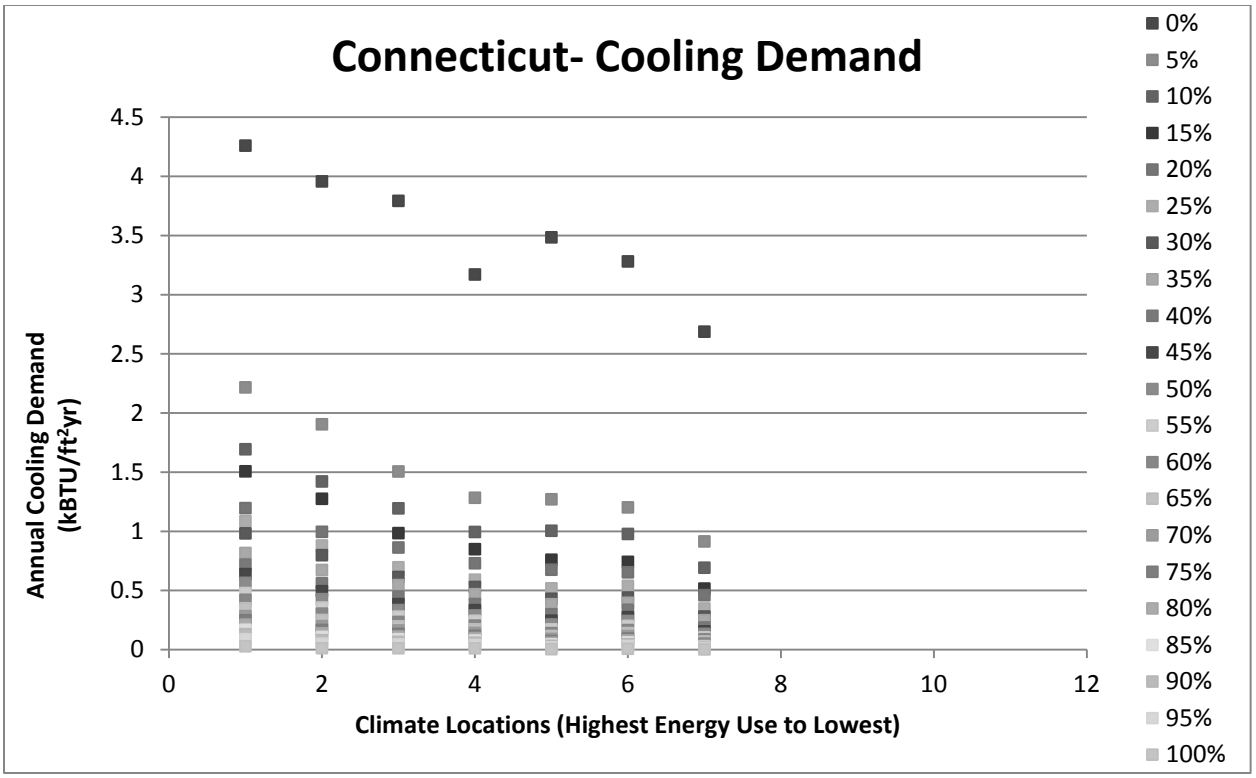
100%


Connecticut- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
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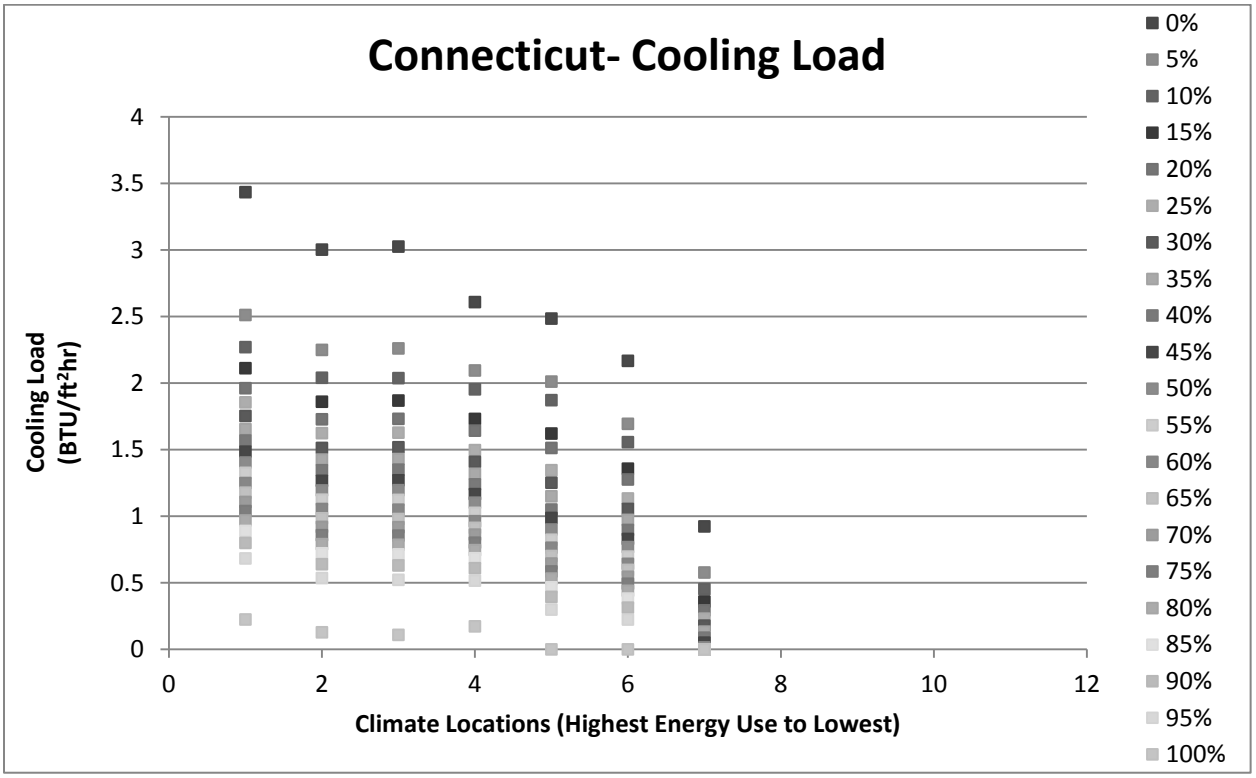
Connecticut- Cooling Load
Cooling Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
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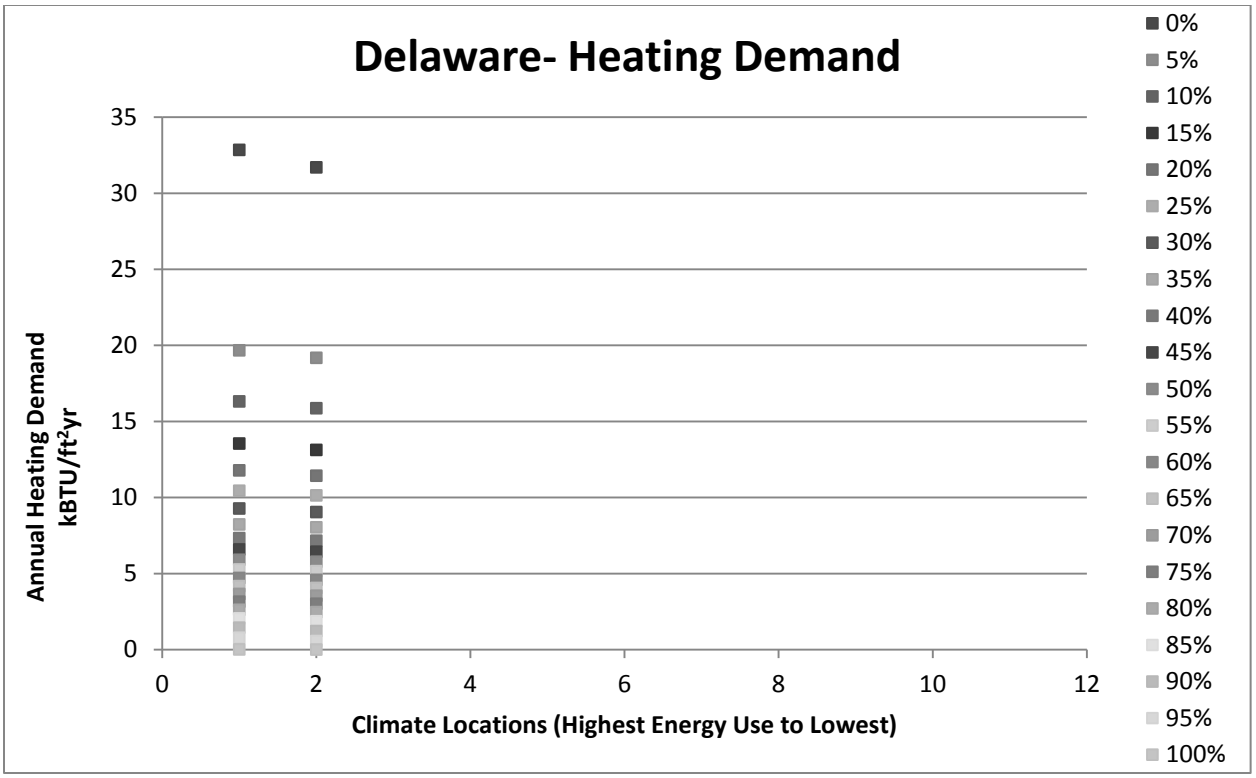
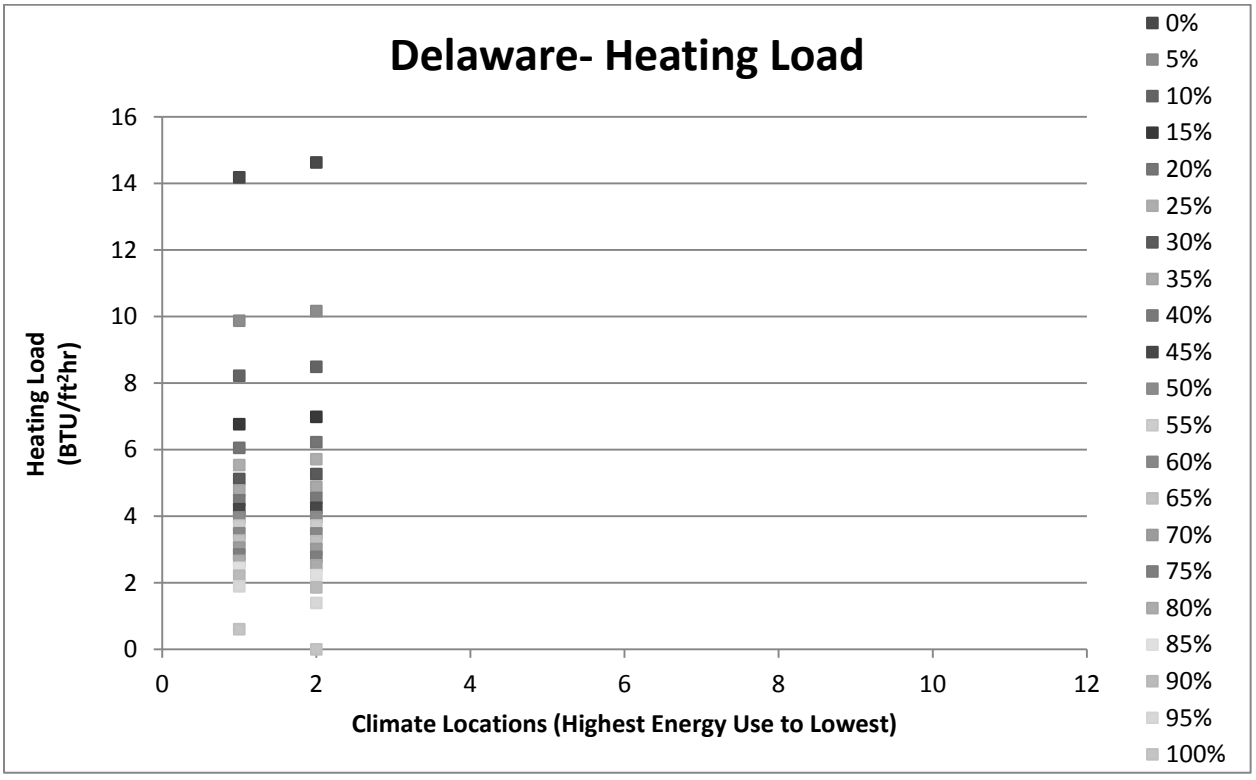

Delaware- Heating Demand
Annual Heating Demand kBTU/ft²yr
0
5
10
15
20
25
30
35
0
2
4
6
8
10
12
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%


Delaware- Heating Load
Heating Load (BTU/ft²hr)
0
2
4
6
8
10
12
14
16
0
2
4
6
8
10
12
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
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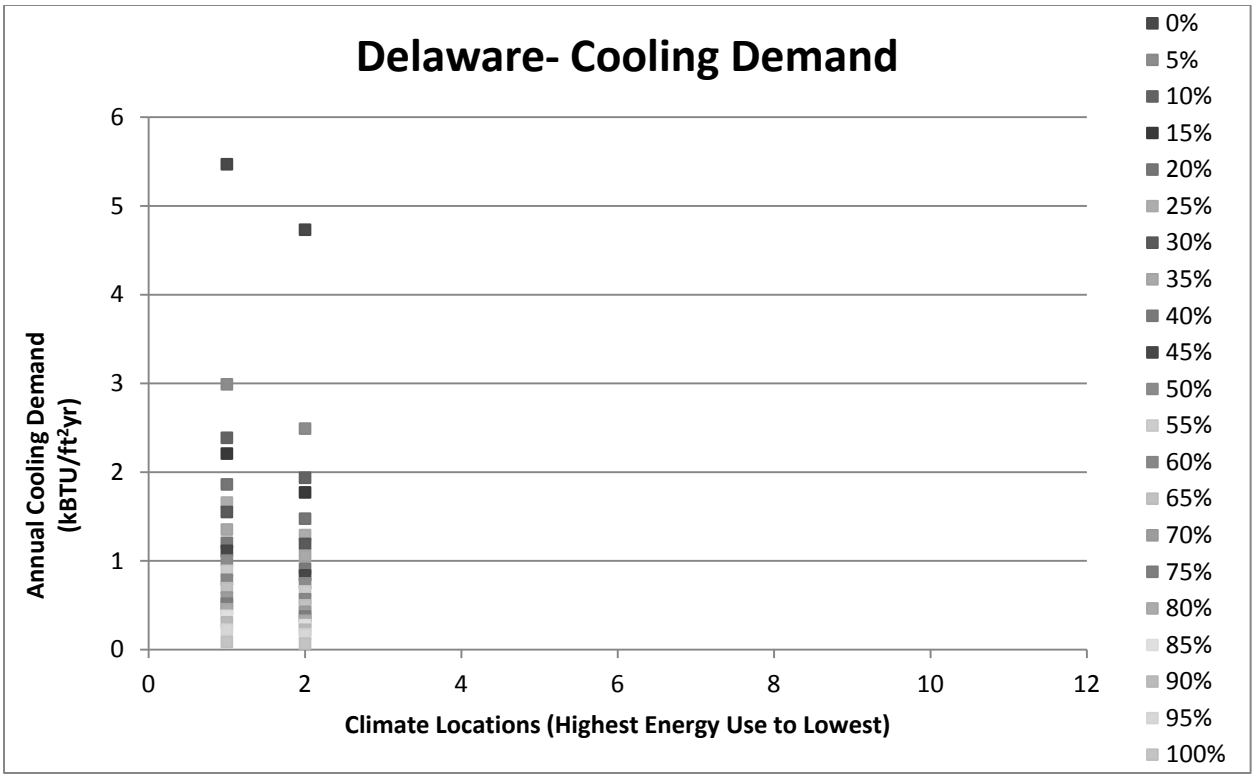
100%


Delaware- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
0
1
2
3
4
5
6
0
2
4
6
8
10
12
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
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75%
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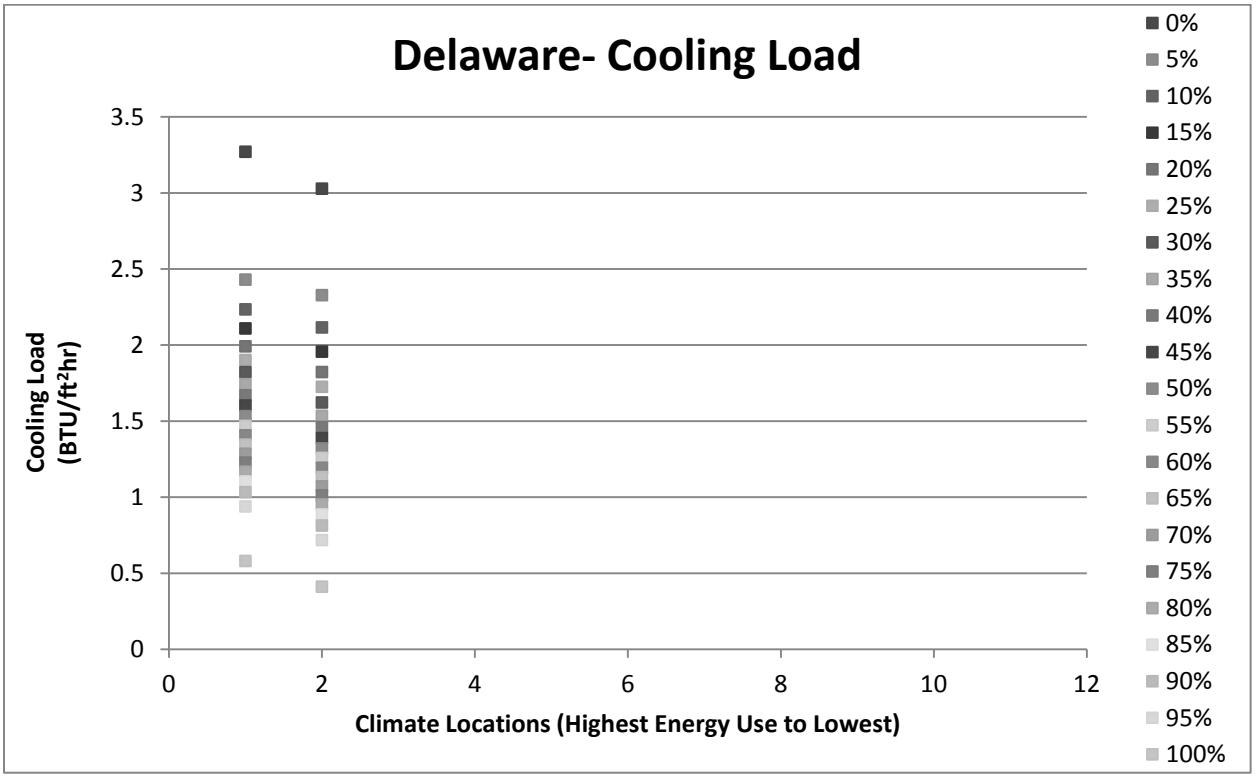
100%


Delaware- Cooling Load
Cooling Load (BTU/ft²hr)
0
0.5
1
1.5
2
2.5
3
3.5
0
2
4
6
8
10
12
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
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75%
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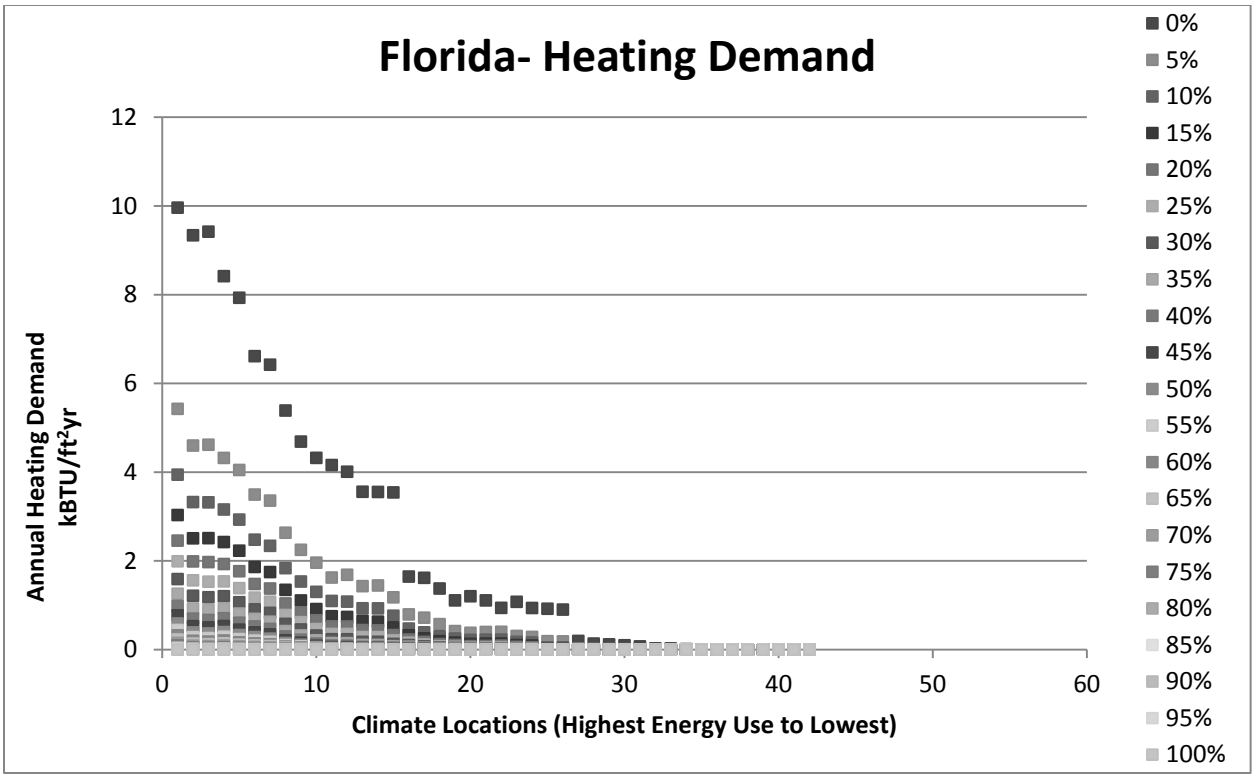
Florida- Heating Demand
Annual Heating Demand kBTU/ft²yr
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
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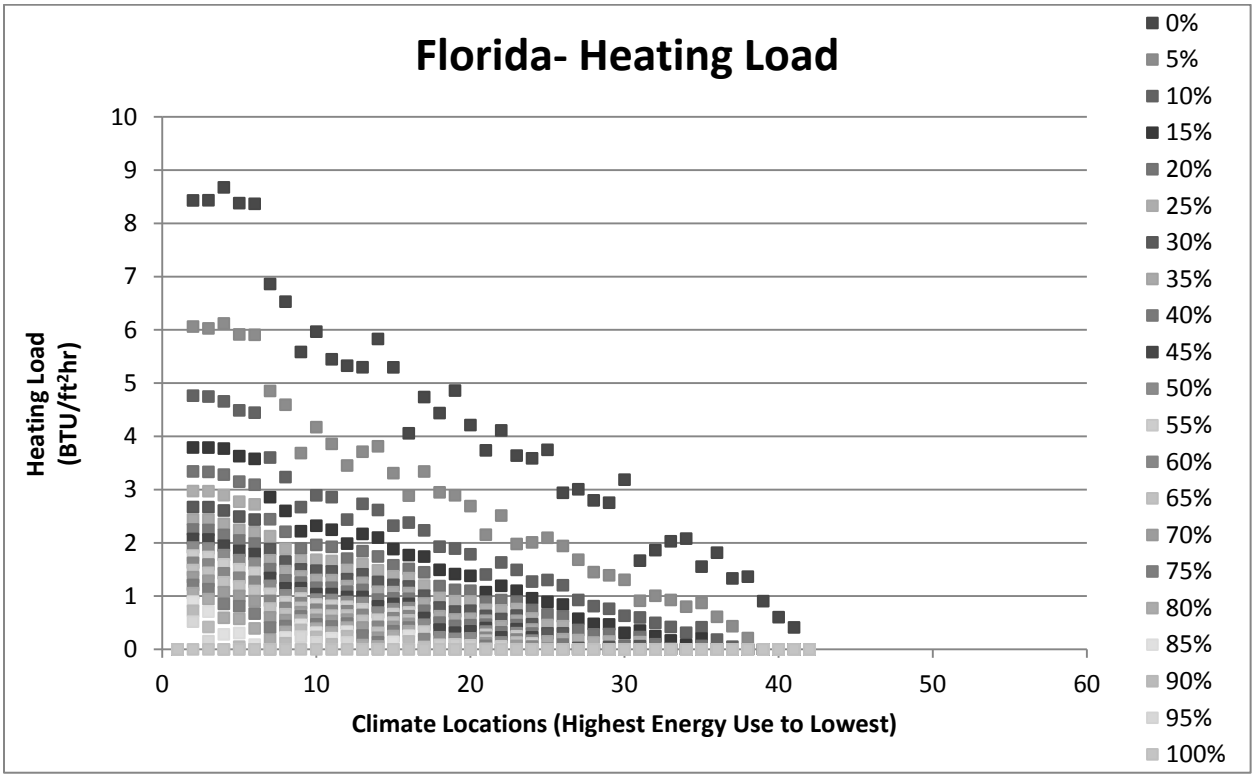
95%
100%


Florida- Heating Load
Heating Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
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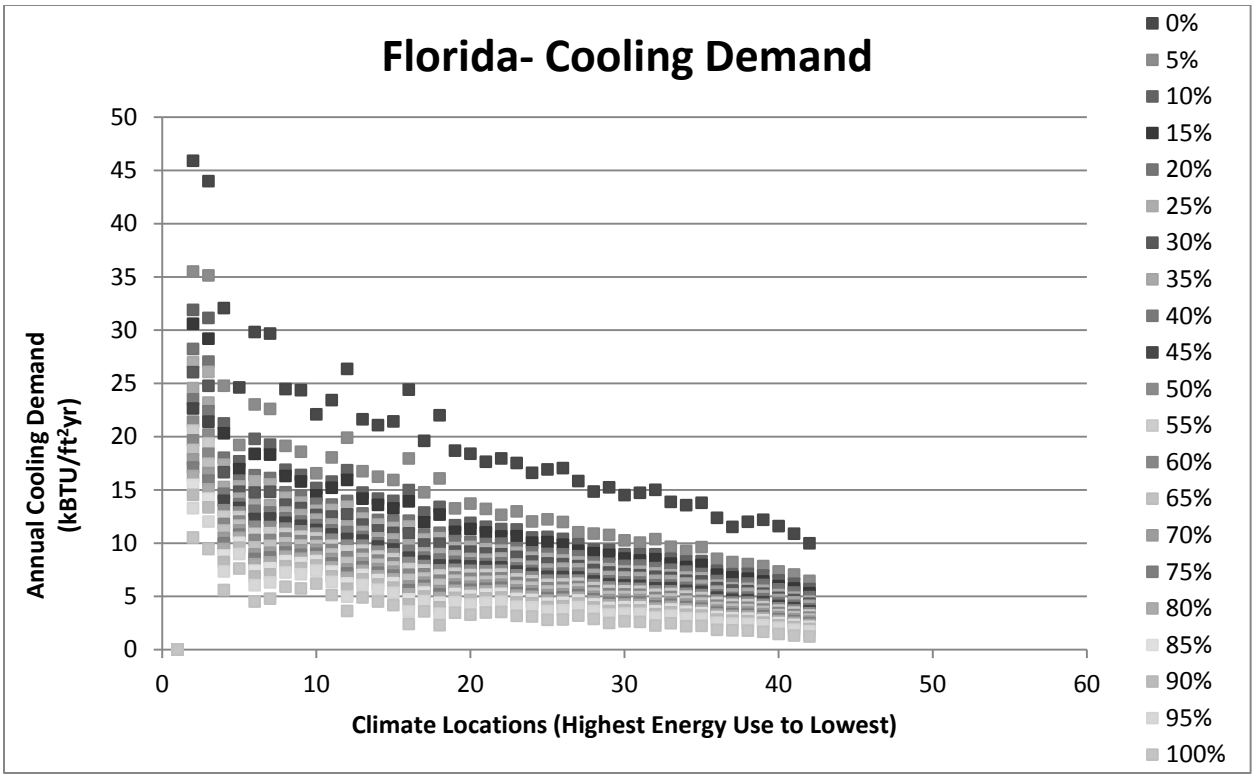
Florida- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
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30%
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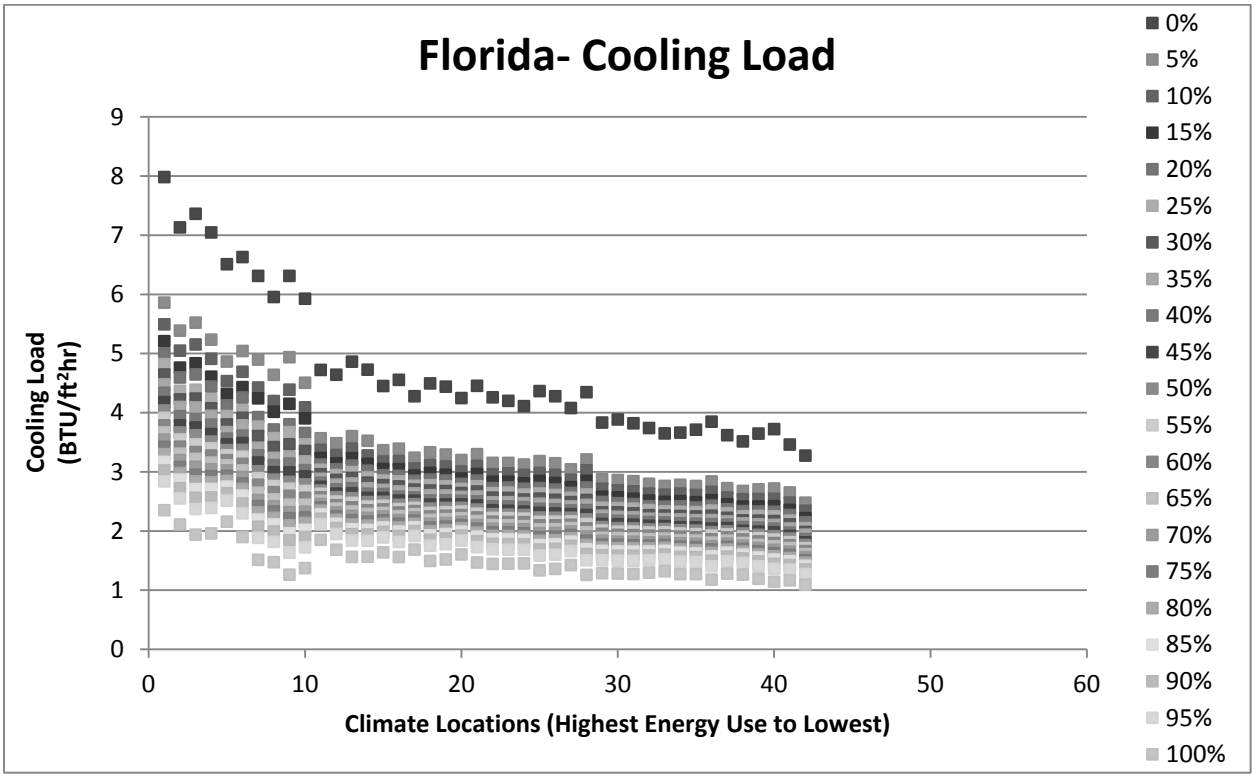
Florida- Cooling Load
Cooling Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
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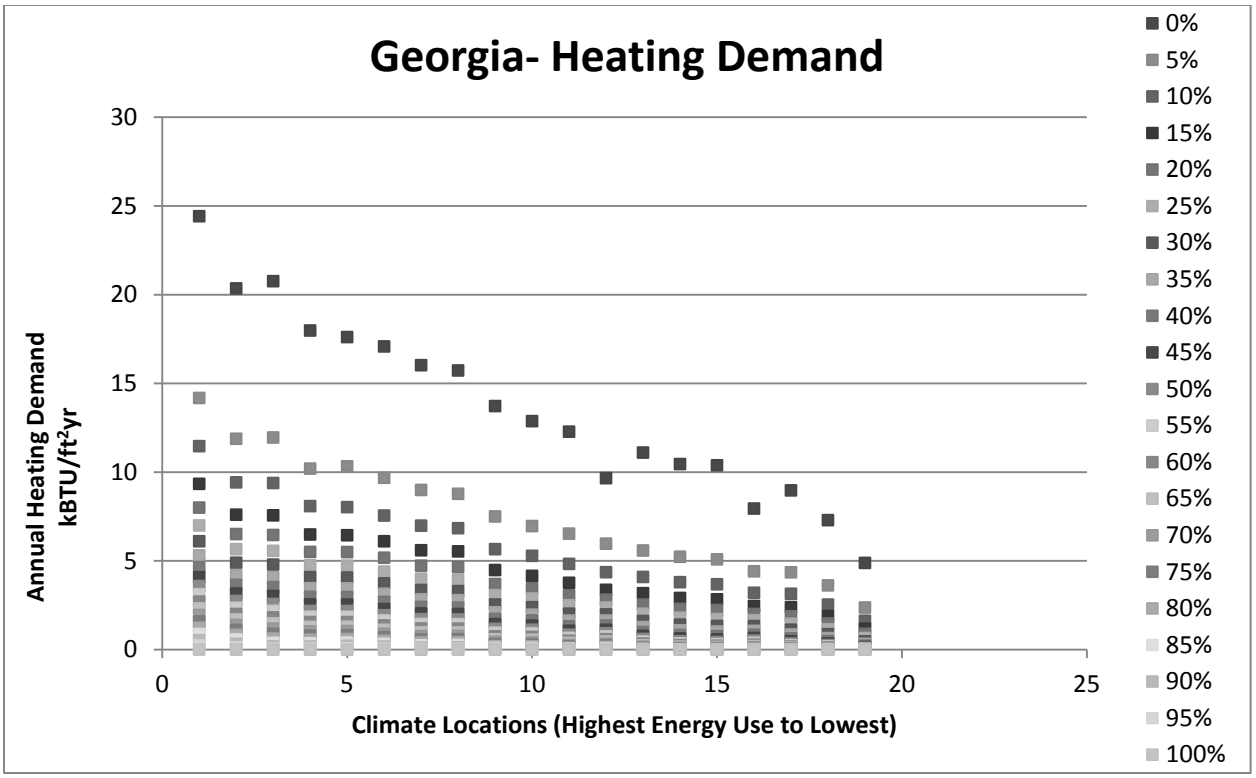
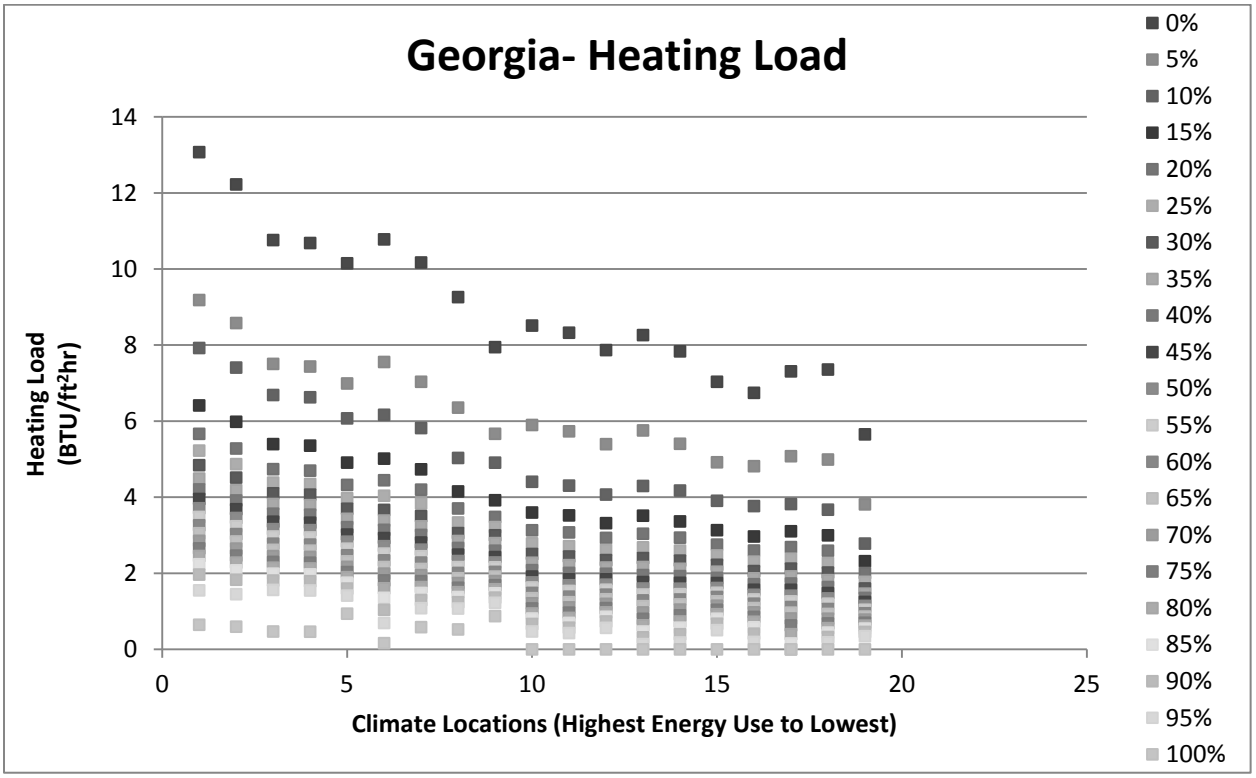
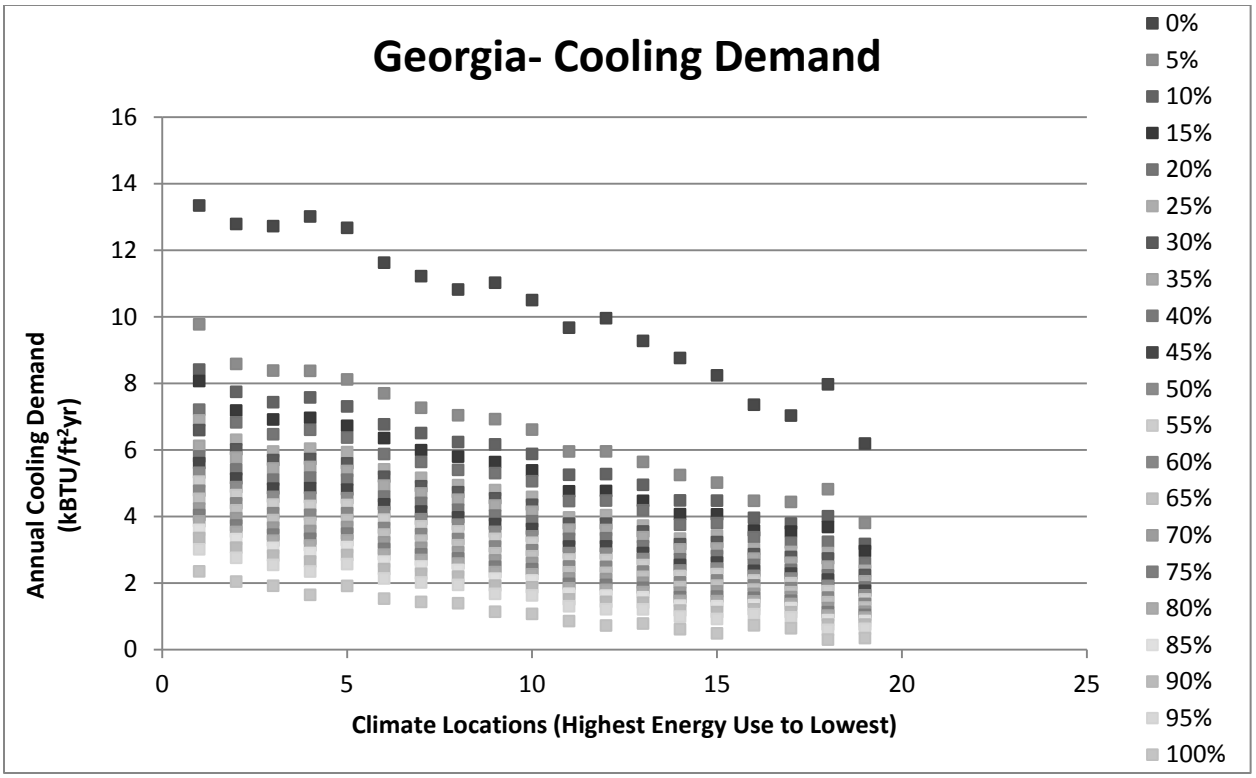
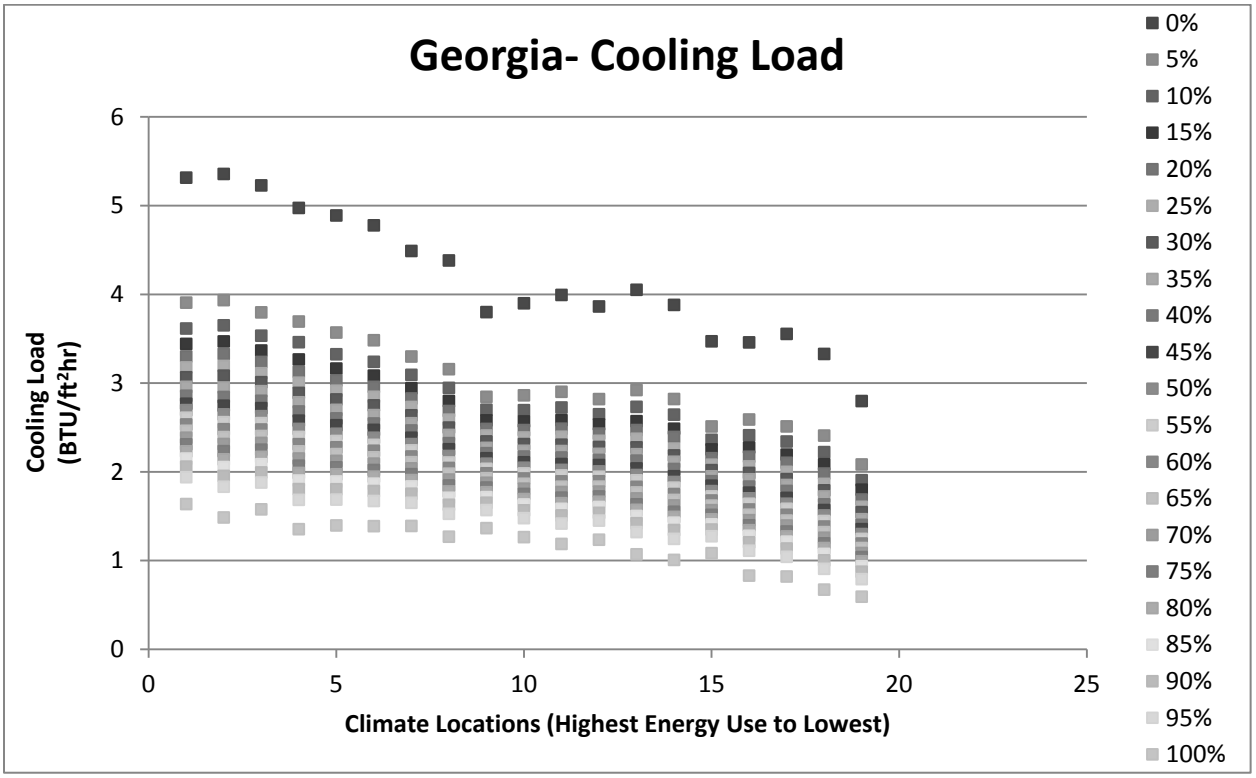
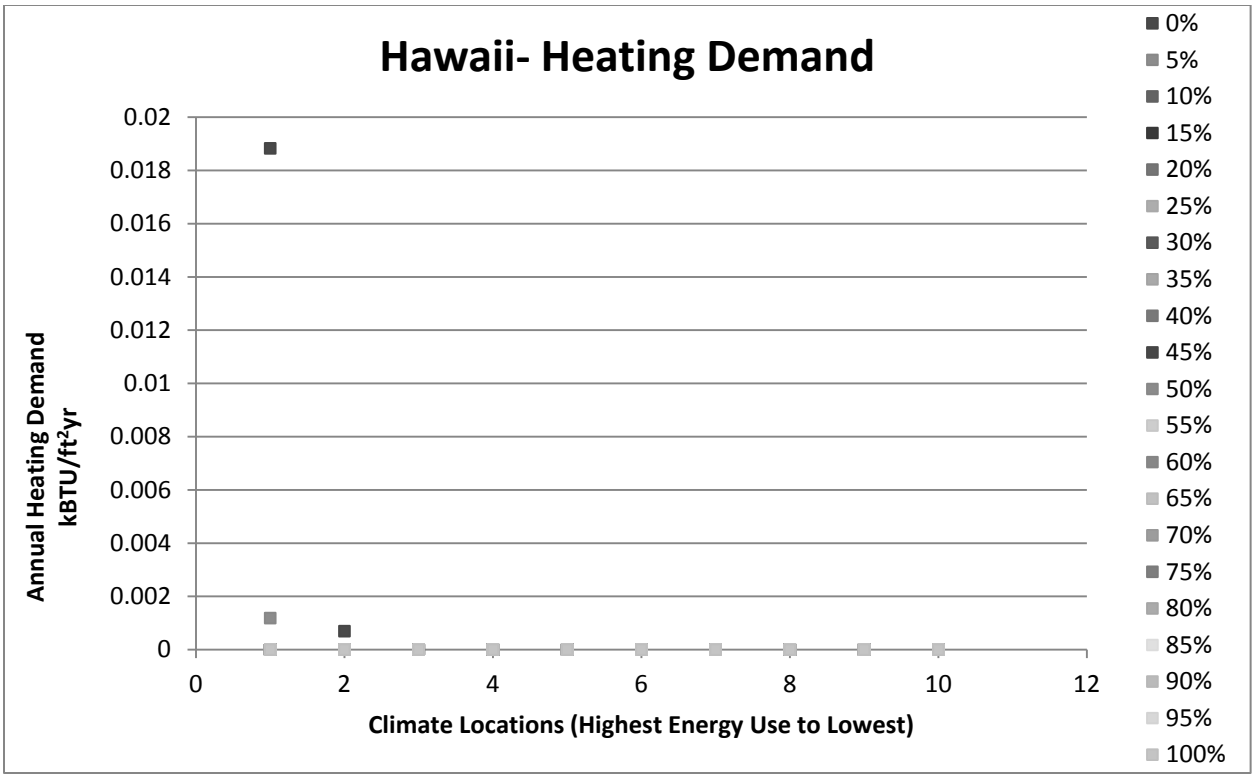
100%

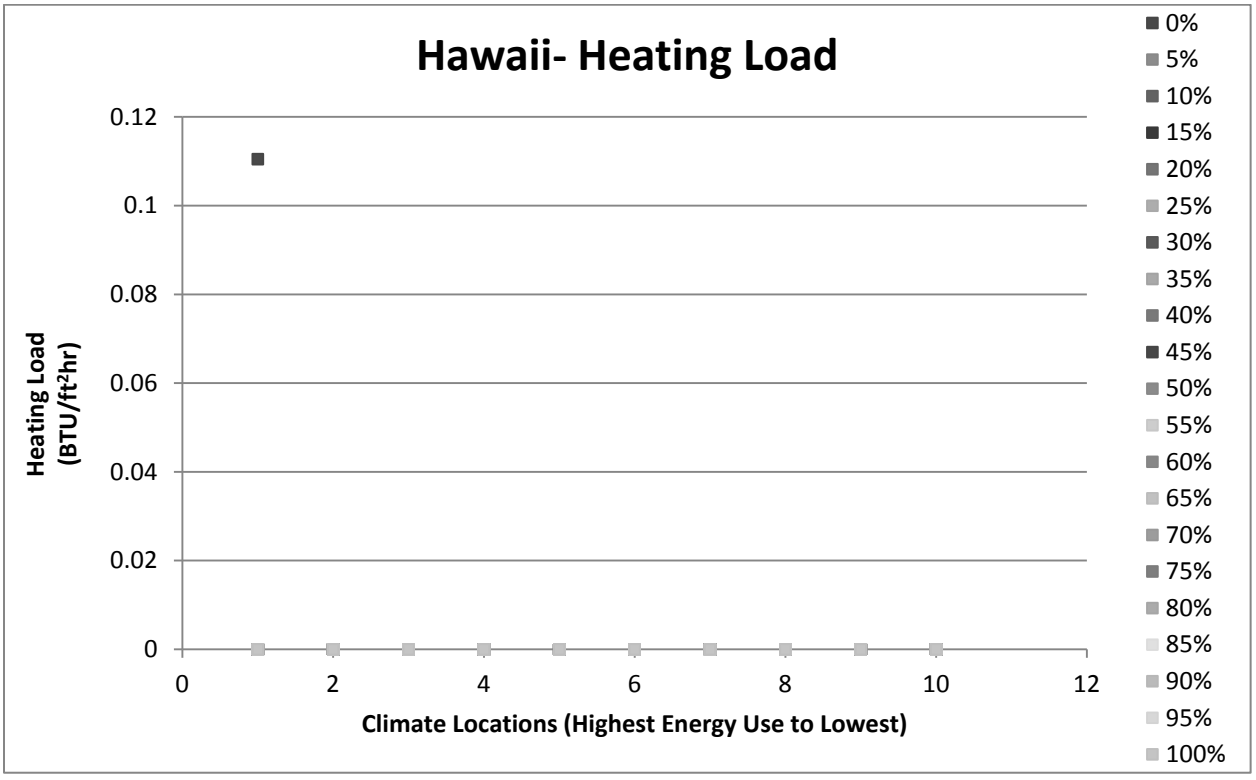

Georgia- Heating Demand
Annual Heating Demand kBTU/ft²yr
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

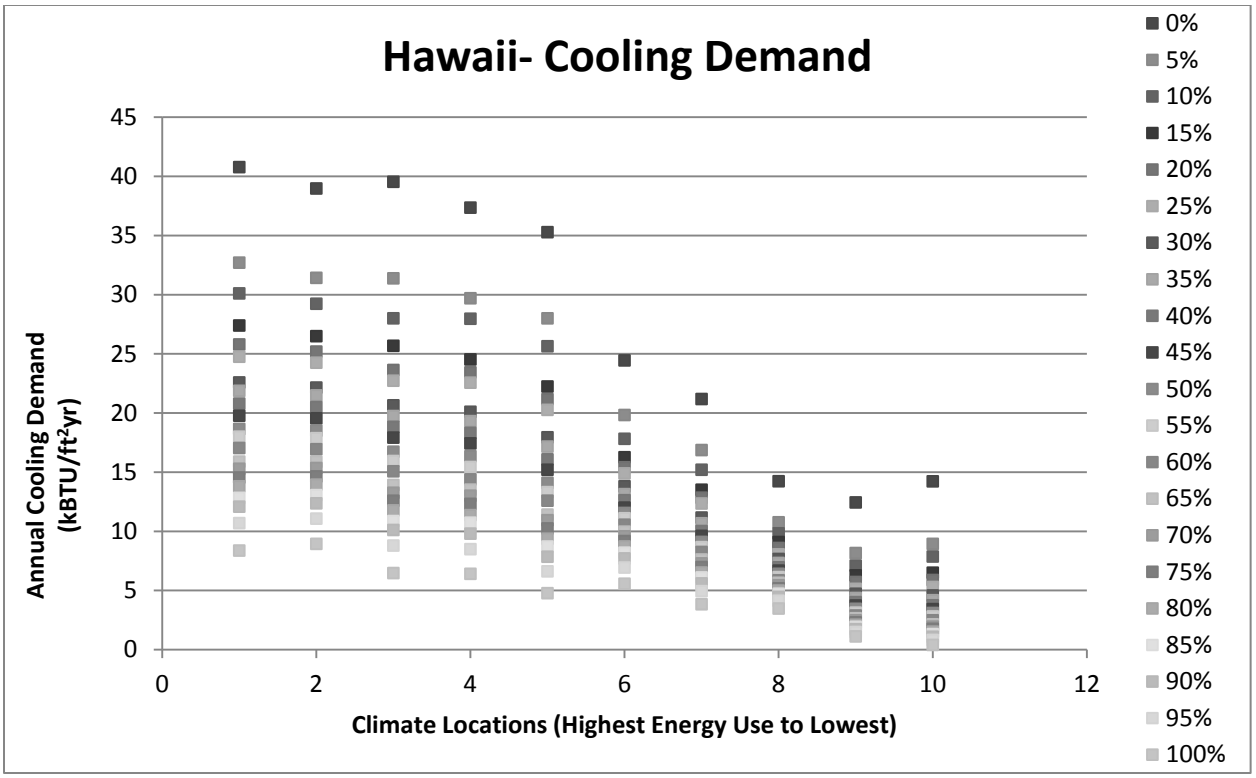

Georgia- Heating Load
Heating Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

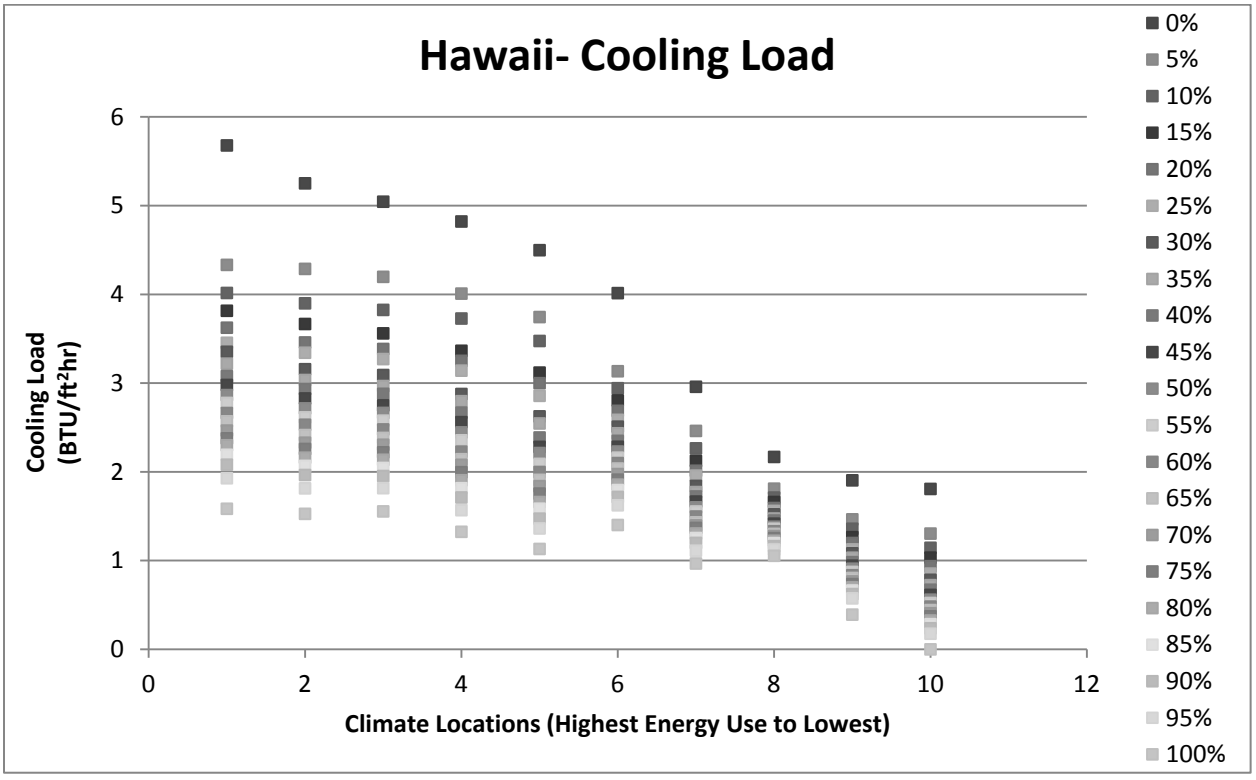

Georgia- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

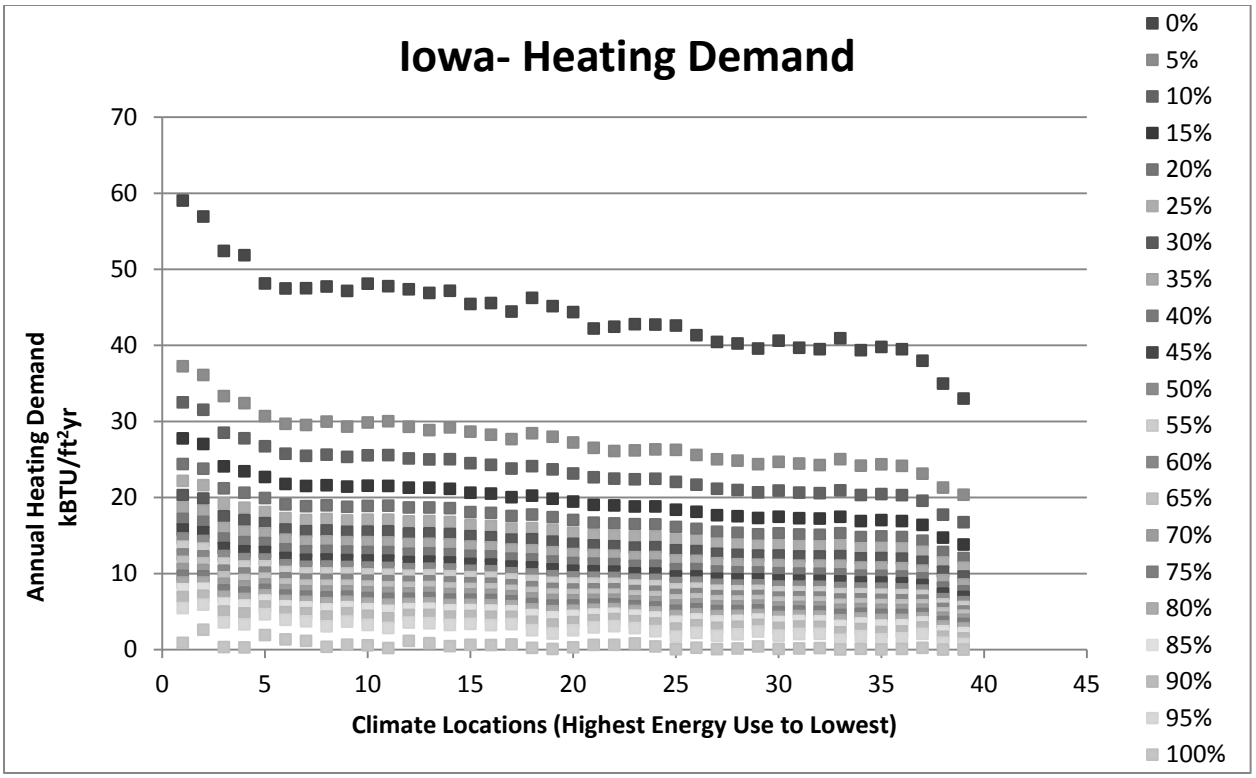

Georgia- Cooling Load
Cooling Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

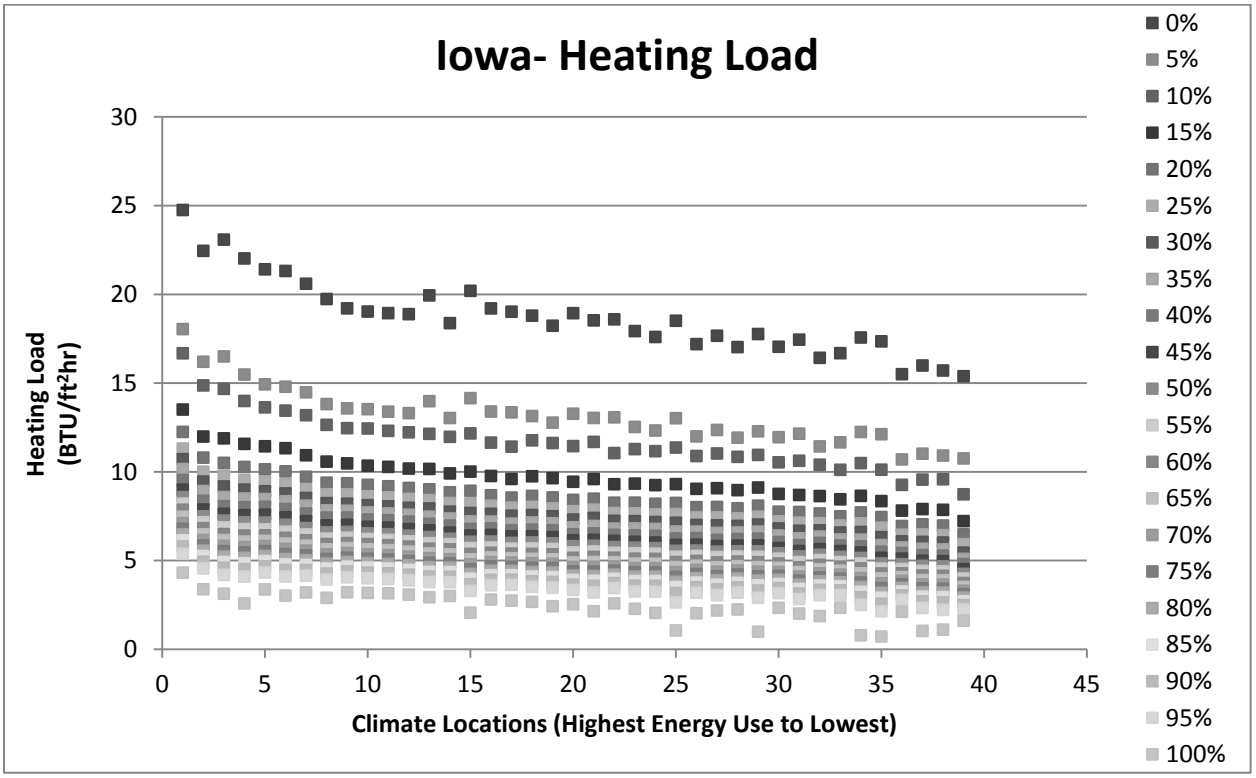

Hawaii- Heating Demand
Annual Heating Demand kBTU/ft²yr
0.02
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
0
2
4
6
8
10
12
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

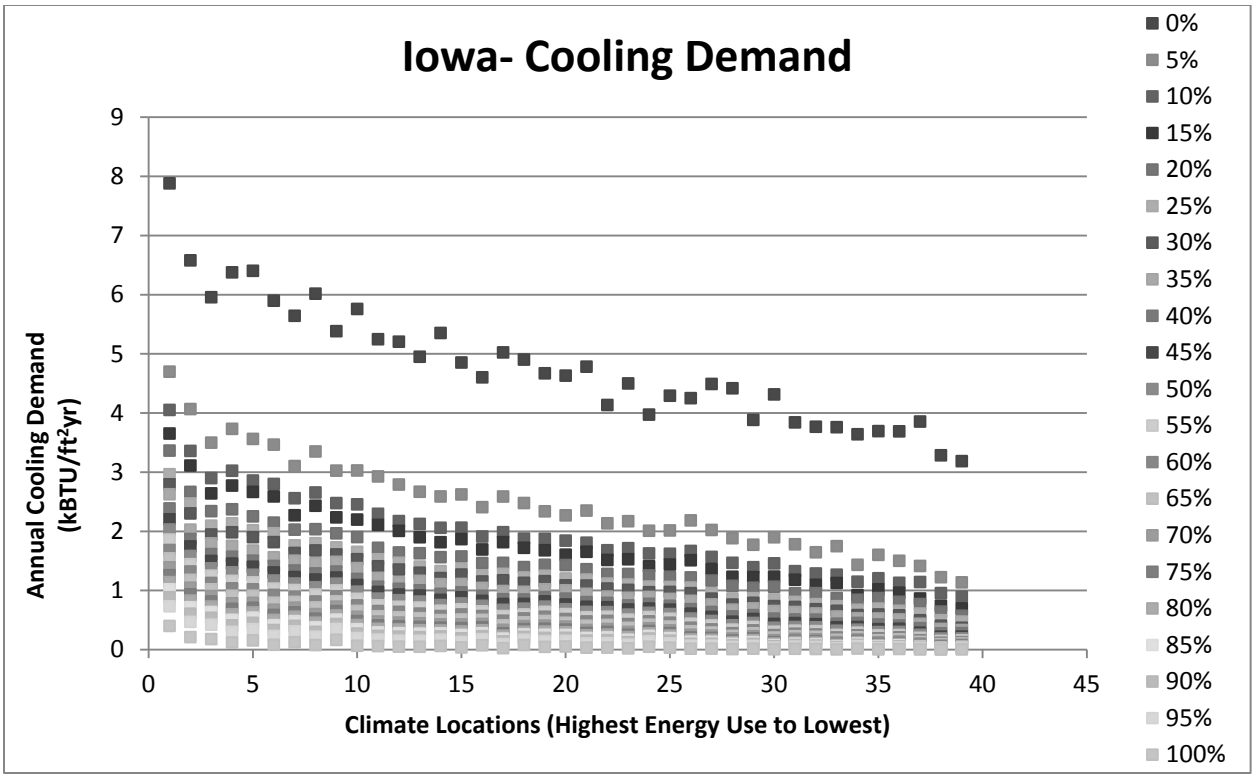

Hawaii- Heating Load
Heating Load (BTU/ft²hr)
0.12
0.1
0.08
0.06
0.04
0.02
0
0
2
4
6
8
10
12
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%


Hawaii- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%


Hawaii- Cooling Load
Cooling Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%


Iowa- Heating Demand
Annual Heating Demand kBTU/ft²yr
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%


Iowa- Heating Load
Heating Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%


Iowa- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
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70%
75%
80%
85%
90%
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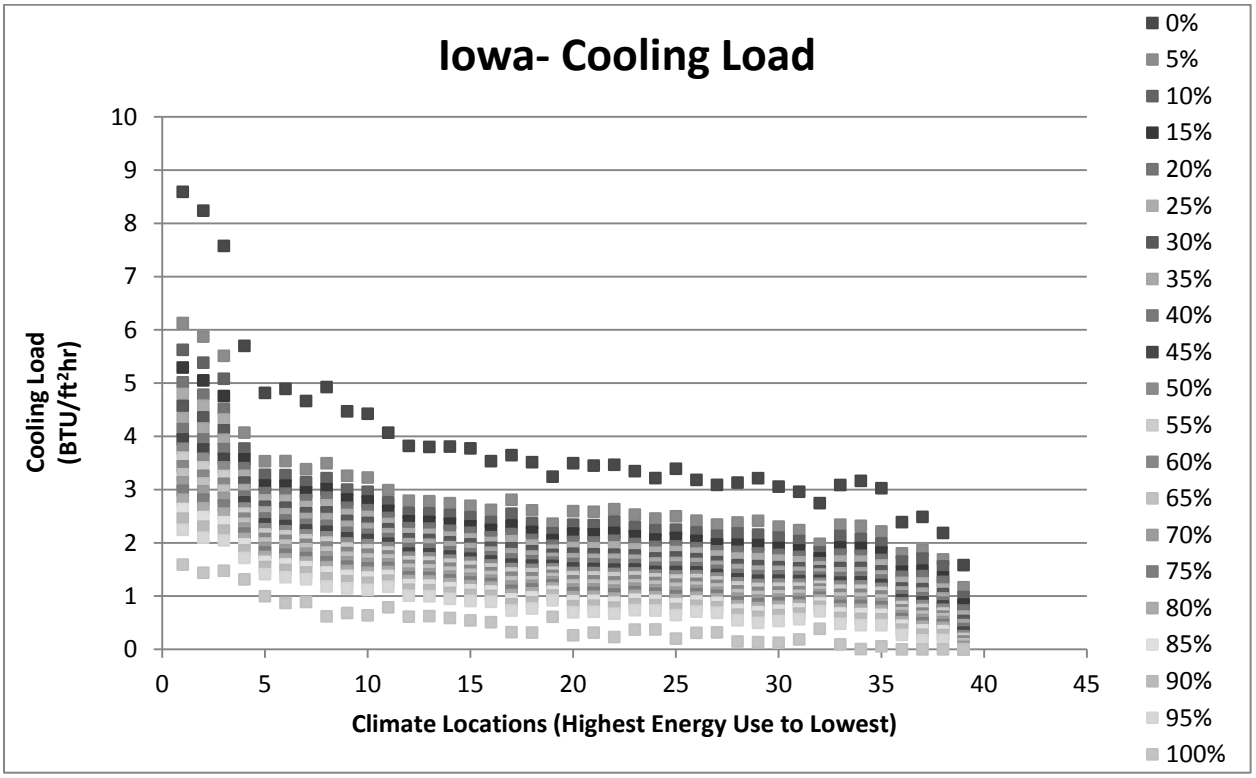
100%


Iowa- Cooling Load
Cooling Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
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90%
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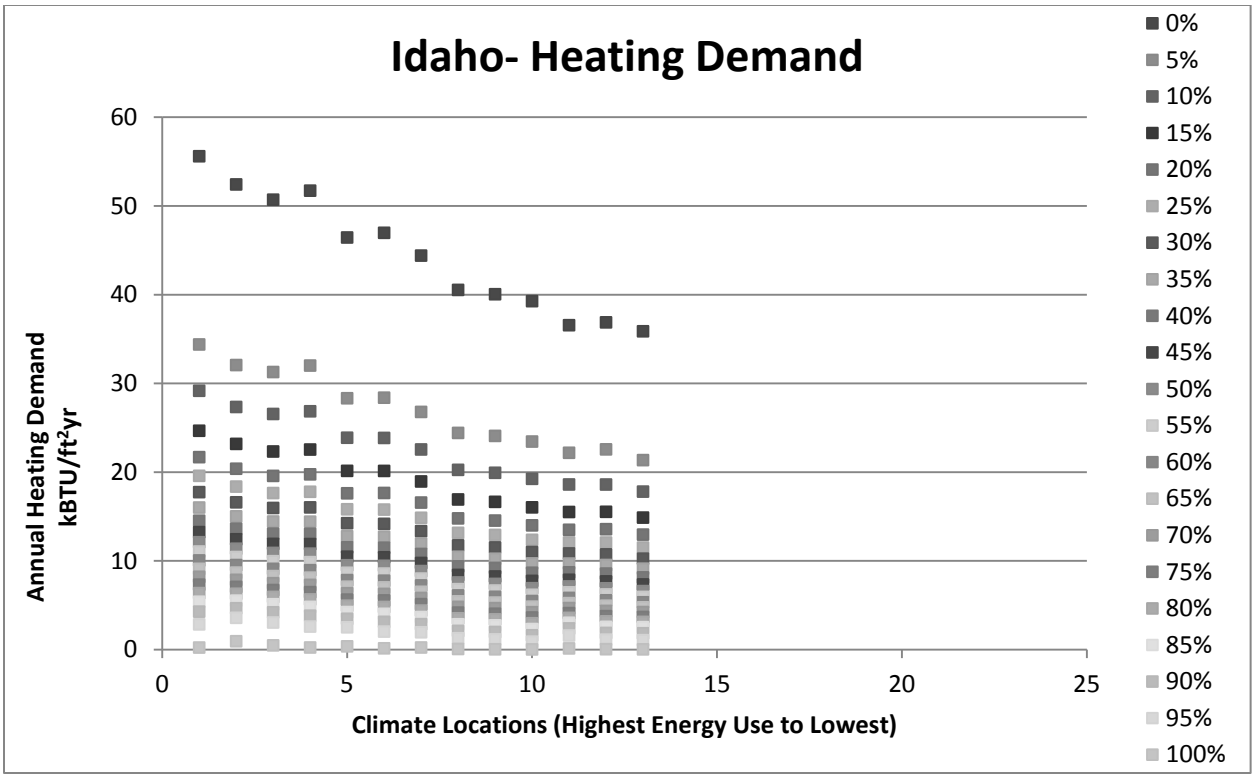
Idaho- Heating Demand
Annual Heating Demand kBTU/ft²yr
0
10
20
30
40
50
60
0
5
10
15
20
25
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
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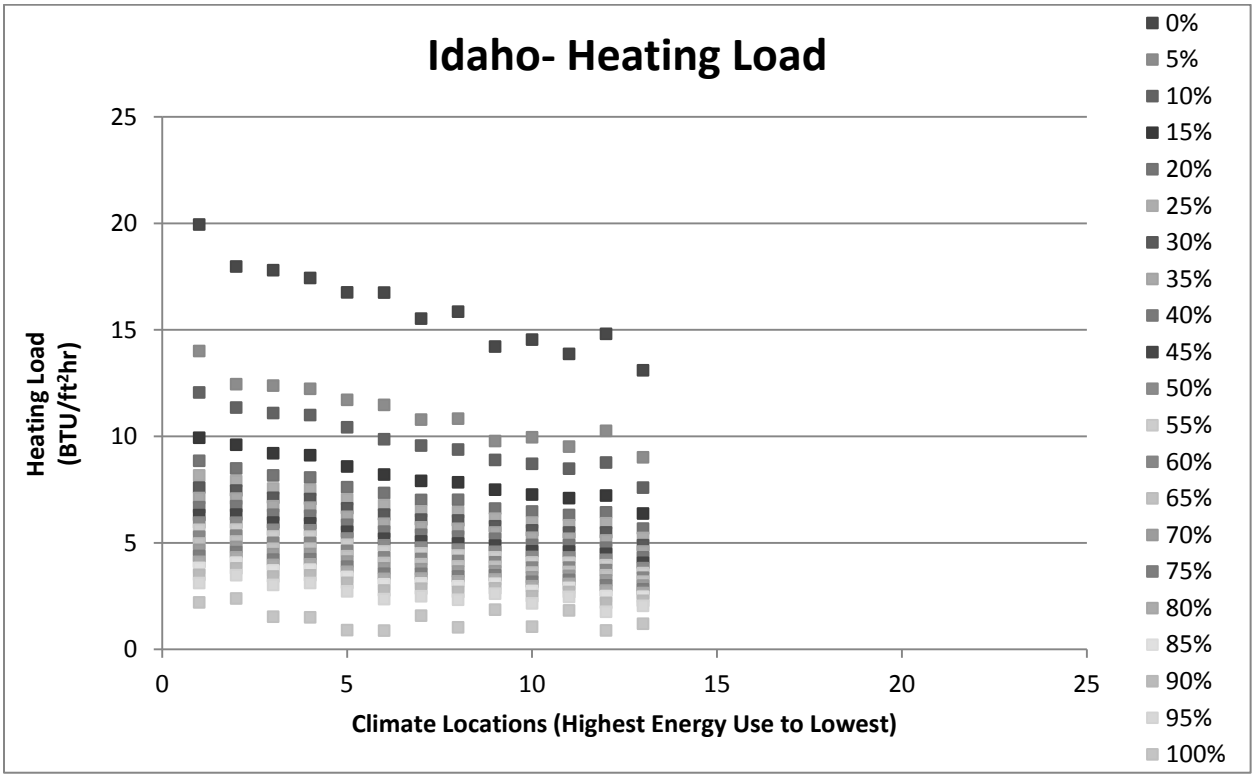
90%
95%
100%


Idaho- Heating Load
Heating Load (BTU/ft²hr)
0
5
10
15
20
25
0
5
10
15
20
25
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
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55%
60%
65%
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75%
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90%
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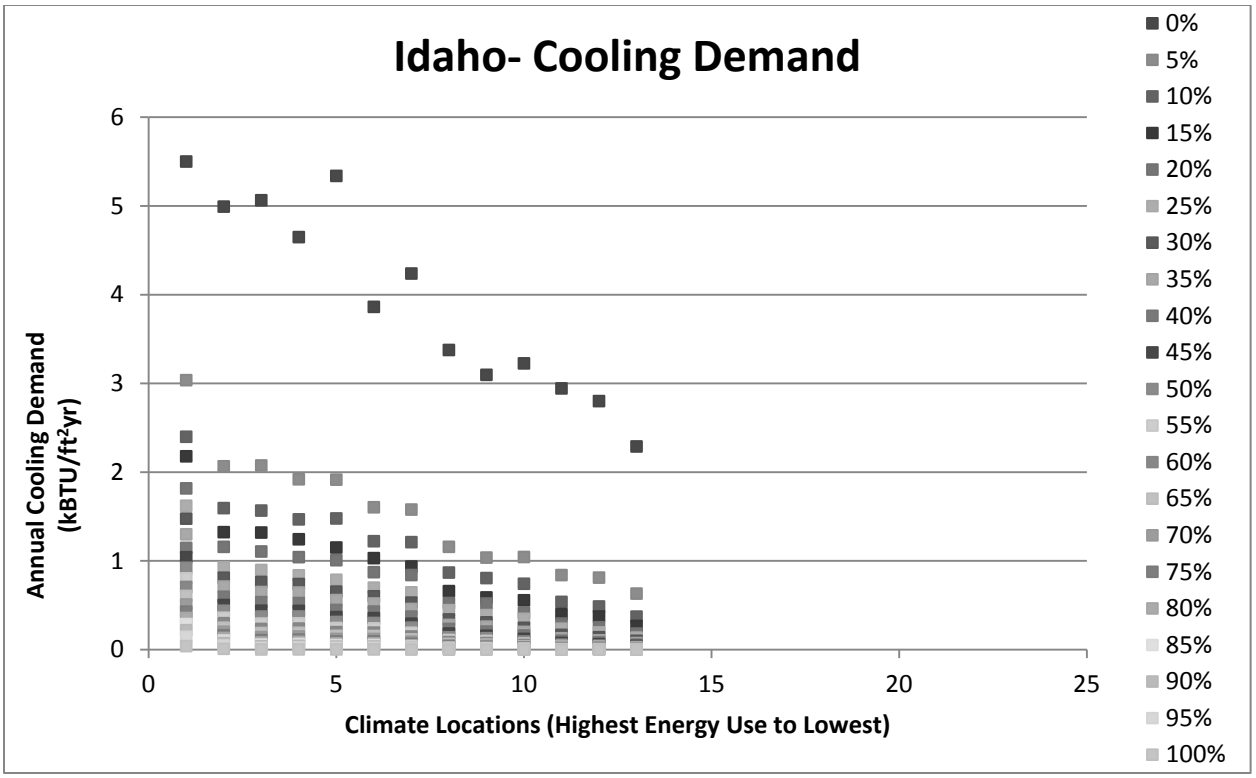
100%


Idaho- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
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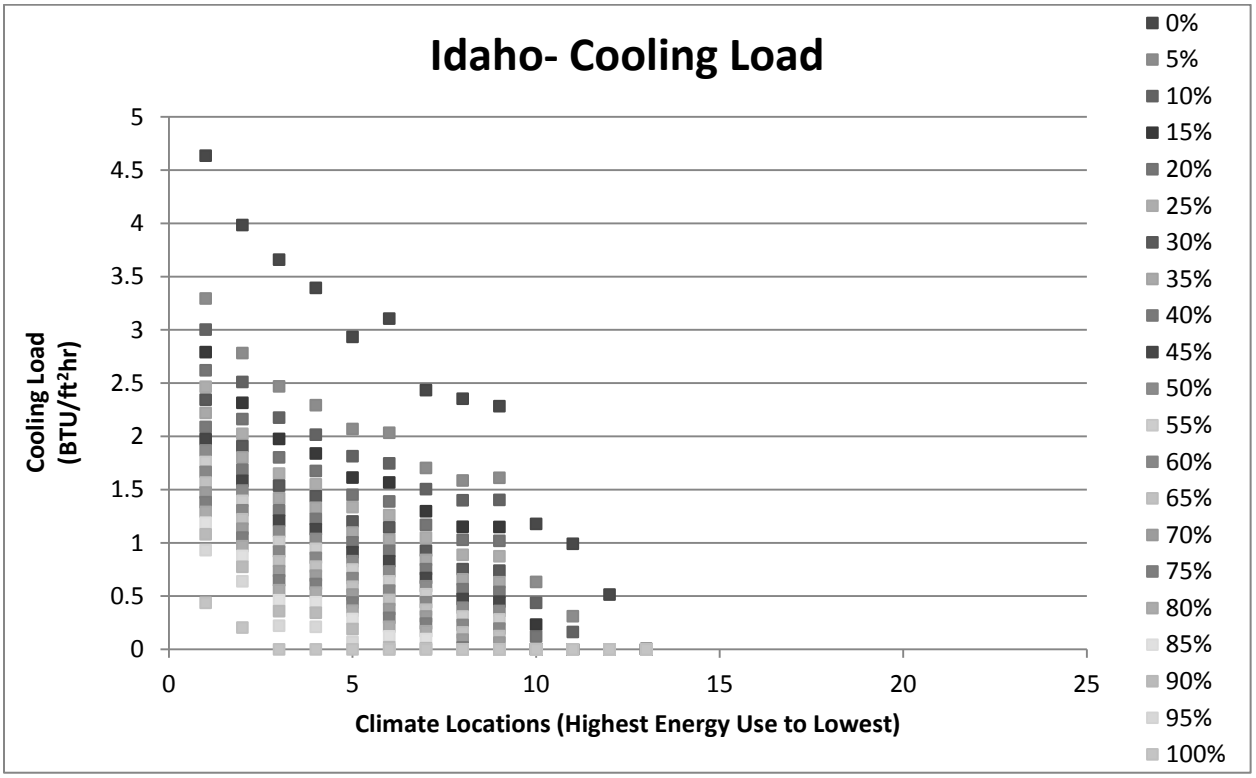
100%


Idaho- Cooling Load
Cooling Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
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40%
45%
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55%
60%
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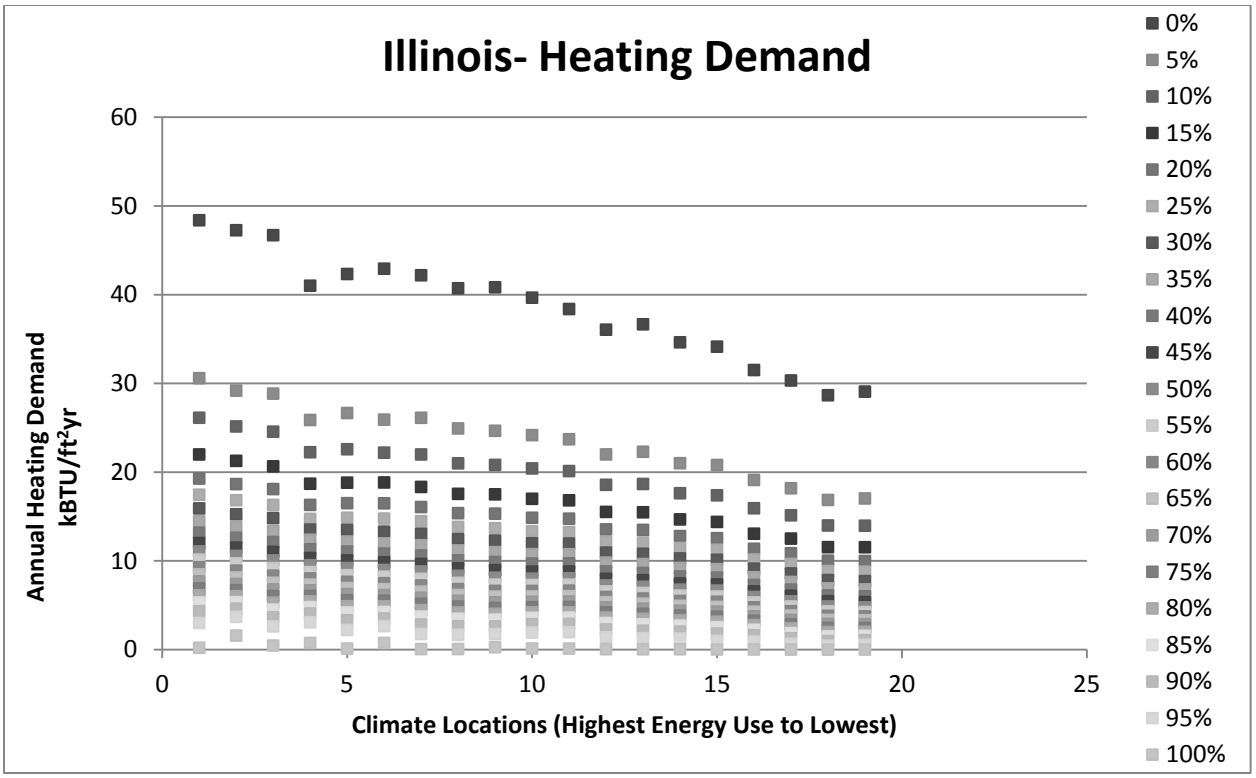
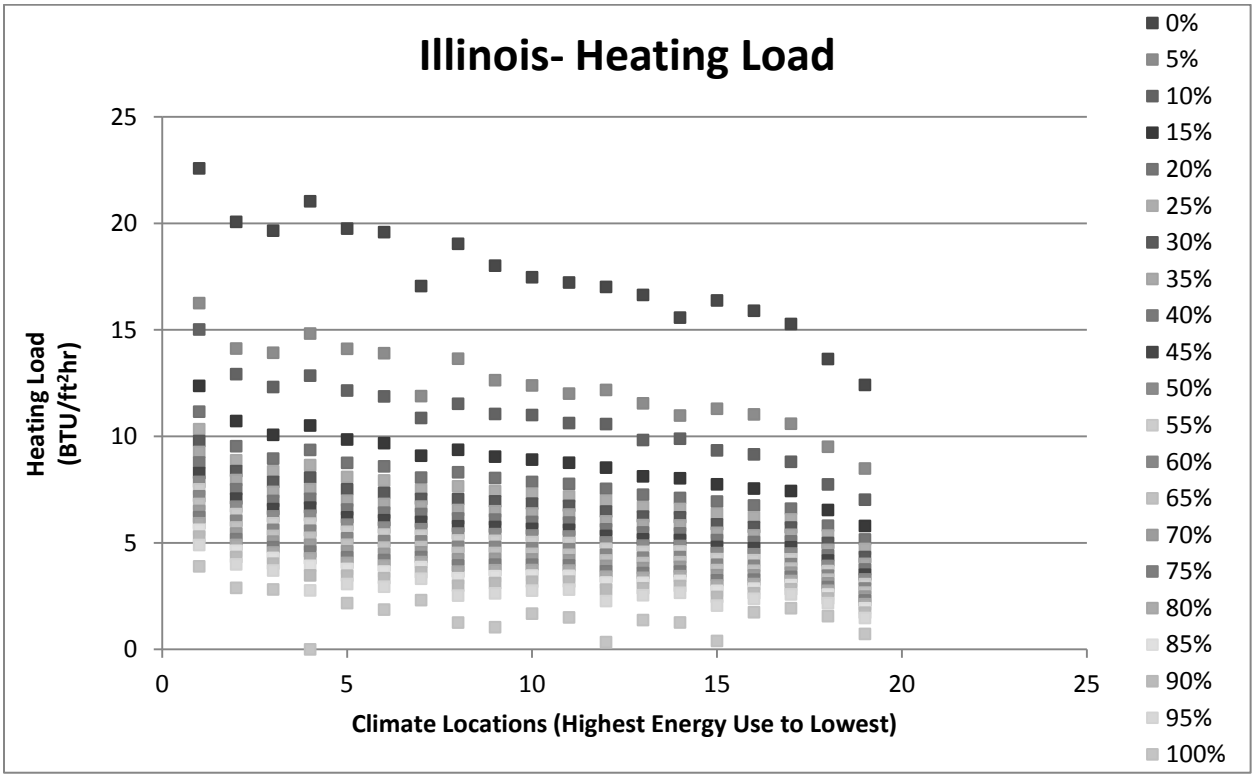

Illinois- Heating Demand
Annual Heating Demand kBTU/ft²yr
0
10
20
30
40
50
60
0
5
10
15
20
25
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%


Illinois- Heating Load
Heating Load (BTU/ft²hr)
0
5
10
15
20
25
0
5
10
15
20
25
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
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90%
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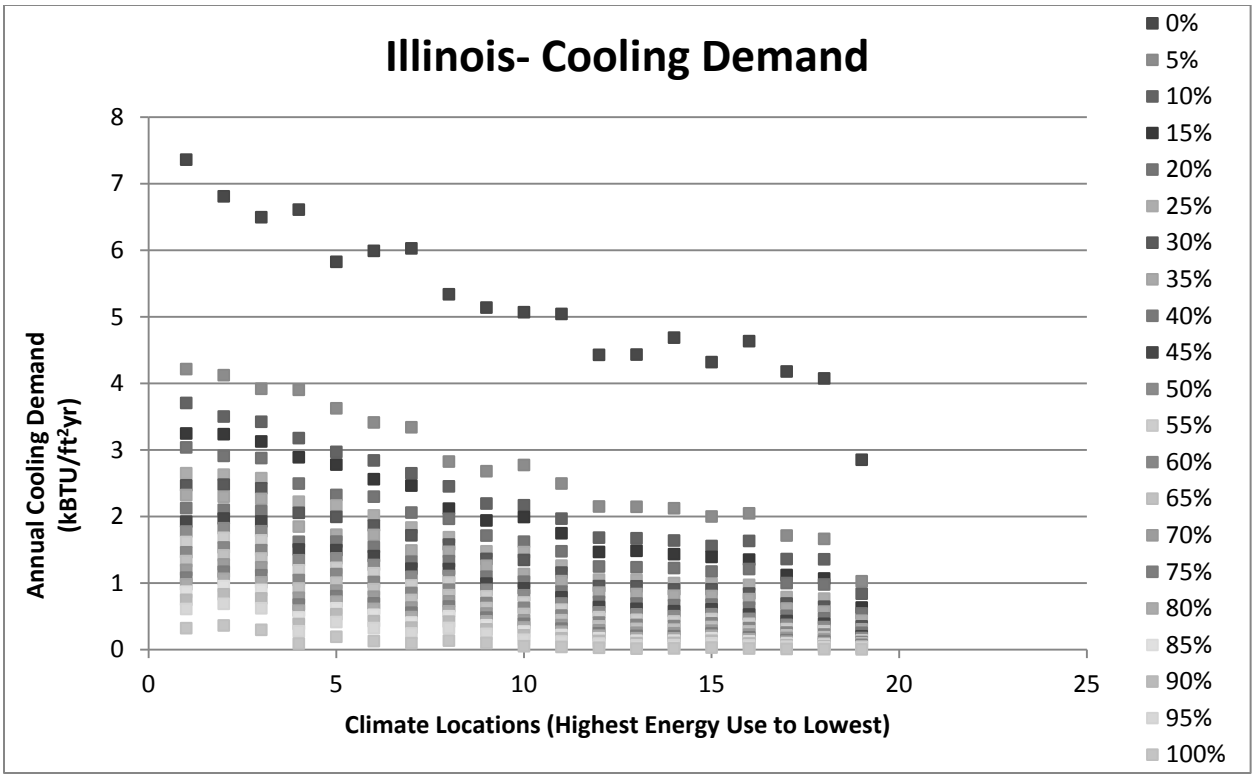
100%


Illinois- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
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20%
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35%
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75%
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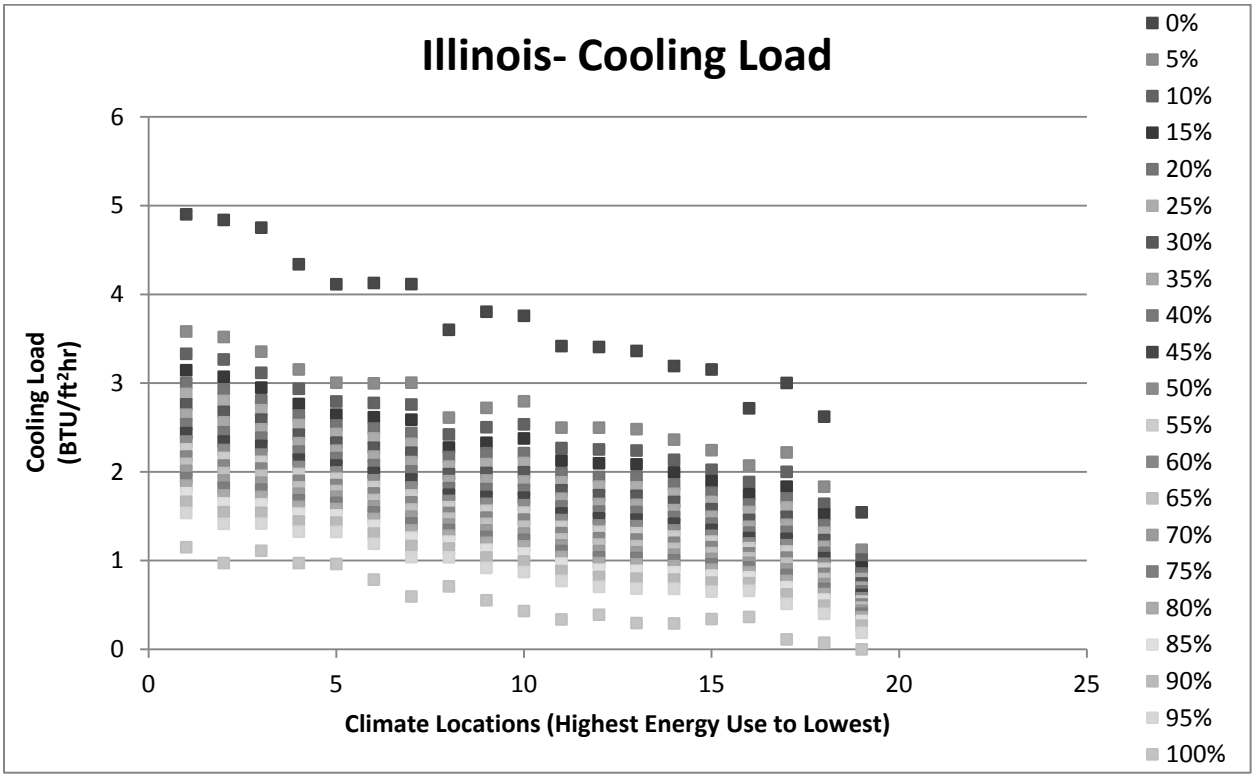
90%
95%
100%


Illinois- Cooling Load
Cooling Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
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75%
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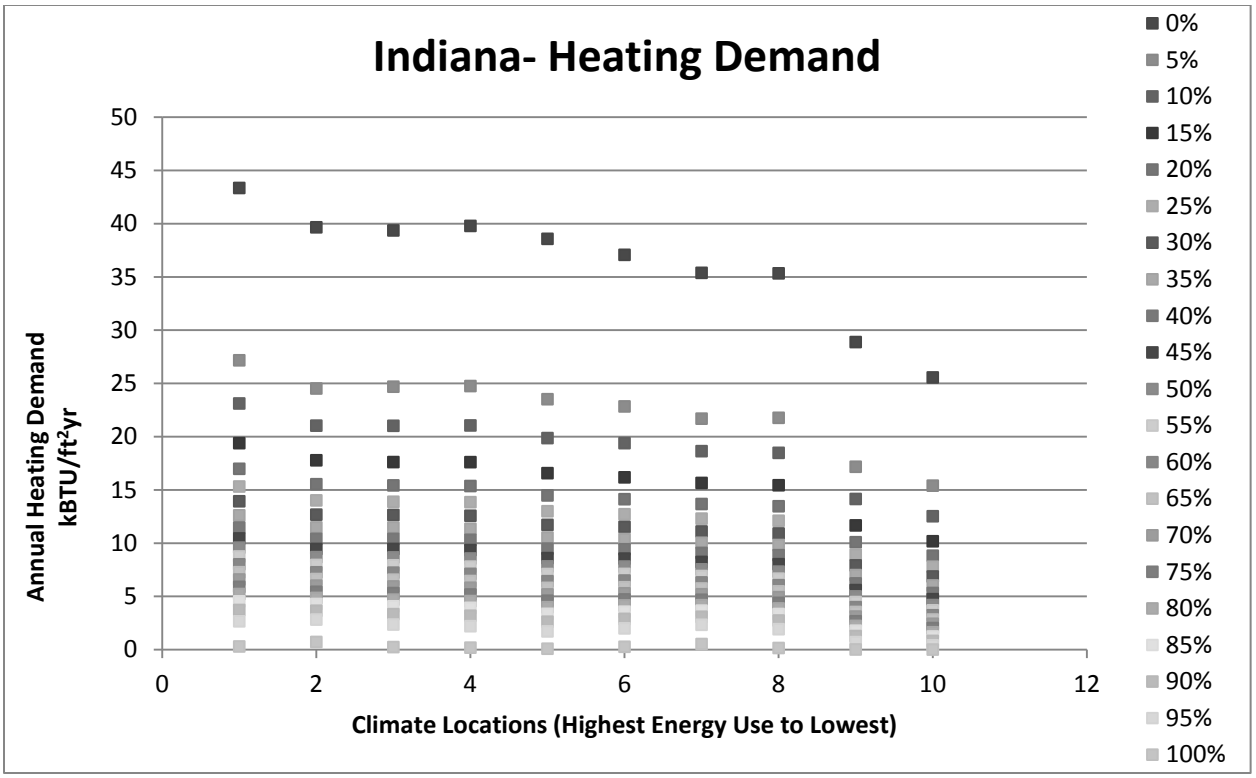
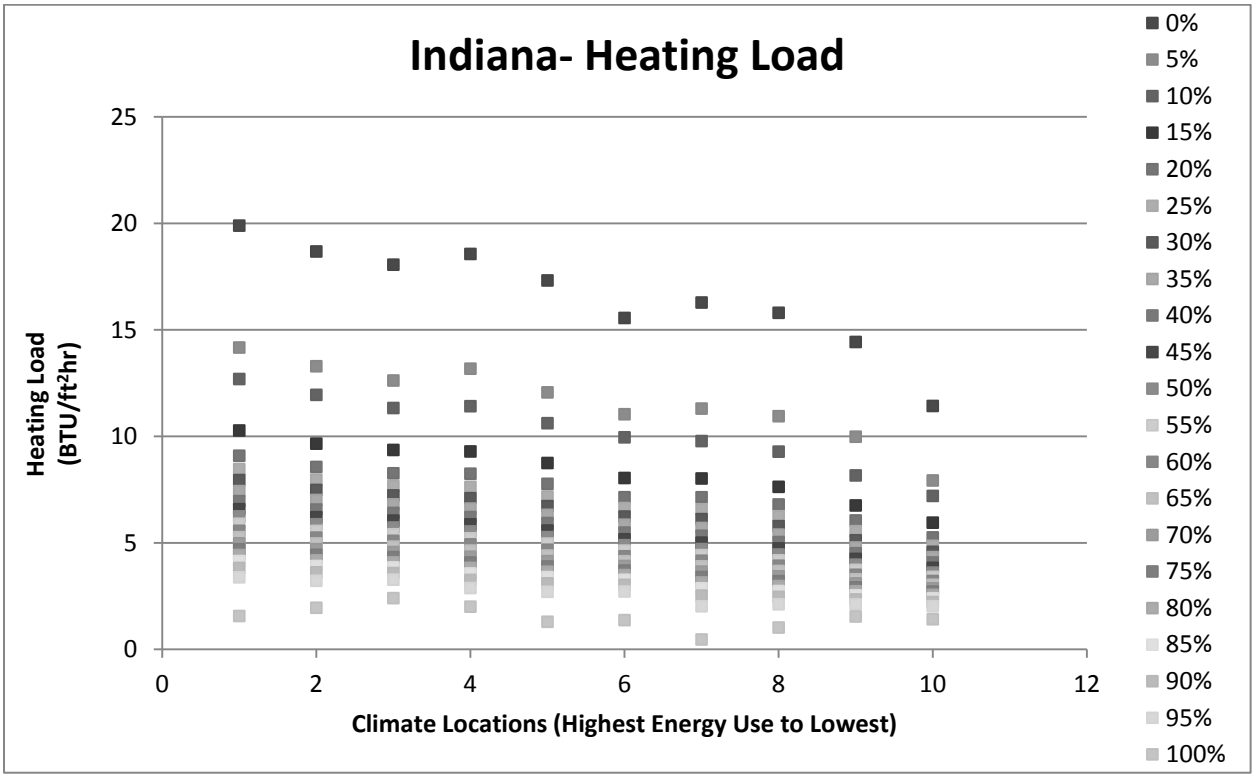
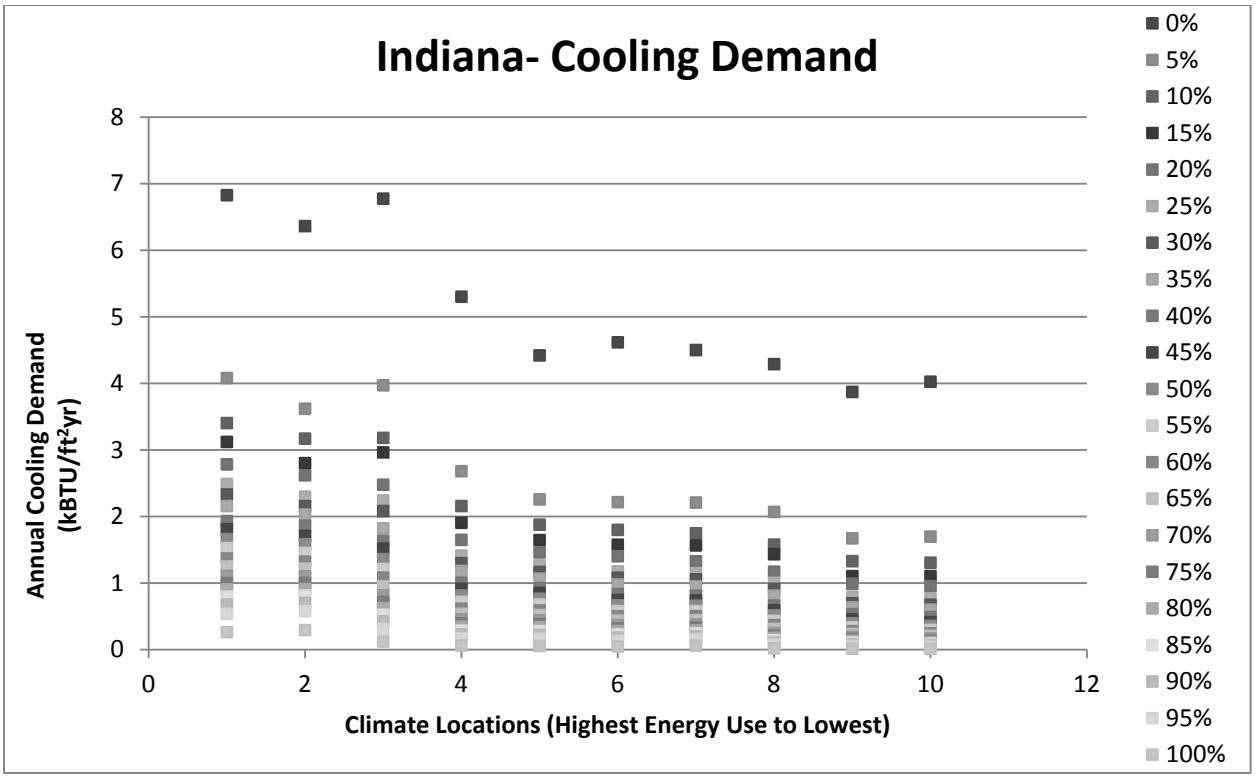
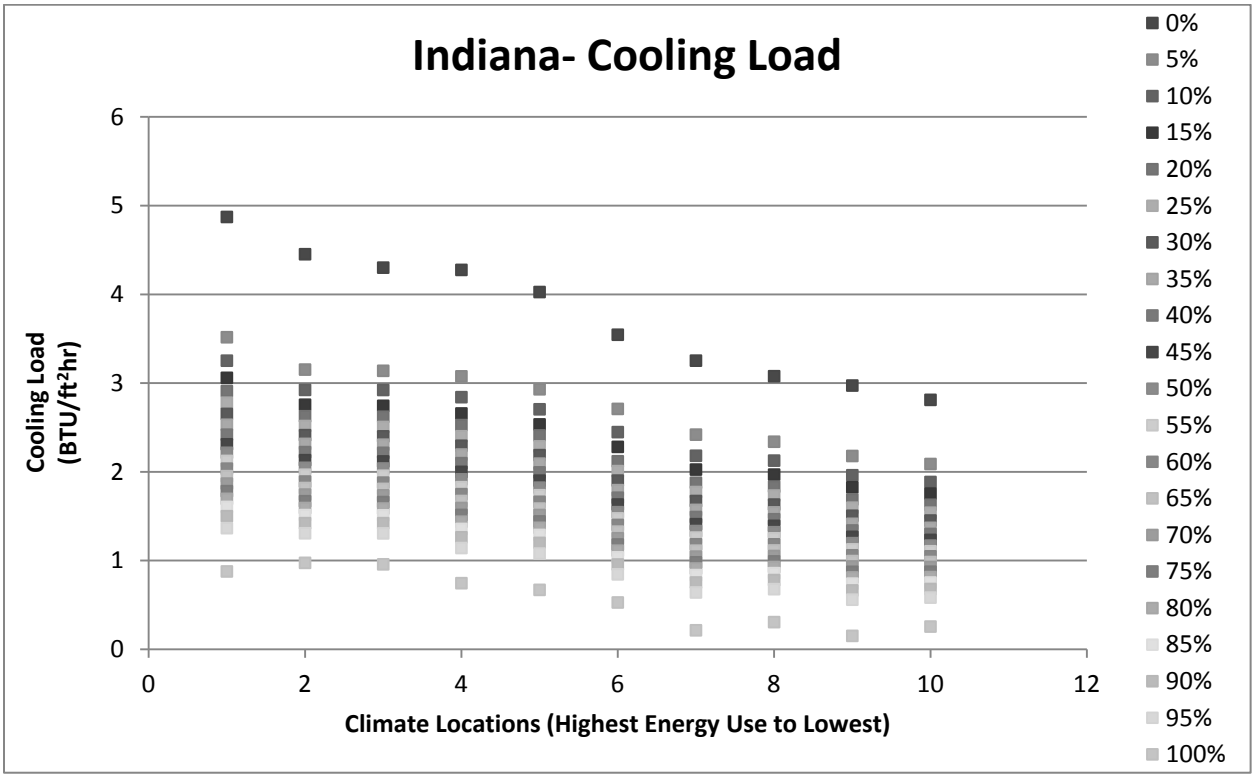
95%
100%


Indiana- Heating Demand
Annual Heating Demand kBTU/ft²yr
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%


Indiana- Heating Load
Heating Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%


Indiana- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
Climate Locations (Highest Energy Use to Lowest)
0
1
2
3
4
5
6
7
8
0
2
4
6
8
10
12
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%


Indiana- Cooling Load
Cooling Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0
1
2
3
4
5
6
0
2
4
6
8
10
12
0%
5%
10%
15%
20%
25%
30%
35%
40%
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50%
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60%
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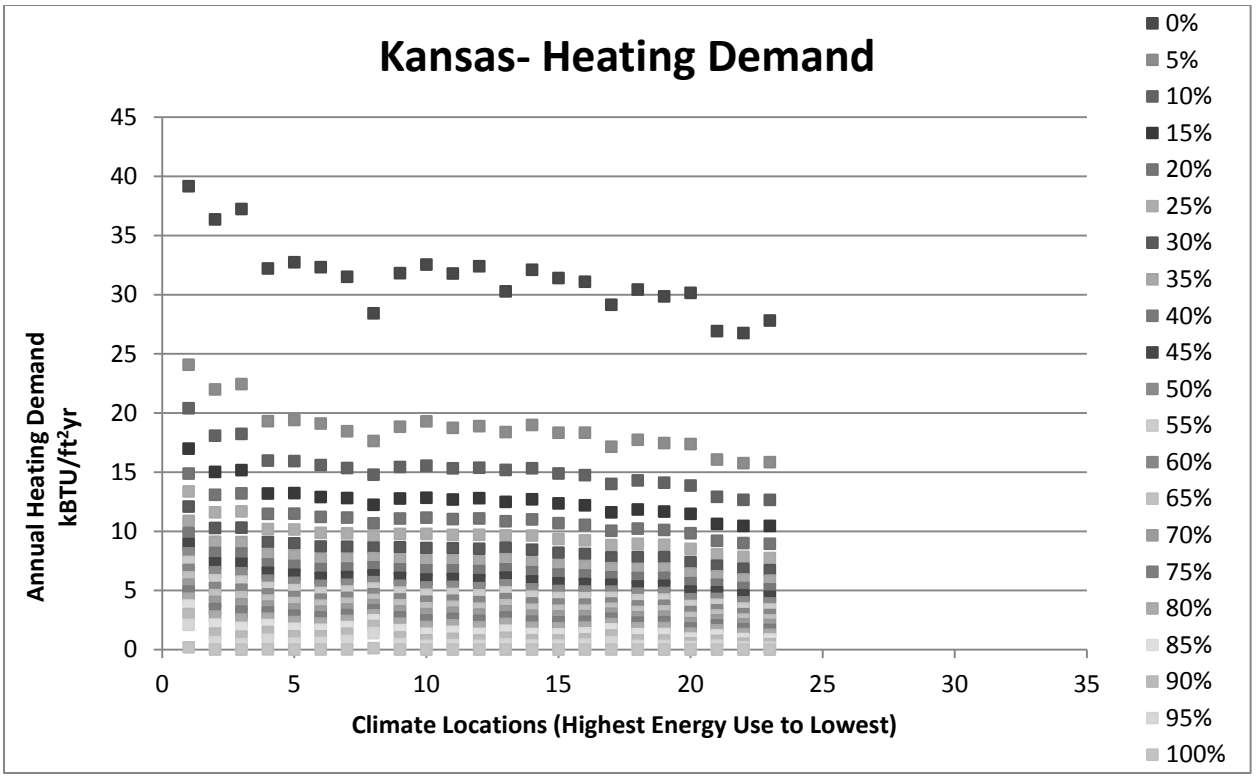
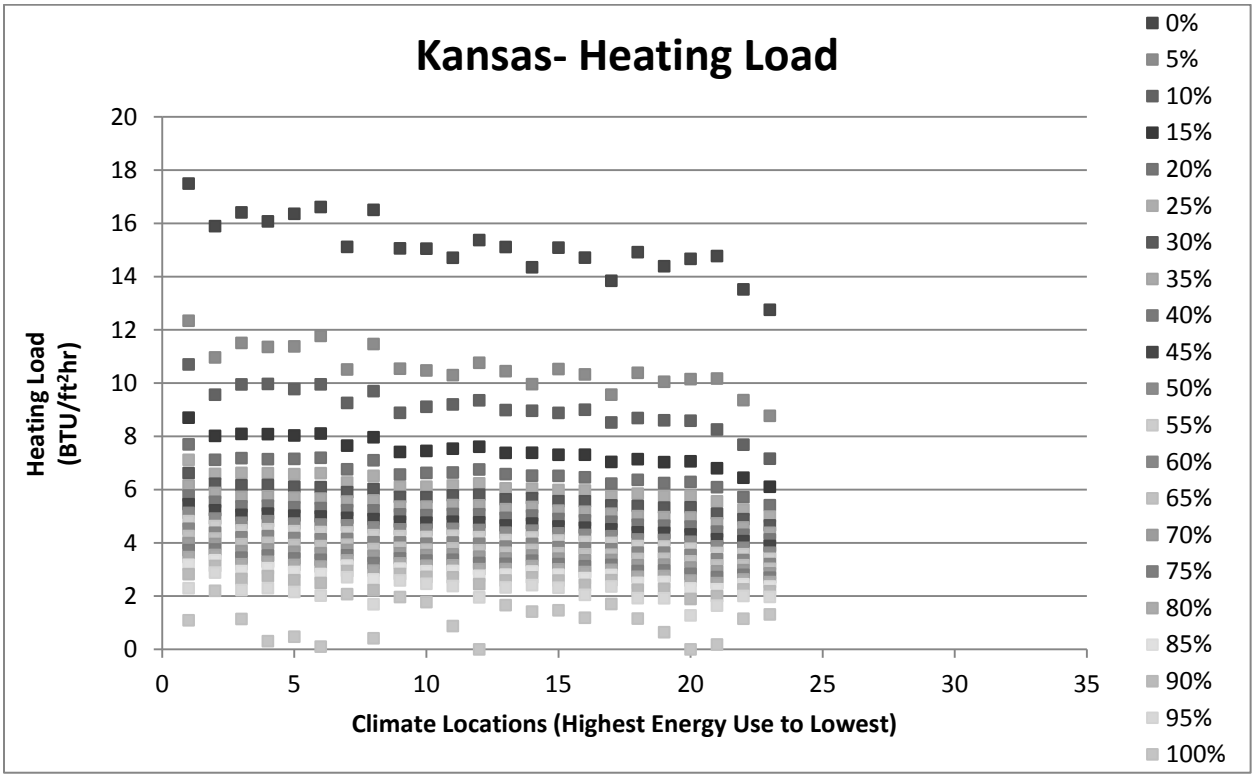
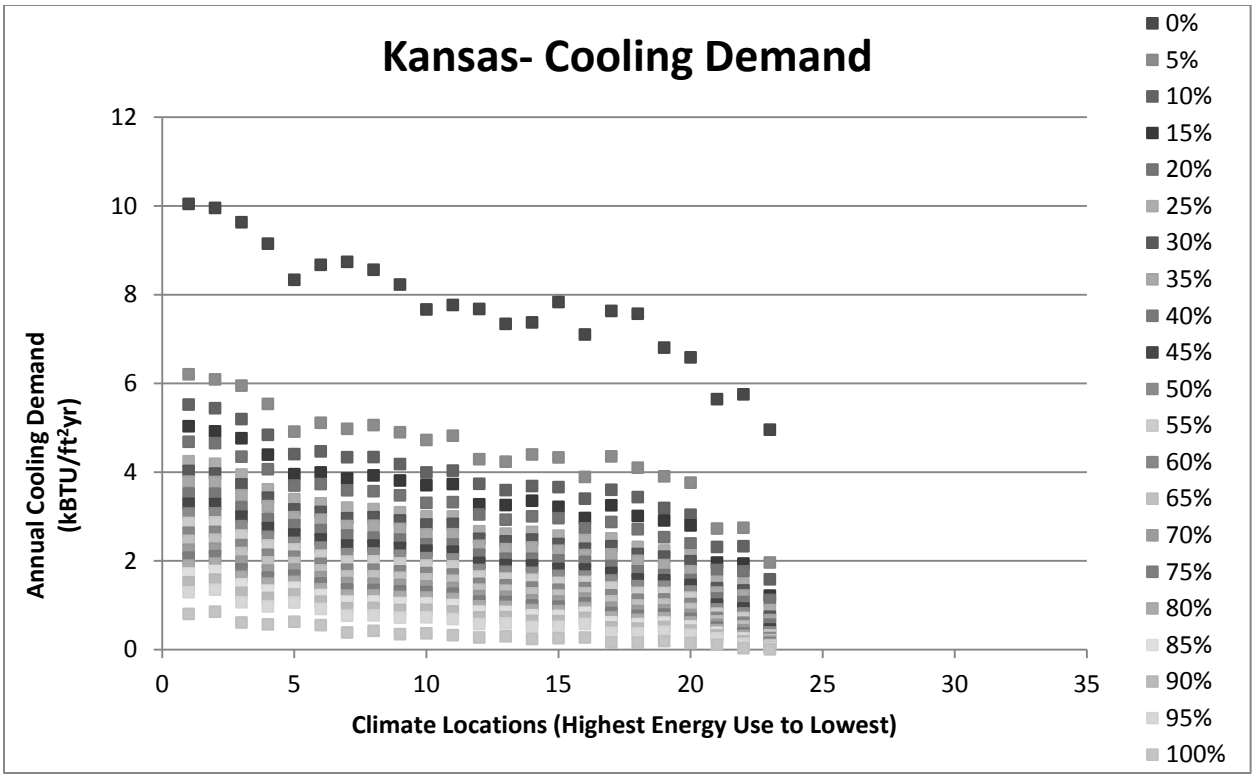
70%
75%
80%
85%
90%
95%
100%


Kansas- Heating Demand
Annual Heating Demand kBTU/ft²yr
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%


Kansas- Heating Load
Heating Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%


Kansas- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
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55%
60%
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75%
80%
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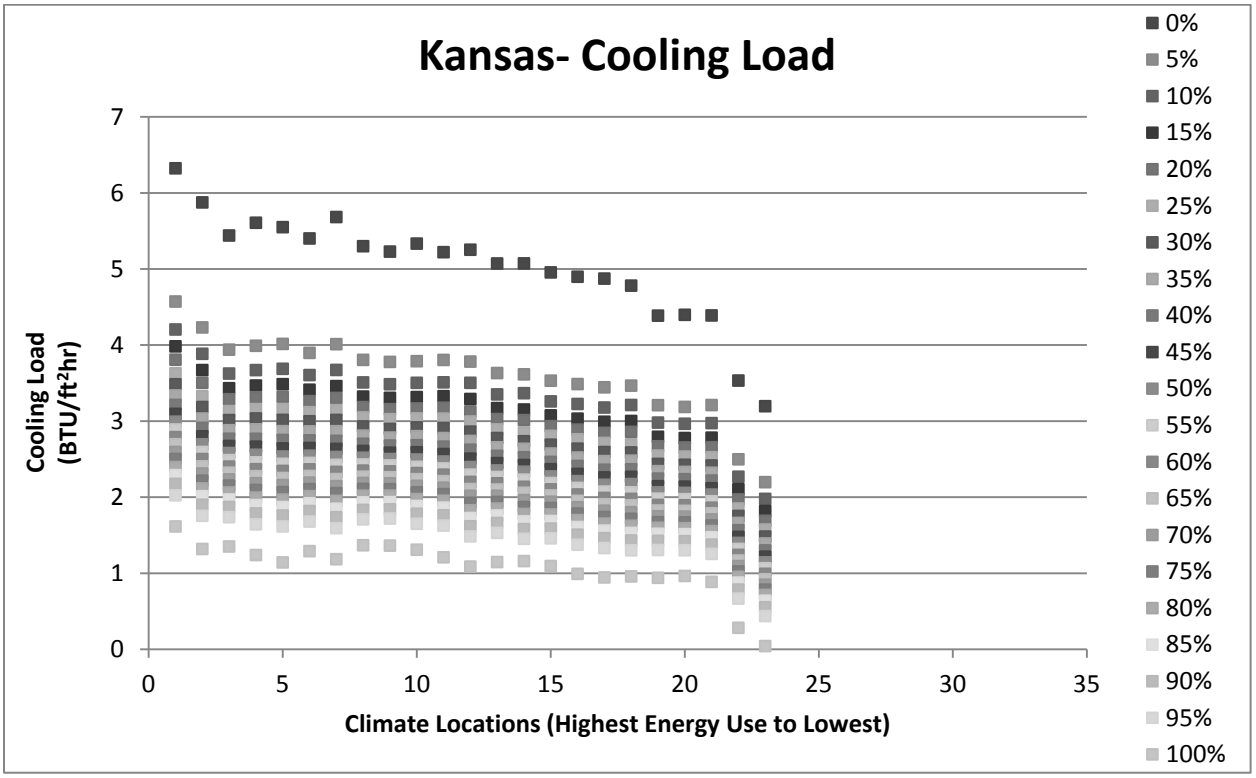
90%
95%
100%


Kansas- Cooling Load
Cooling Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
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75%
80%
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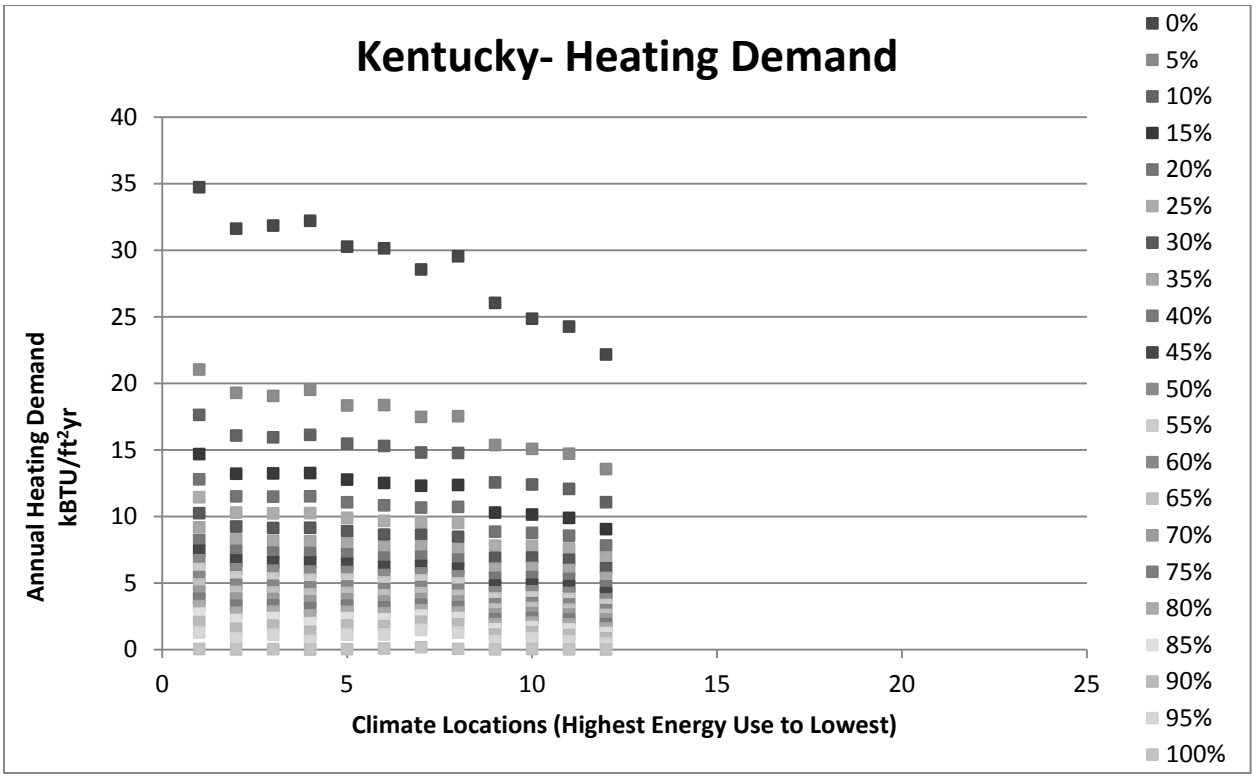
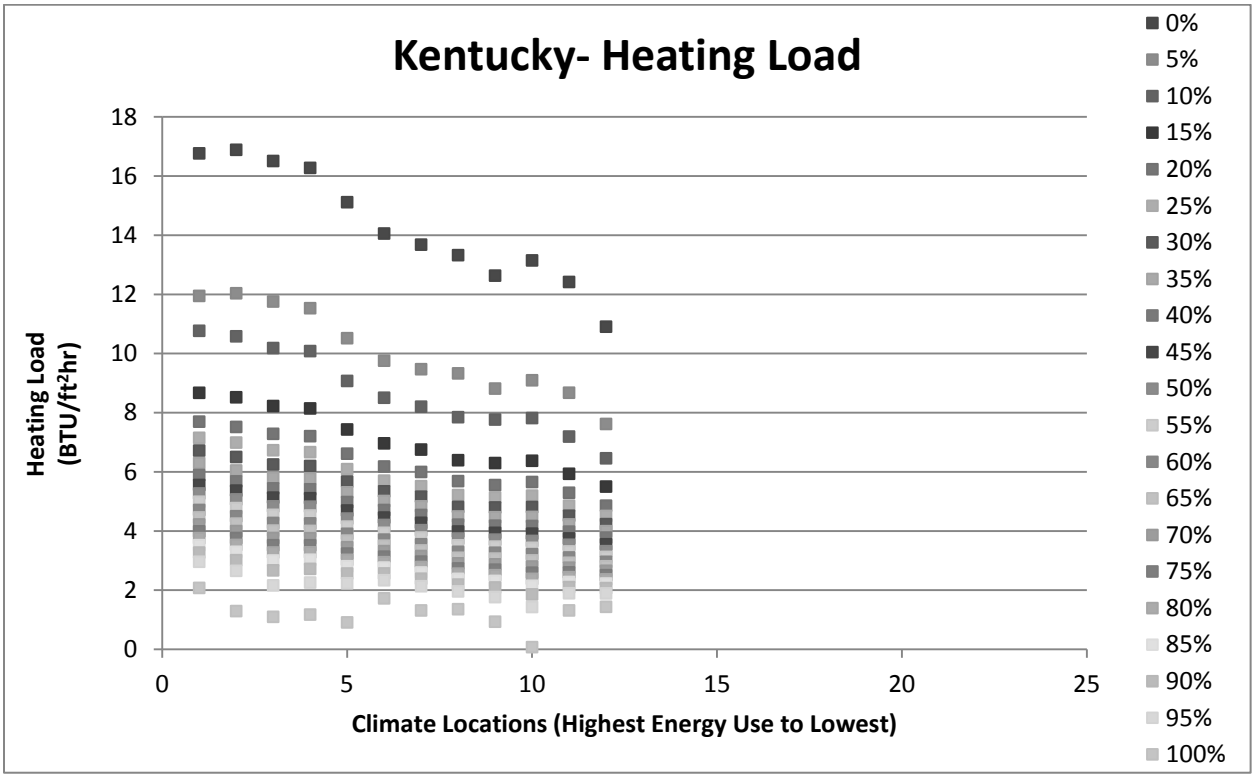
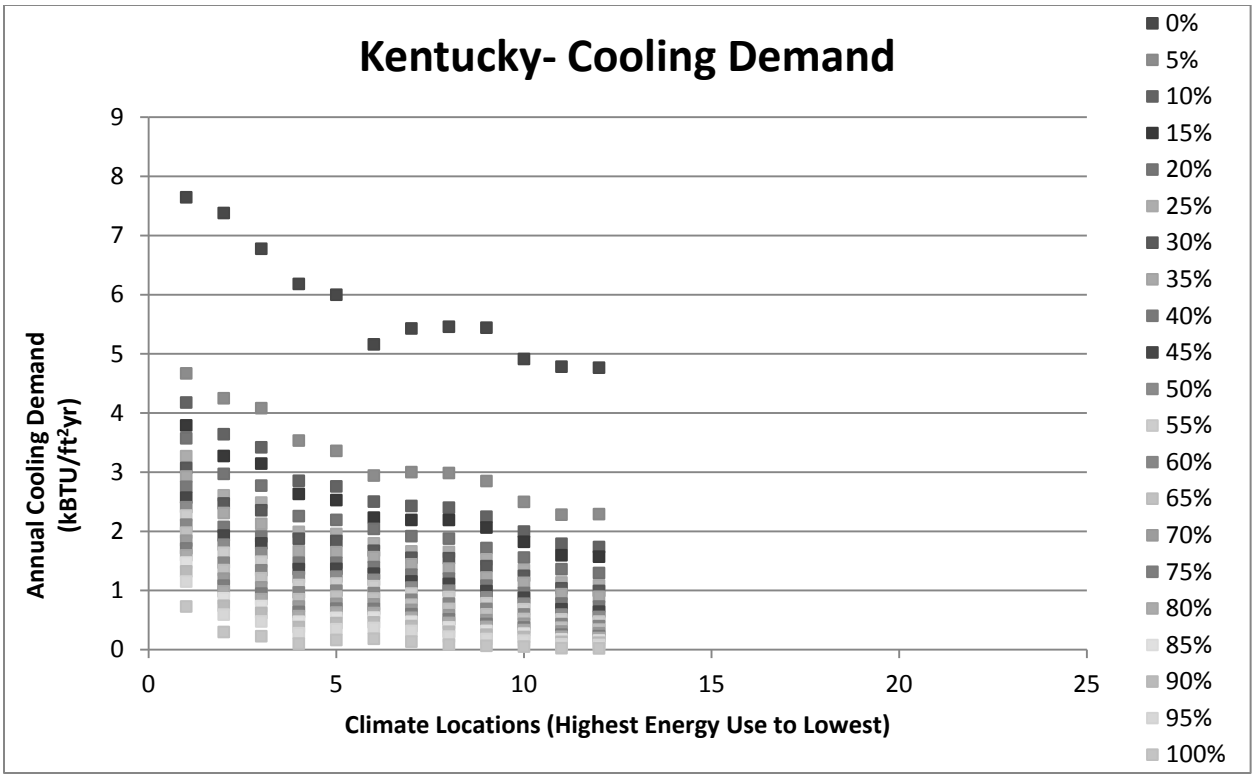
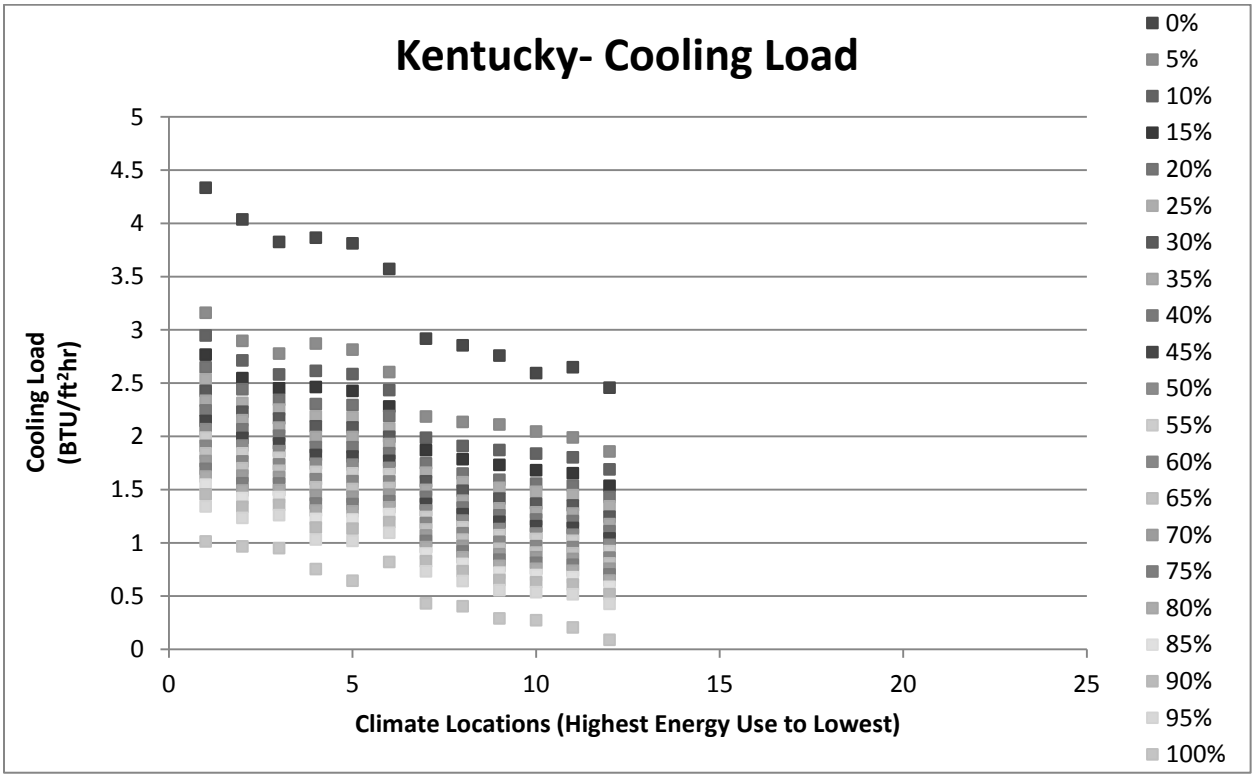
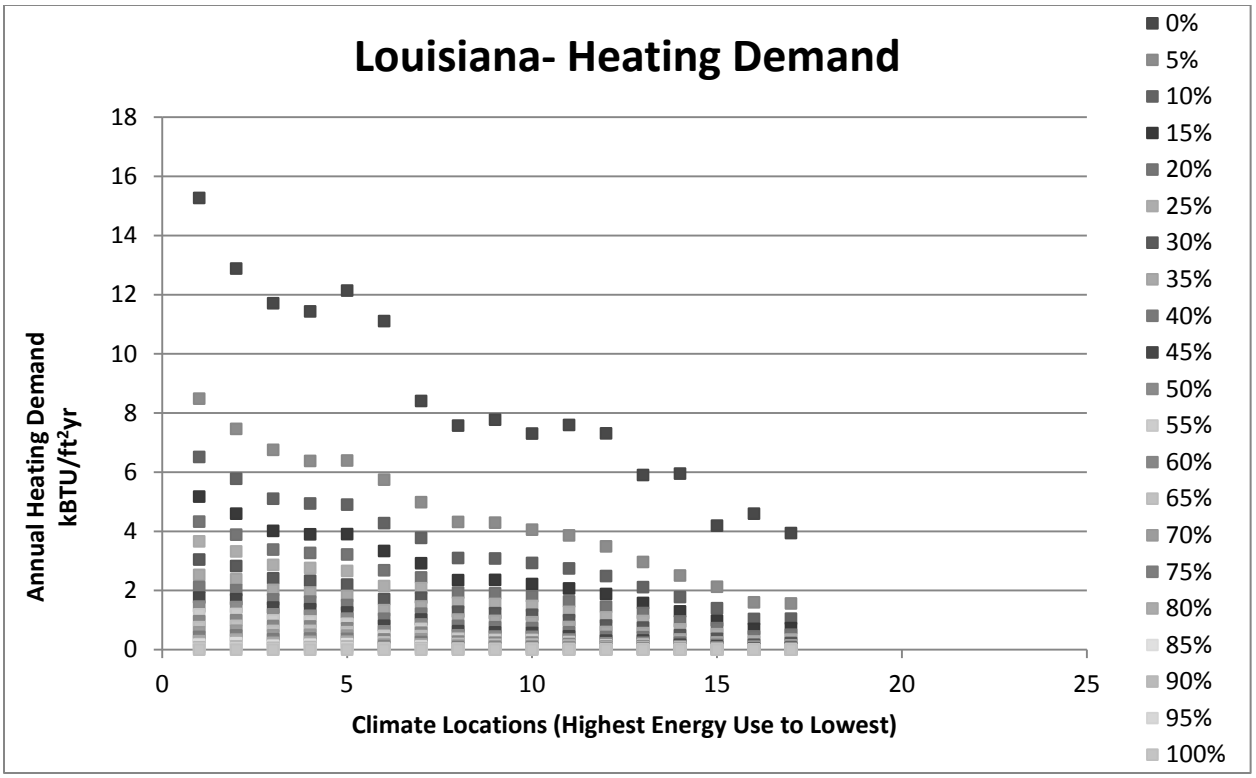
90%
95%
100%

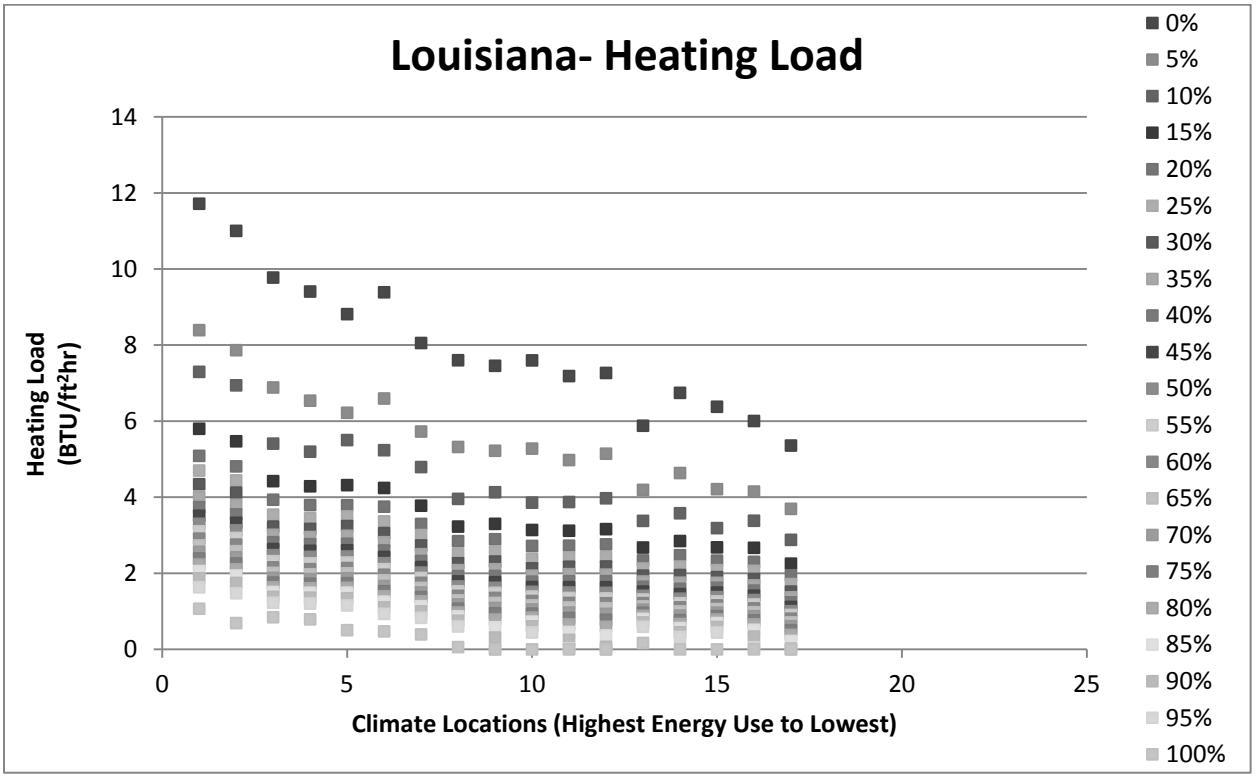

Kentucky- Heating Demand
Annual Heating Demand kBTU/ft²yr
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

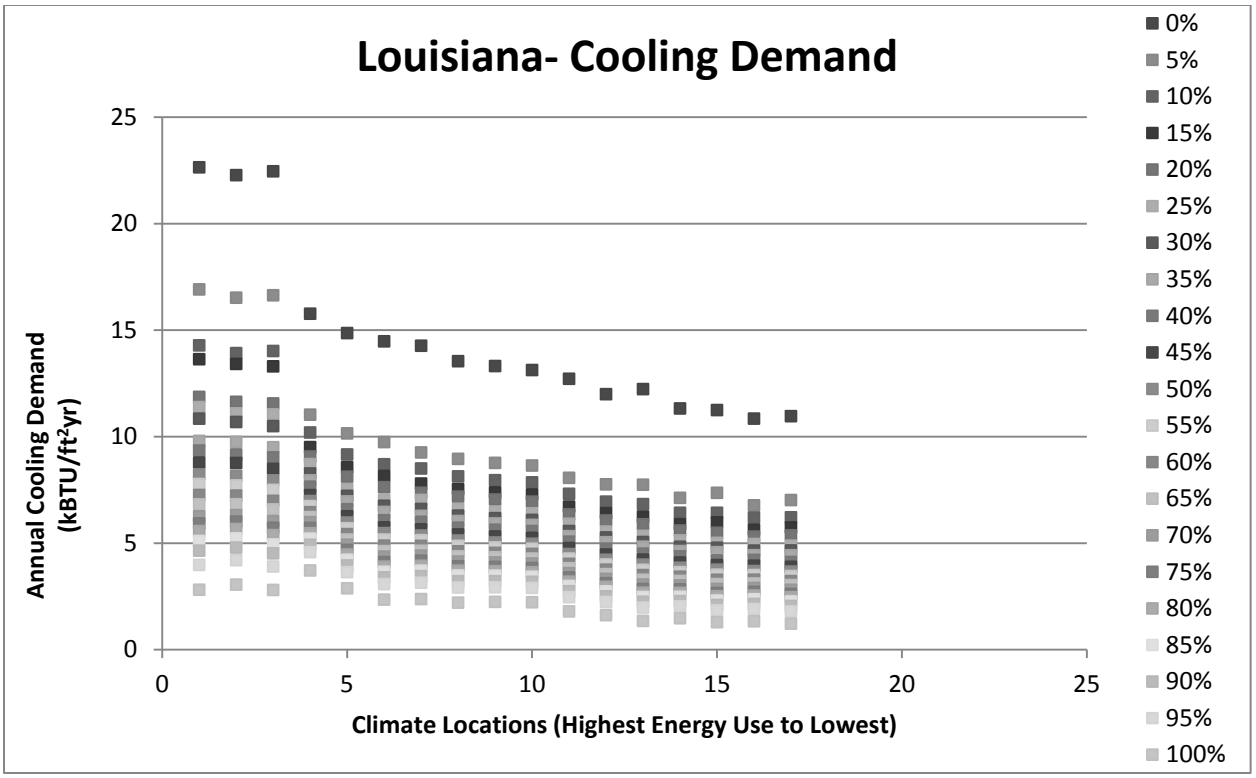

Kentucky- Heating Load
Heating Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

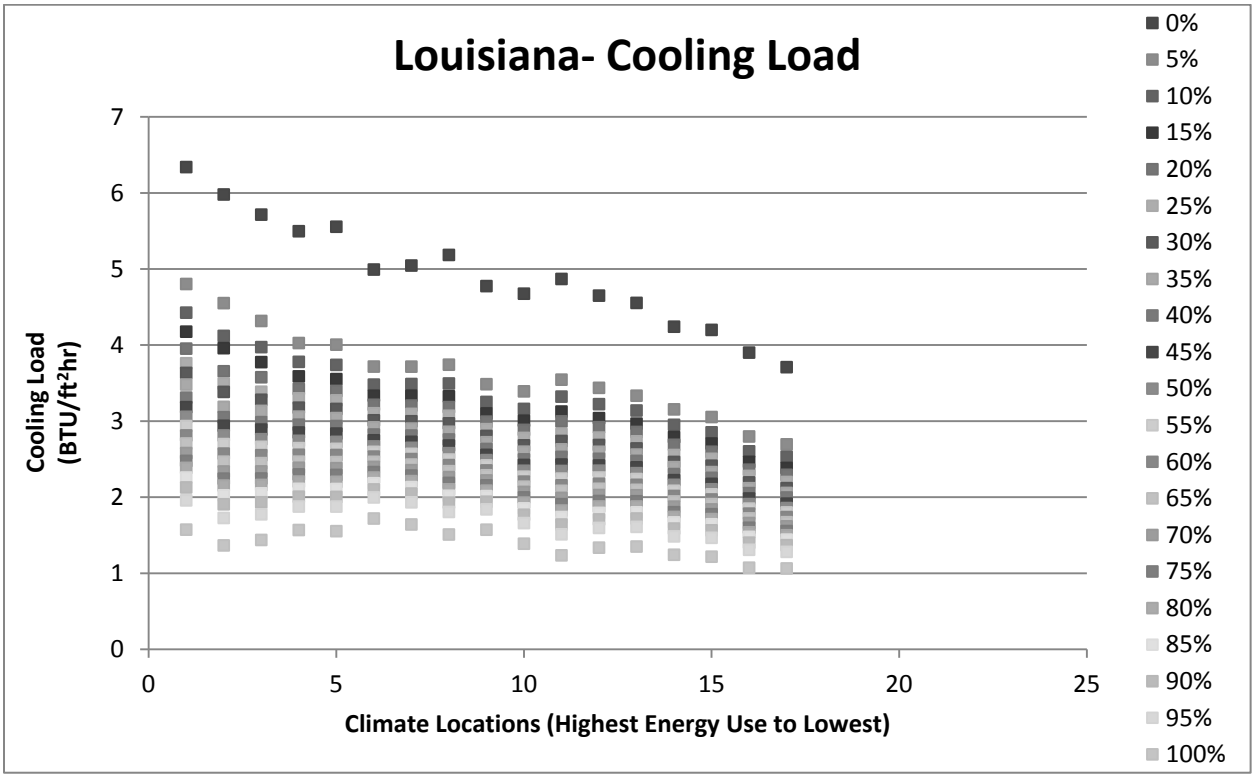

Kentucky- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

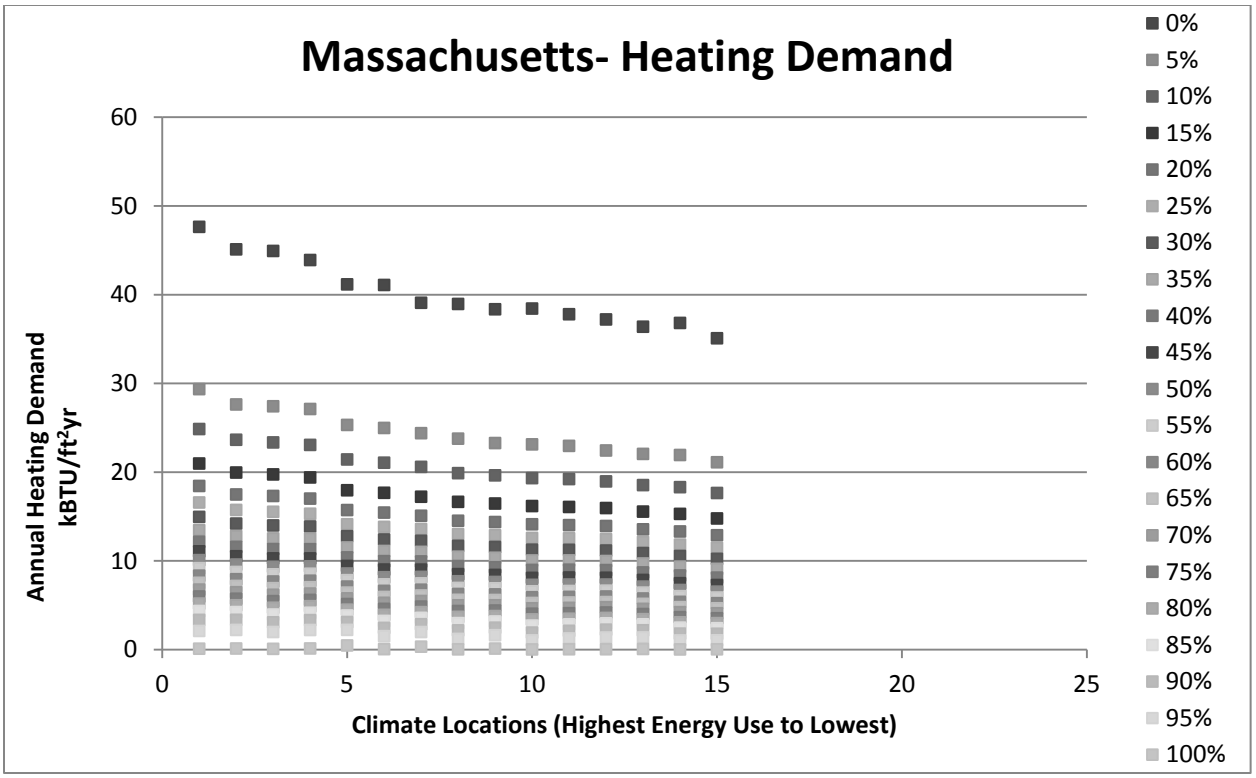

Kentucky- Cooling Load
Cooling Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

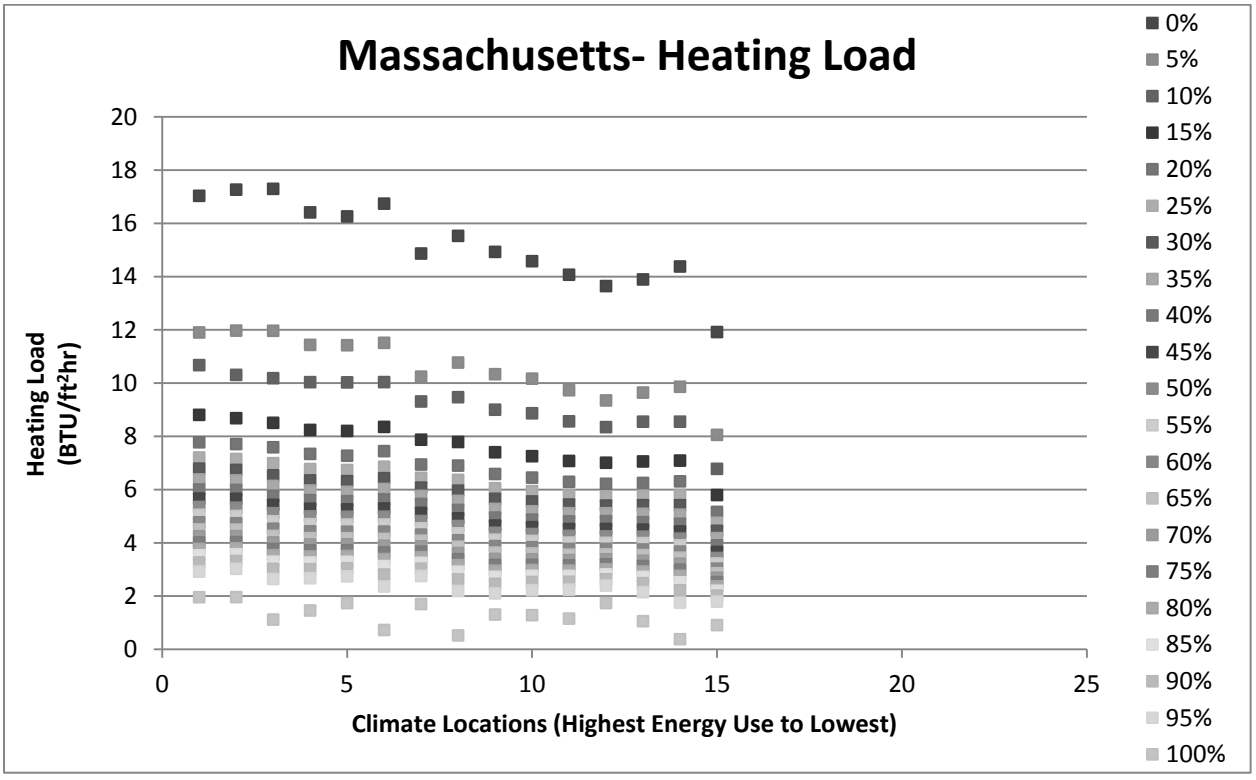

Louisiana- Heating Demand
Annual Heating Demand kBTU/ft²yr
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

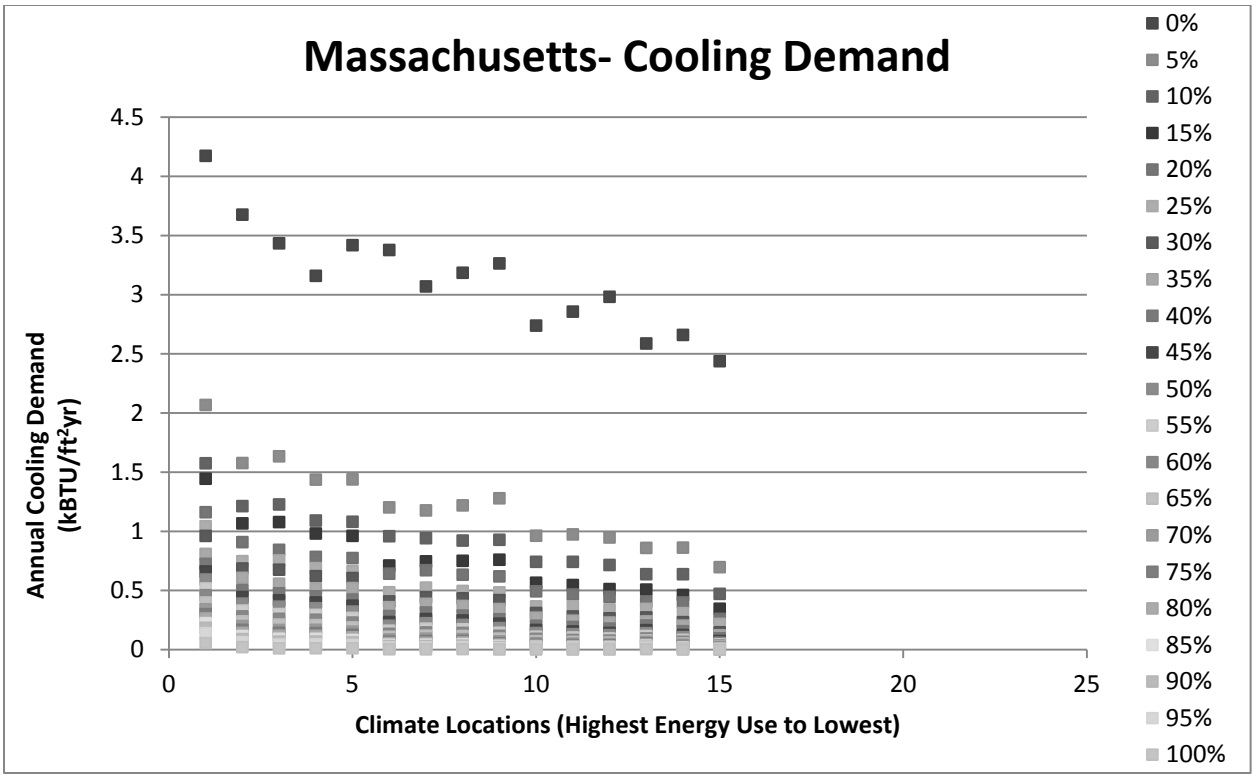

Louisiana- Heating Load
Heating Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

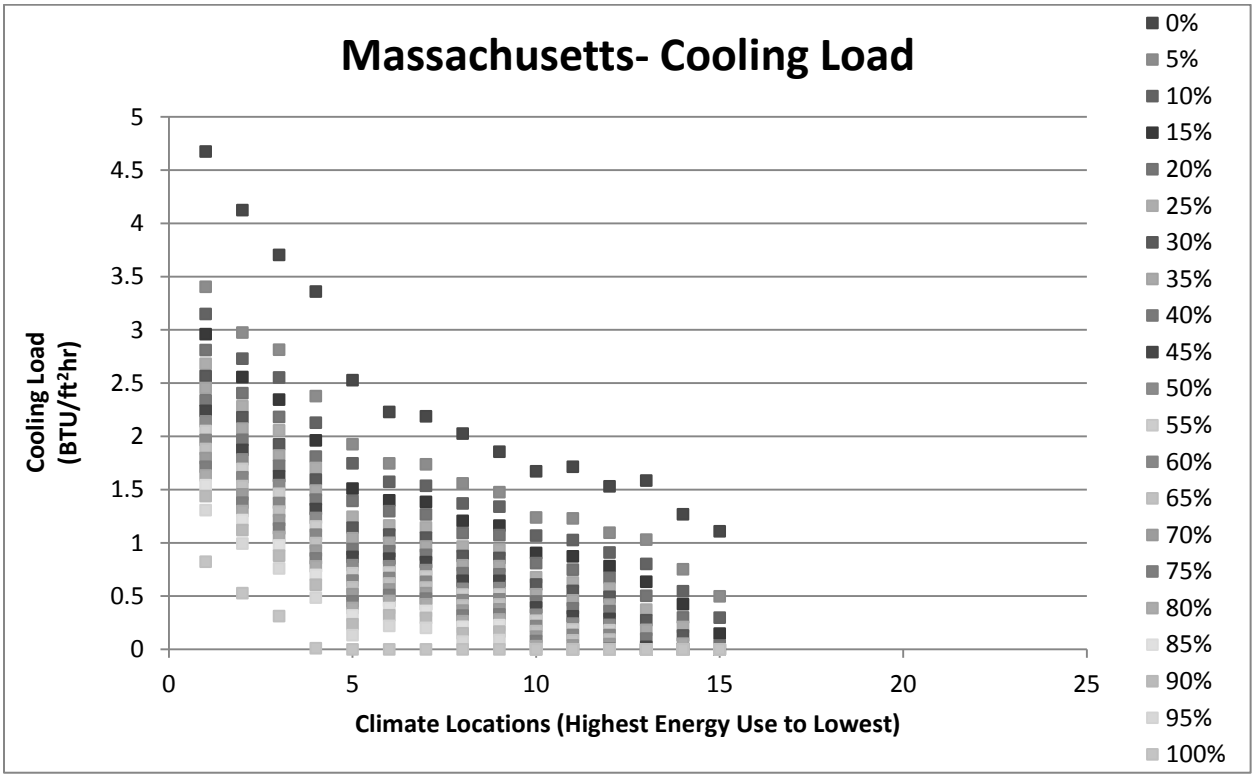

Louisiana- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
Climate Locations (Highest Energy Use to Lowest)
0
5
10
15
20
25
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

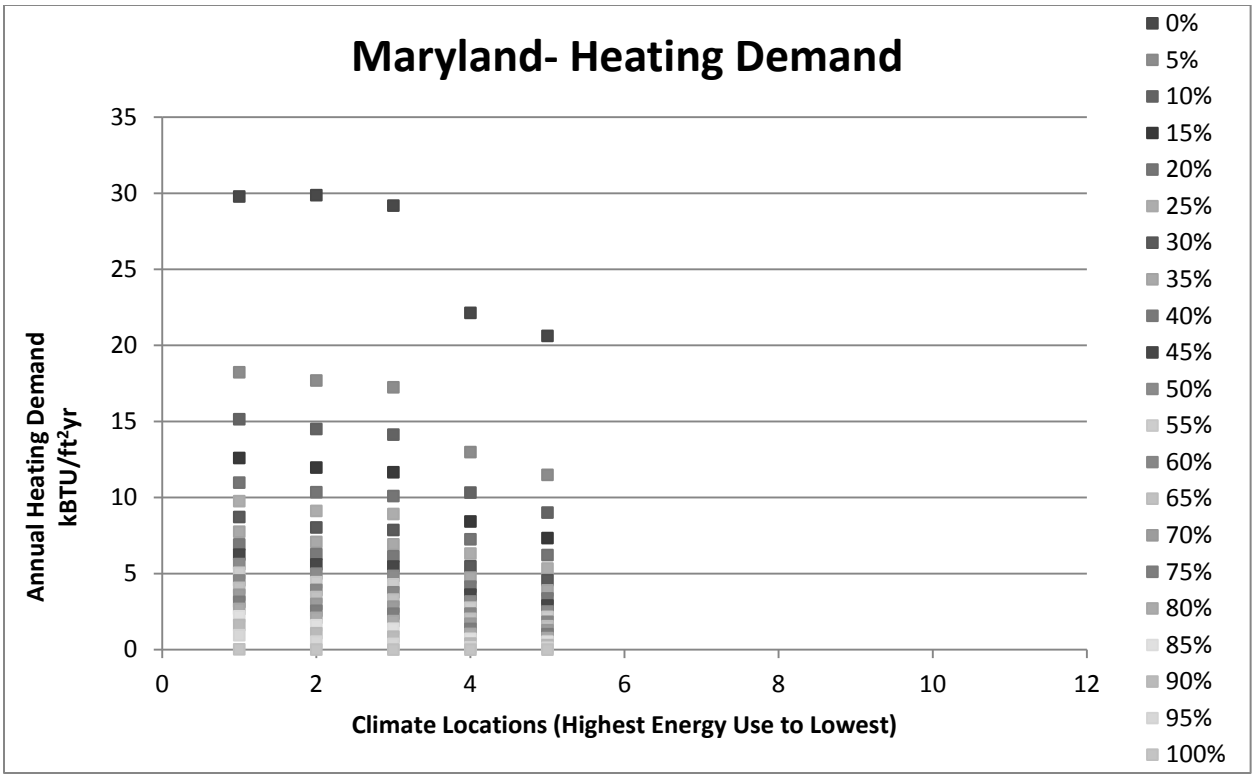

Louisiana- Cooling Load
Cooling Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0
1
2
3
4
5
6
7
0
5
10
15
20
25
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

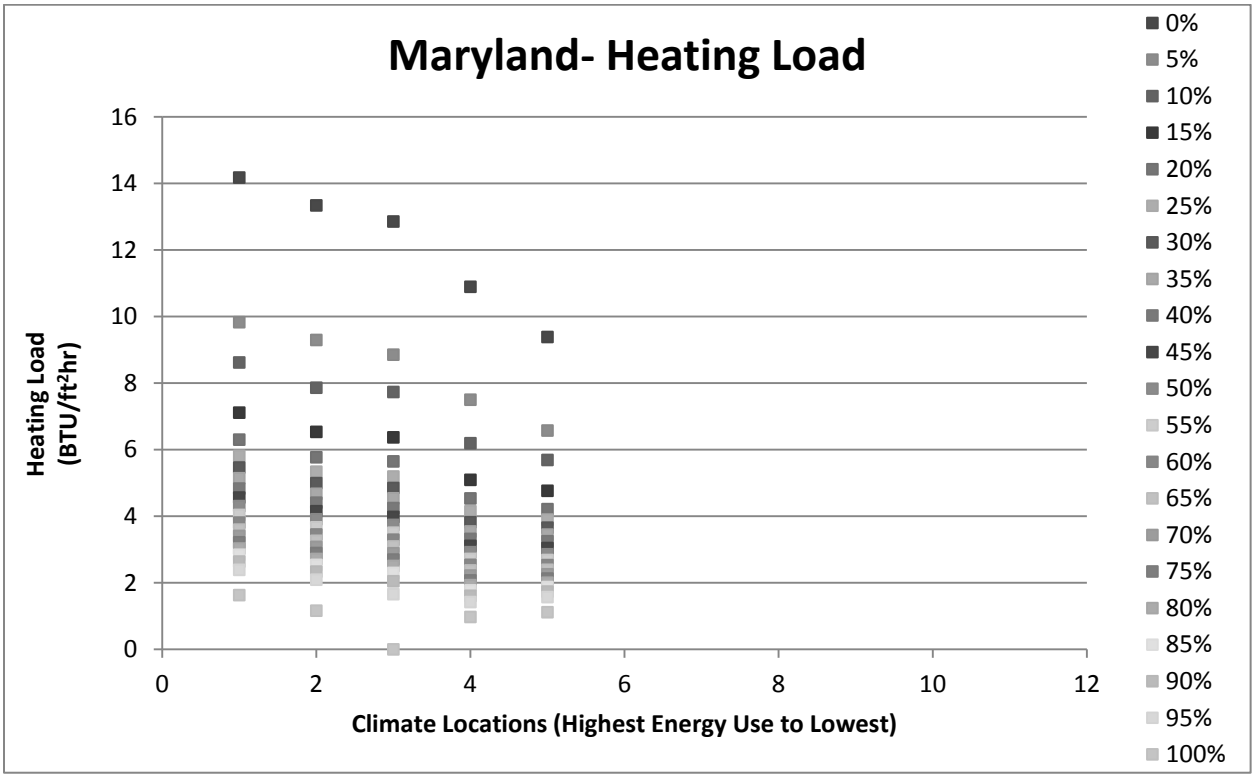

Massachusetts- Heating Demand
Annual Heating Demand kBTU/ft²yr
60
50
40
30
20
10
0
0
5
10
15
20
25
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

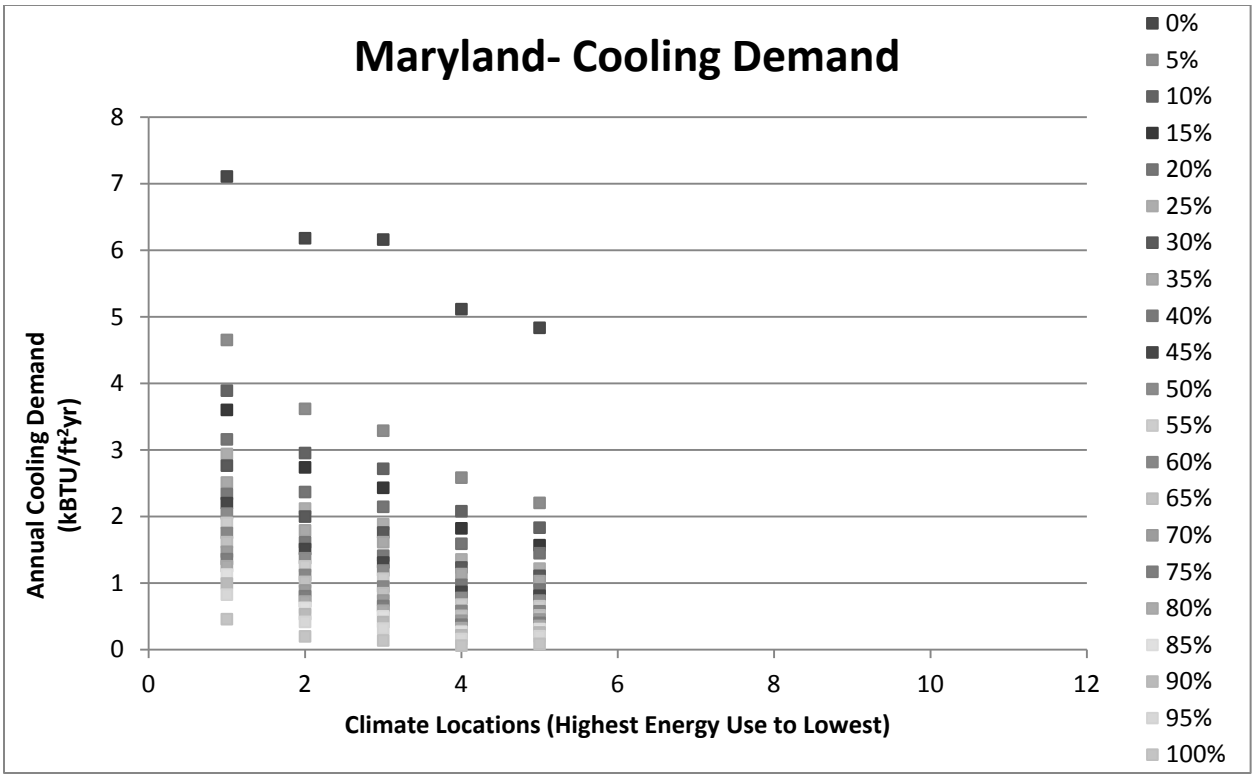

Massachusetts- Heating Load
Heating Load (BTU/ft²hr)
20
18
16
14
12
10
8
6
4
2
0
0
5
10
15
20
25
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

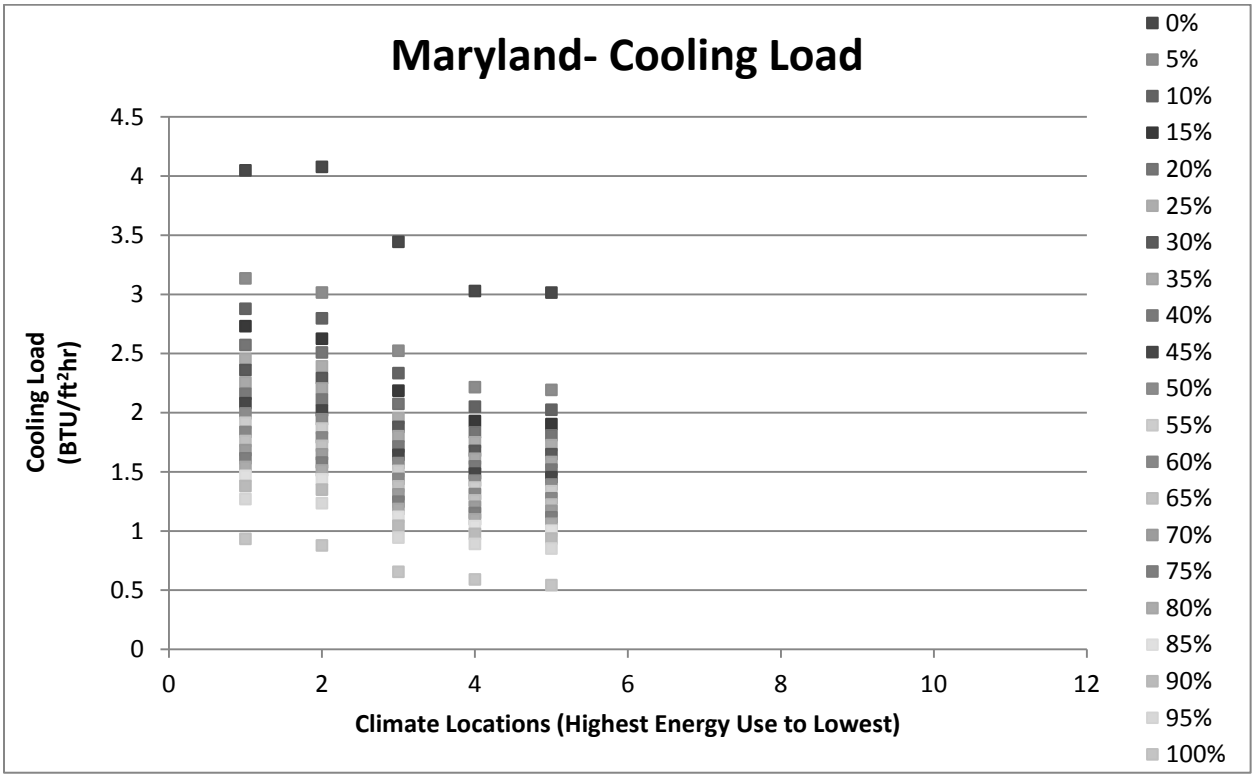

Massachusetts- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
5
10
15
20
25
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

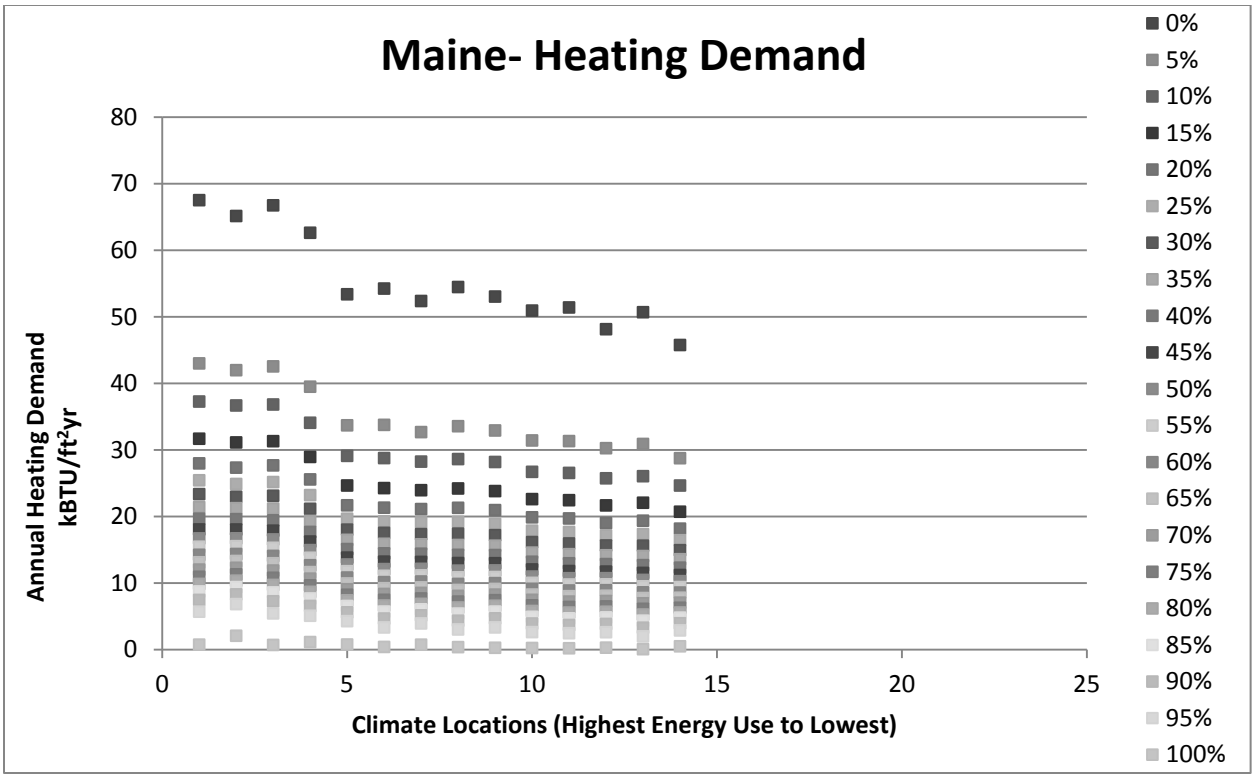

Massachusetts- Cooling Load
Cooling Load (BTU/ft²hr)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
5
10
15
20
25
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

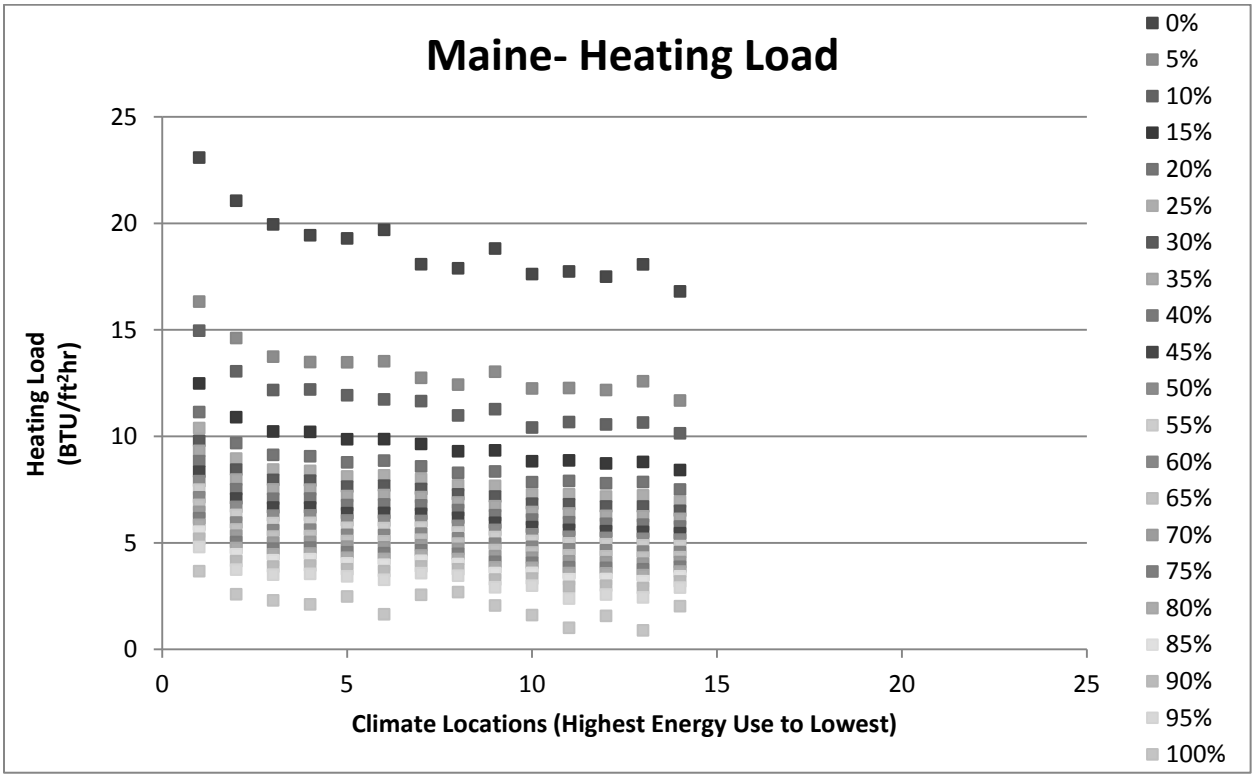

Maryland- Heating Demand
Annual Heating Demand kBTU/ft²yr
0
5
10
15
20
25
30
35
0
2
4
6
8
10
12
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

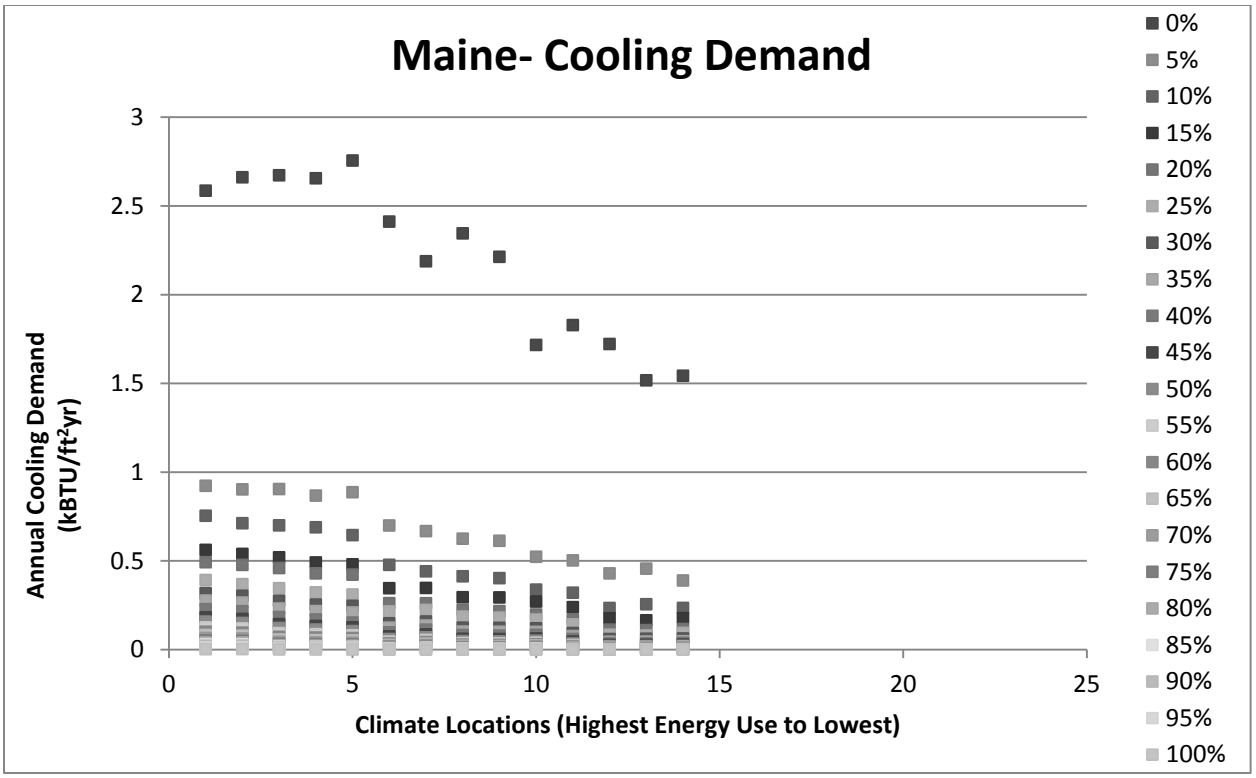

Maryland- Heating Load
Heating Load (BTU/ft²hr)
0
2
4
6
8
10
12
14
16
0
2
4
6
8
10
12
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

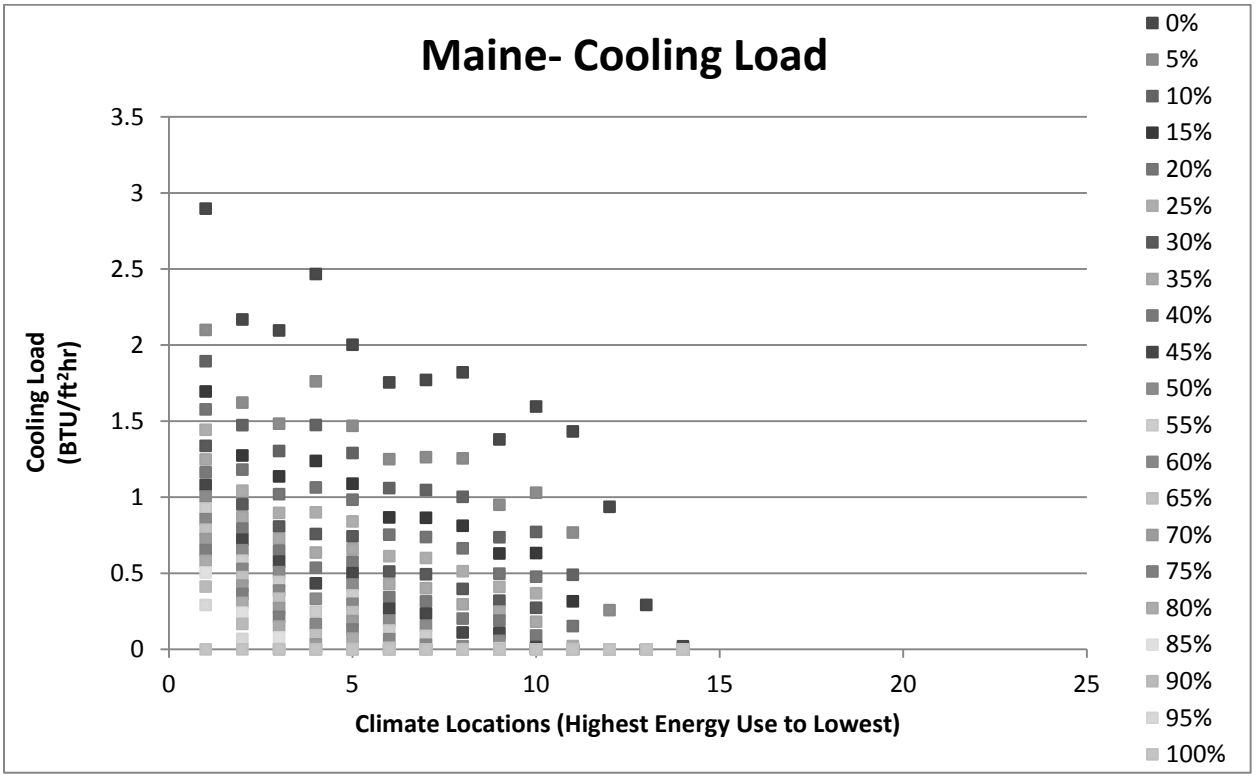

Maryland- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

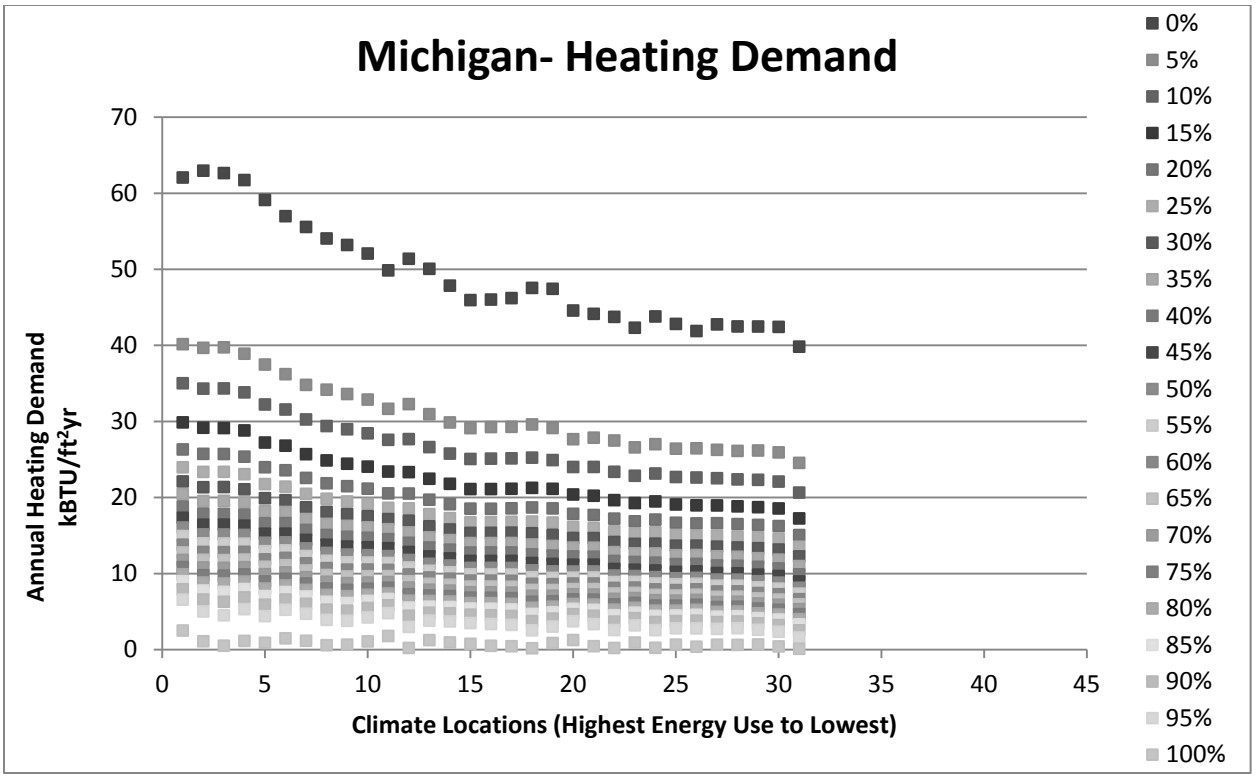

Maryland- Cooling Load
Cooling Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

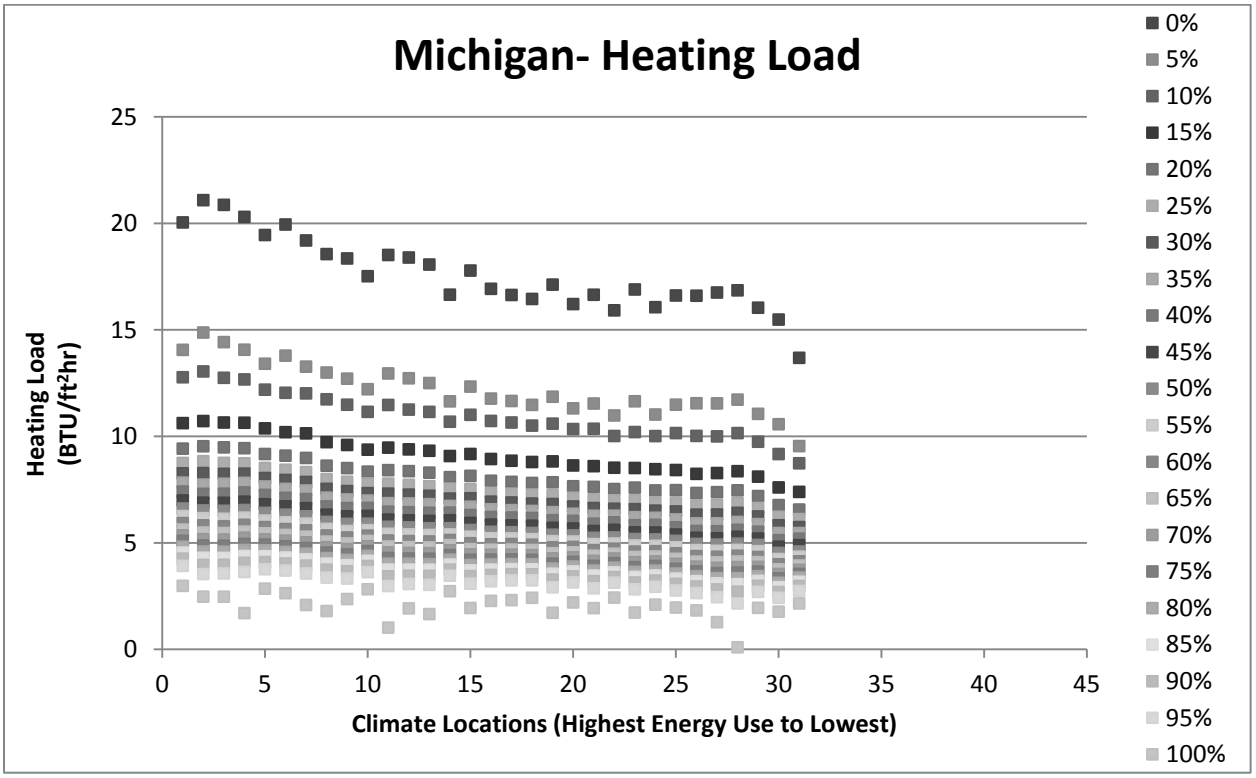

Maine- Heating Demand
Annual Heating Demand kBTU/ft²yr
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

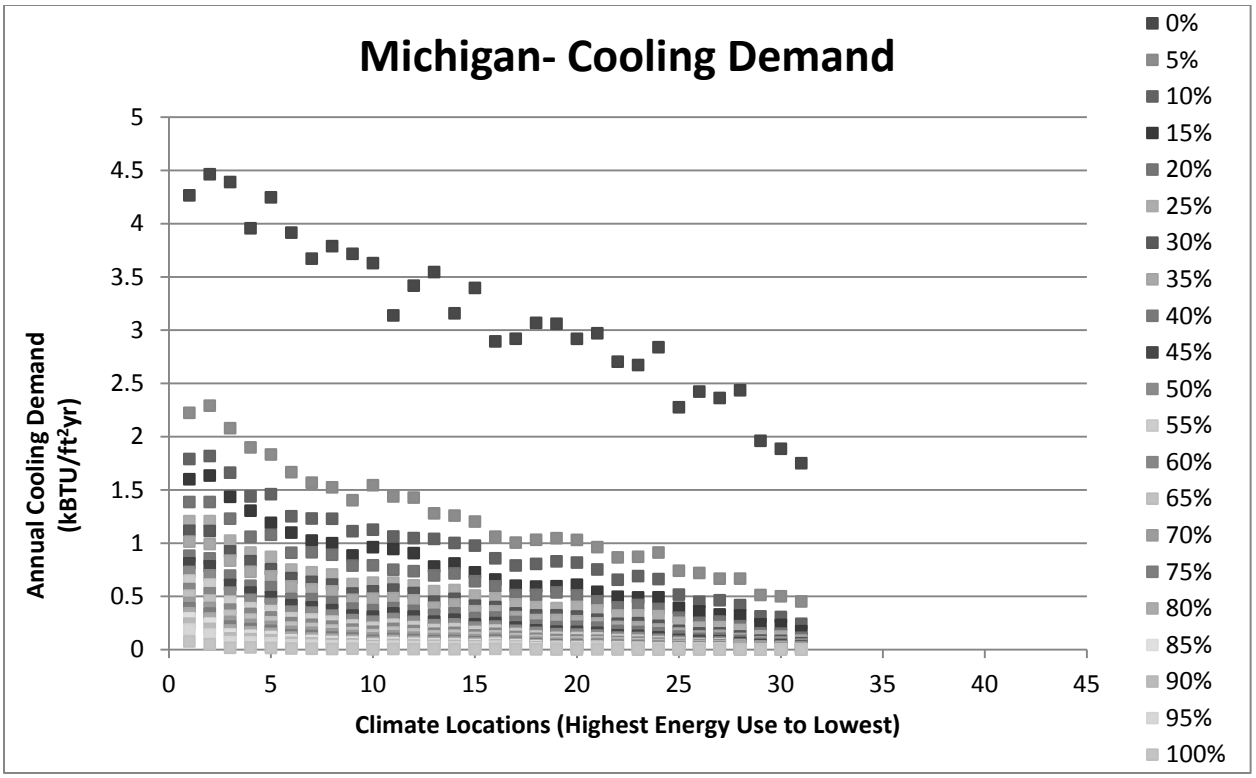

Maine- Heating Load
Heating Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

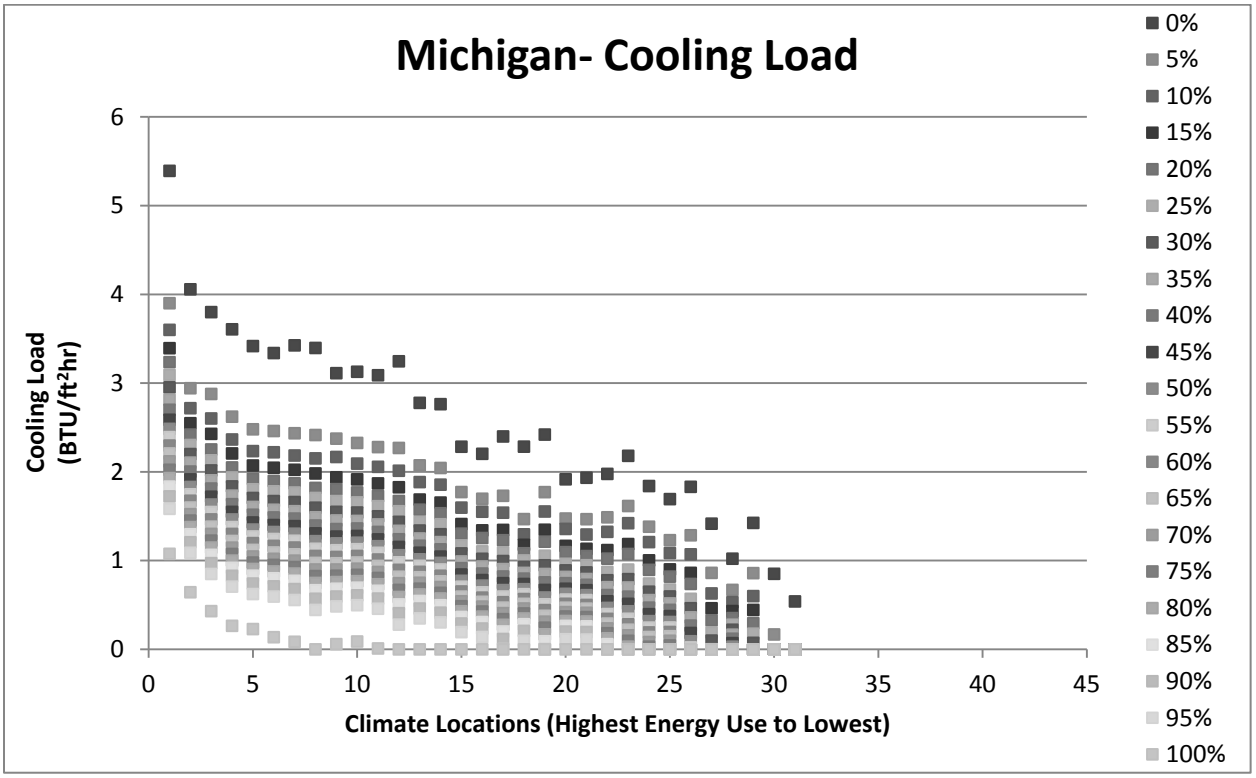

Maine- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

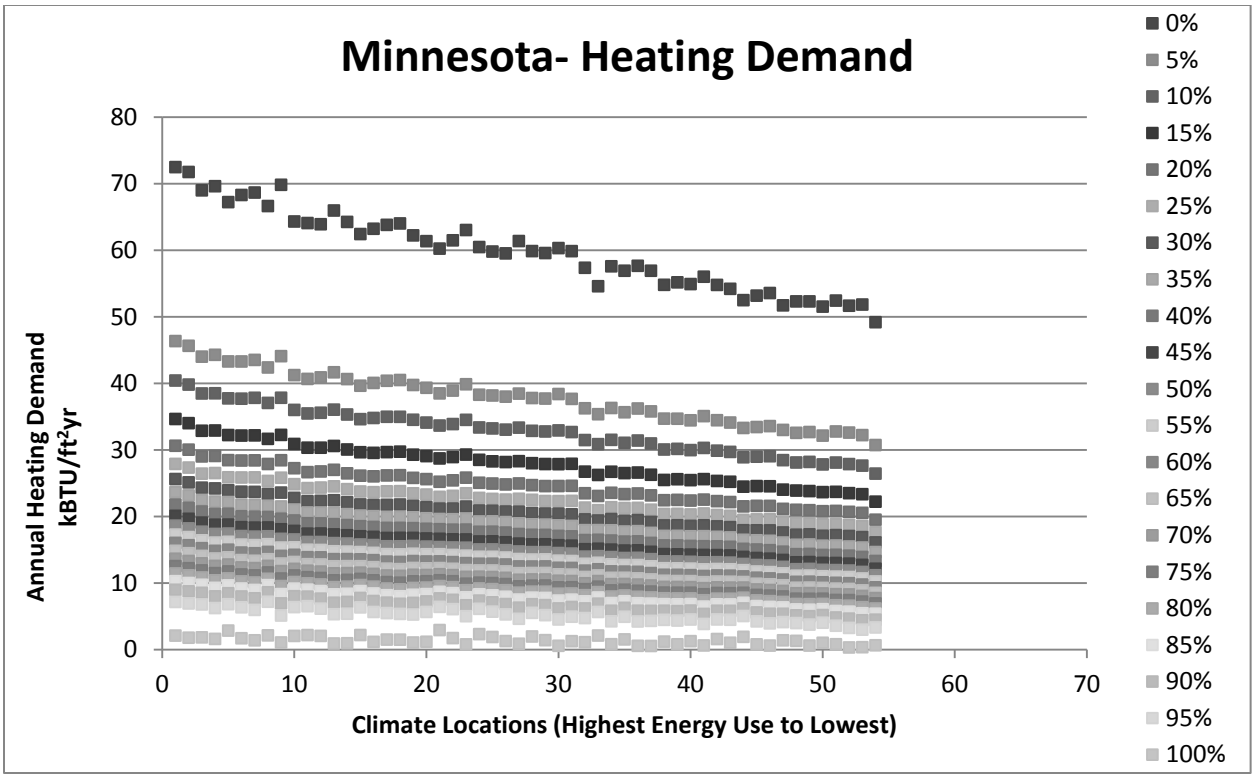

Maine- Cooling Load
Cooling Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

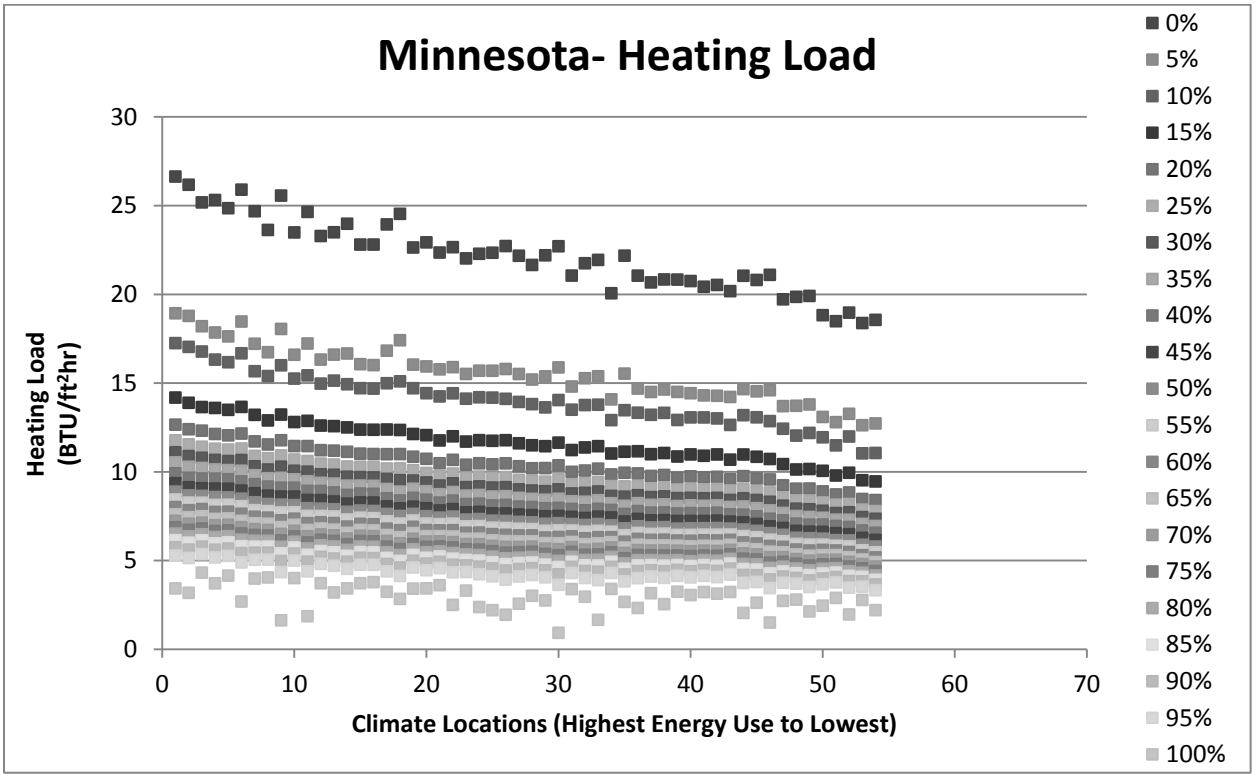

Michigan- Heating Demand
Annual Heating Demand kBTU/ft²yr
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

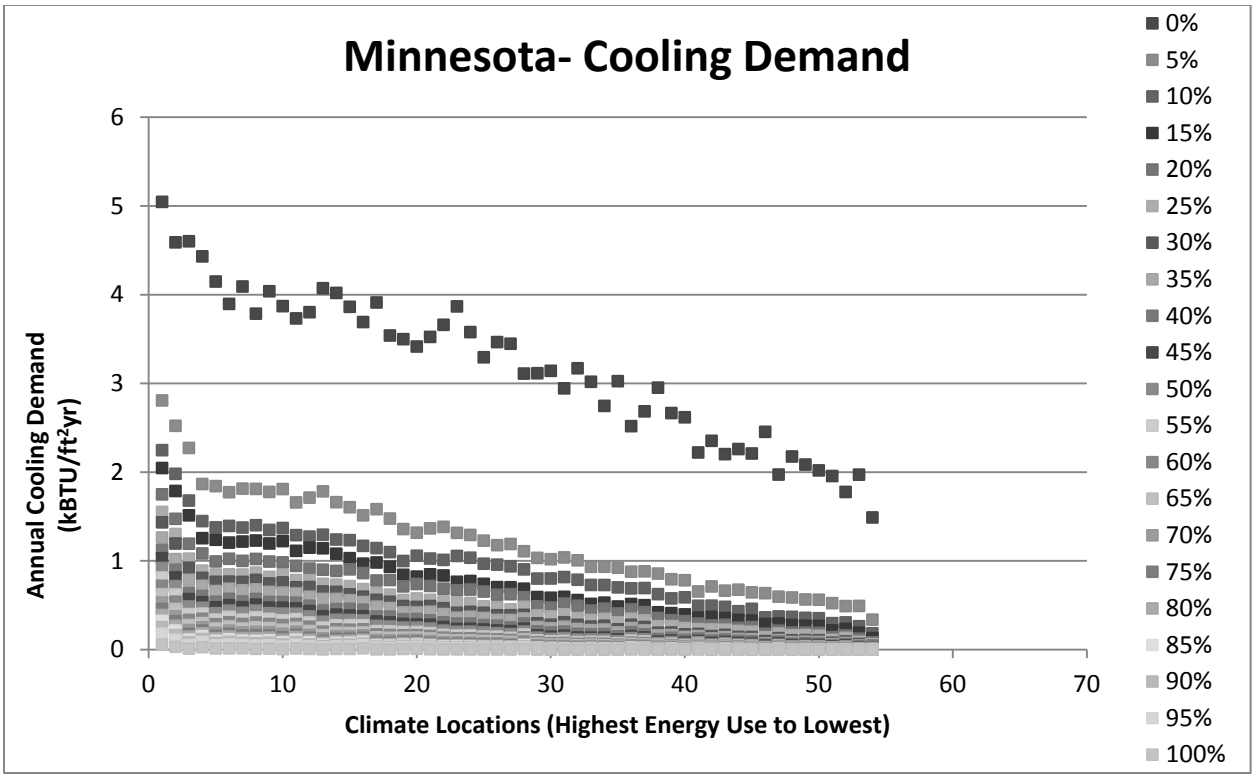

Michigan- Heating Load
Heating Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

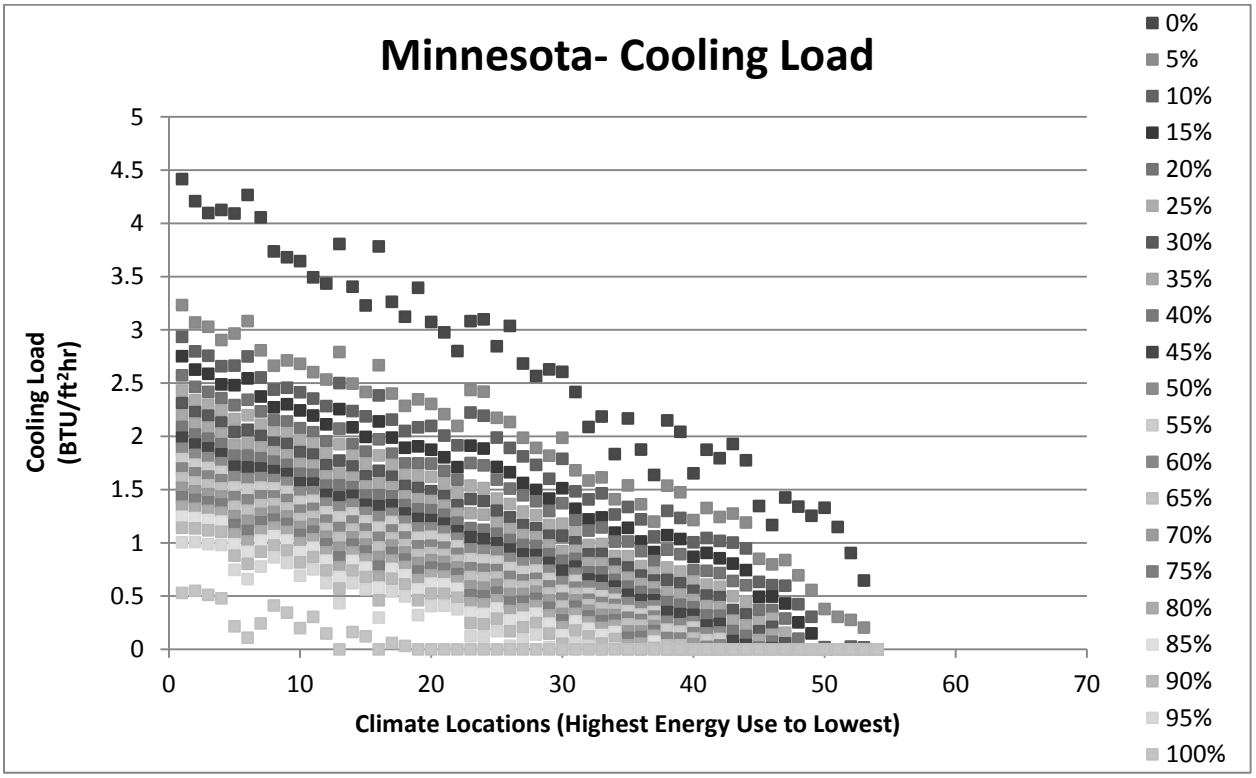

Michigan- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

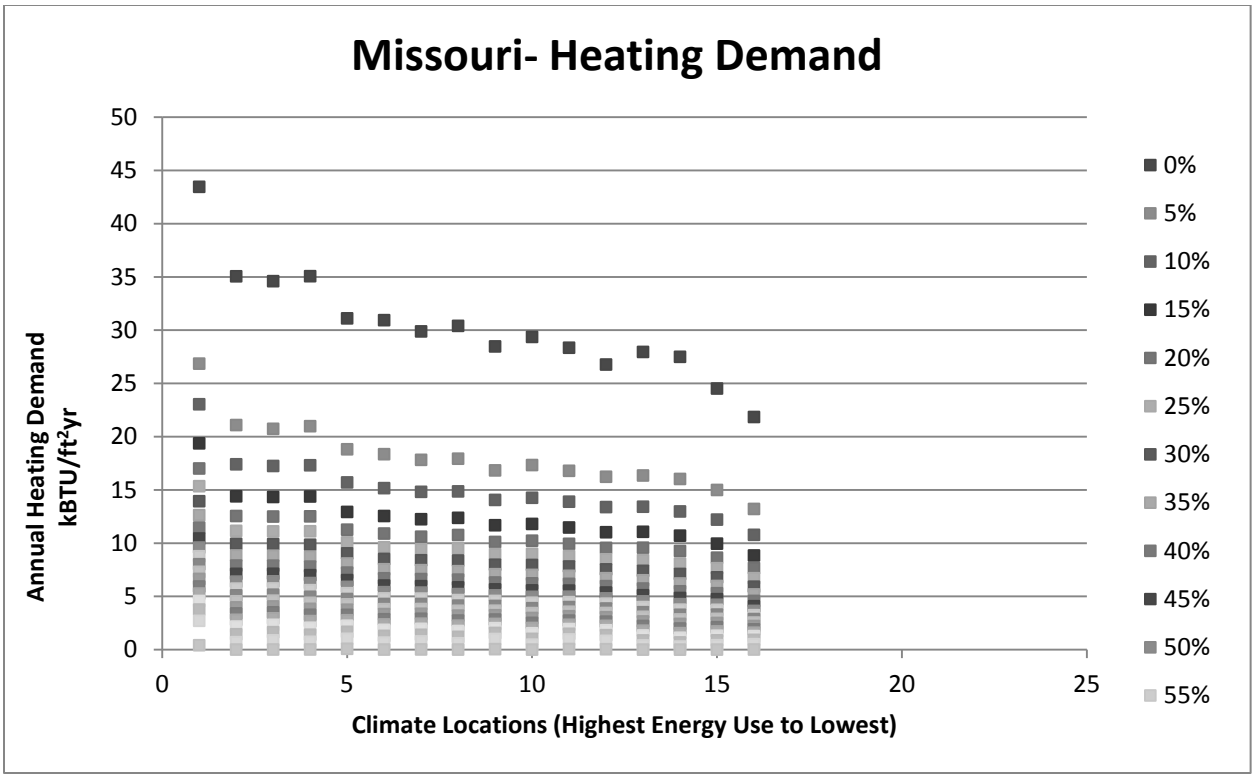

Michigan- Cooling Load
Cooling Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

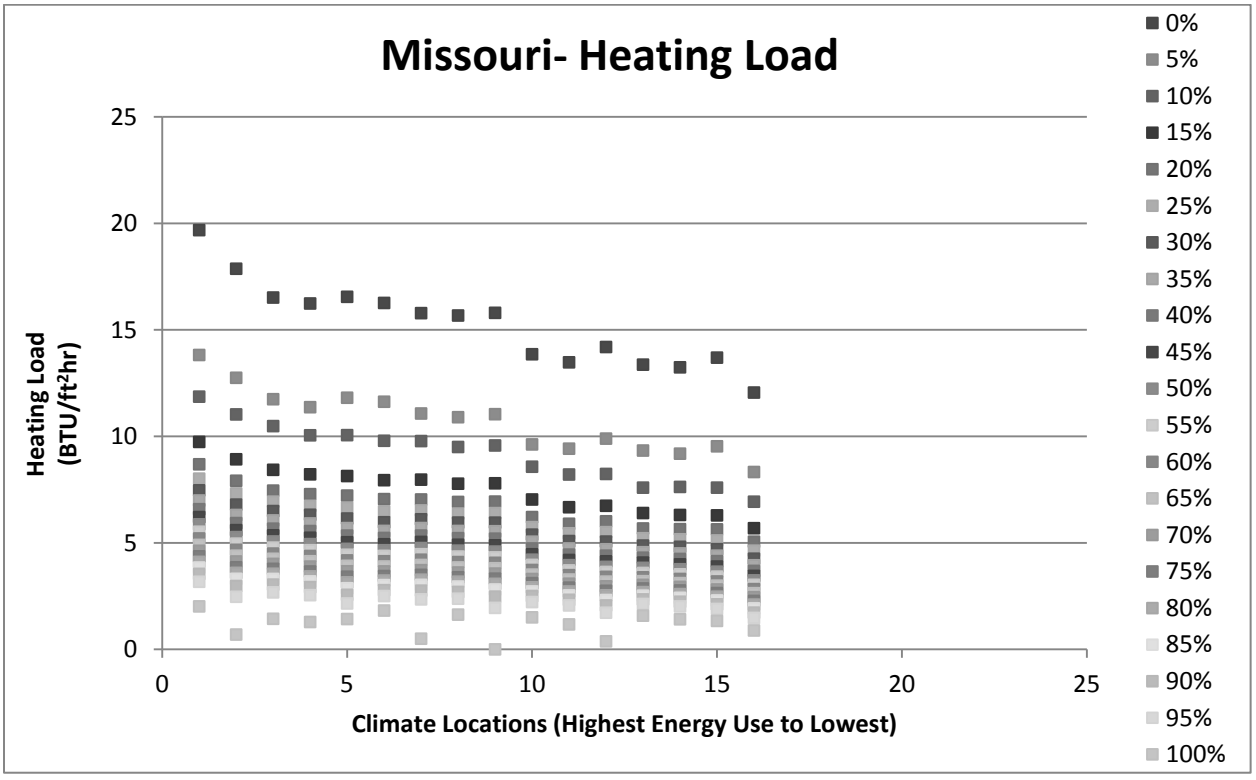

Minnesota- Heating Demand
Annual Heating Demand kBTU/ft²yr
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

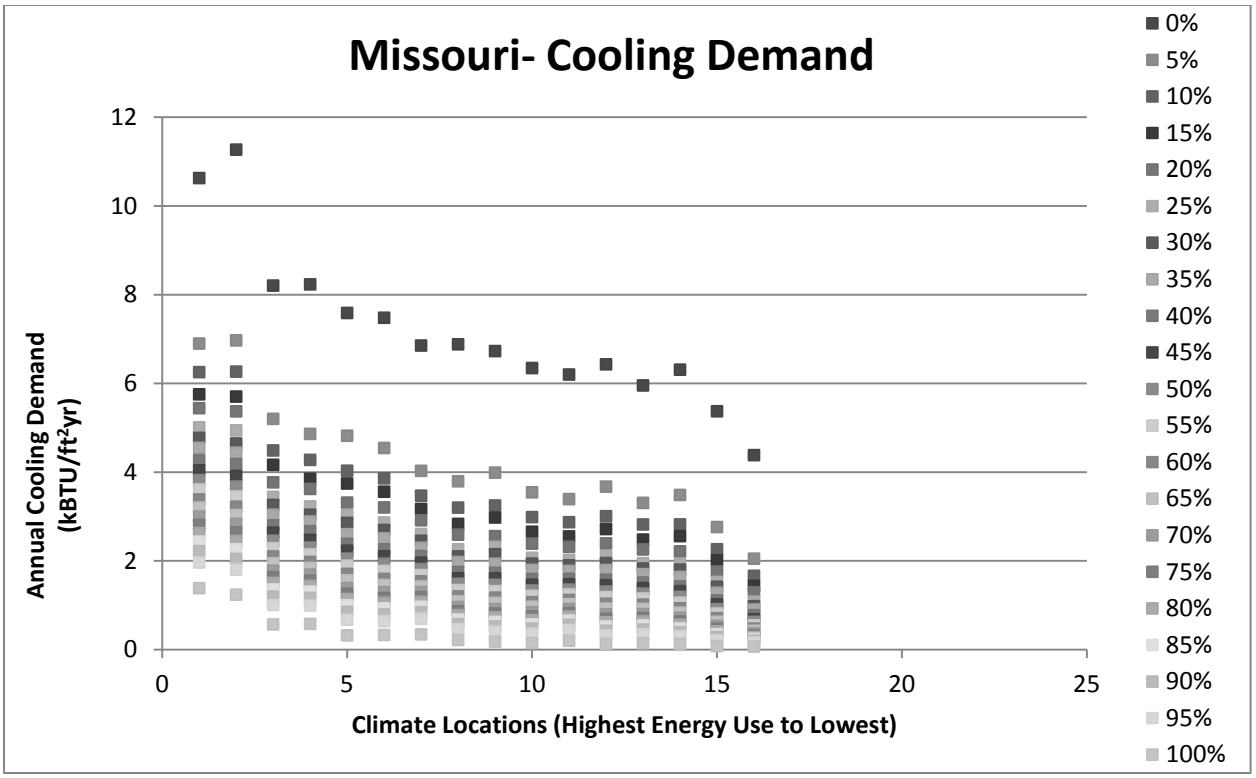

Minnesota- Heating Load
Heating Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

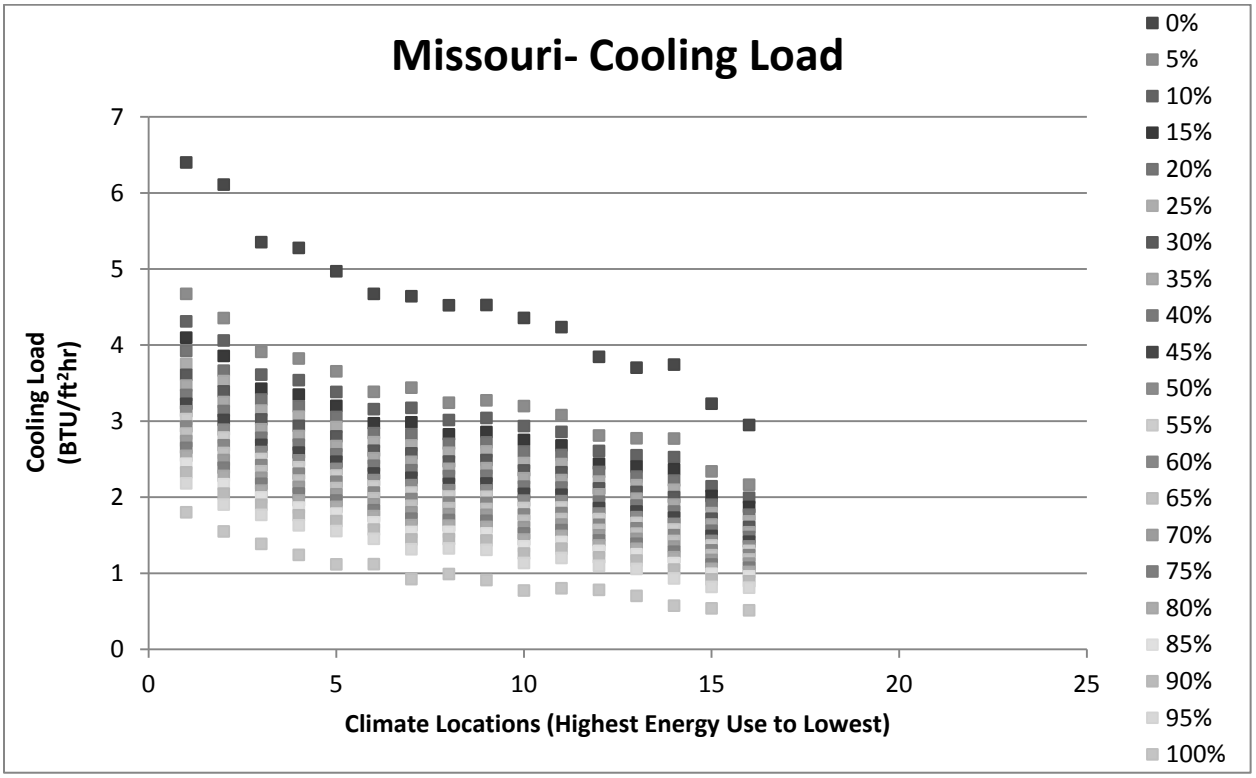

Minnesota- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
Climate Locations (Highest Energy Use to Lowest)
0
1
2
3
4
5
6
0
10
20
30
40
50
60
70
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

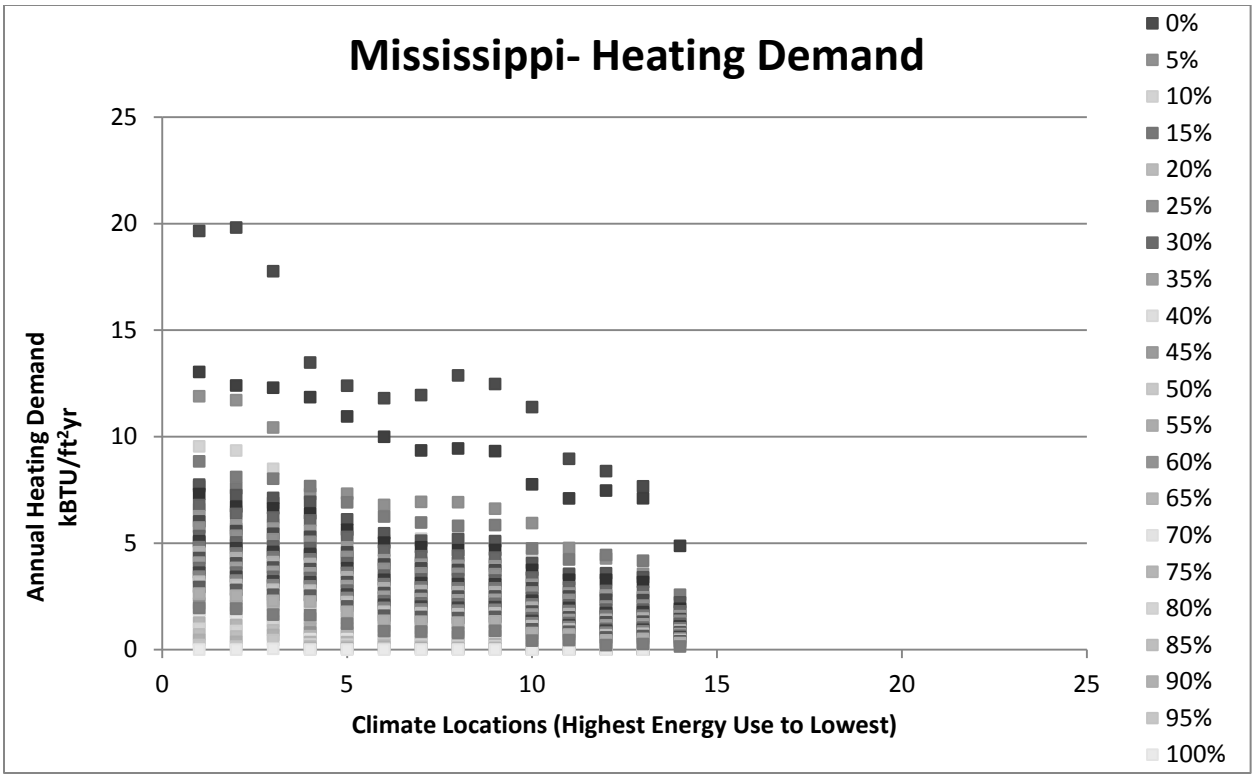

Minnesota- Cooling Load
Cooling Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
10
20
30
40
50
60
70
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

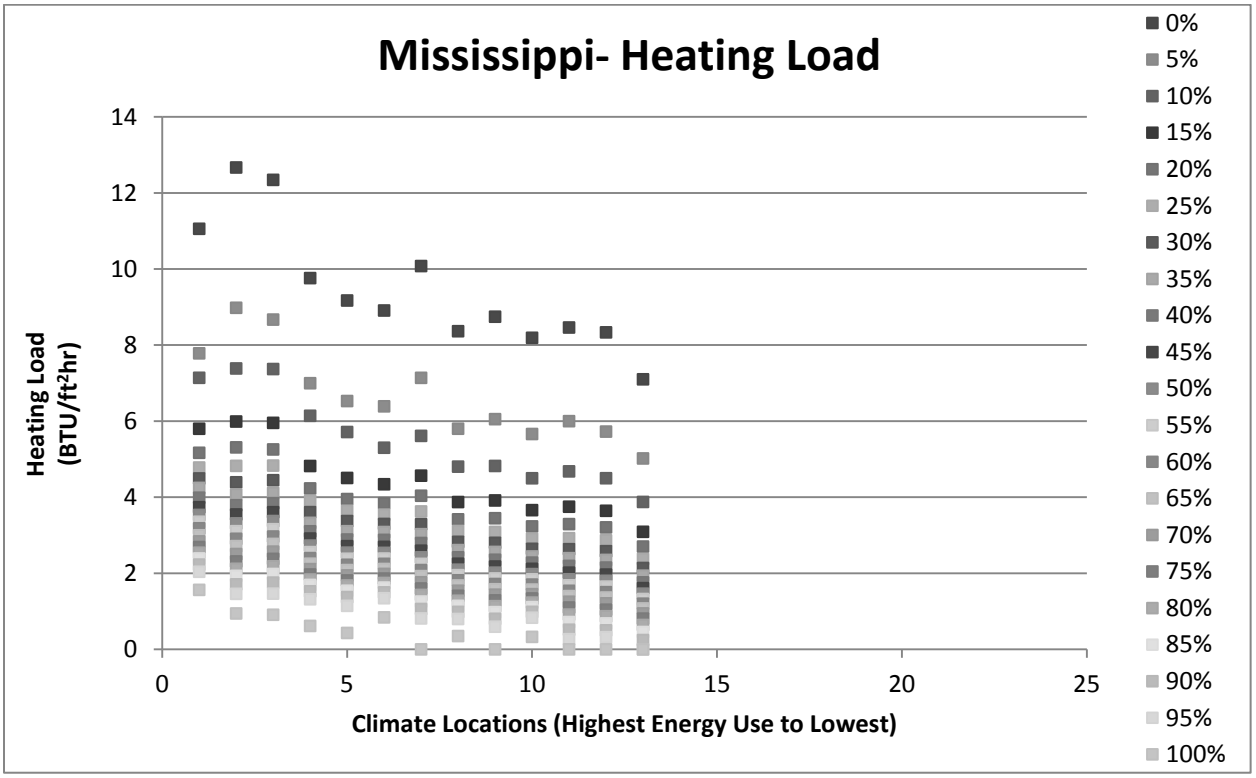

Missouri- Heating Demand
Annual Heating Demand kBTU/ft²yr
50
45
40
35
30
25
20
15
10
5
0
0
5
10
15
20
25
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%

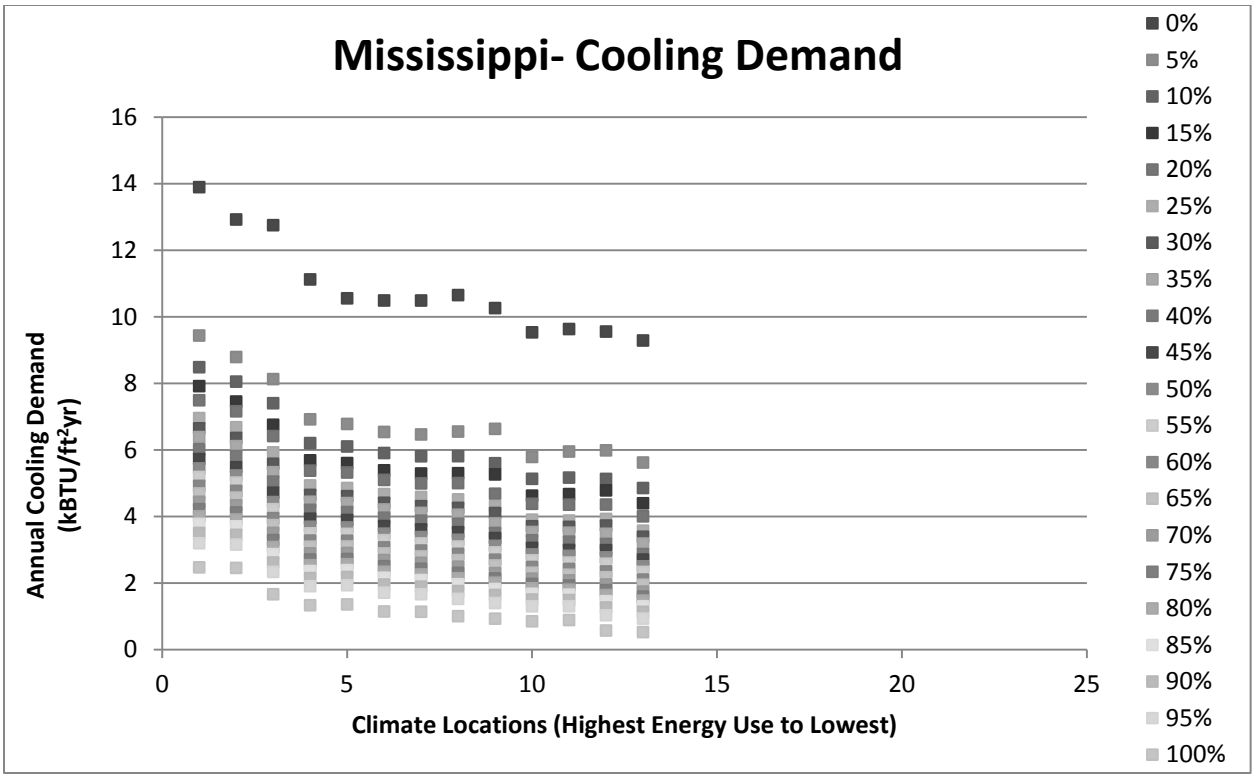

Missouri- Heating Load
Heating Load (BTU/ft²hr)
25
20
15
10
5
0
0
5
10
15
20
25
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

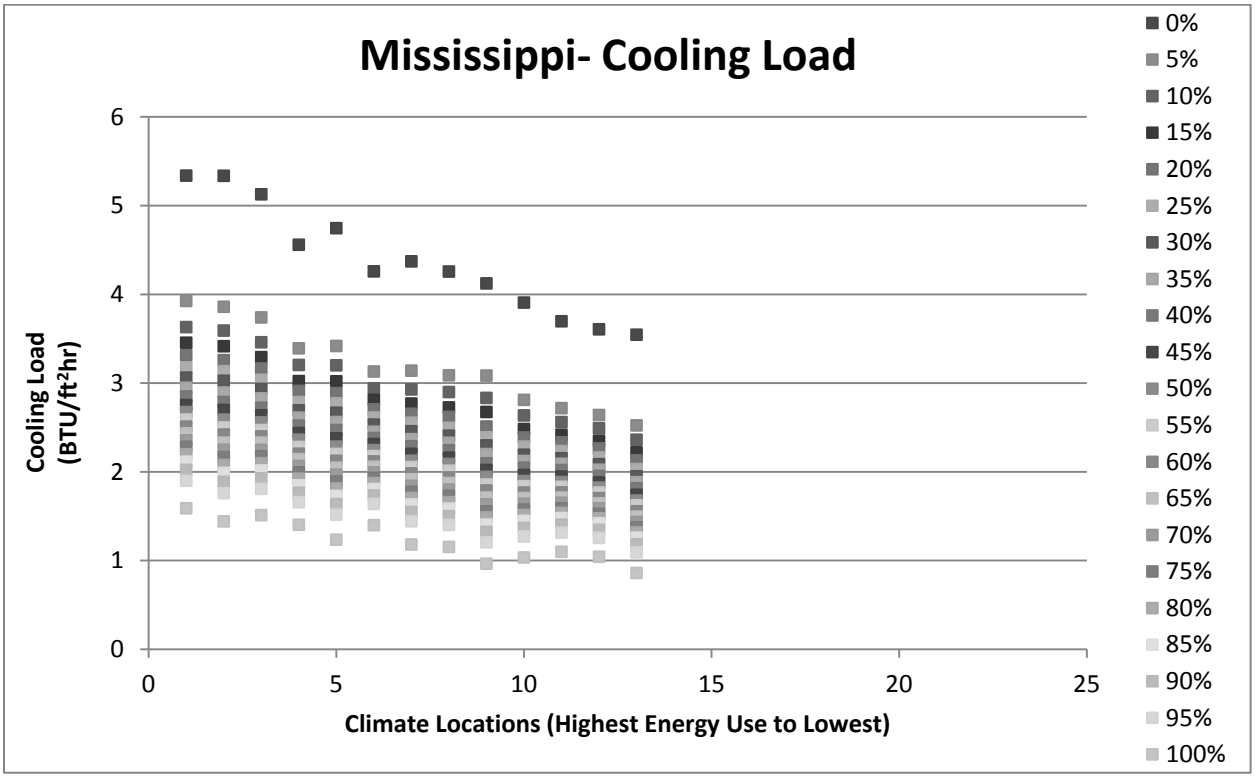

Missouri- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

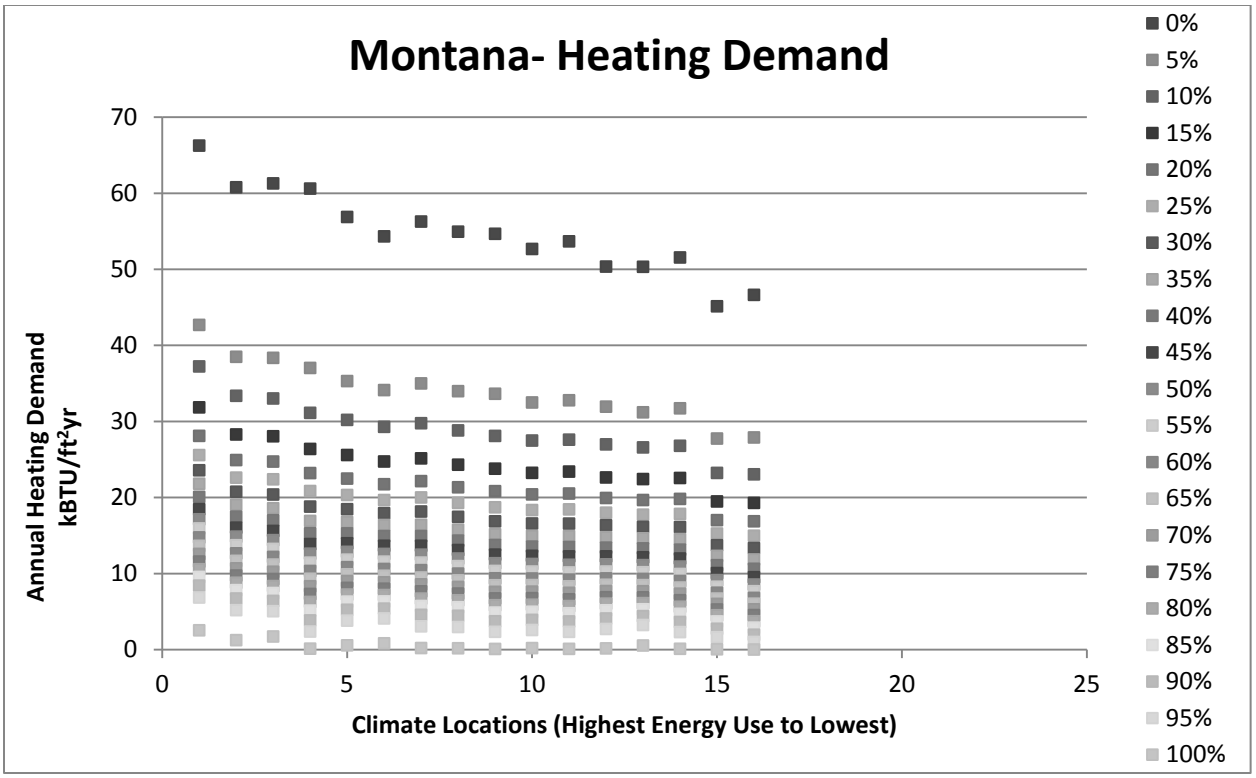

Missouri- Cooling Load
Cooling Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

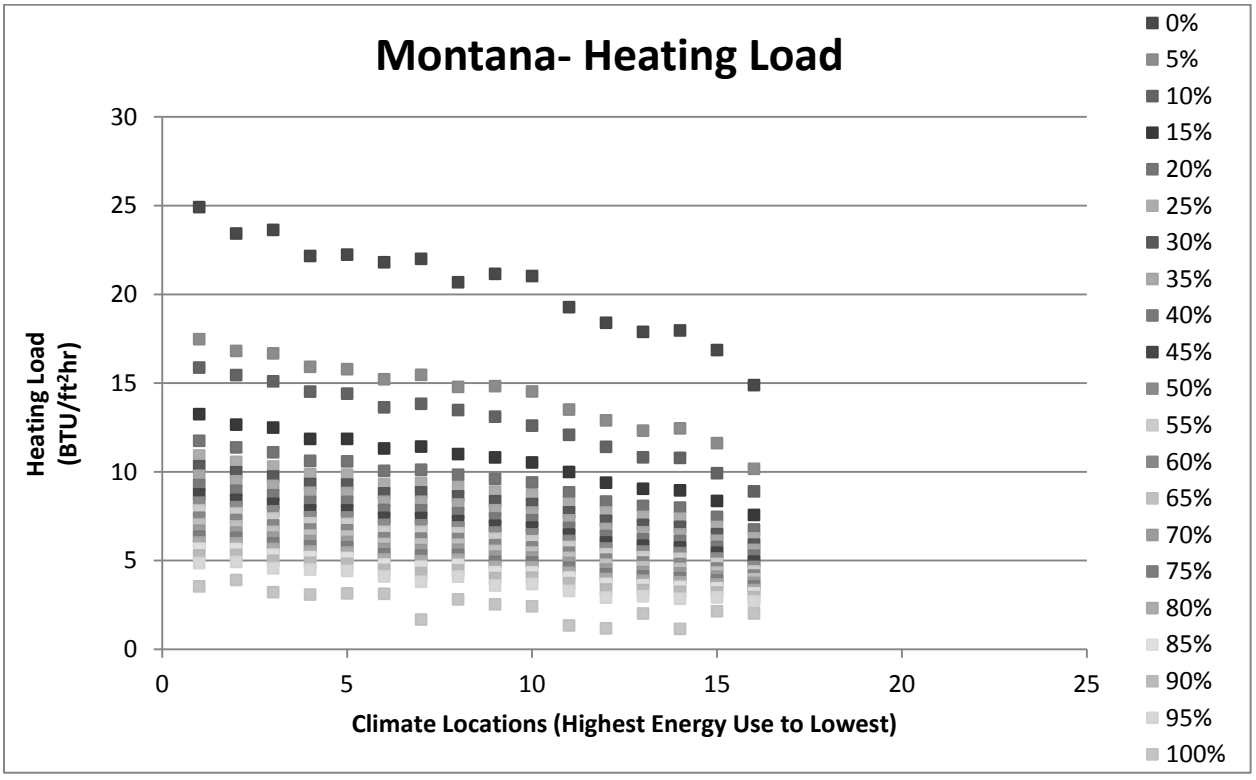

Mississippi- Heating Demand
Annual Heating Demand kBTU/ft²yr
Climate Locations (Highest Energy Use to Lowest)
0
5
10
15
20
25
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

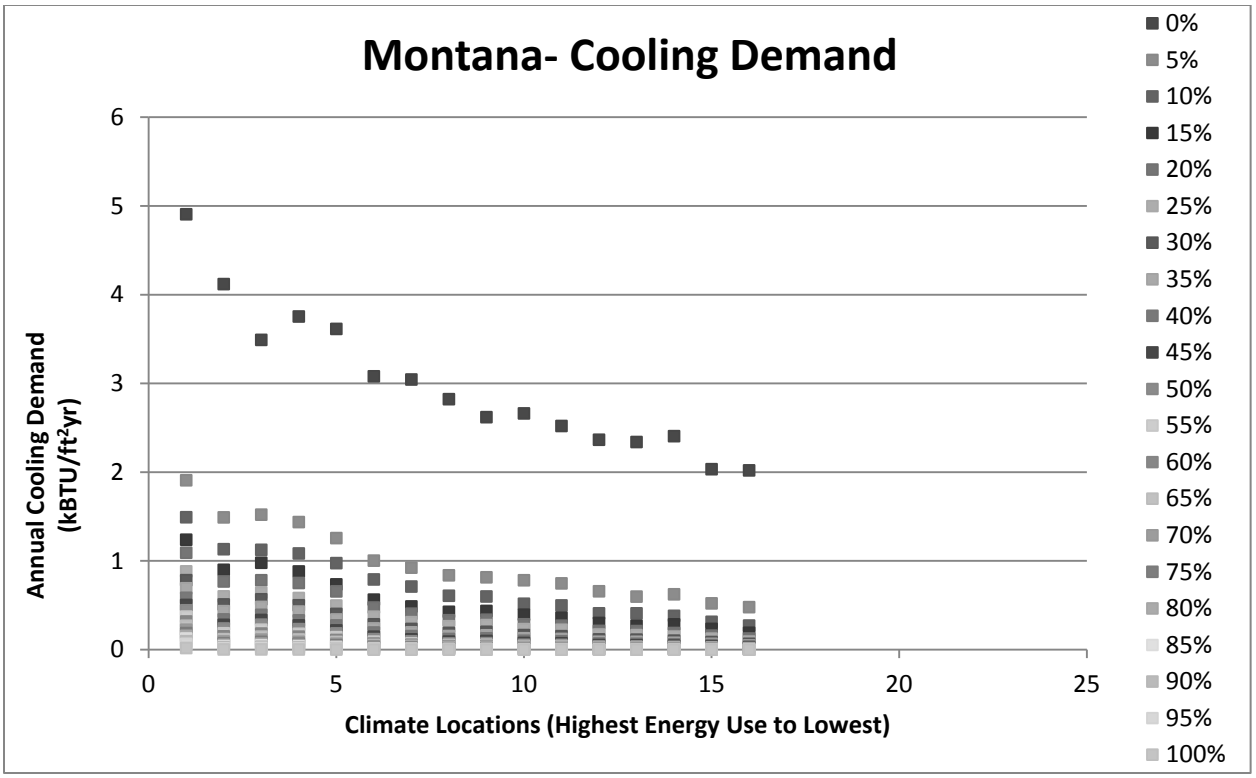

Mississippi- Heating Load
Heating Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0
2
4
6
8
10
12
14
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

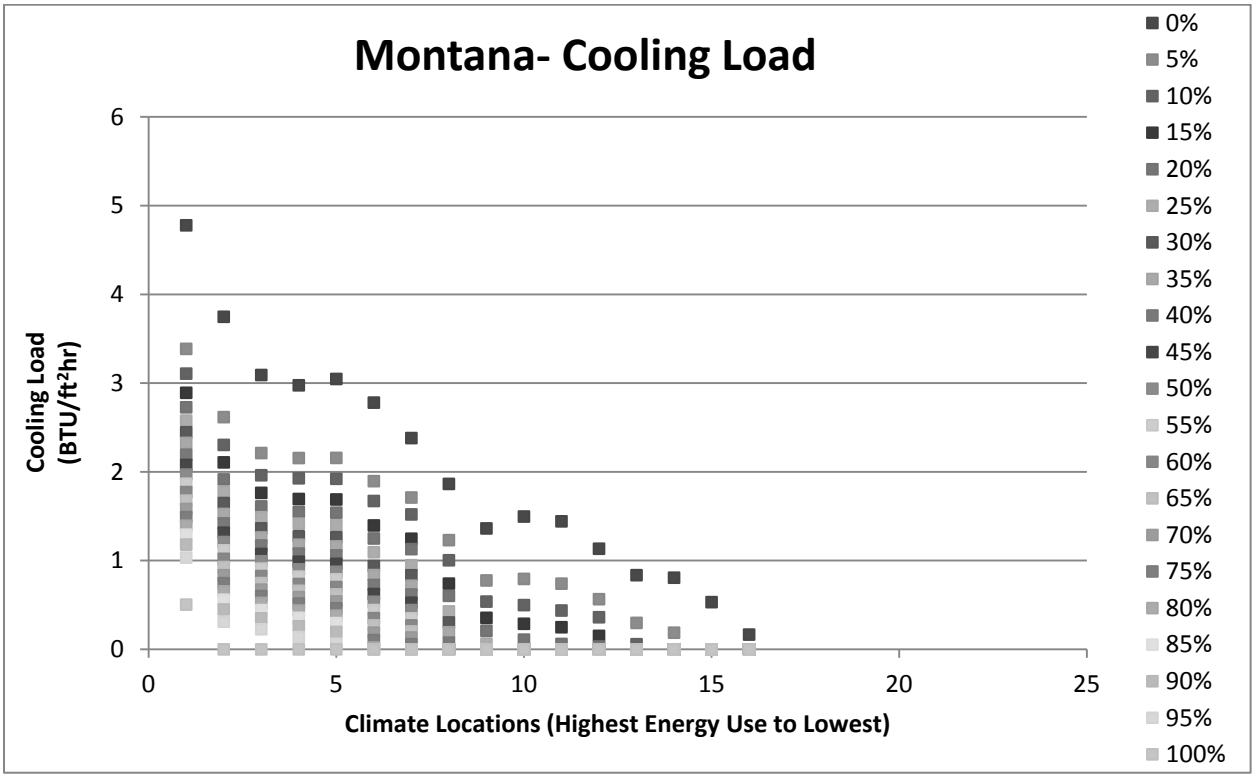

Mississippi- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

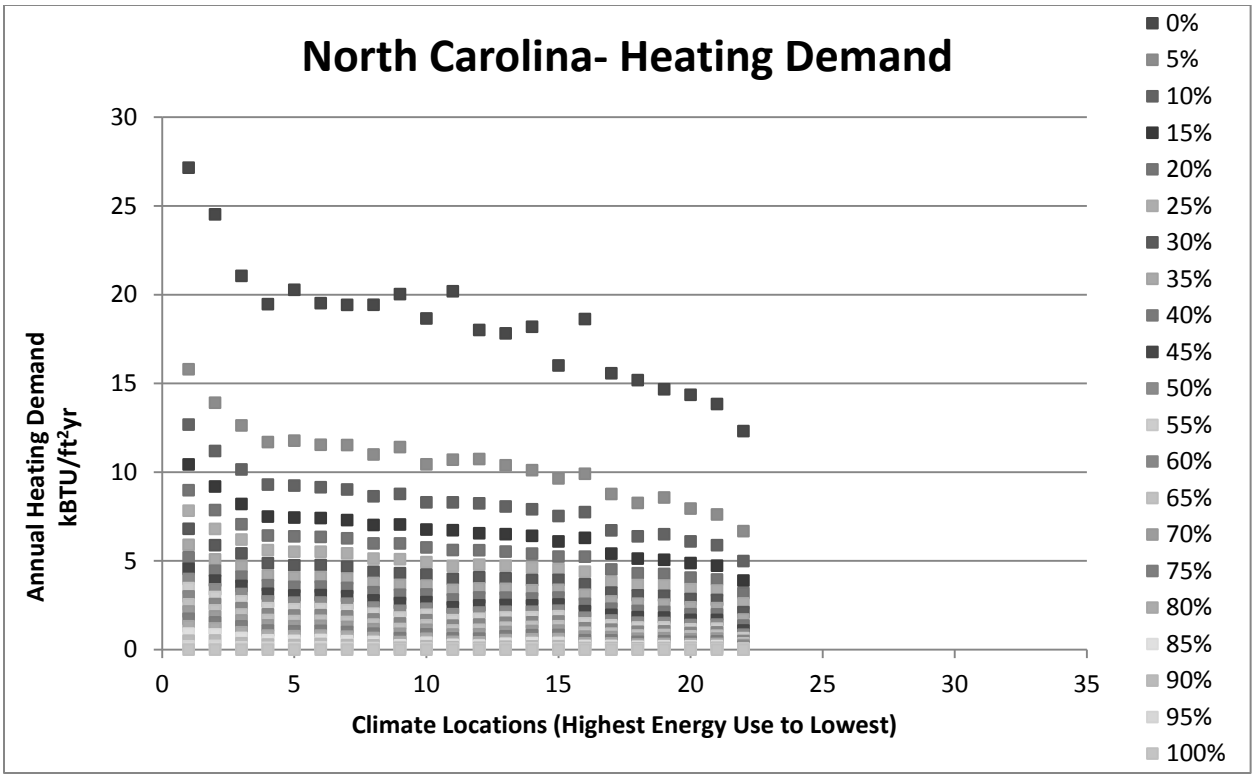

Mississippi- Cooling Load
Cooling Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

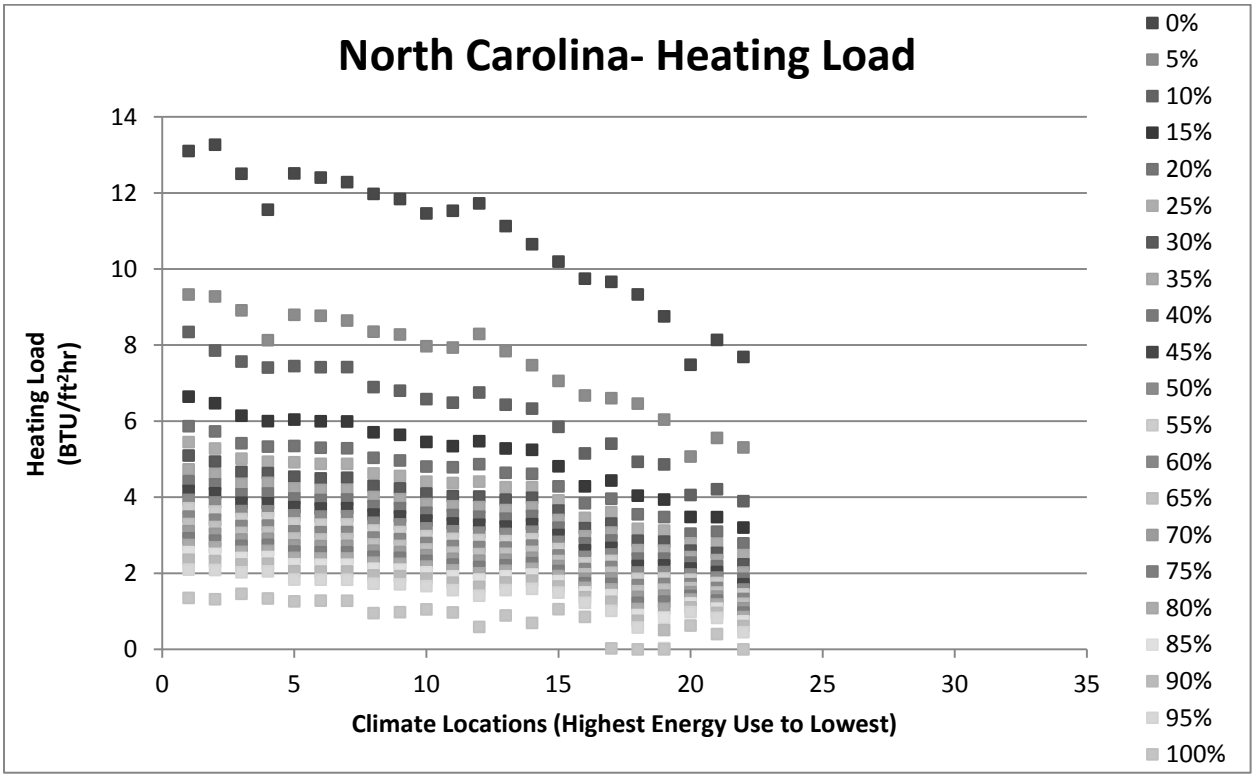

Montana- Heating Demand
Annual Heating Demand kBTU/ft²yr
0
10
20
30
40
50
60
70
0
5
10
15
20
25
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

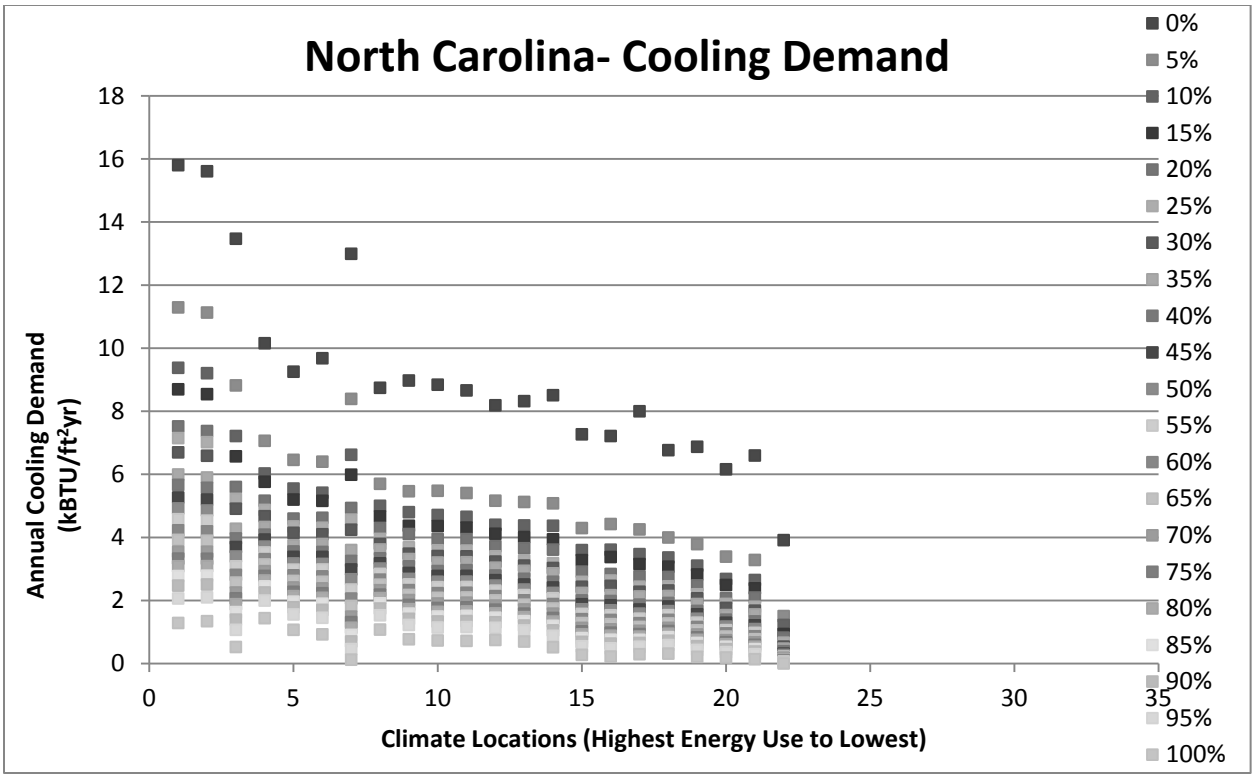

Montana- Heating Load
Heating Load (BTU/ft²hr)
0
5
10
15
20
25
30
0
5
10
15
20
25
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

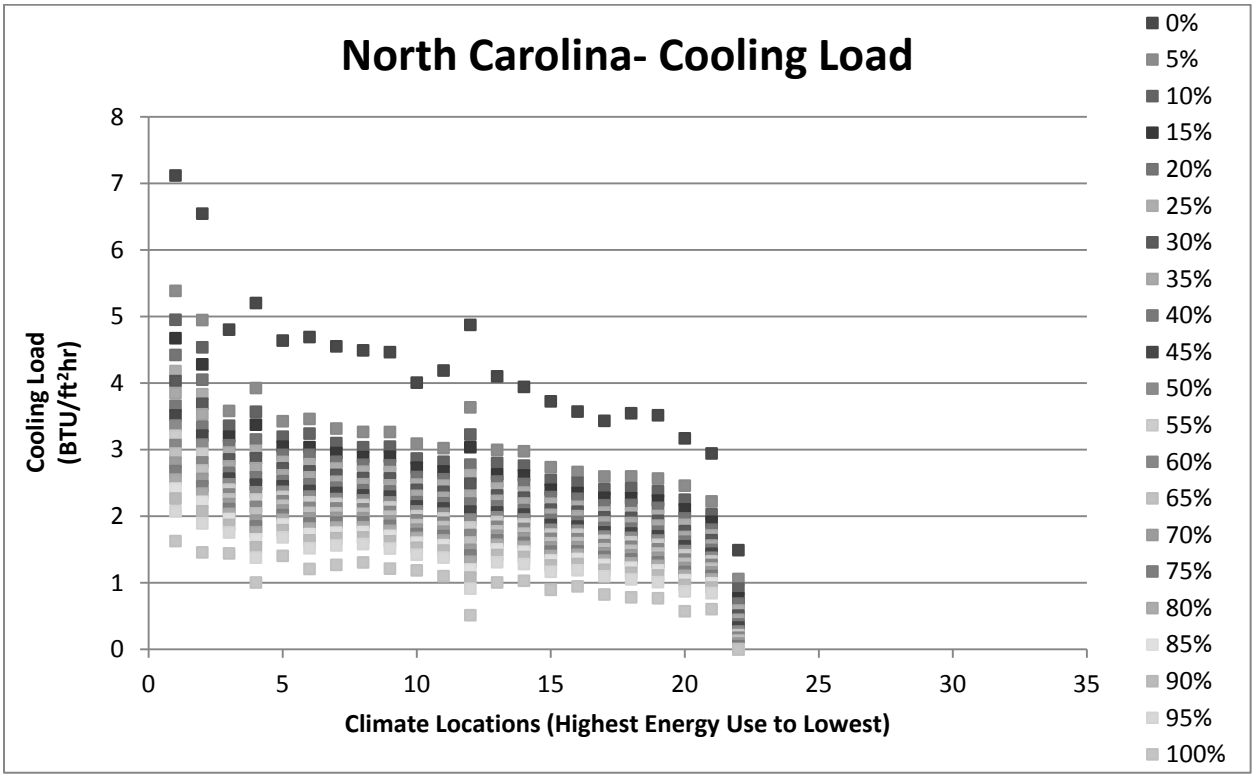

Montana- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
Climate Locations (Highest Energy Use to Lowest)
0
1
2
3
4
5
6
0
5
10
15
20
25
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

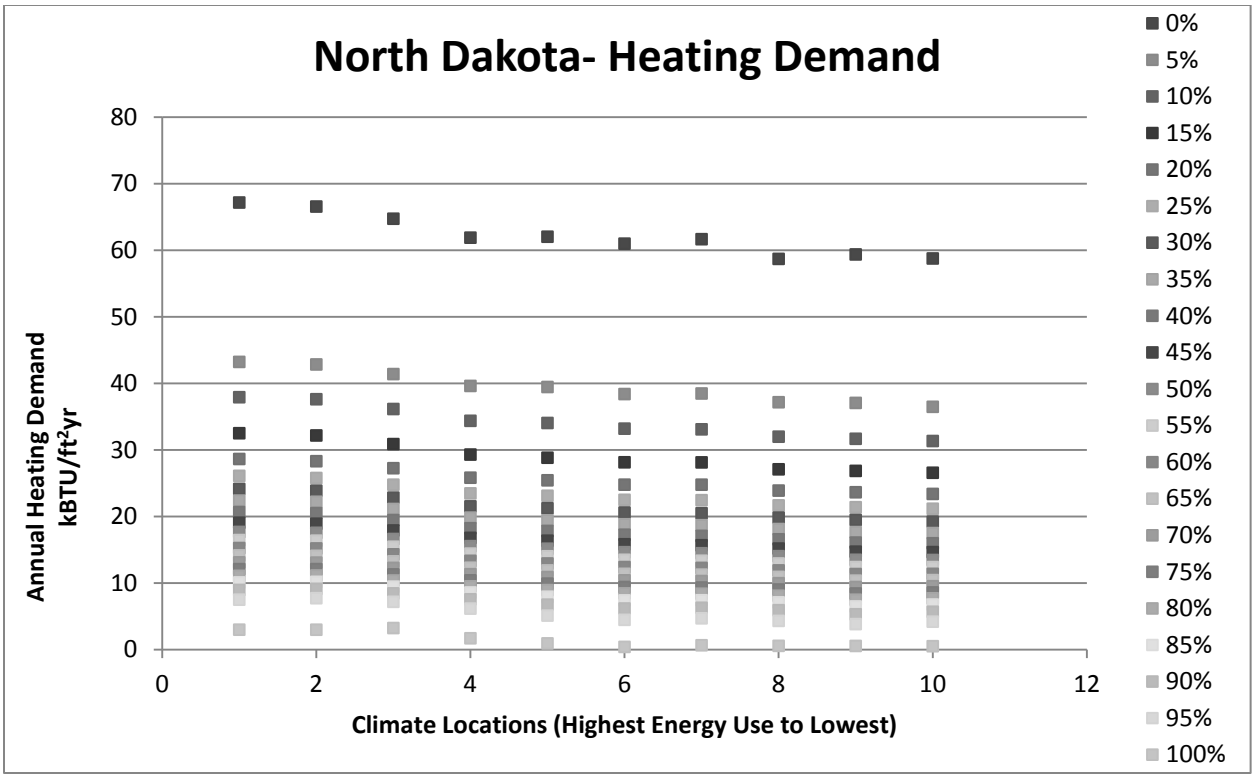

Montana- Cooling Load
Cooling Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0
1
2
3
4
5
6
0
5
10
15
20
25
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

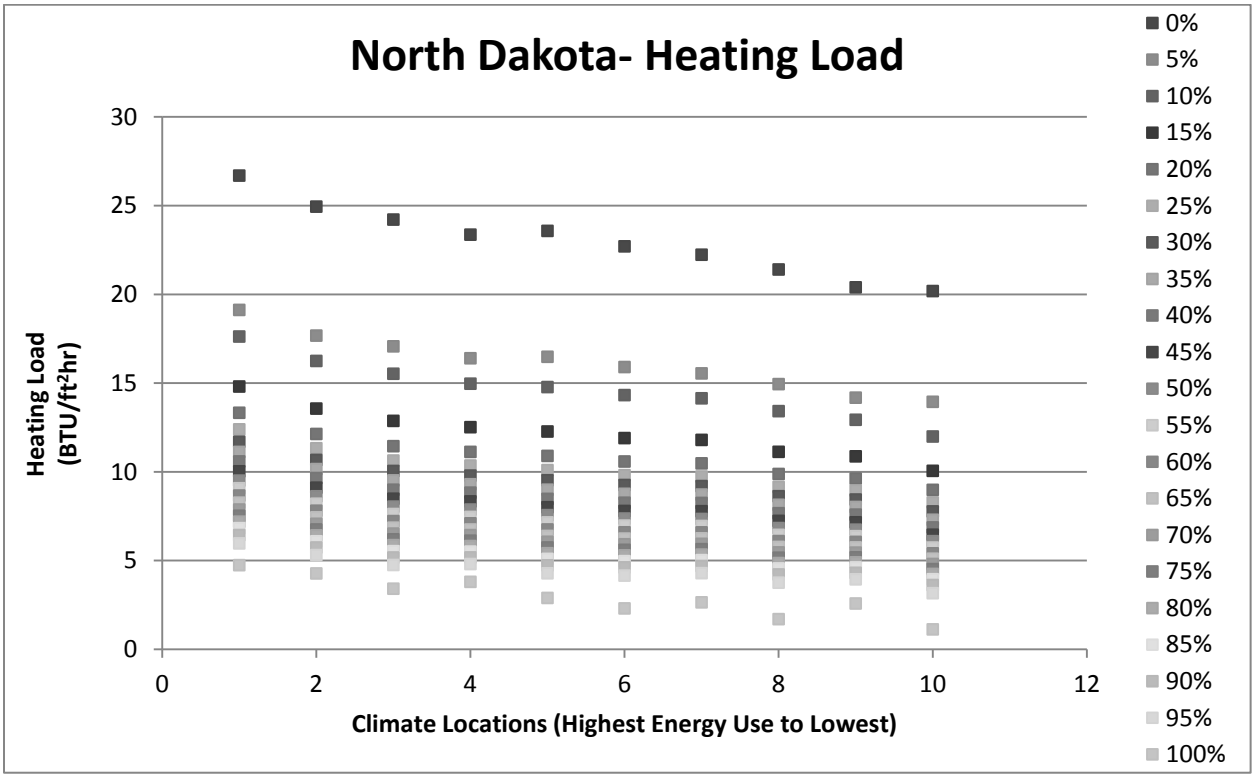

North Carolina- Heating Demand
Annual Heating Demand kBTU/ft²yr
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

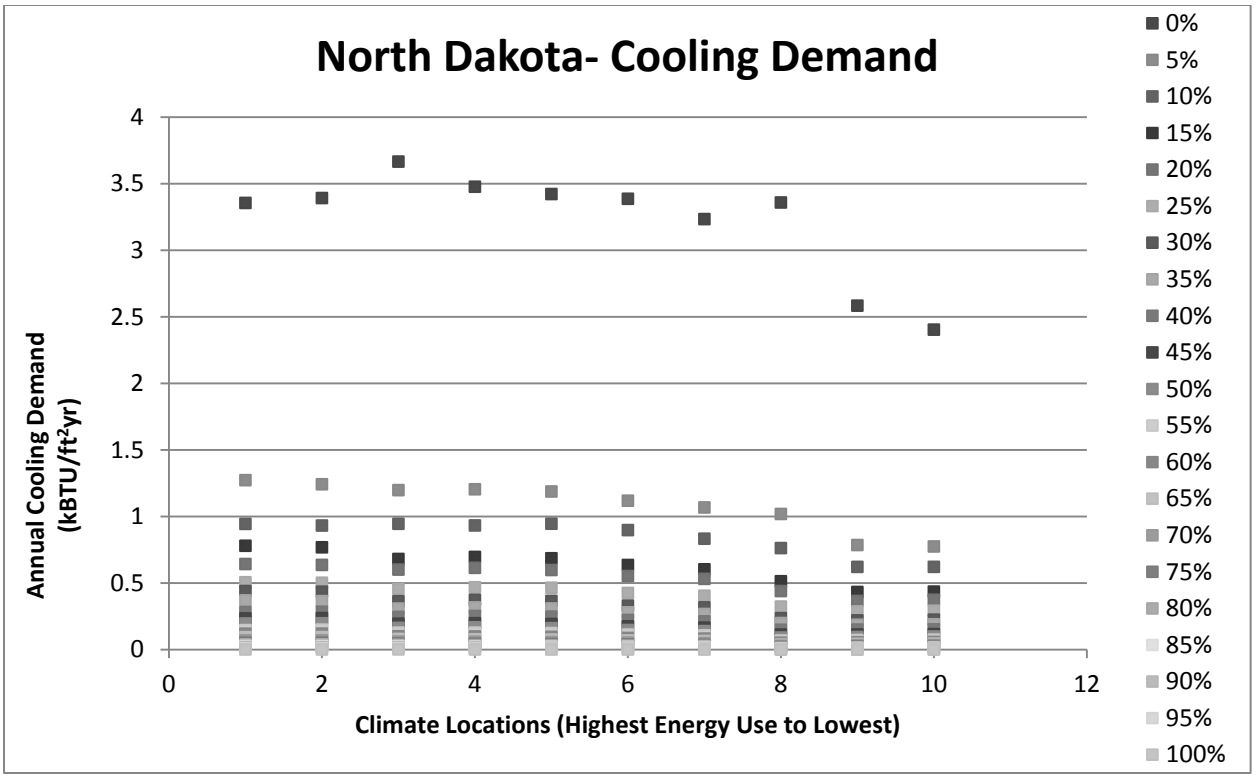

North Carolina- Heating Load
Heating Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

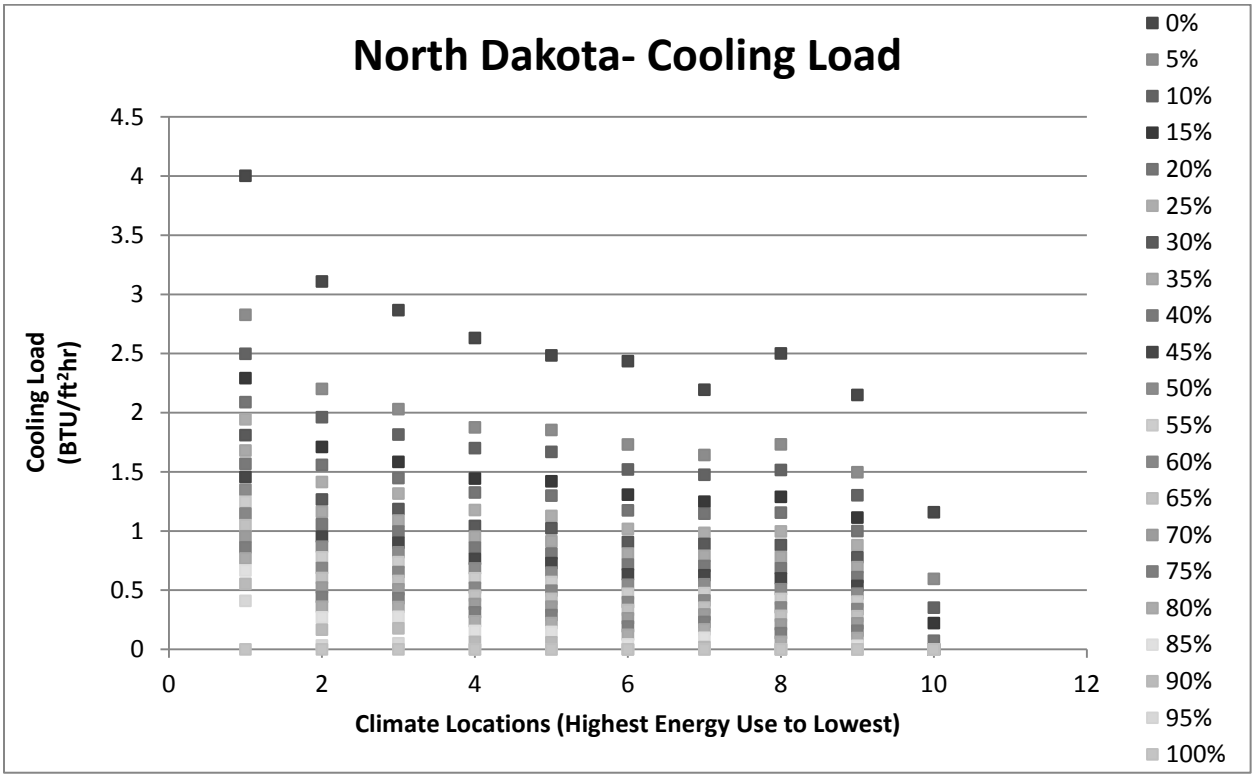

North Carolina- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

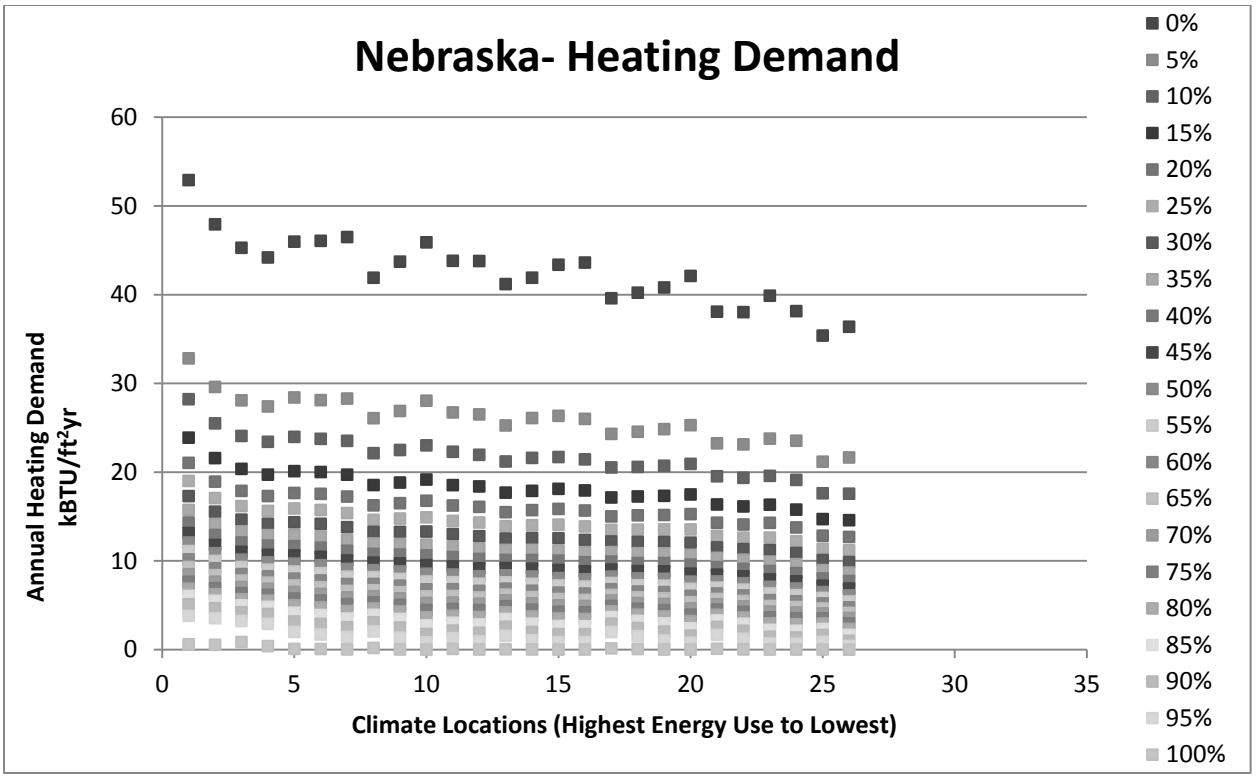

North Carolina- Cooling Load
Cooling Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

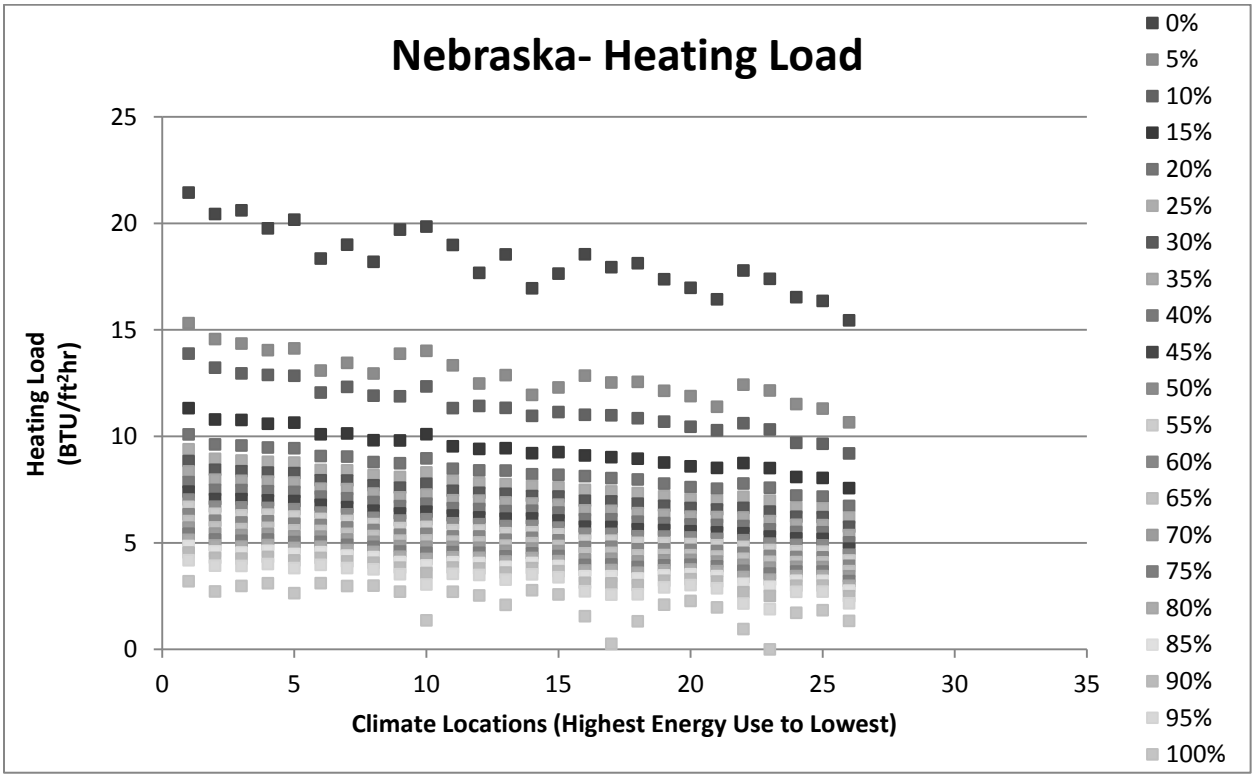

North Dakota- Heating Demand
Annual Heating Demand kBTU/ft²yr
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

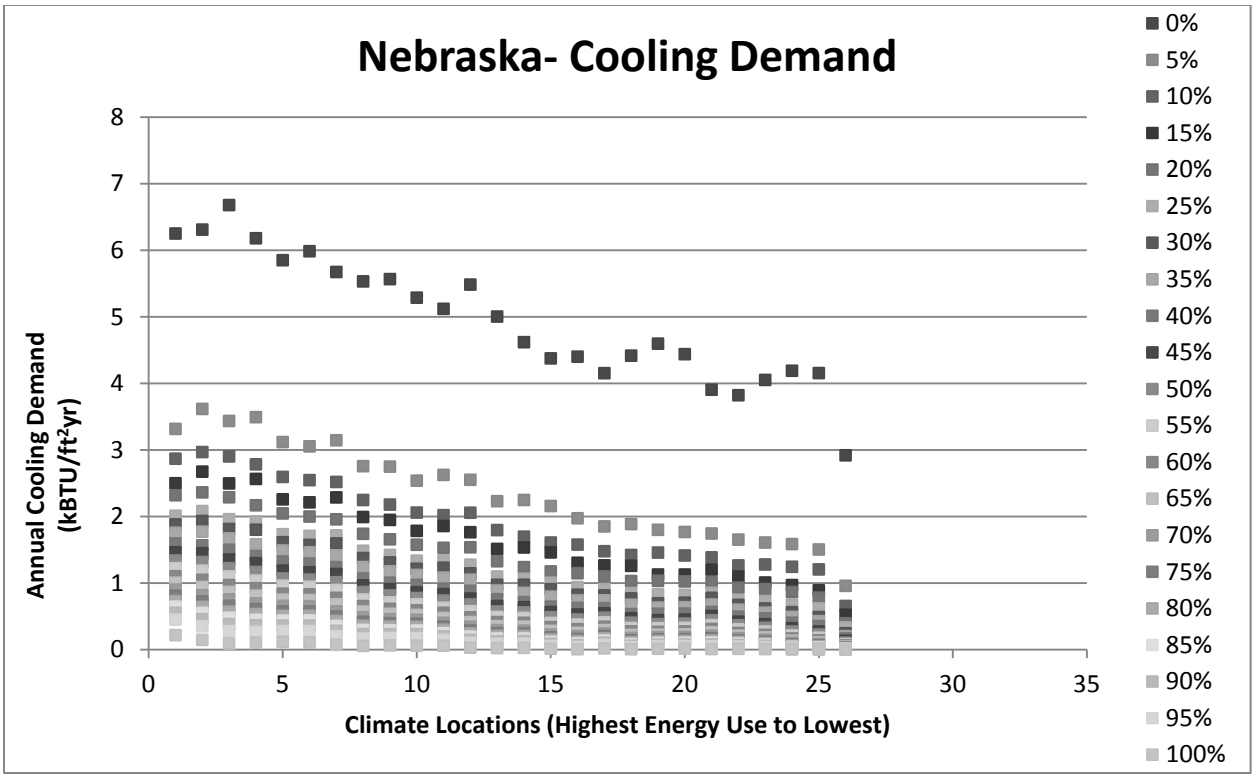

North Dakota- Heating Load
Heating Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

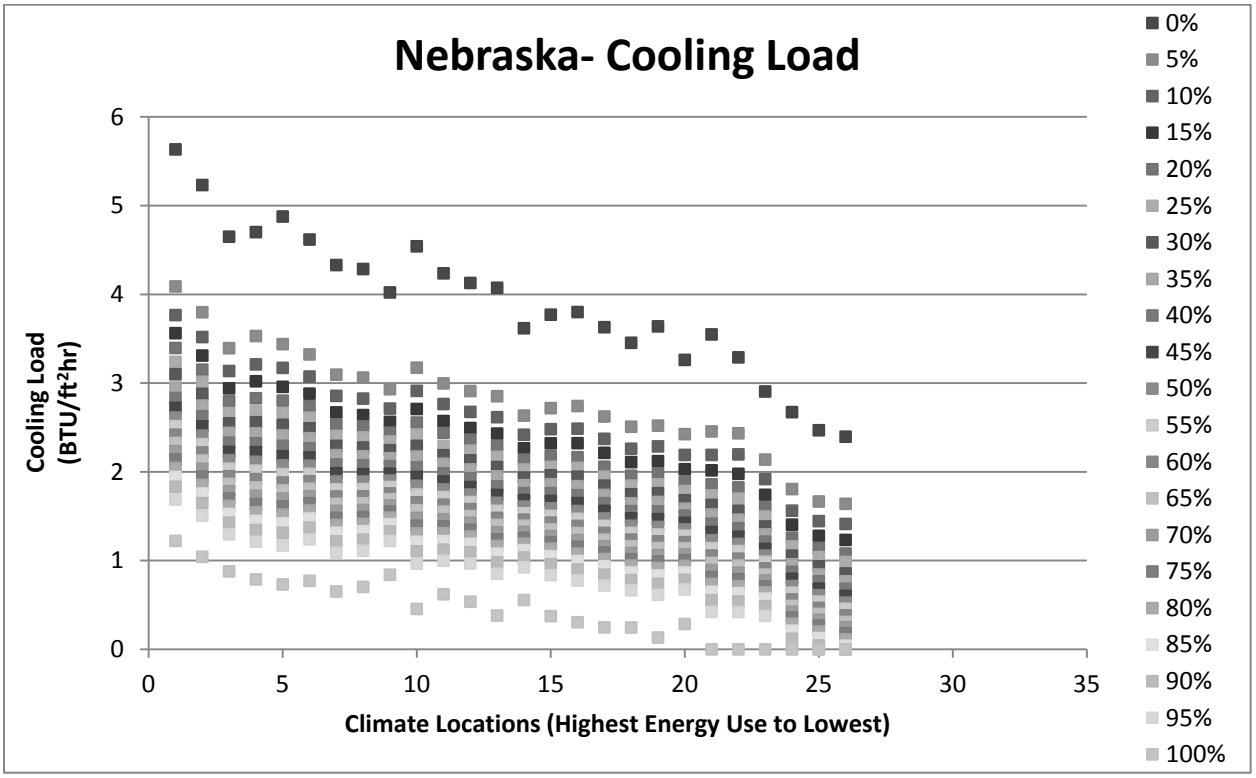

North Dakota- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
Climate Locations (Highest Energy Use to Lowest)
0
0.5
1
1.5
2
2.5
3
3.5
4
0
2
4
6
8
10
12
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

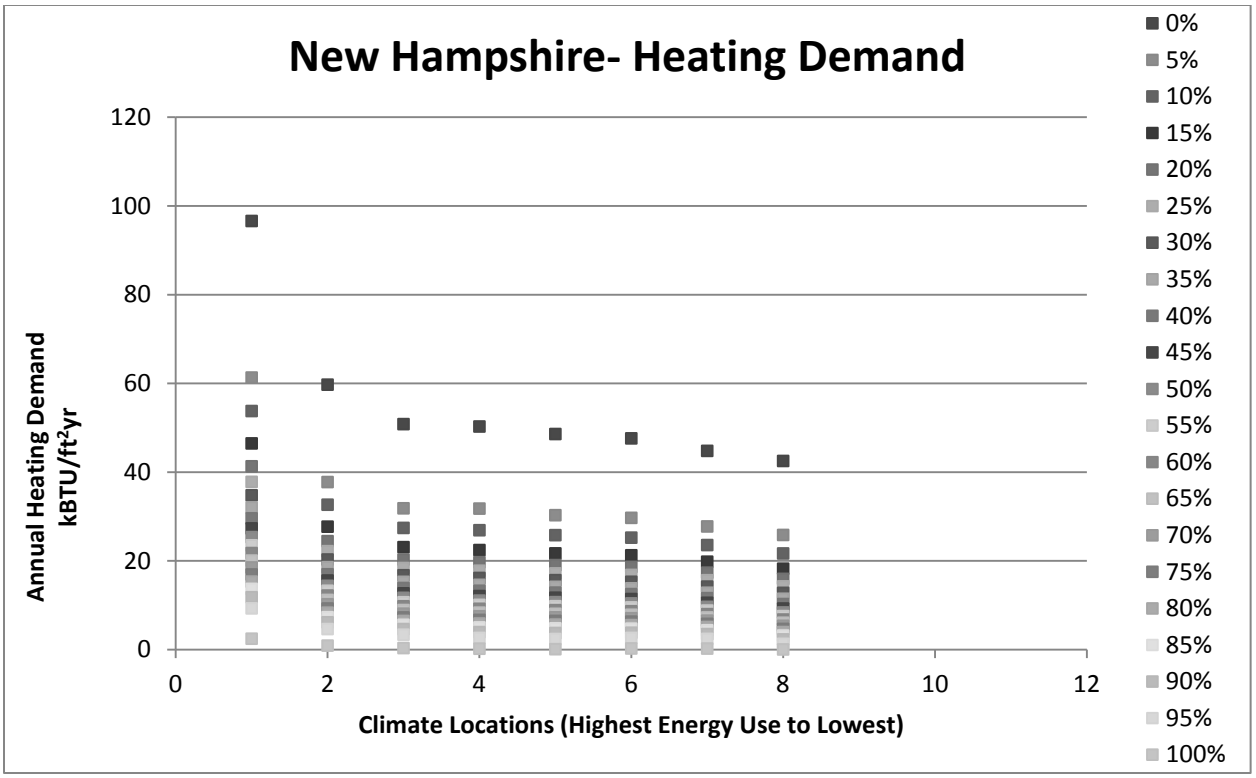

North Dakota- Cooling Load
Cooling Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
0
2
4
6
8
10
12
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

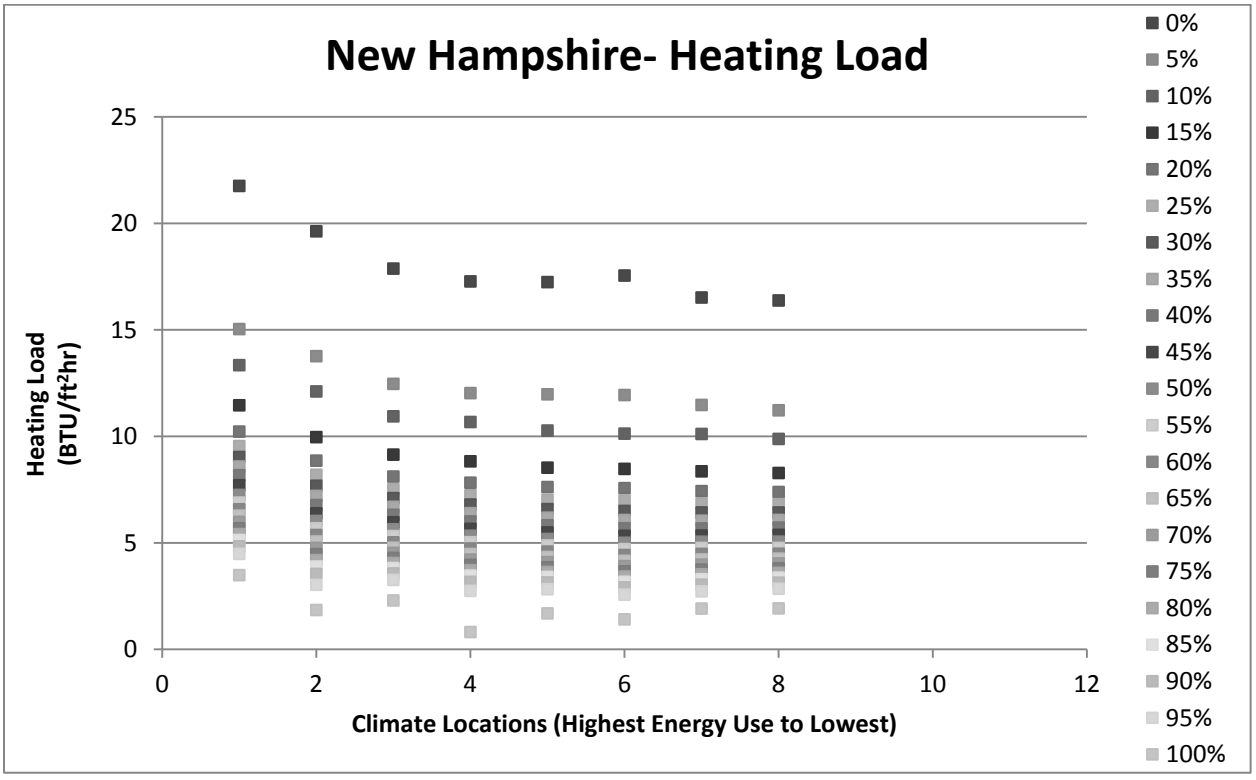

Nebraska- Heating Demand
Annual Heating Demand kBTU/ft²yr
0
10
20
30
40
50
60
0
5
10
15
20
25
30
35
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

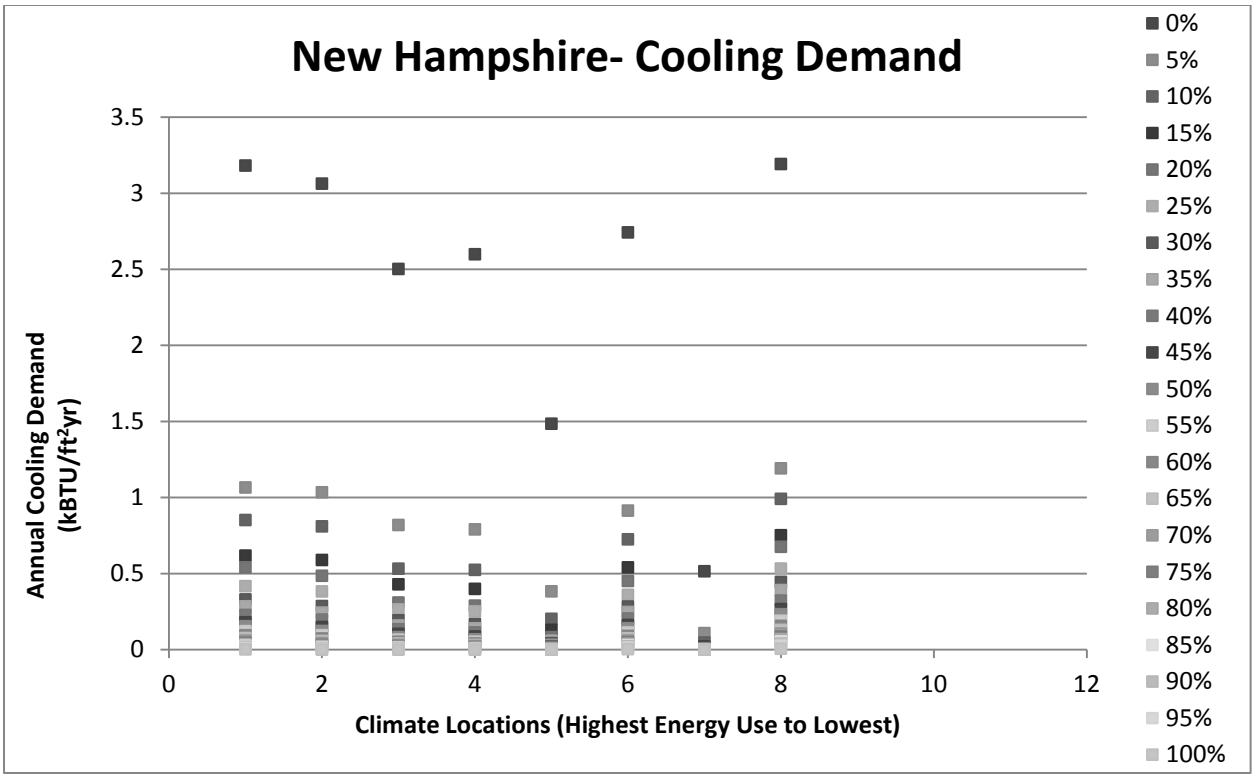

Nebraska- Heating Load
Heating Load (BTU/ft²hr)
0
5
10
15
20
25
0
5
10
15
20
25
30
35
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

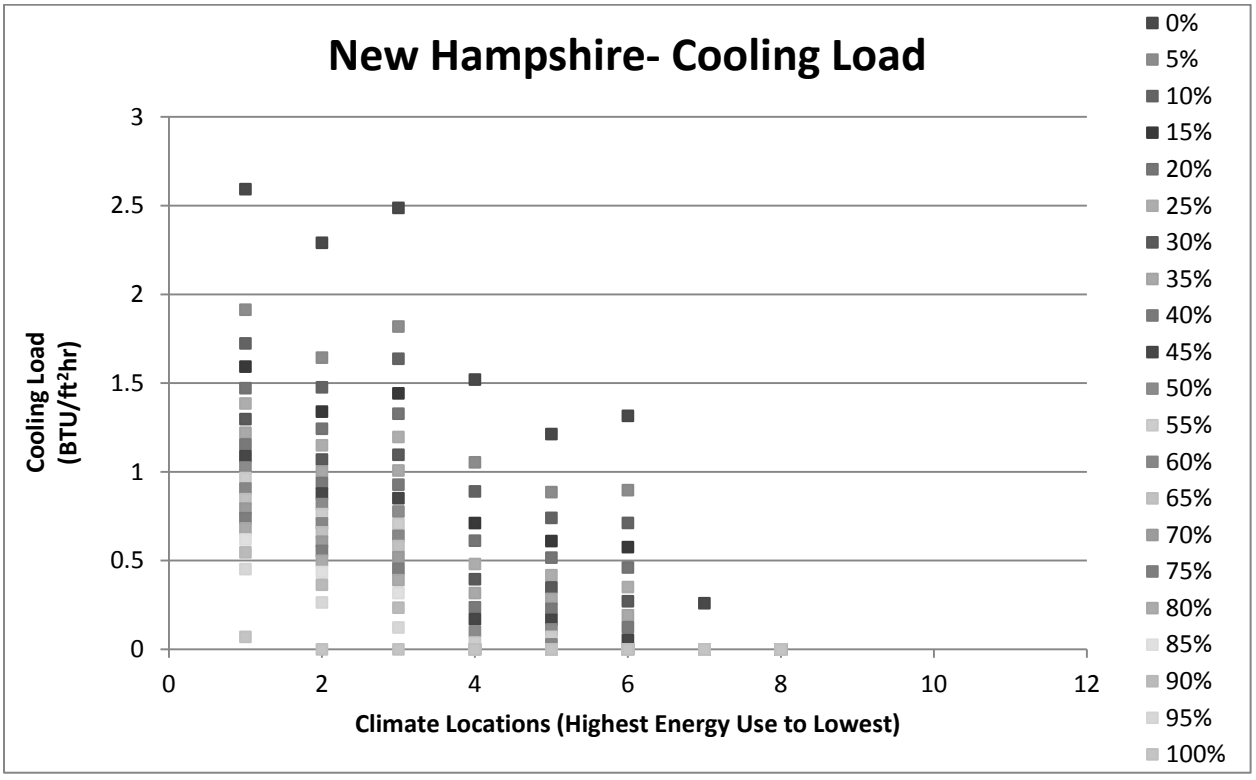

Nebraska- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

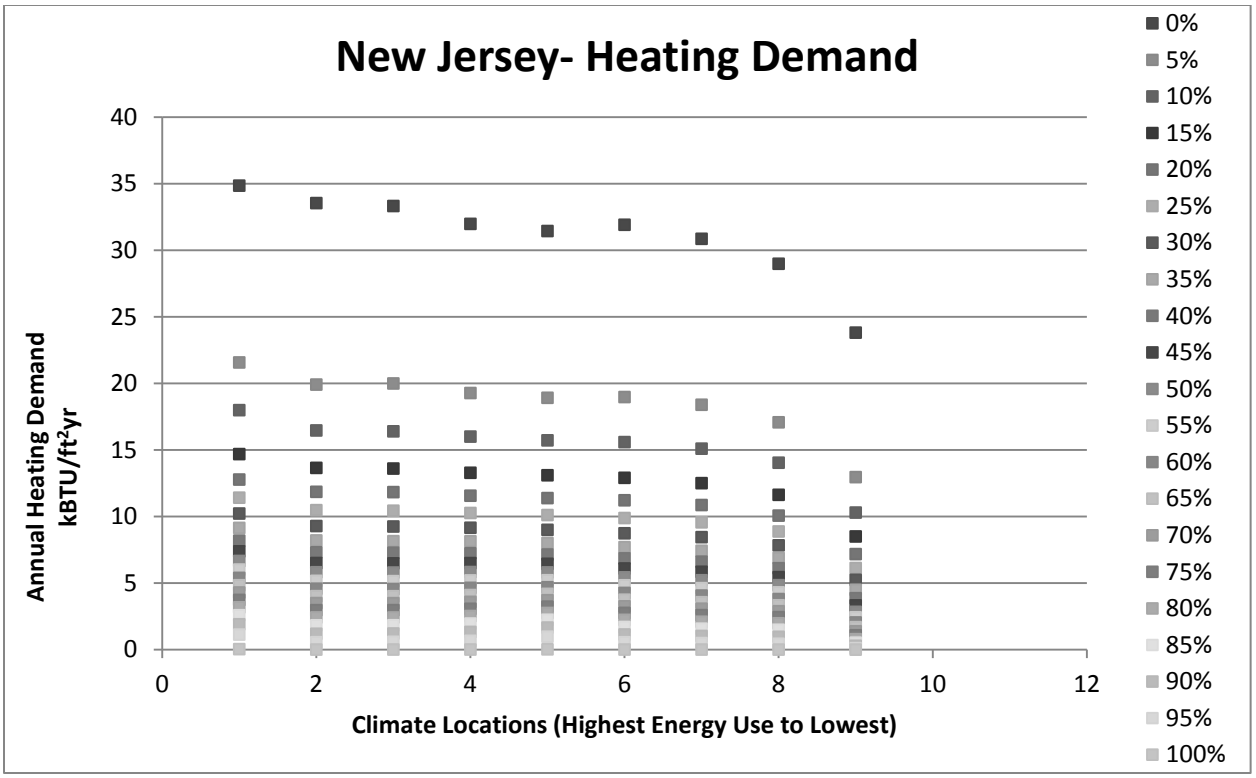

Nebraska- Cooling Load
Cooling Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

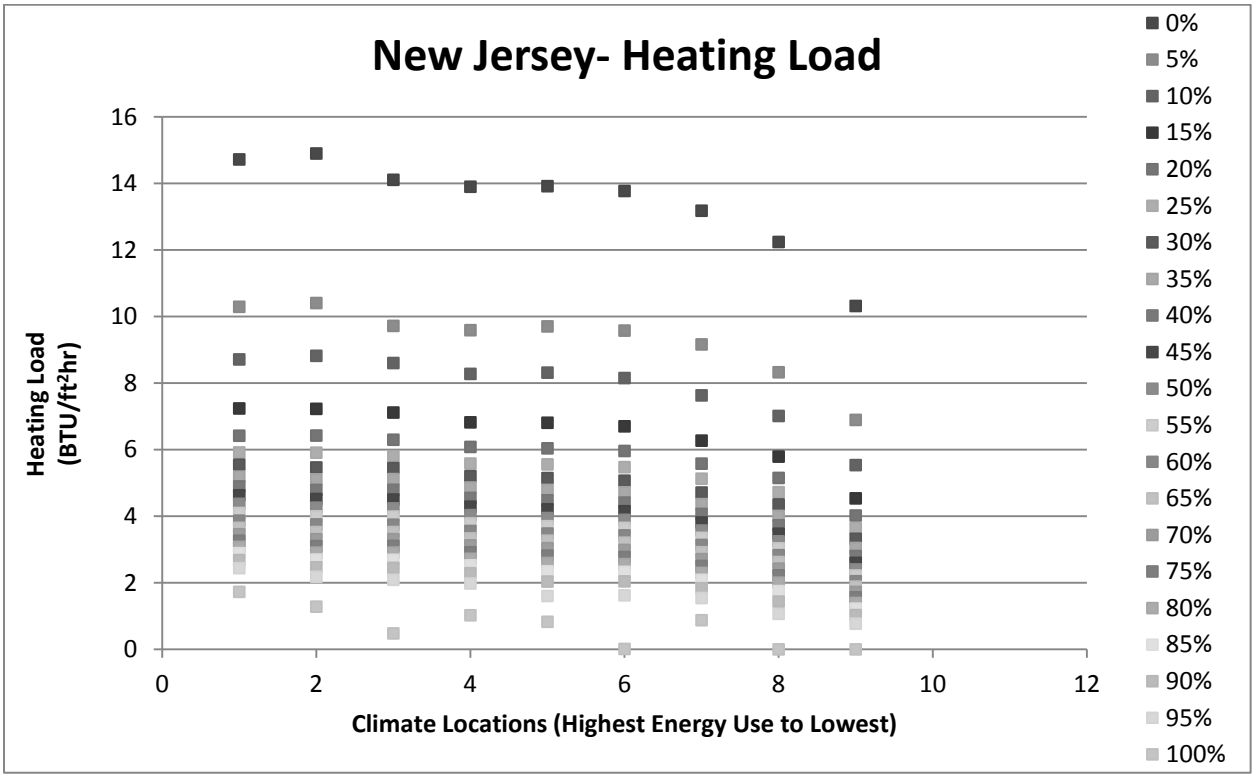

New Hampshire- Heating Demand
Annual Heating Demand kBTU/ft²yr
120
100
80
60
40
20
0
0
2
4
6
8
10
12
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

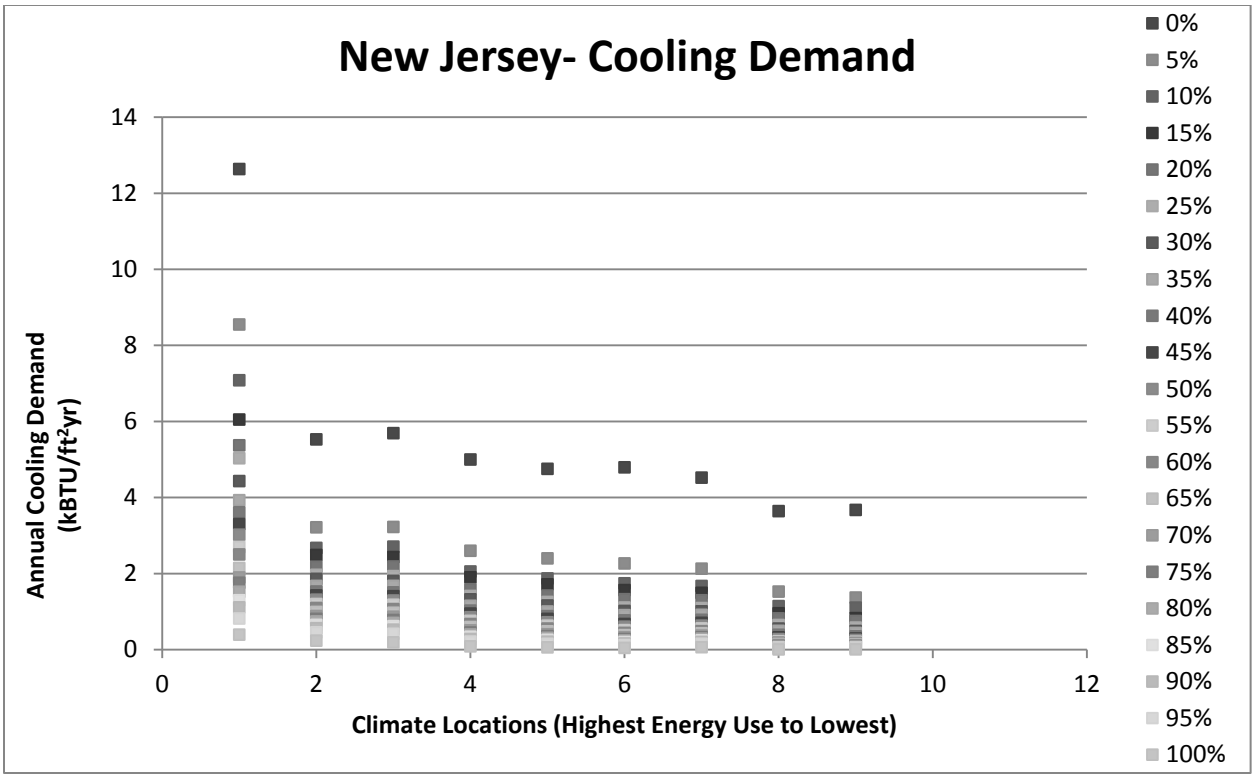

New Hampshire- Heating Load
Heating Load (BTU/ft²hr)
25
20
15
10
5
0
0
2
4
6
8
10
12
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

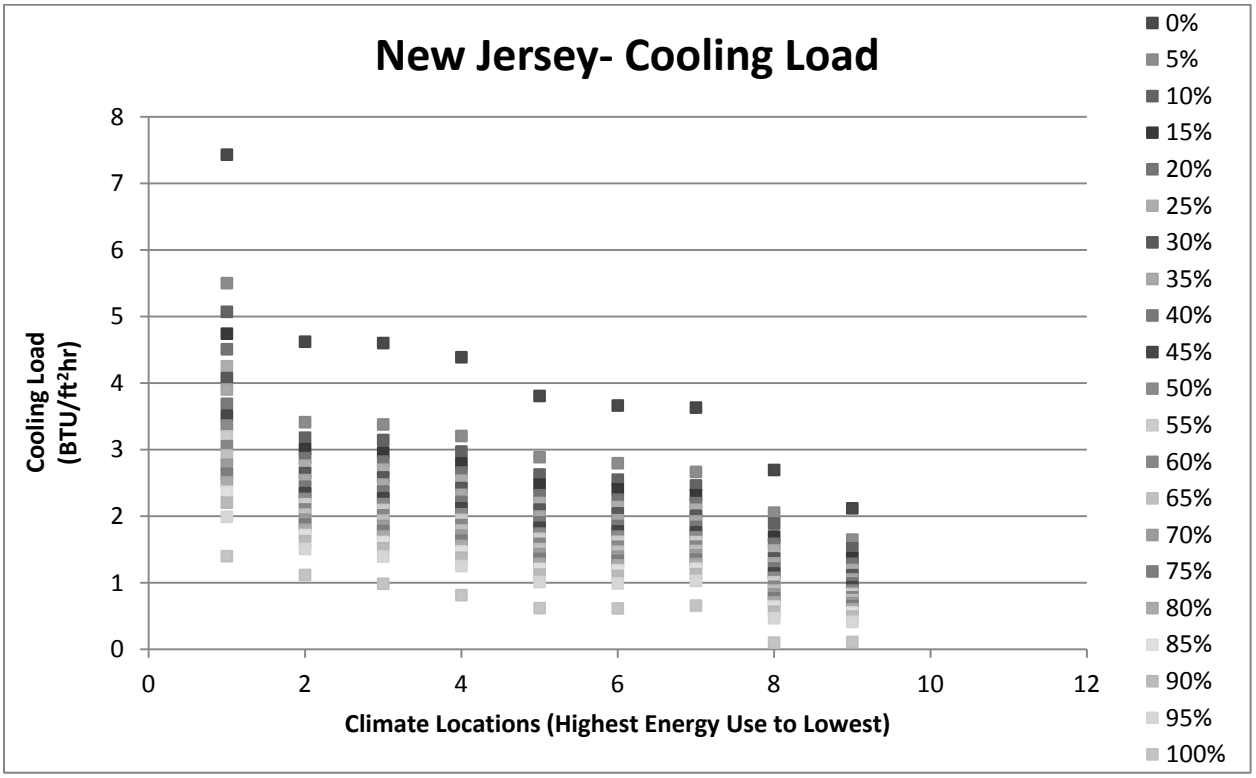

New Hampshire- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
3.5
3
2.5
2
1.5
1
0.5
0
0
2
4
6
8
10
12
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

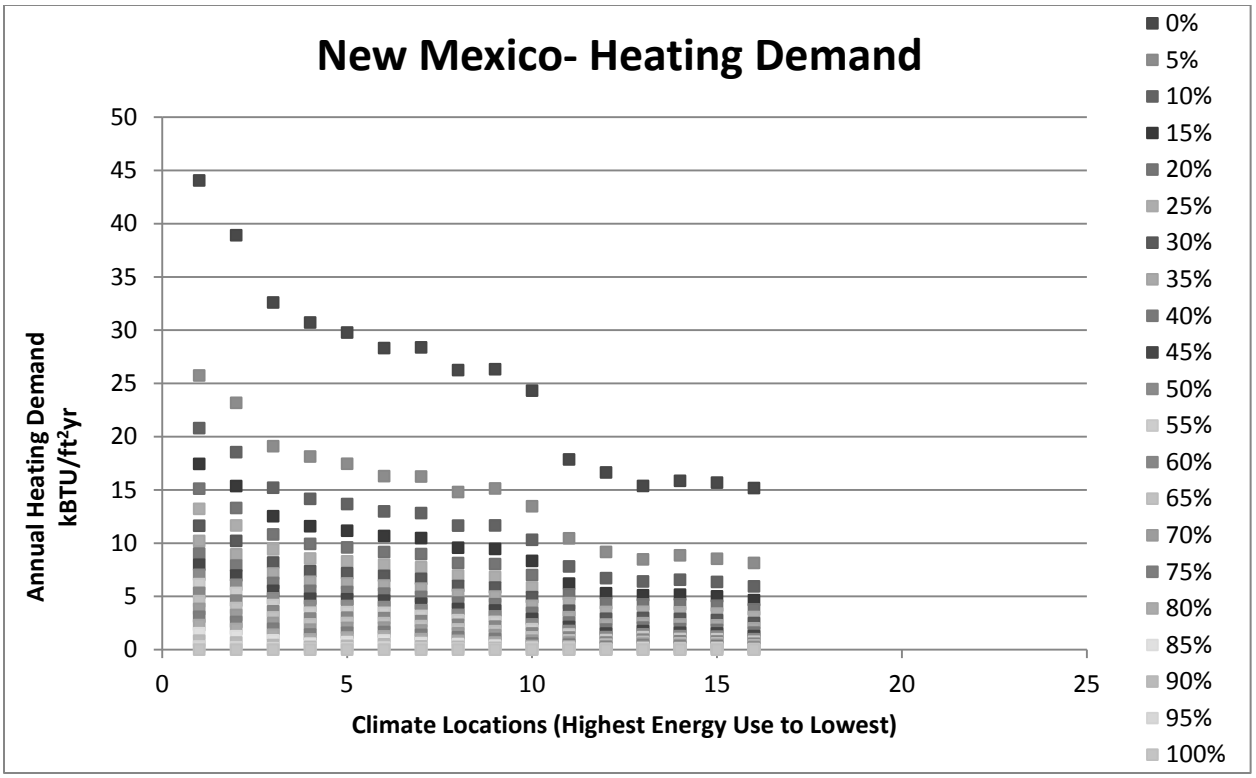

New Hampshire- Cooling Load
Cooling Load (BTU/ft²hr)
3
2.5
2
1.5
1
0.5
0
0
2
4
6
8
10
12
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

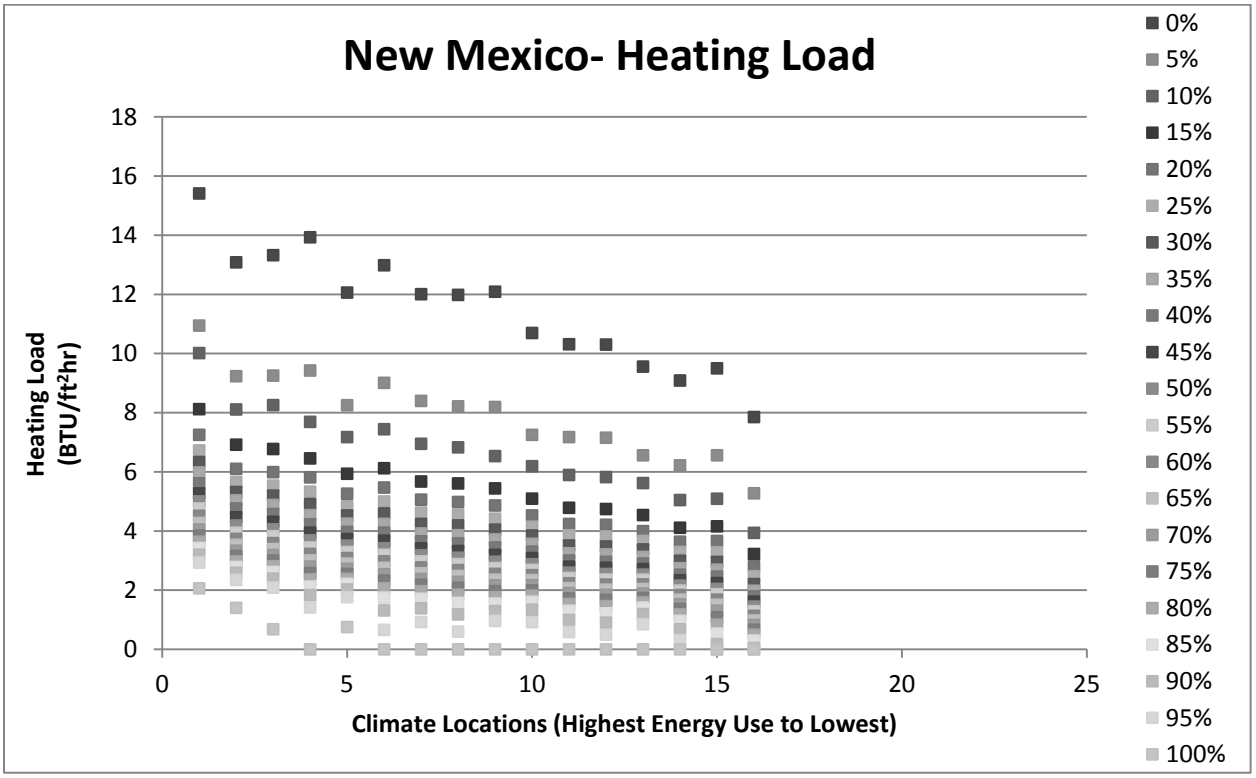

New Jersey- Heating Demand
Annual Heating Demand kBTU/ft²yr
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

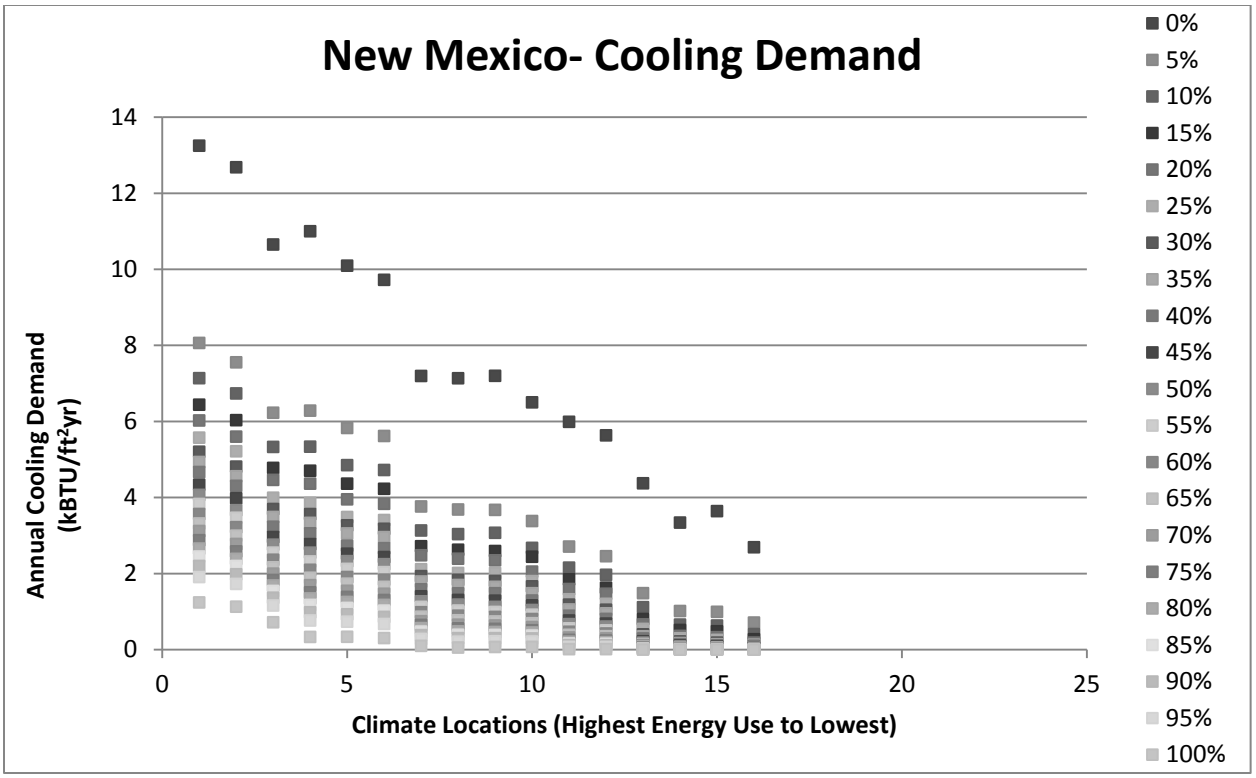

New Jersey- Heating Load
Heating Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%


New Jersey- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
Climate Locations (Highest Energy Use to Lowest)
0
2
4
6
8
10
12
14
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%


New Jersey- Cooling Load
Cooling Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0
1
2
3
4
5
6
7
8
10
12
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%


New Mexico- Heating Demand
Annual Heating Demand kBTU/ft²yr
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%


New Mexico- Heating Load
Heating Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%


New Mexico- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
Climate Locations (Highest Energy Use to Lowest)
0
2
4
6
8
10
12
14
0
5
10
15
20
25
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
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60%
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75%
80%
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90%
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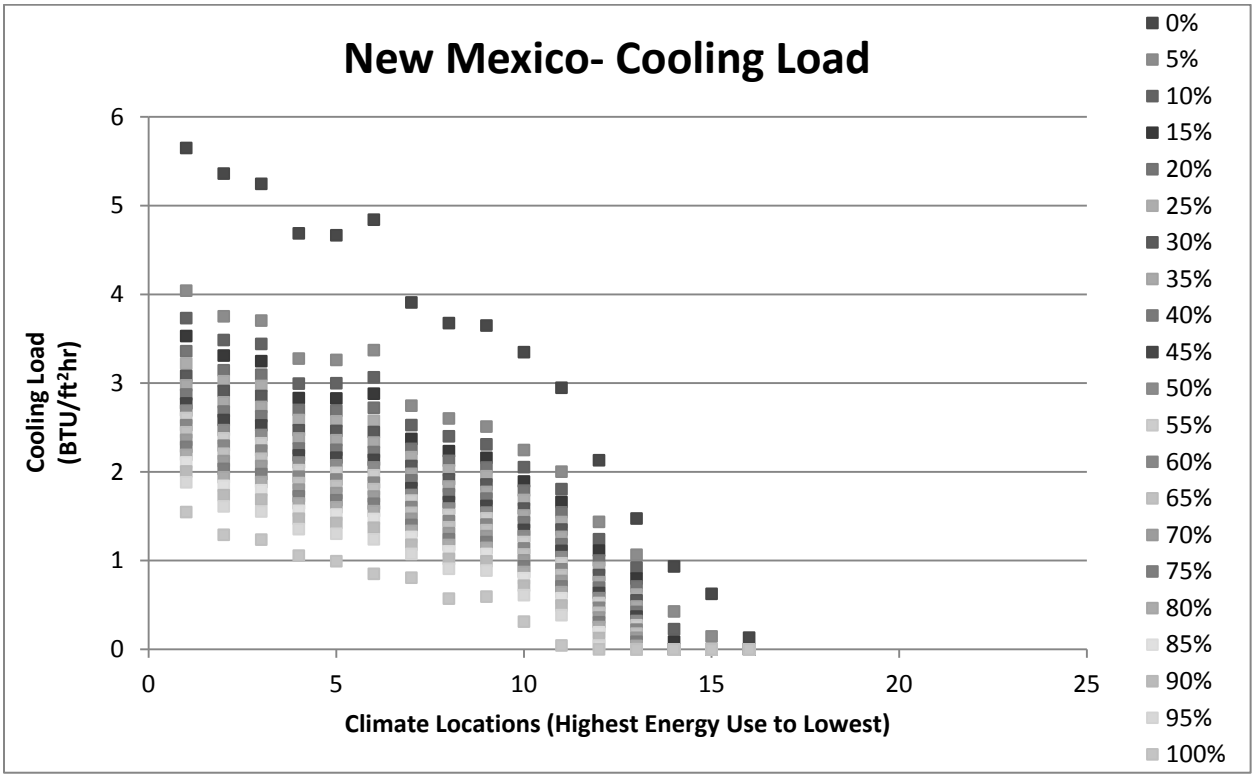
100%


New Mexico- Cooling Load
Cooling Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0
1
2
3
4
5
6
0
5
10
15
20
25
0%
5%
10%
15%
20%
25%
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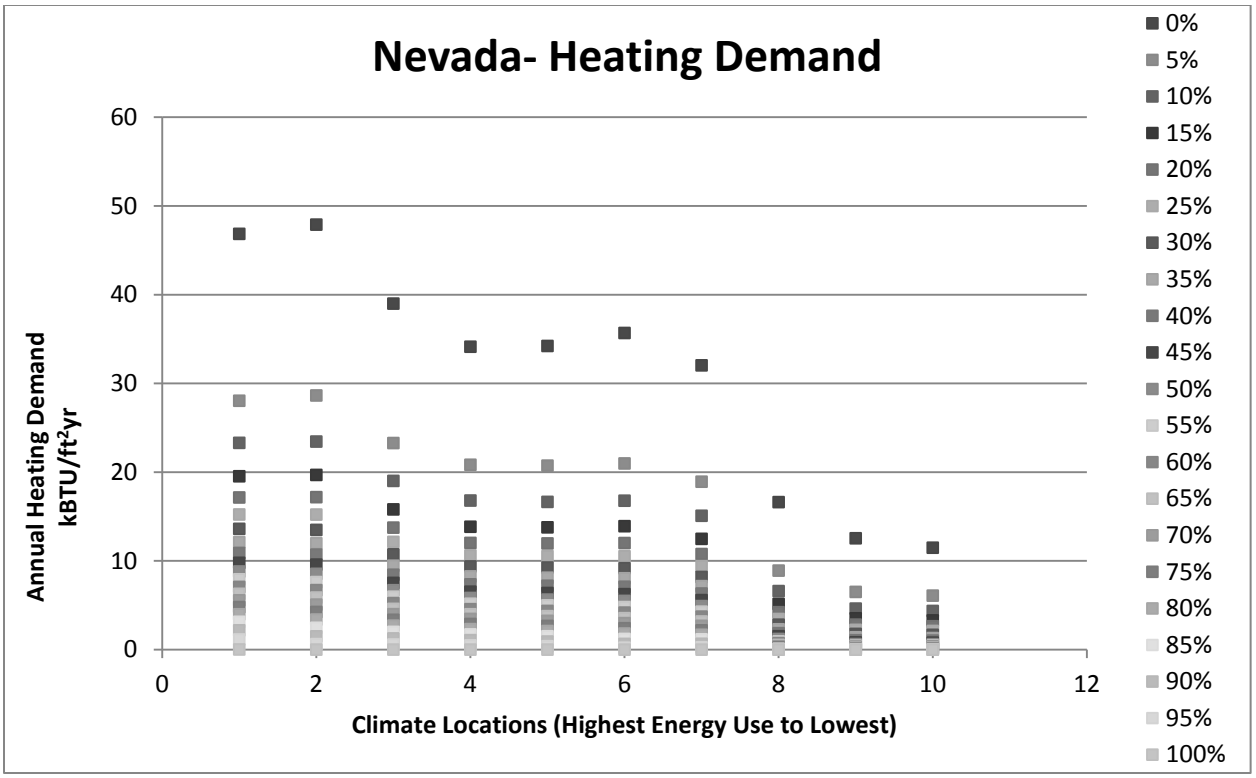
75%
80%
85%
90%
95%
100%


Nevada- Heating Demand
Annual Heating Demand kBTU/ft²yr
Climate Locations (Highest Energy Use to Lowest)
0
10
20
30
40
50
60
0
2
4
6
8
10
12
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
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60%
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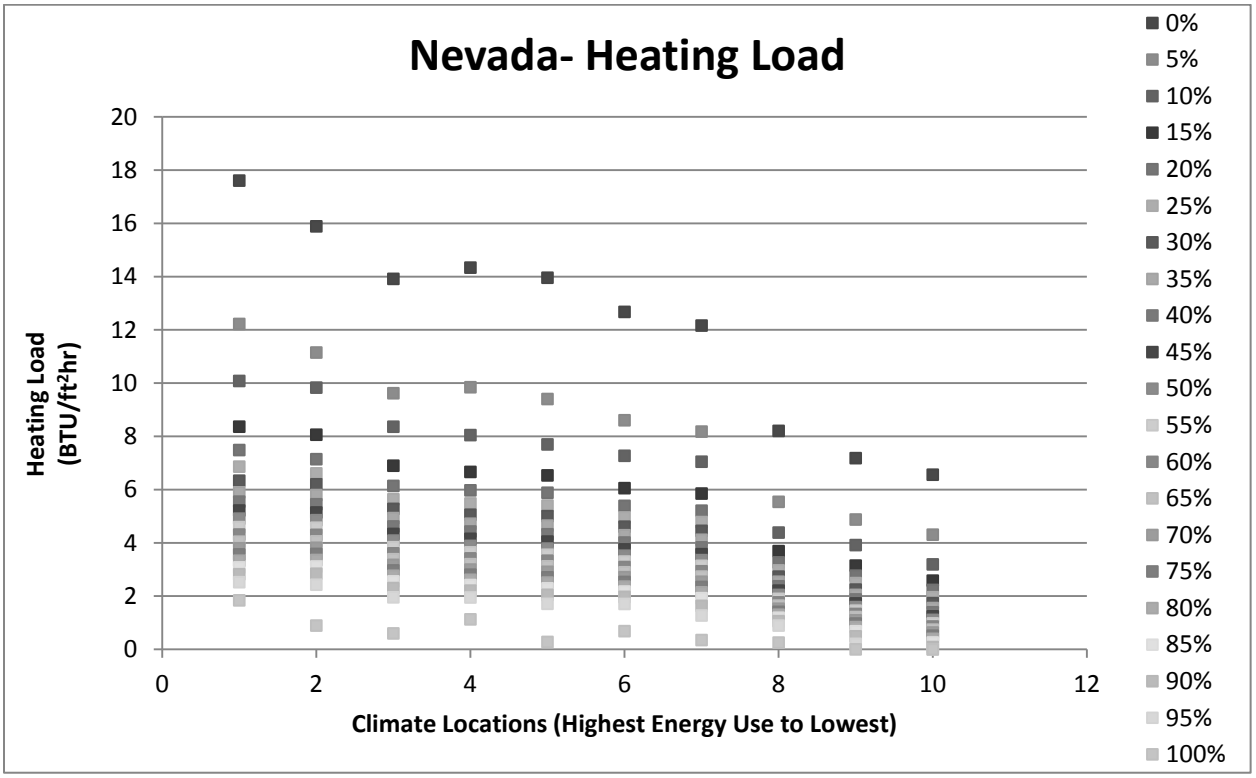
75%
80%
85%
90%
95%
100%


Nevada- Heating Load
Heating Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0
2
4
6
8
10
12
14
16
18
20
0
2
4
6
8
10
12
0%
5%
10%
15%
20%
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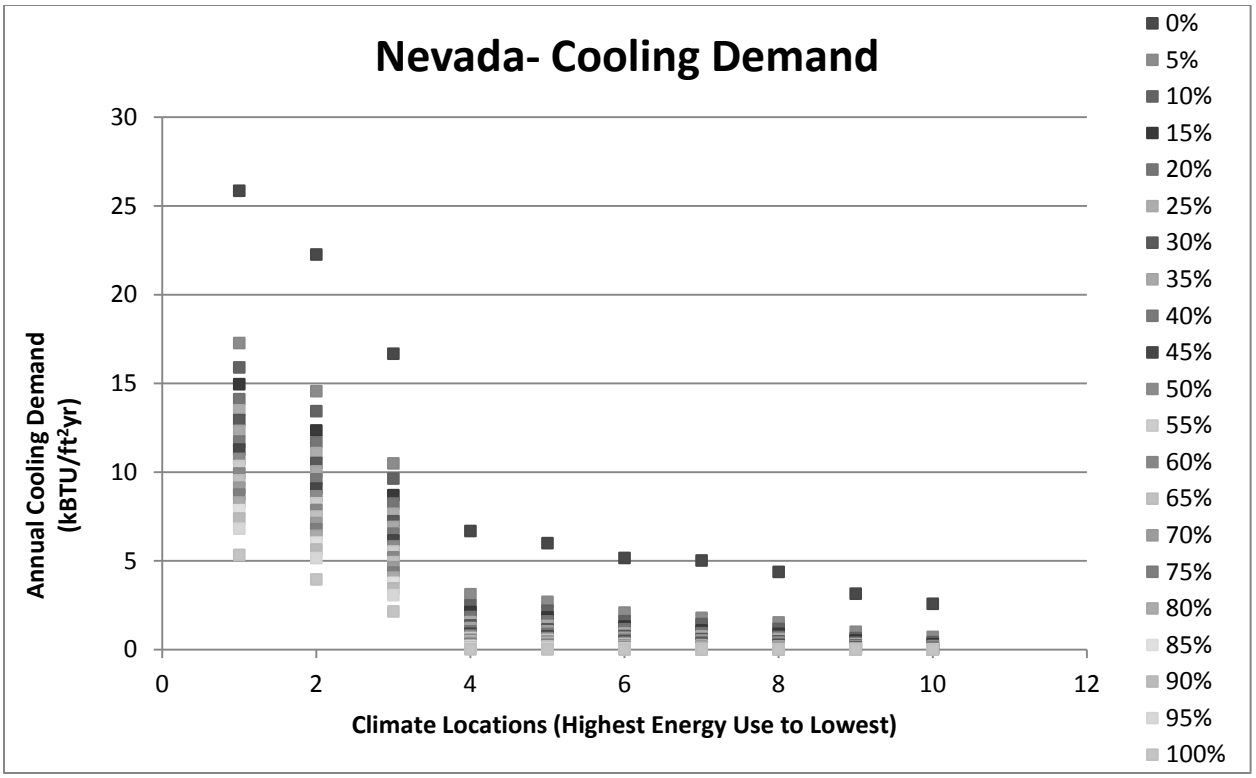
100%


Nevada- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
Climate Locations (Highest Energy Use to Lowest)
0
5
10
15
20
25
30
0
2
4
6
8
10
12
0%
5%
10%
15%
20%
25%
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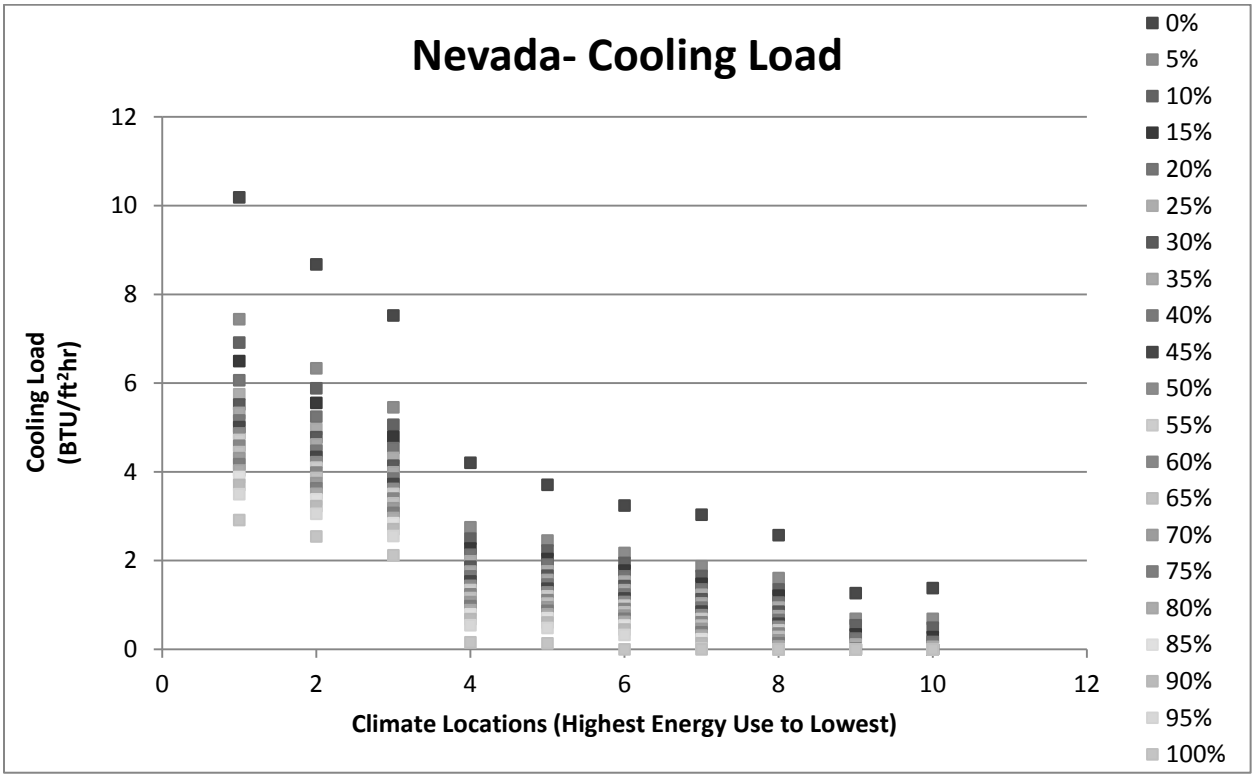
Nevada- Cooling Load
Cooling Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0
2
4
6
8
10
12
0
2
4
6
8
10
12
0%
5%
10%
15%
20%
25%
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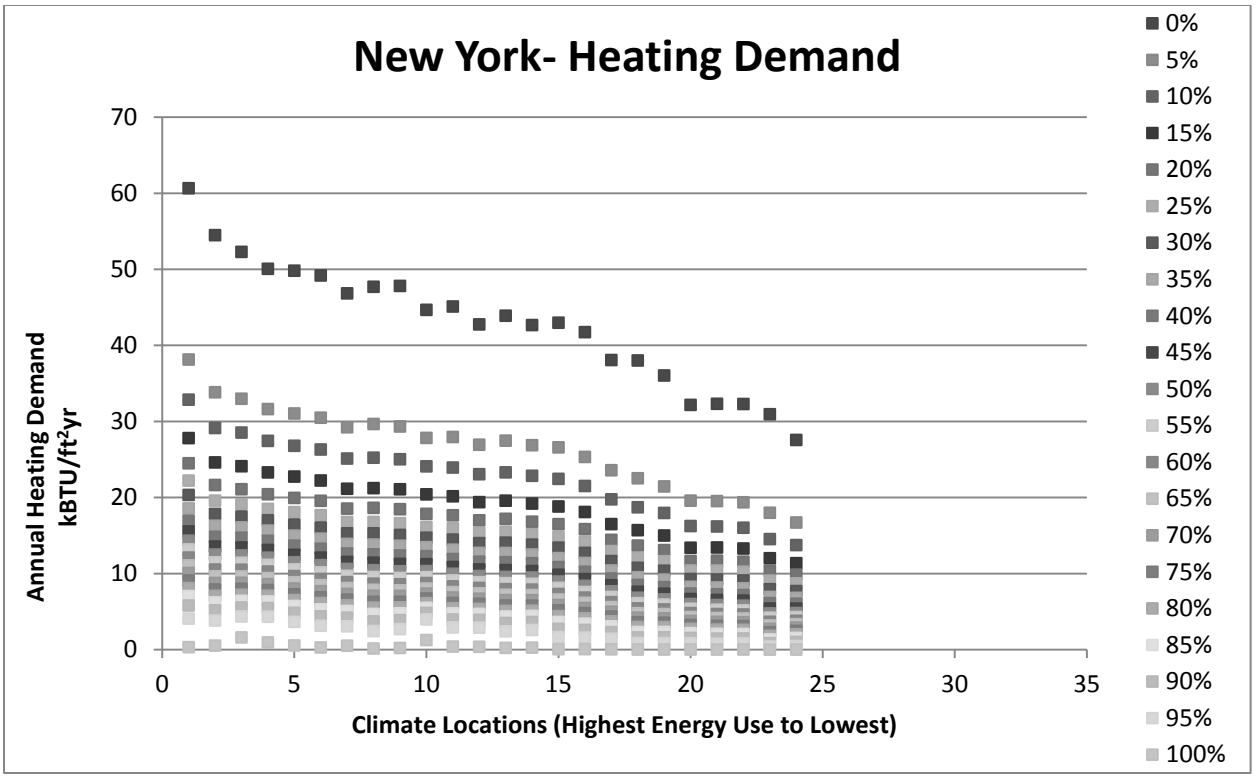
New York- Heating Demand
Annual Heating Demand kBTU/ft²yr
0
10
20
30
40
50
60
70
0
5
10
15
20
25
30
35
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
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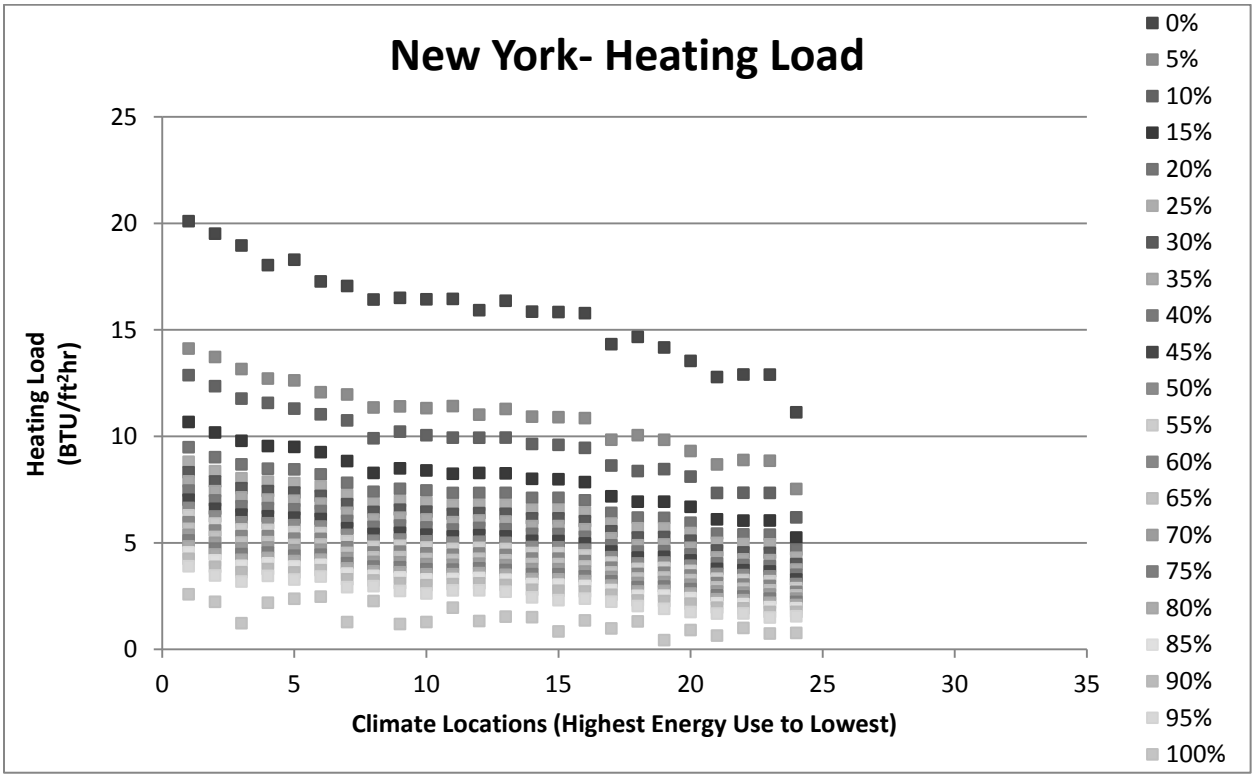
New York- Heating Load
Heating Load (BTU/ft²hr)
0
5
10
15
20
25
0
5
10
15
20
25
30
35
Climate Locations (Highest Energy Use to Lowest)
0%
5%
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20%
25%
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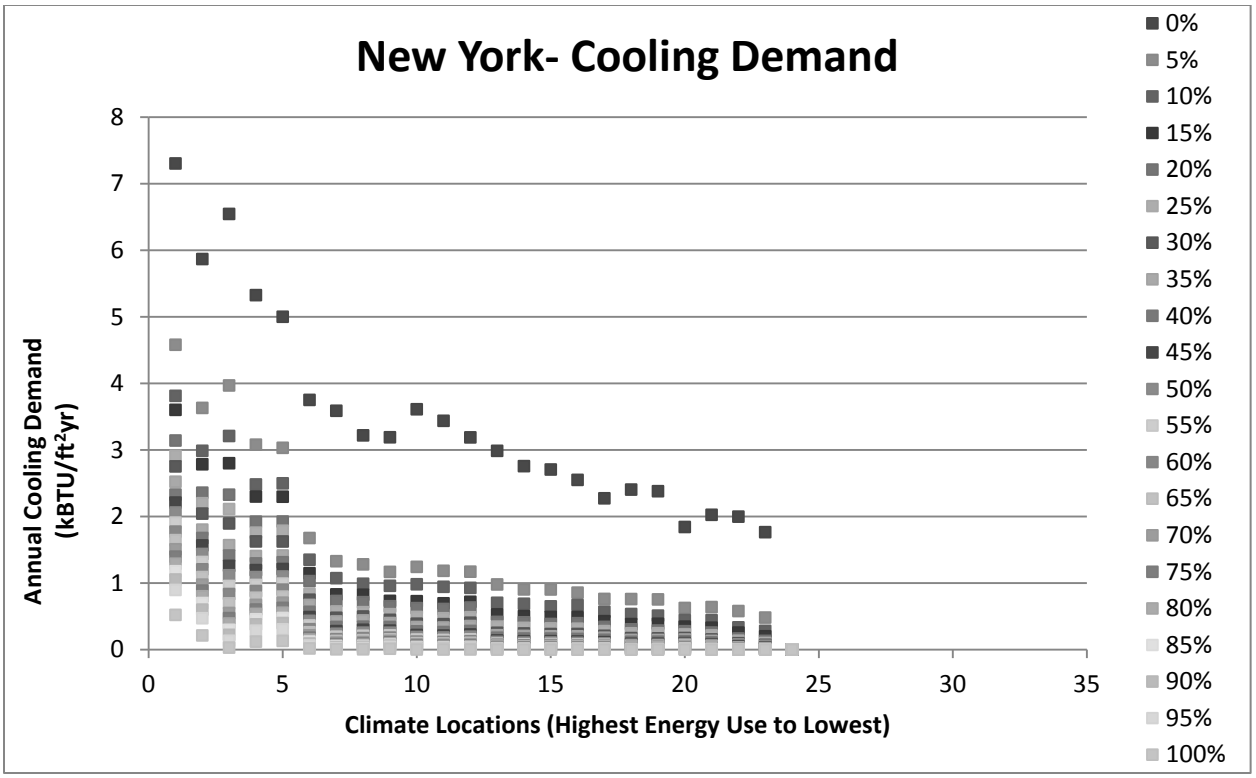
New York- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
Climate Locations (Highest Energy Use to Lowest)
0%
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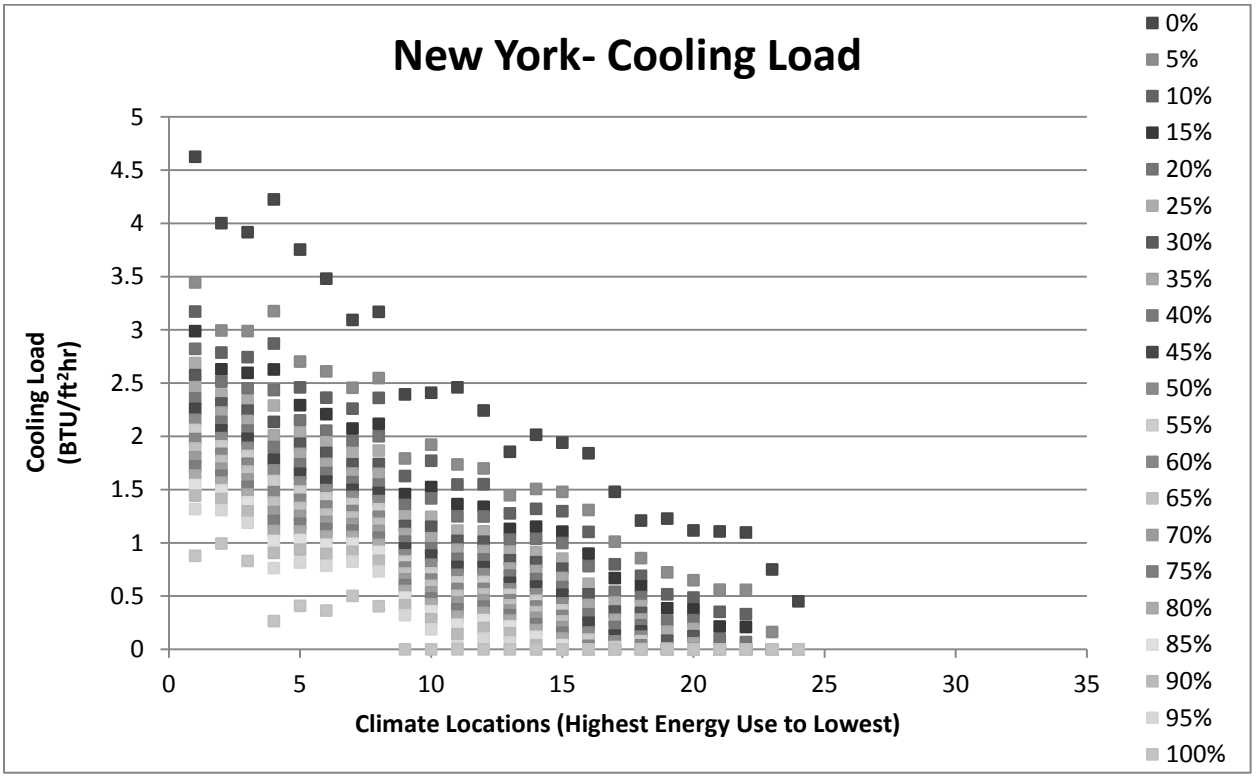
New York- Cooling Load
Cooling Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
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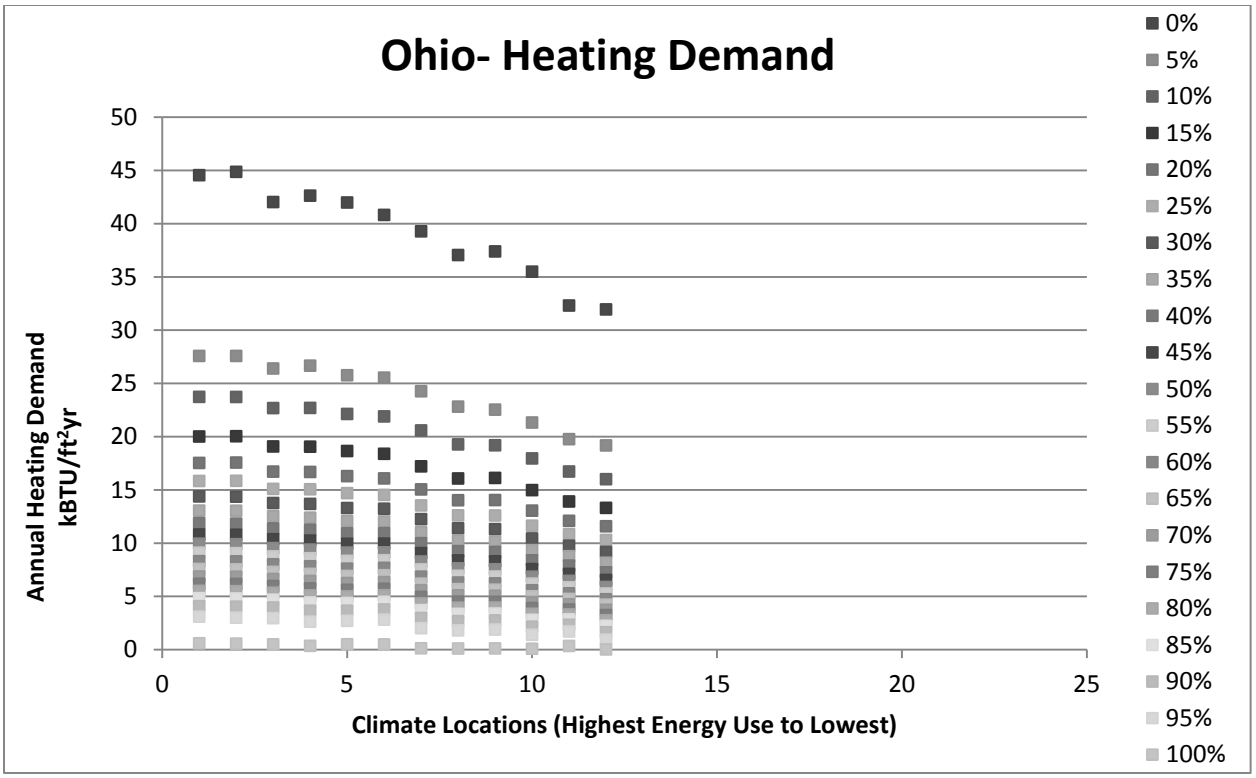
Ohio- Heating Demand
Annual Heating Demand kBTU/ft²yr
0
5
10
15
20
25
30
35
40
45
50
0
5
10
15
20
25
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
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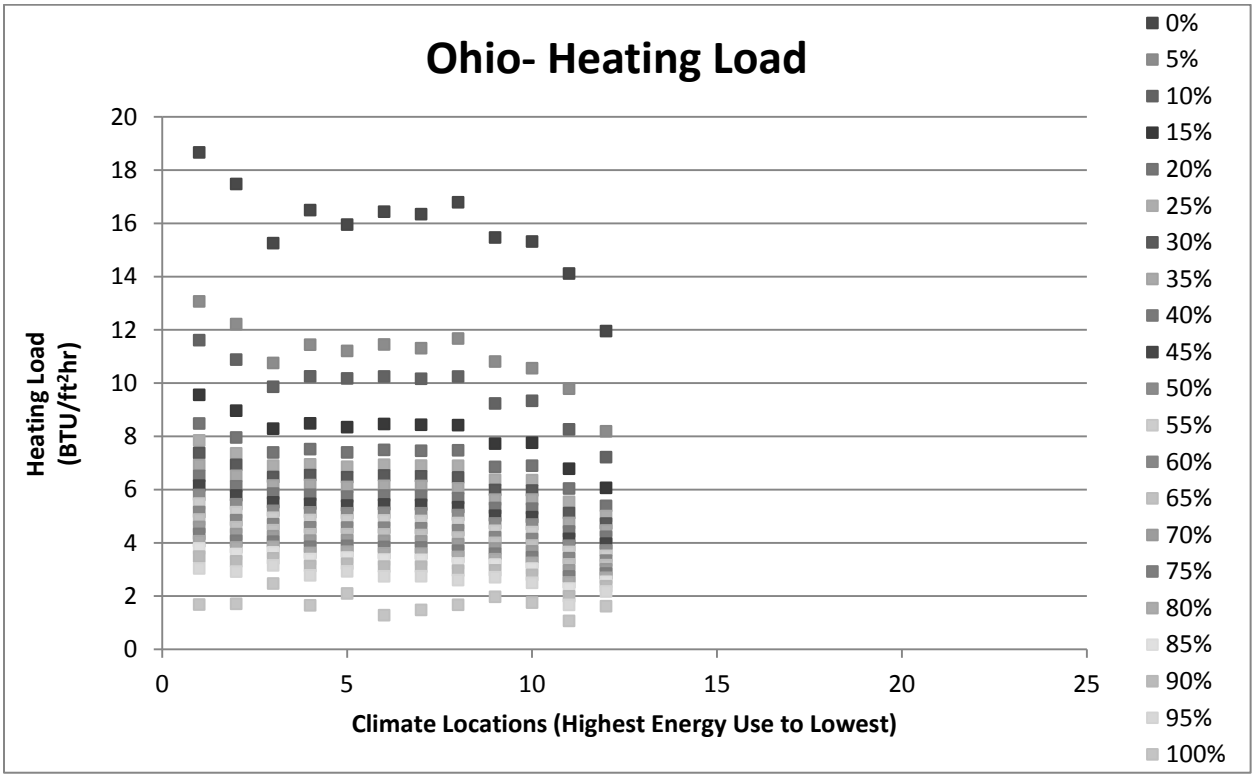
Ohio- Heating Load
Heating Load (BTU/ft²hr)
0
2
4
6
8
10
12
14
16
18
20
0
5
10
15
20
25
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
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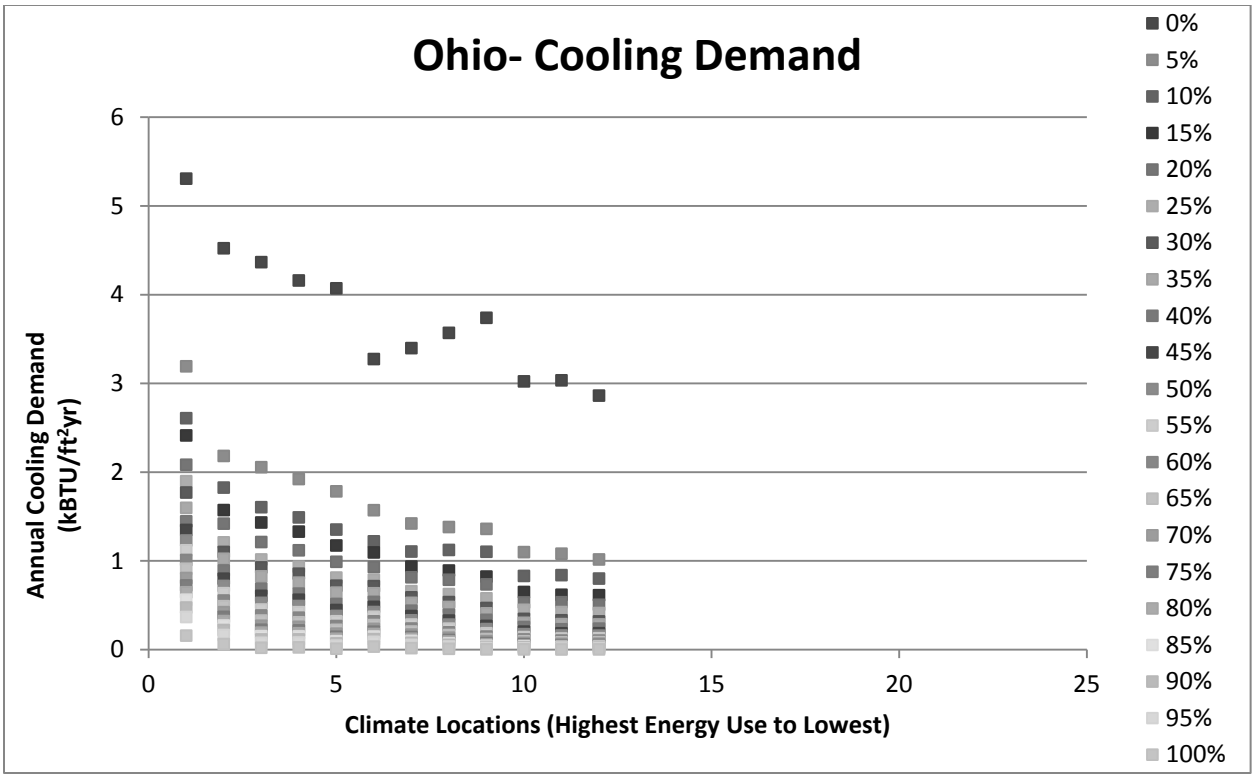
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%


Ohio- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
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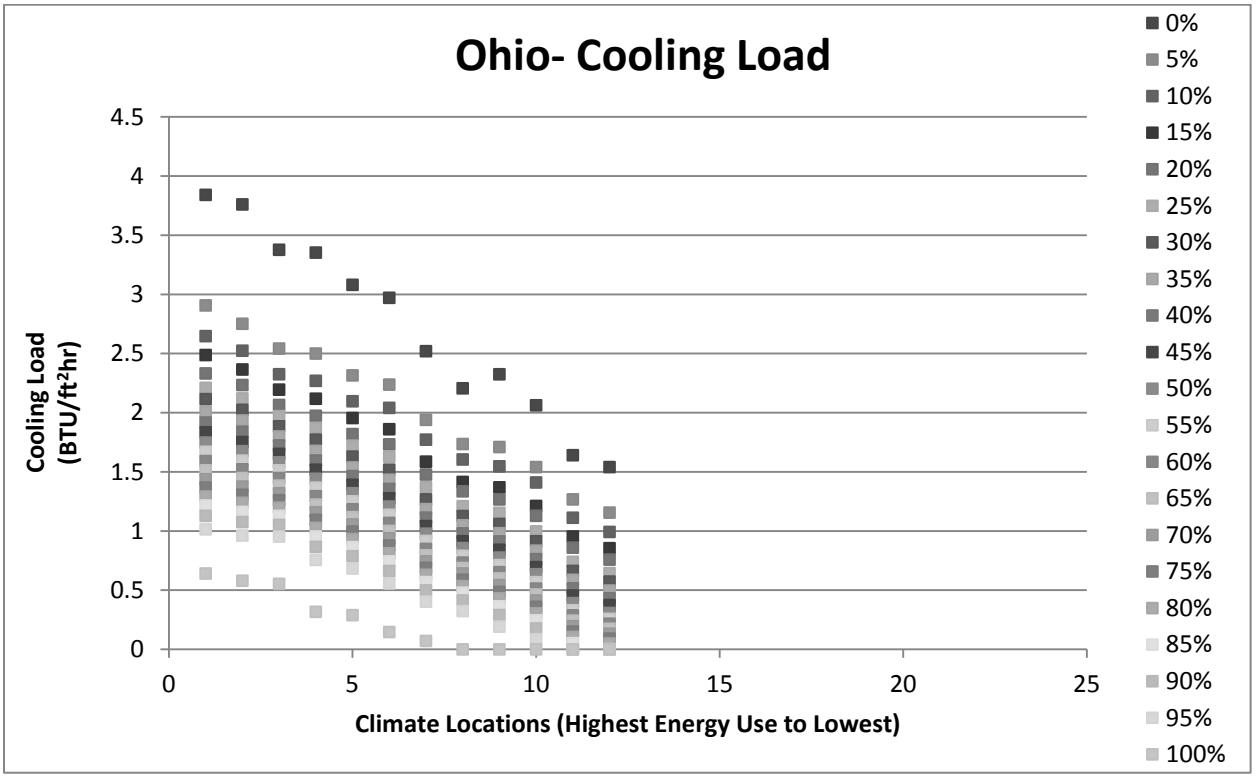
95%
100%


Ohio- Cooling Load
Cooling Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
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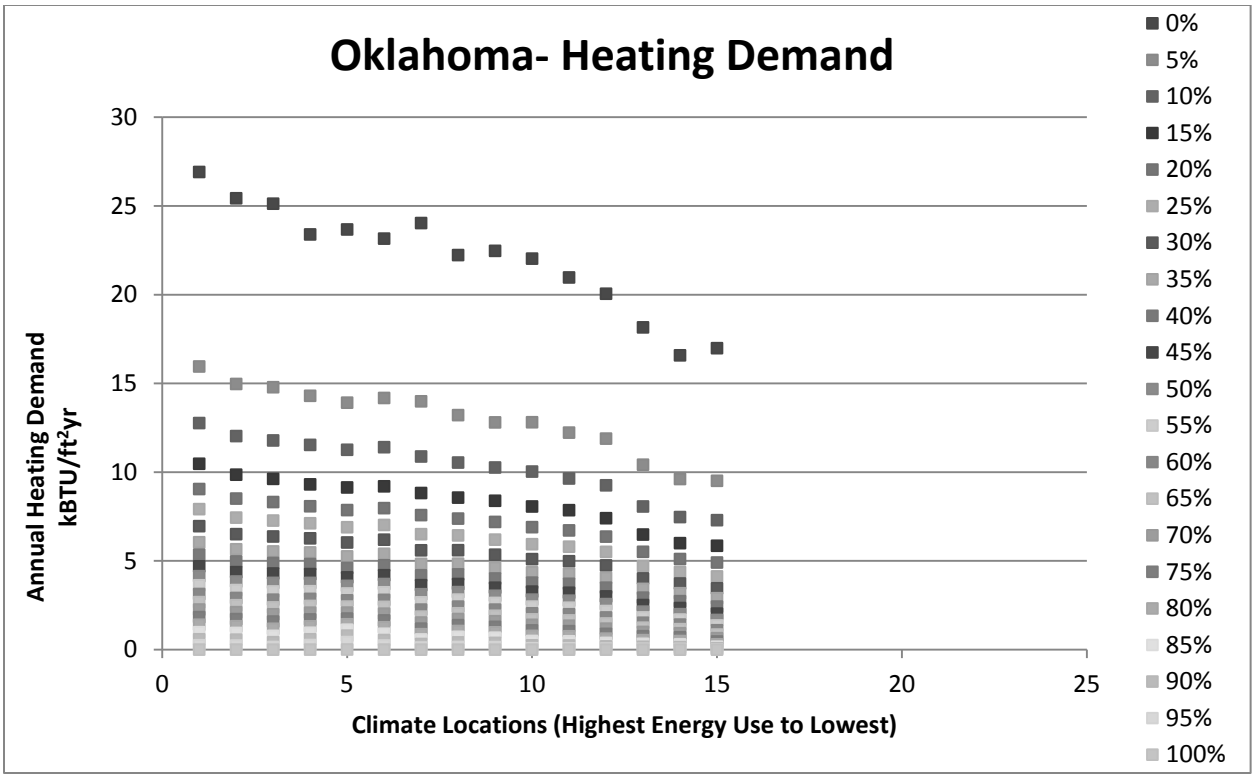
Oklahoma- Heating Demand
Annual Heating Demand kBTU/ft²yr
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
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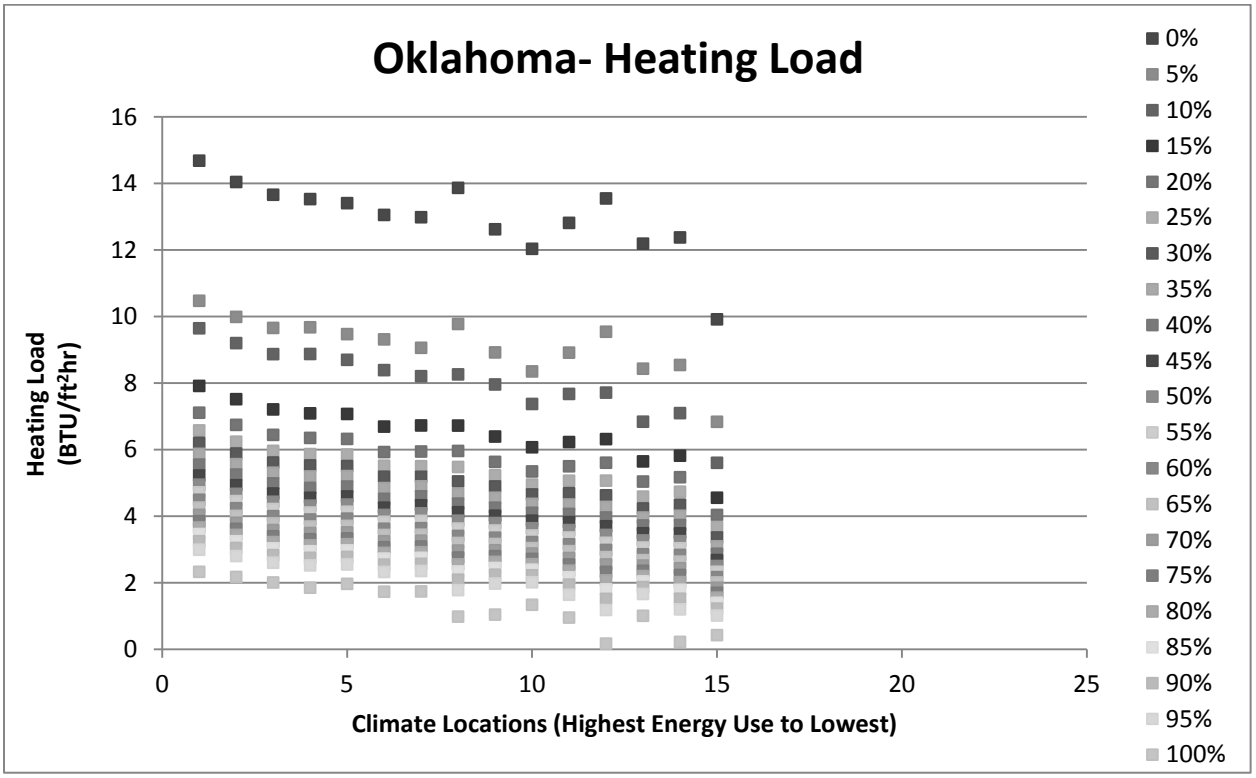
90%
95%
100%


Oklahoma- Heating Load
Heating Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
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75%
80%
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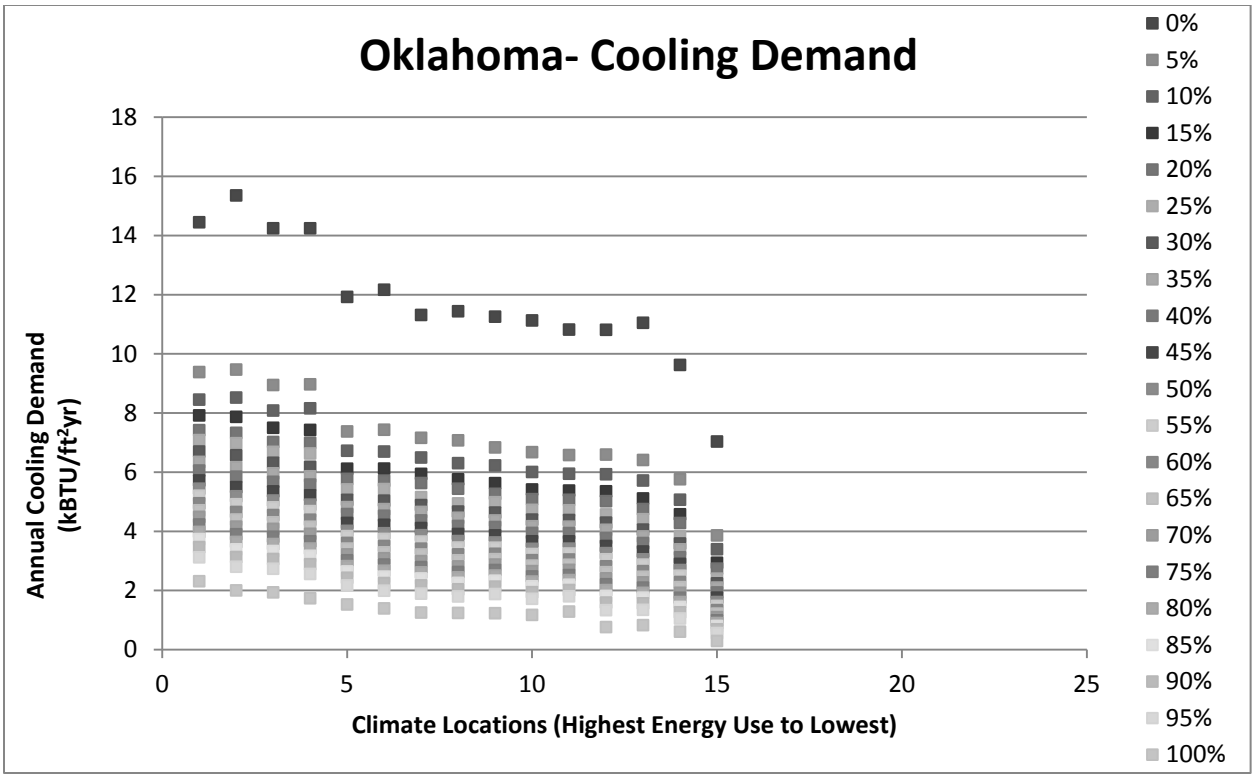
Oklahoma- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
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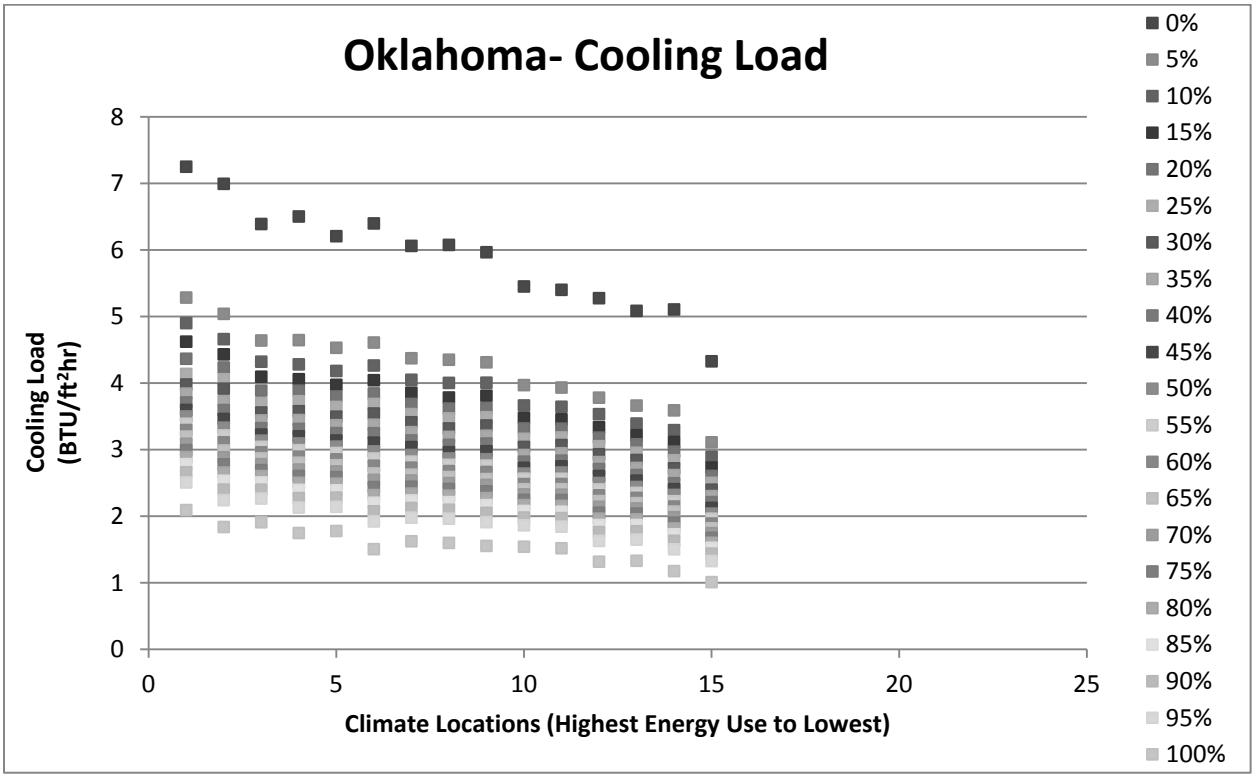
Oklahoma- Cooling Load
Cooling Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
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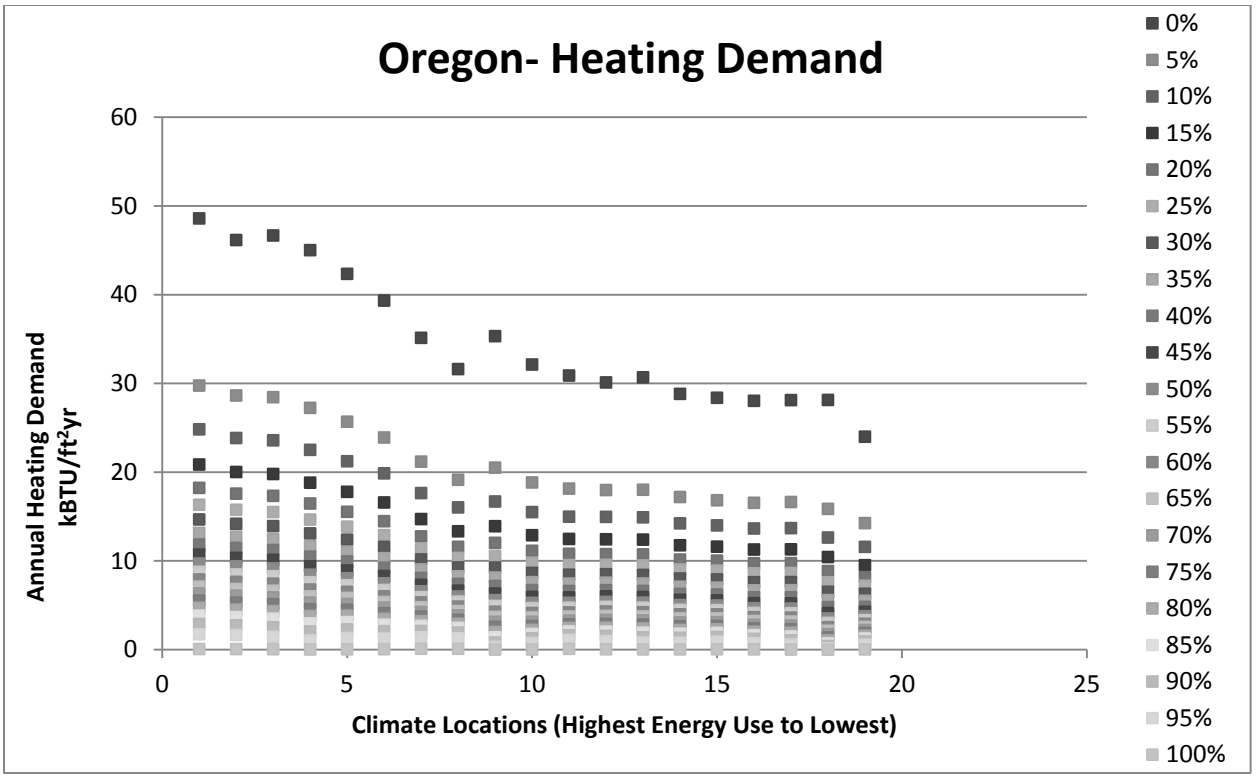
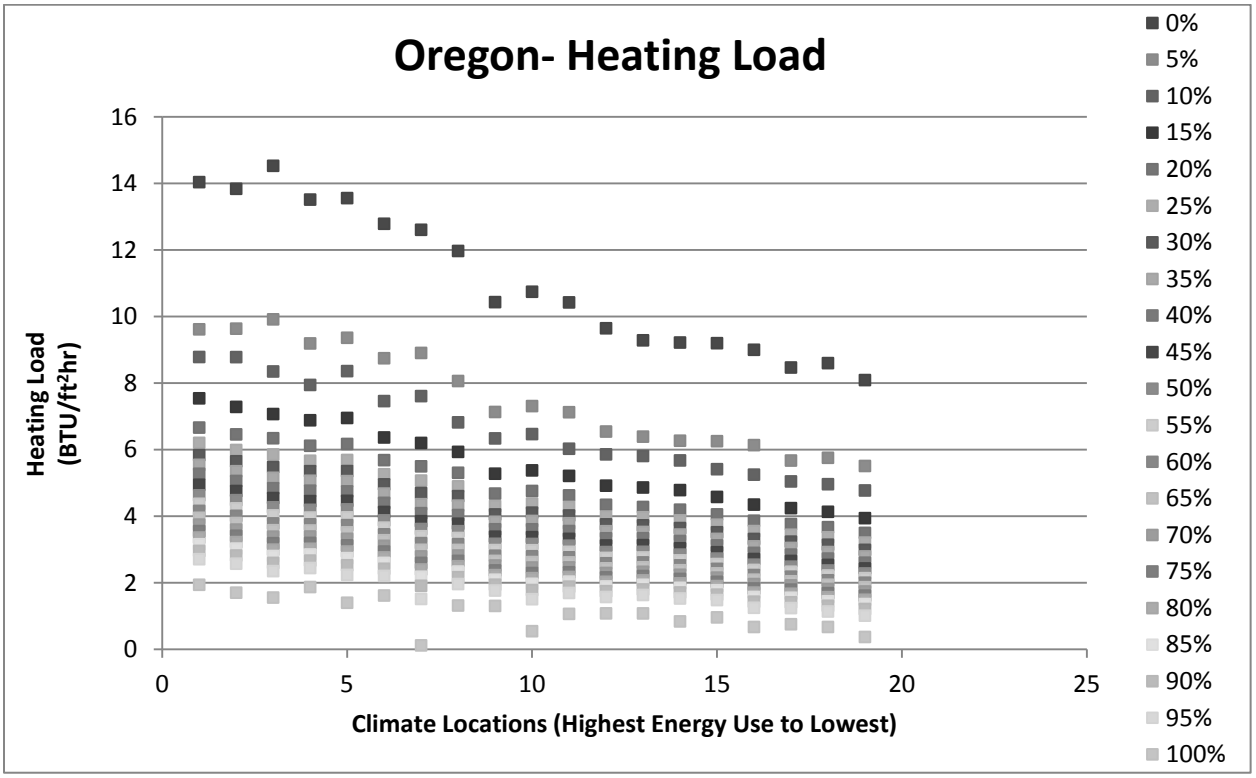

Oregon- Heating Demand
Annual Heating Demand kBTU/ft²yr
Climate Locations (Highest Energy Use to Lowest)
0
10
20
30
40
50
60
0
5
10
15
20
25
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%


Oregon- Heating Load
Heating Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0
2
4
6
8
10
12
14
16
0
5
10
15
20
25
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
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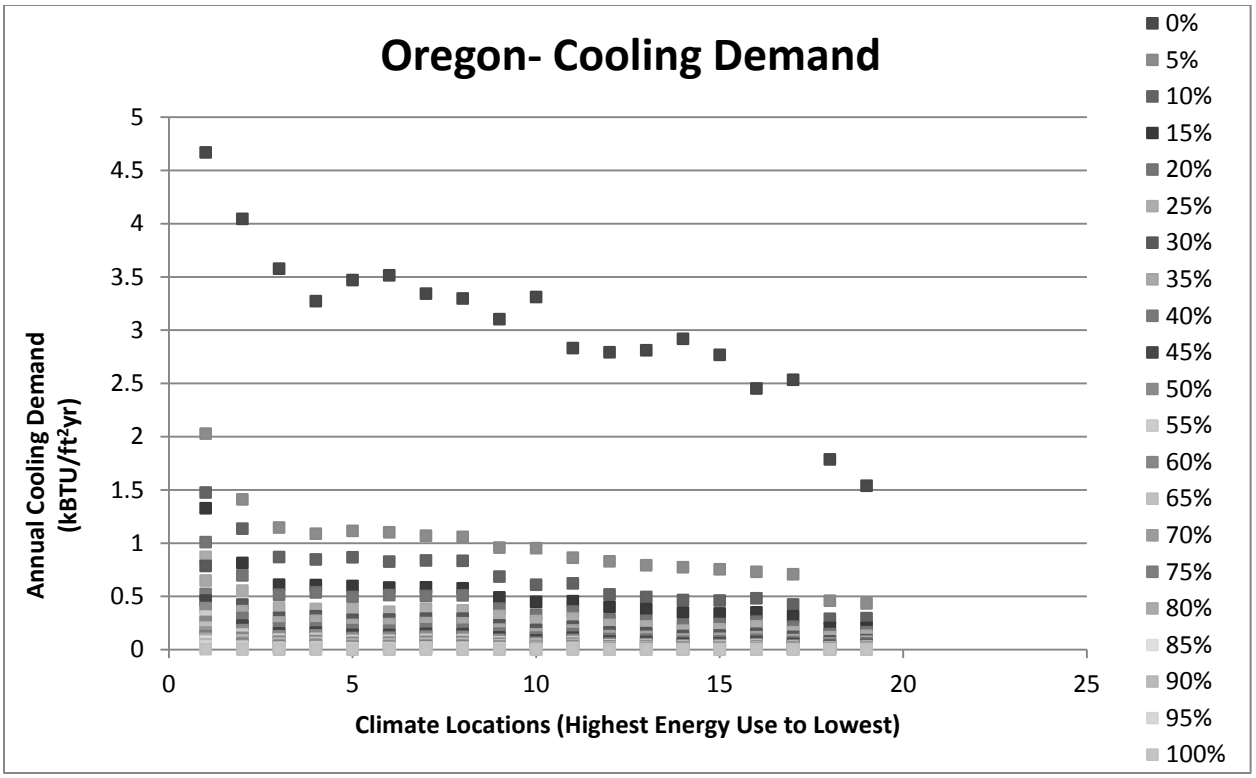
75%
80%
85%
90%
95%
100%


Oregon- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
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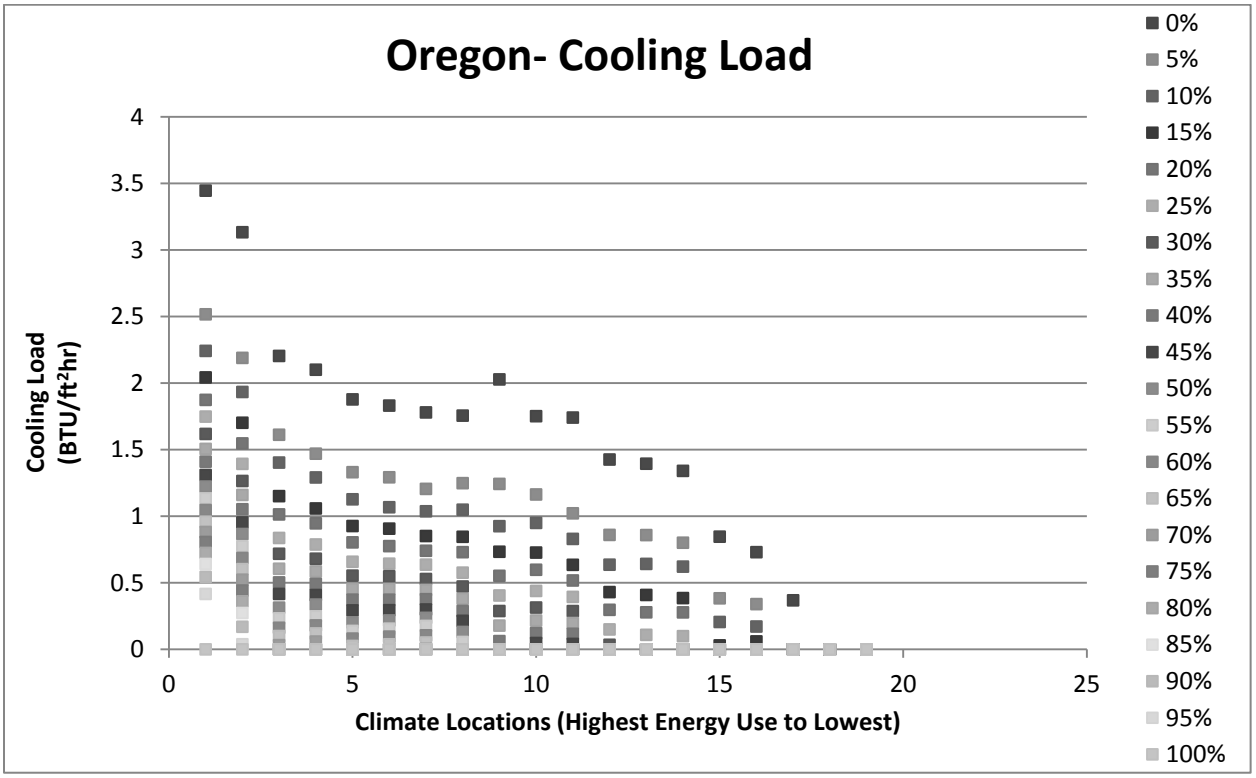
Oregon- Cooling Load
Cooling Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
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55%
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70%
75%
80%
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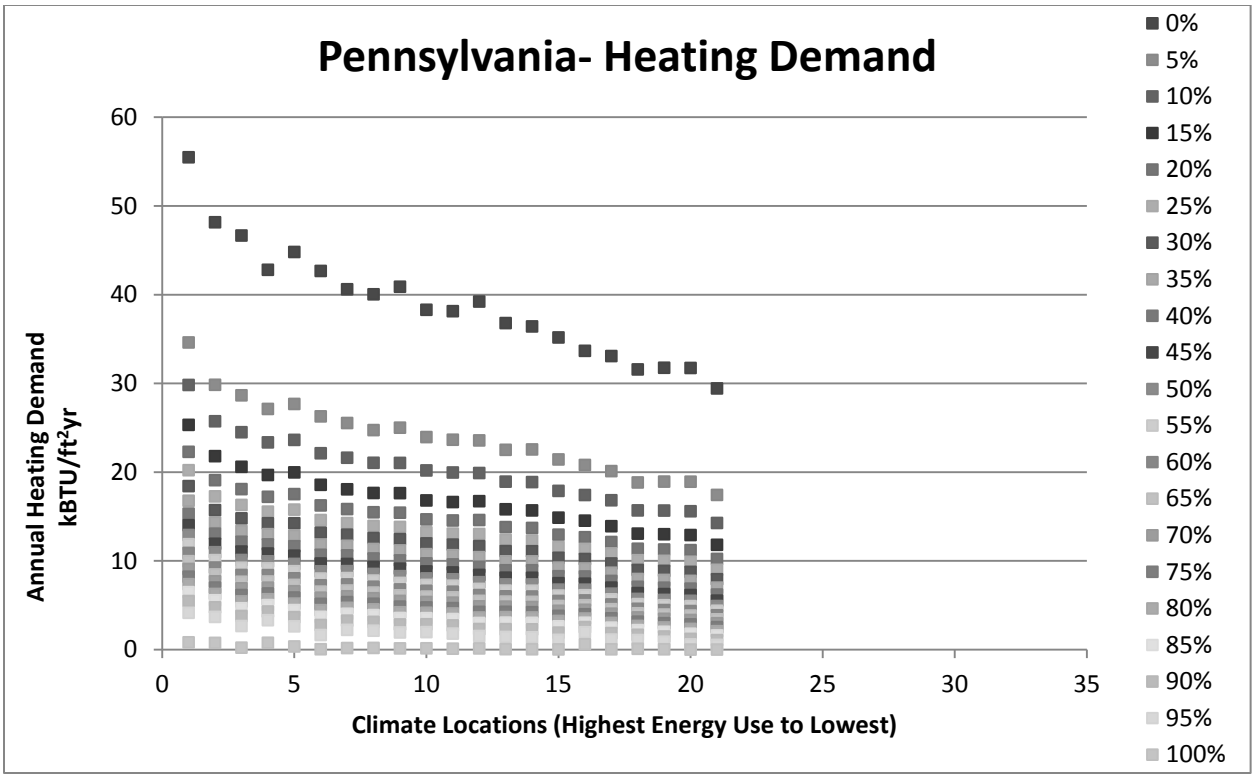
90%
95%
100%


Pennsylvania- Heating Demand
Annual Heating Demand kBTU/ft²yr
Climate Locations (Highest Energy Use to Lowest)
0
10
20
30
40
50
60
0
5
10
15
20
25
30
35
0%
5%
10%
15%
20%
25%
30%
35%
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75%
80%
85%
90%
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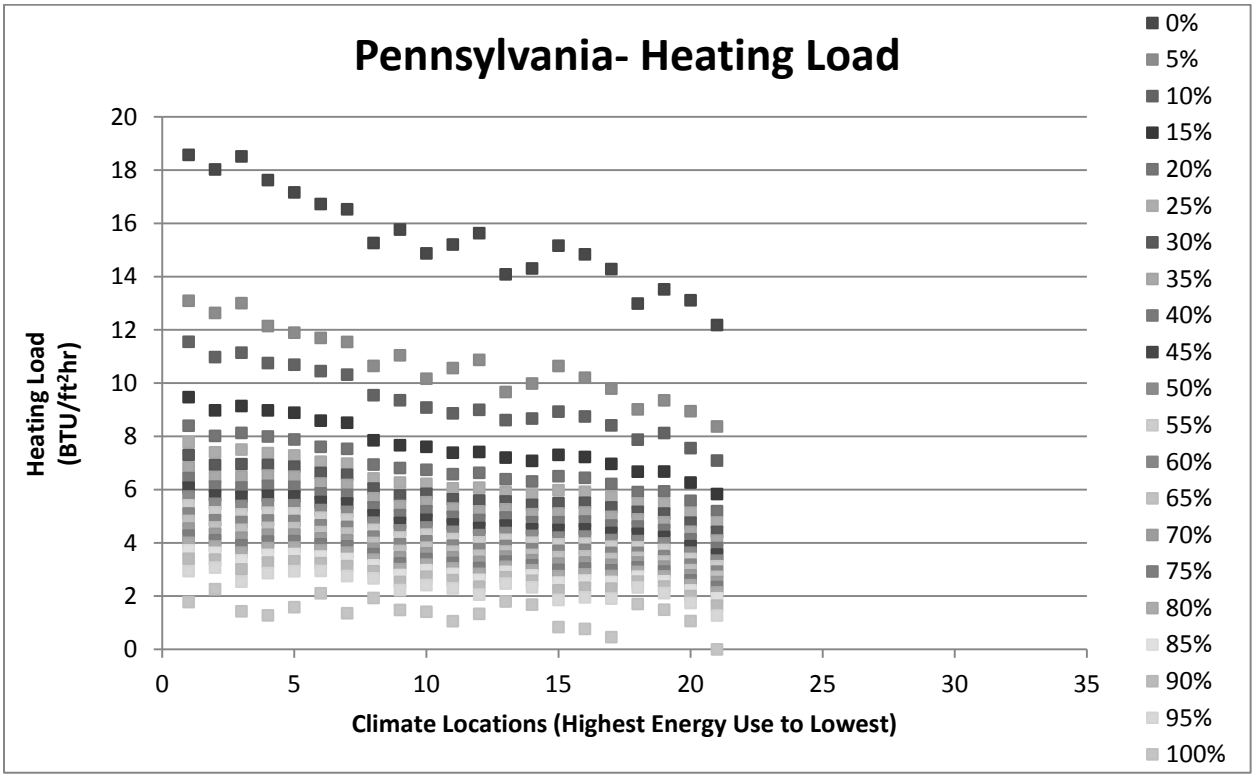
100%


Pennsylvania- Heating Load
Heating Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0
2
4
6
8
10
12
14
16
18
20
0
5
10
15
20
25
30
35
0%
5%
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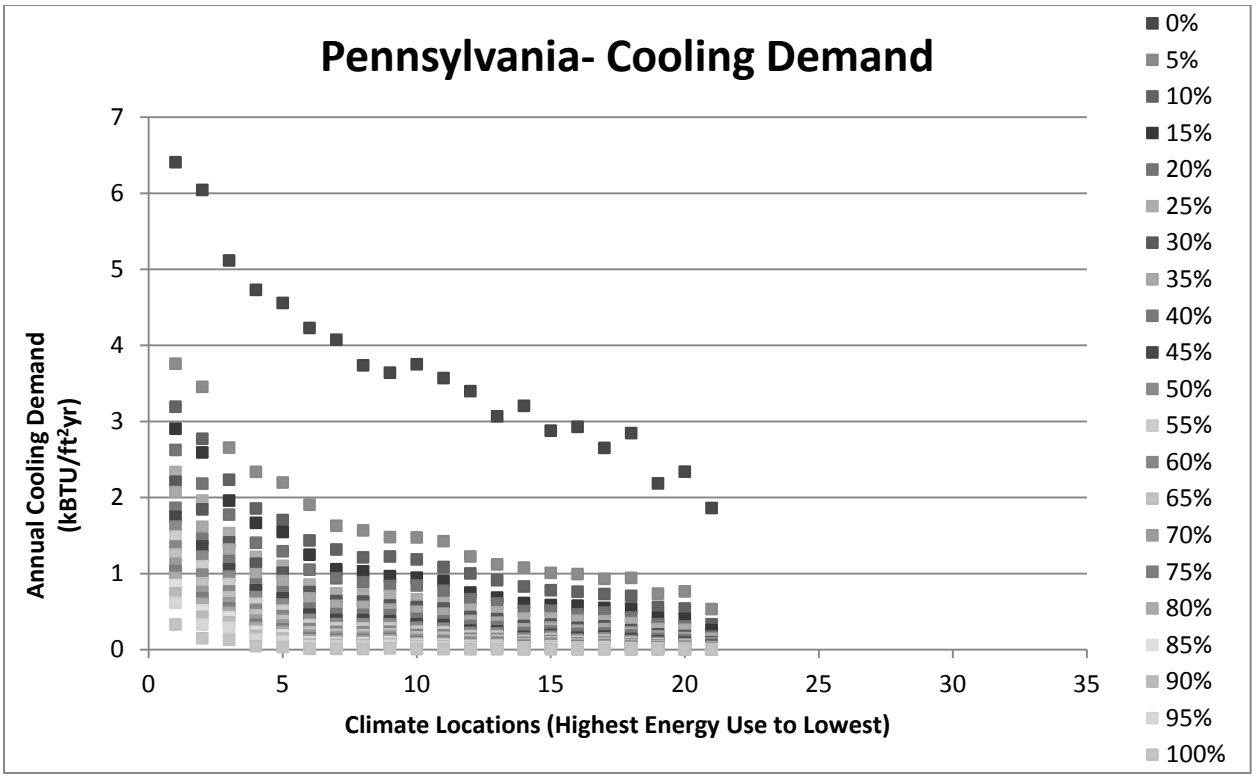
Pennsylvania- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
Climate Locations (Highest Energy Use to Lowest)
0
1
2
3
4
5
6
7
0
5
10
15
20
25
30
35
0%
5%
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15%
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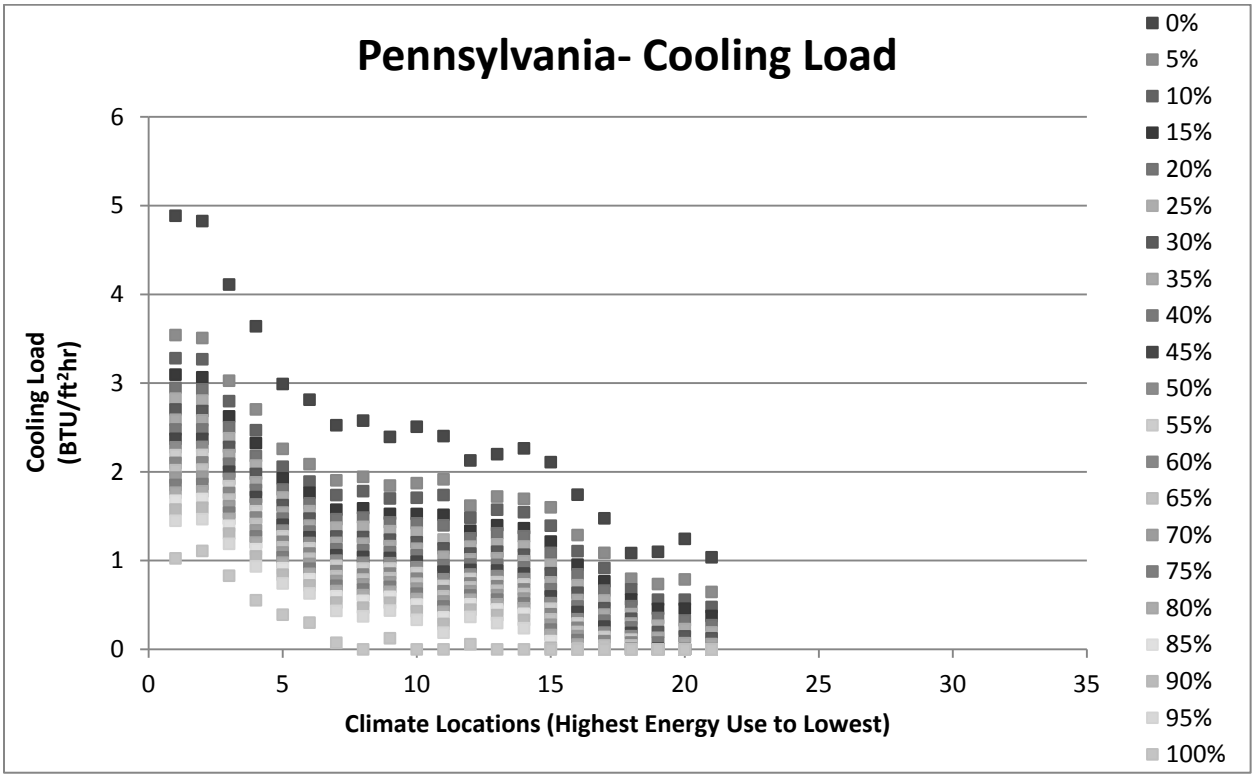
Pennsylvania- Cooling Load
Cooling Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0
1
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5
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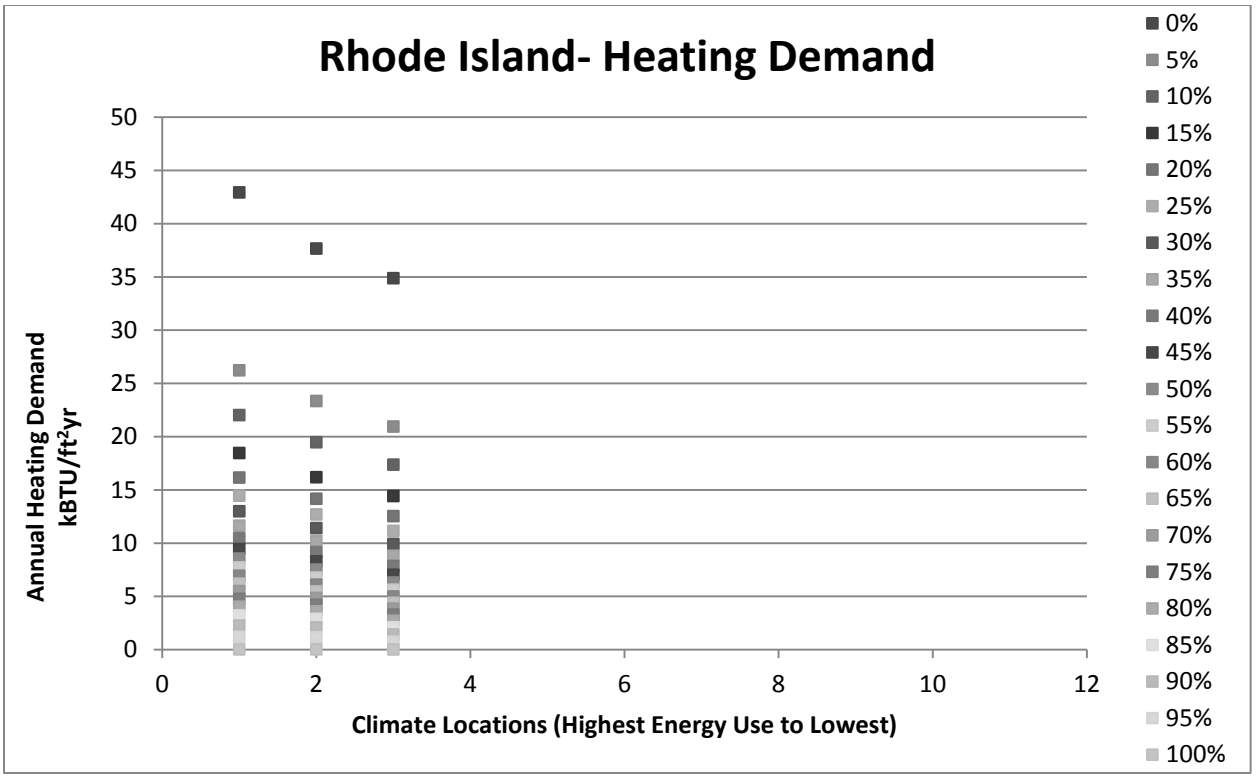
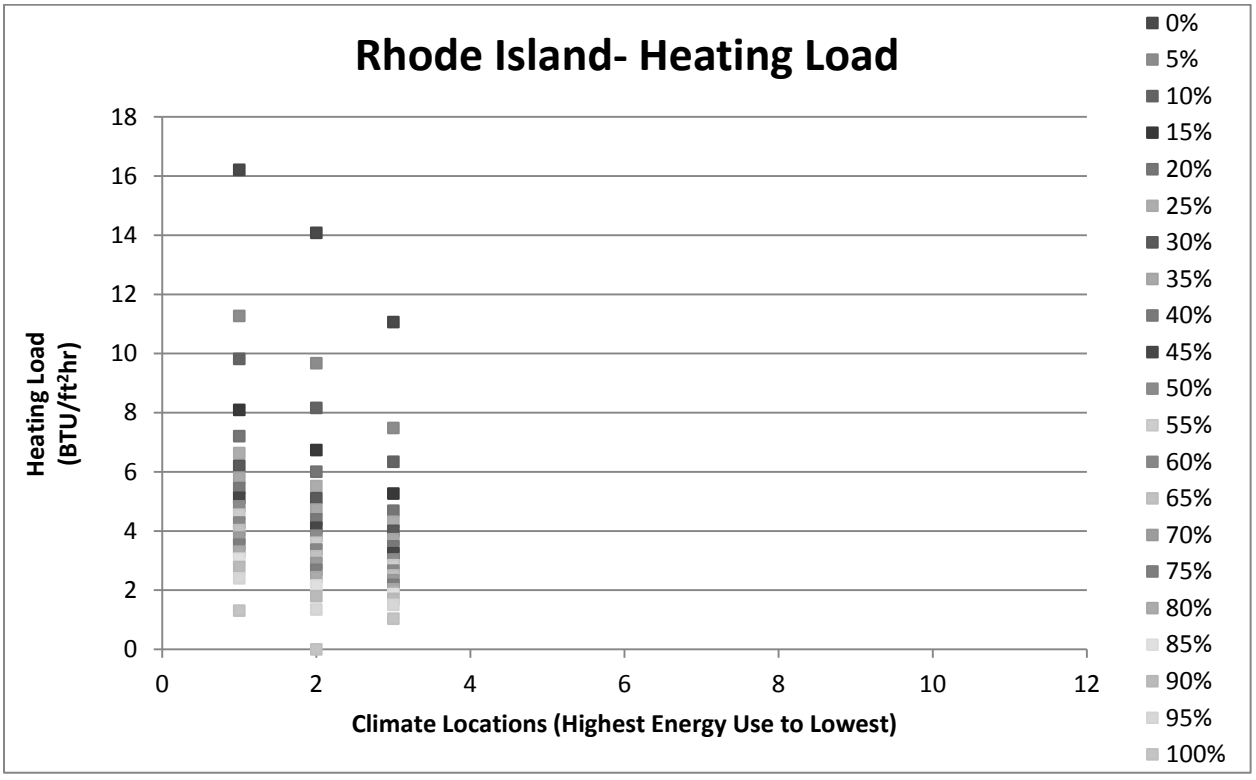
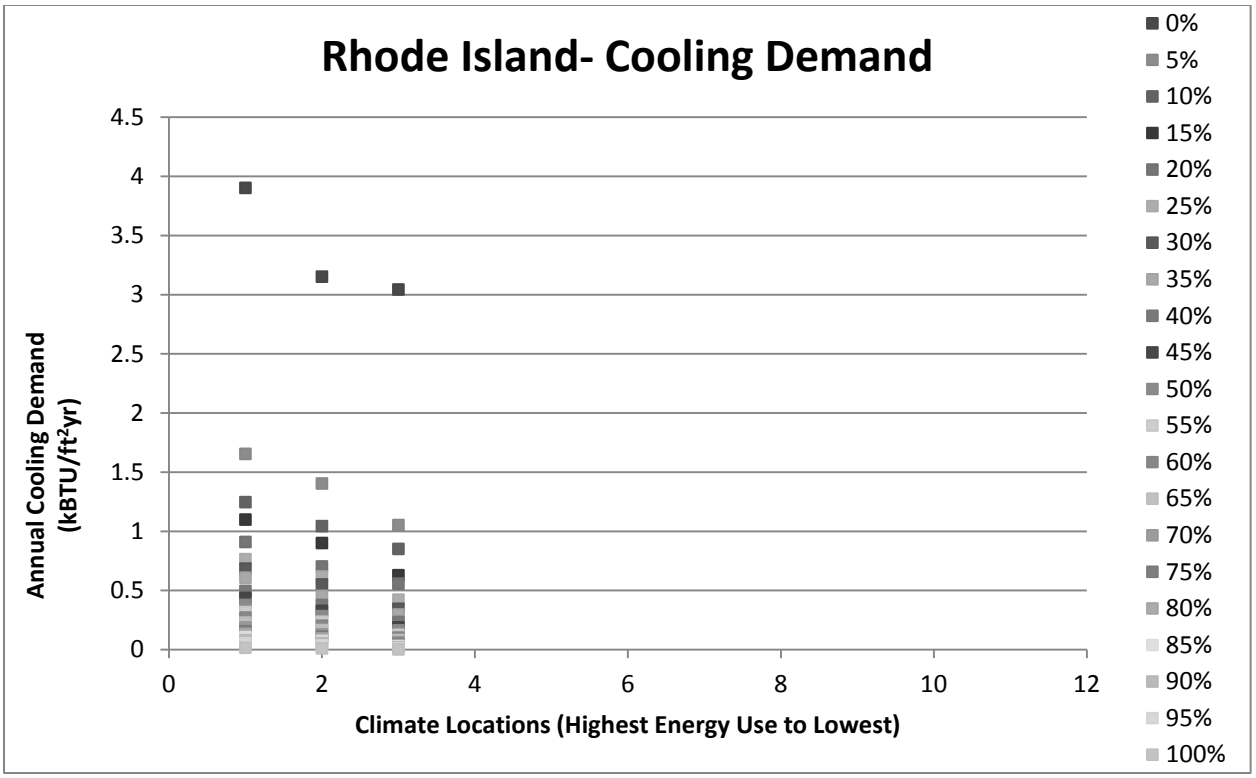
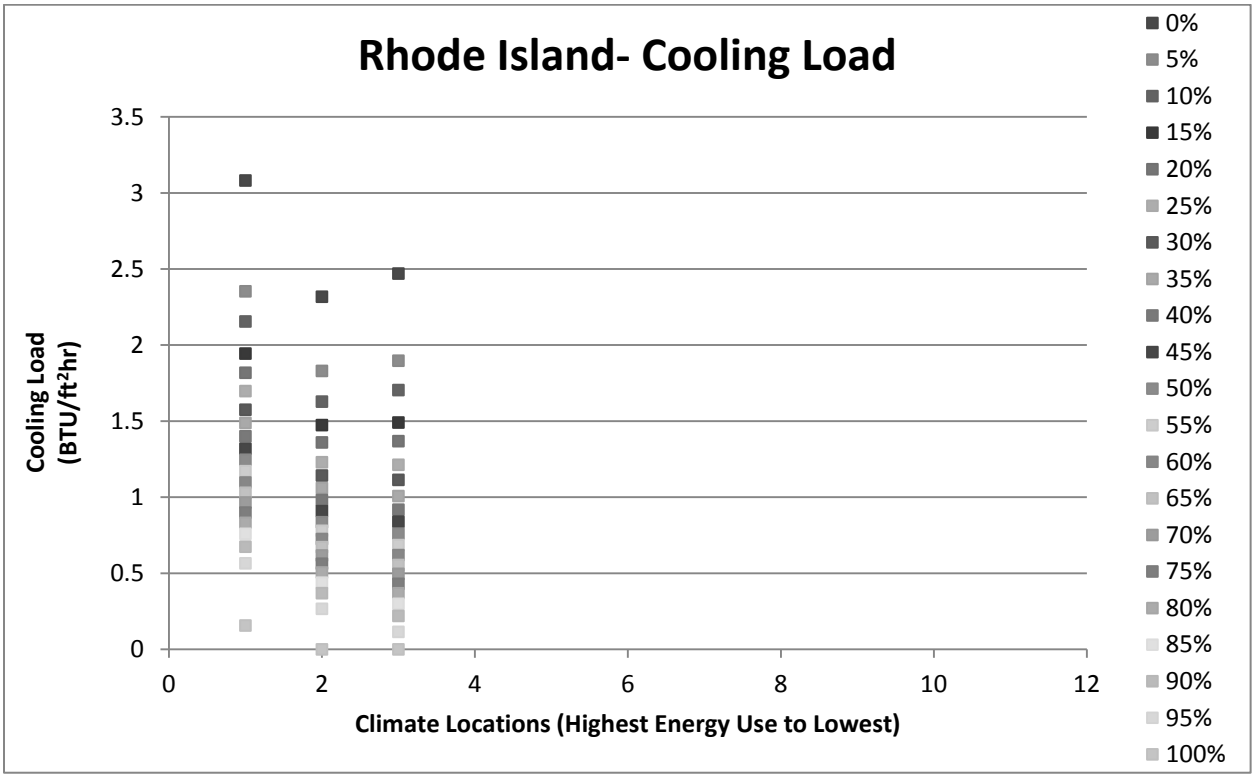
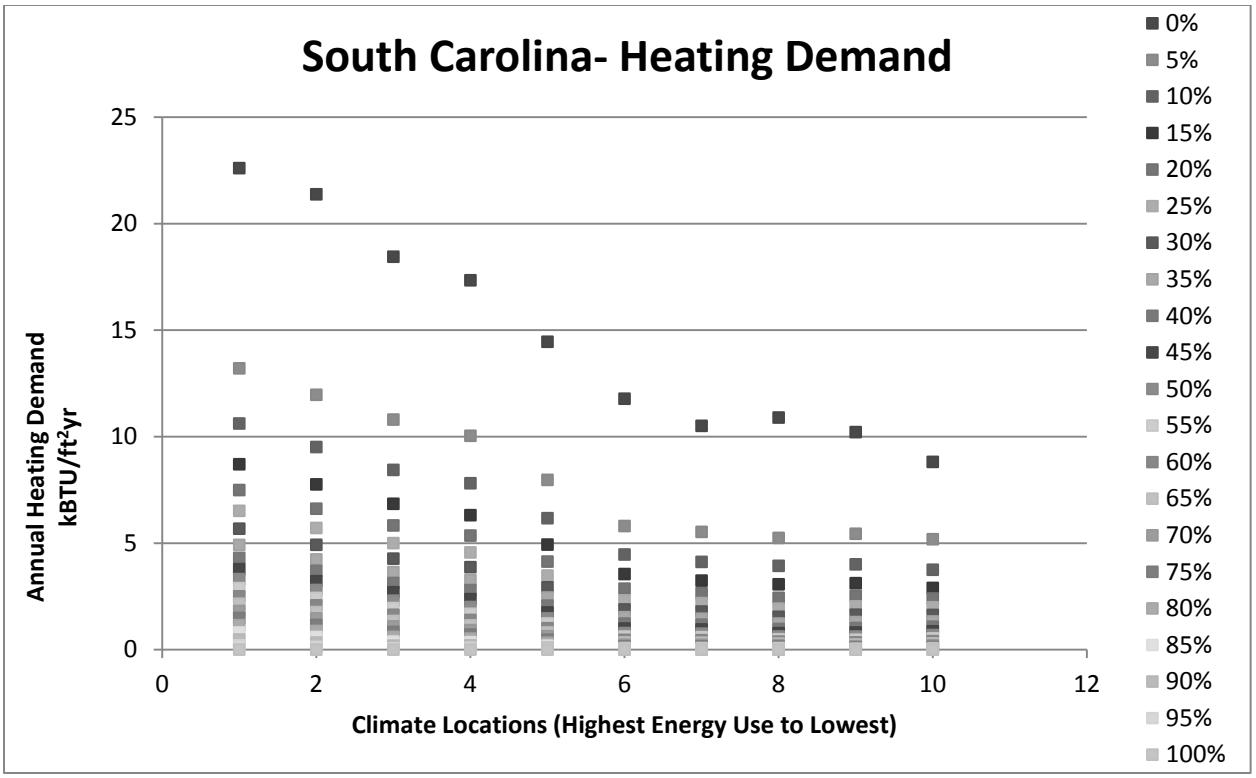
95%
100%

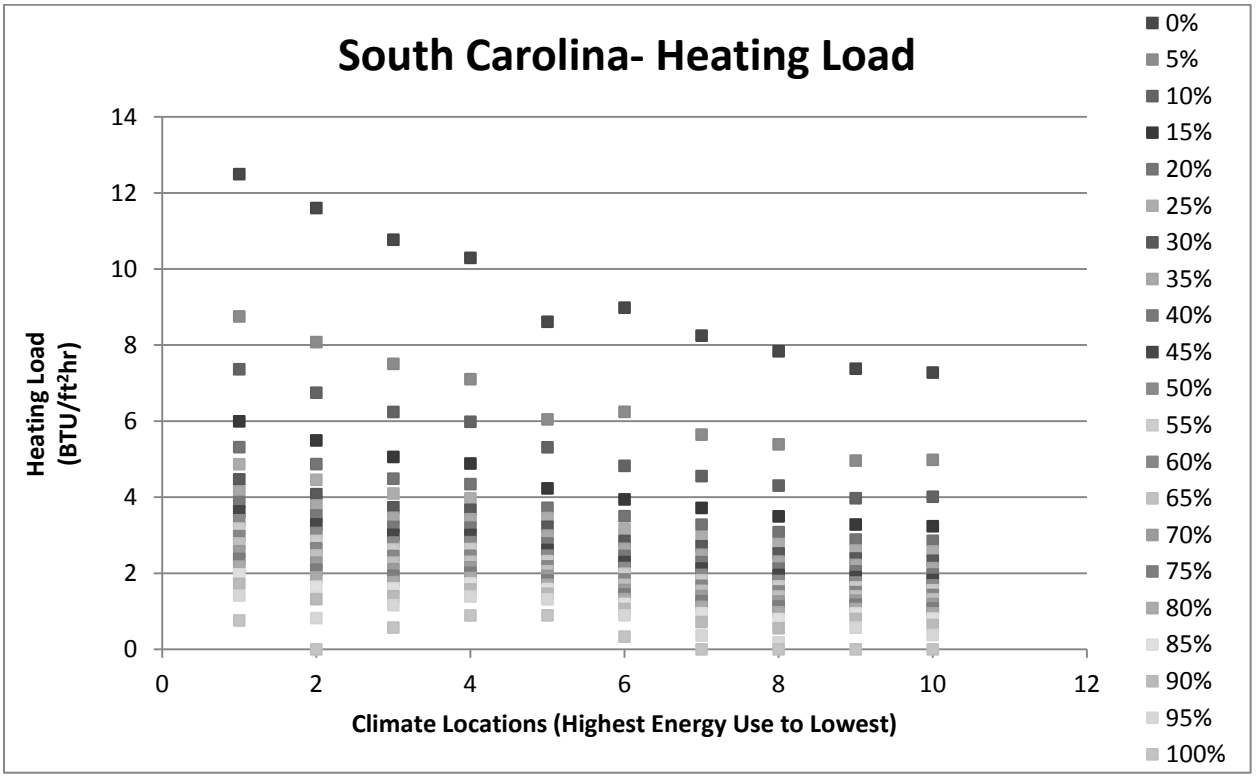

Rhode Island- Heating Demand
Annual Heating Demand kBTU/ft²yr
0
5
10
15
20
25
30
35
40
45
50
0
2
4
6
8
10
12
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

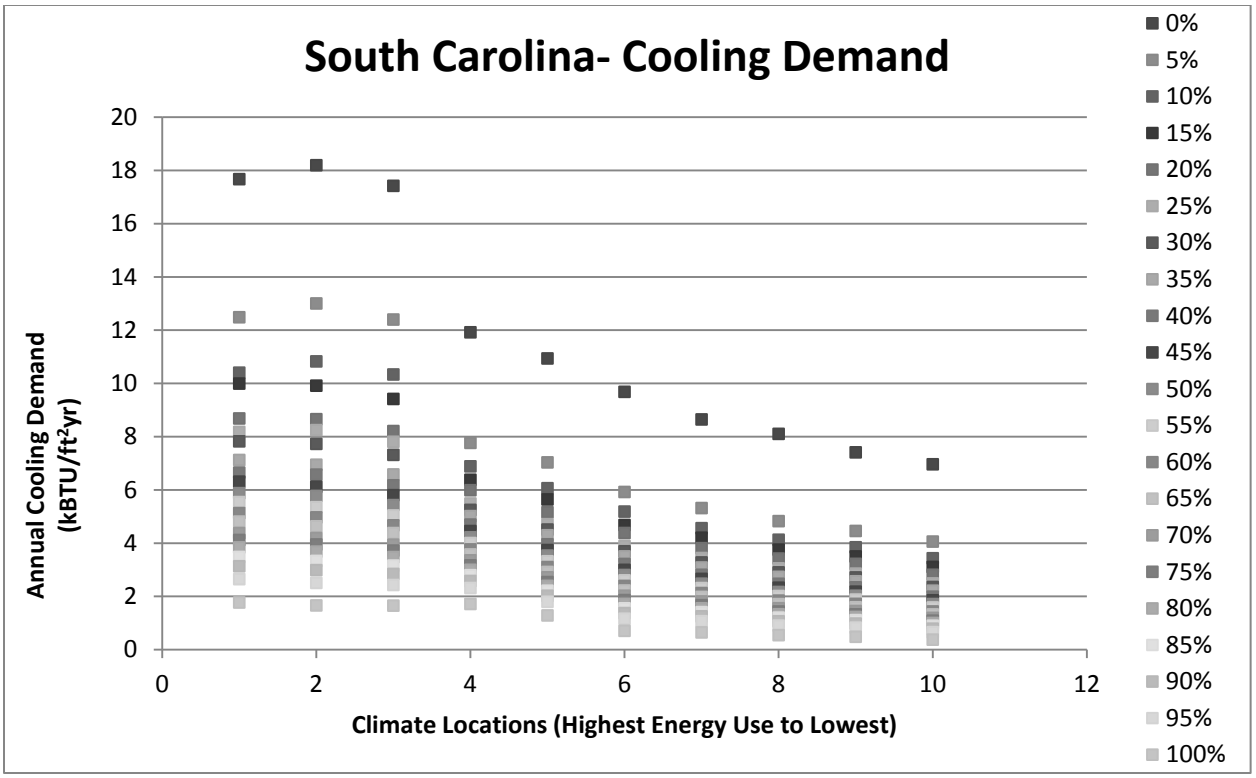

Rhode Island- Heating Load
Heating Load (BTU/ft²hr)
0
2
4
6
8
10
12
14
16
18
0
2
4
6
8
10
12
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

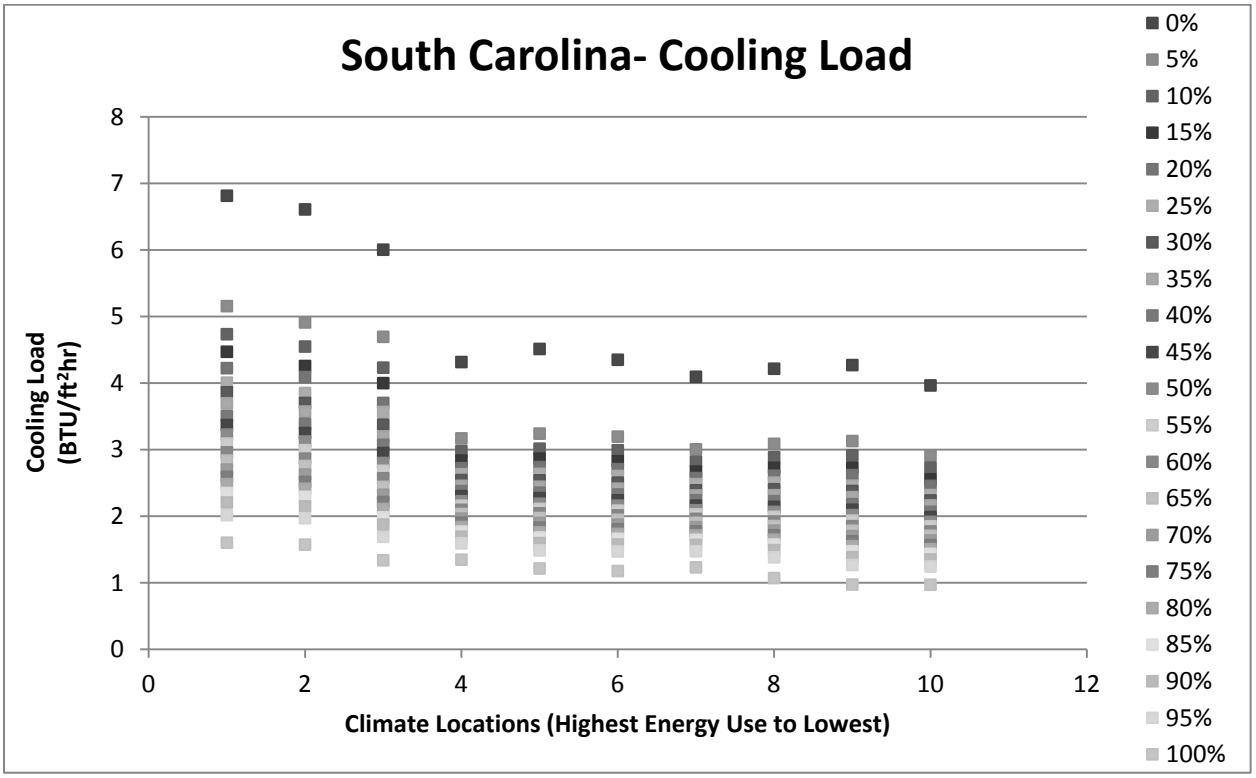

Rhode Island- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
2
4
6
8
10
12
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

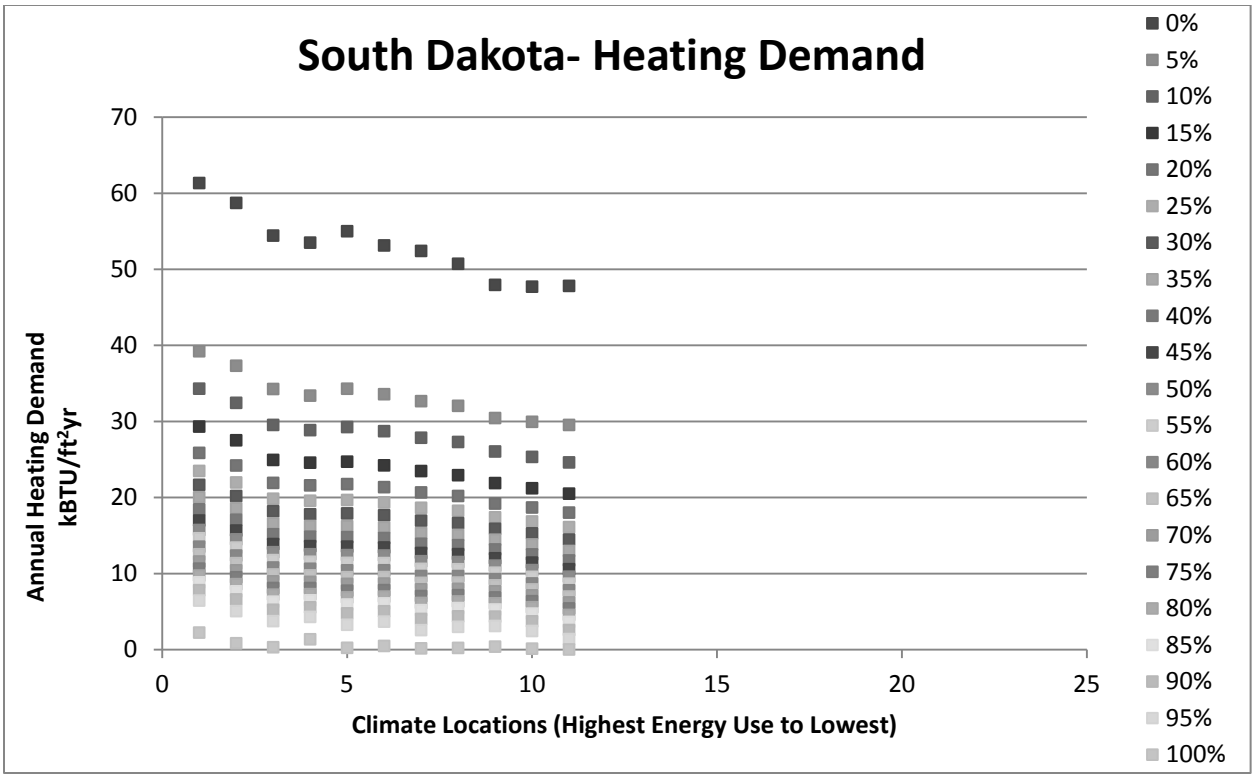

Rhode Island- Cooling Load
Cooling Load (BTU/ft²hr)
3.5
3
2.5
2
1.5
1
0.5
0
0
2
4
6
8
10
12
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

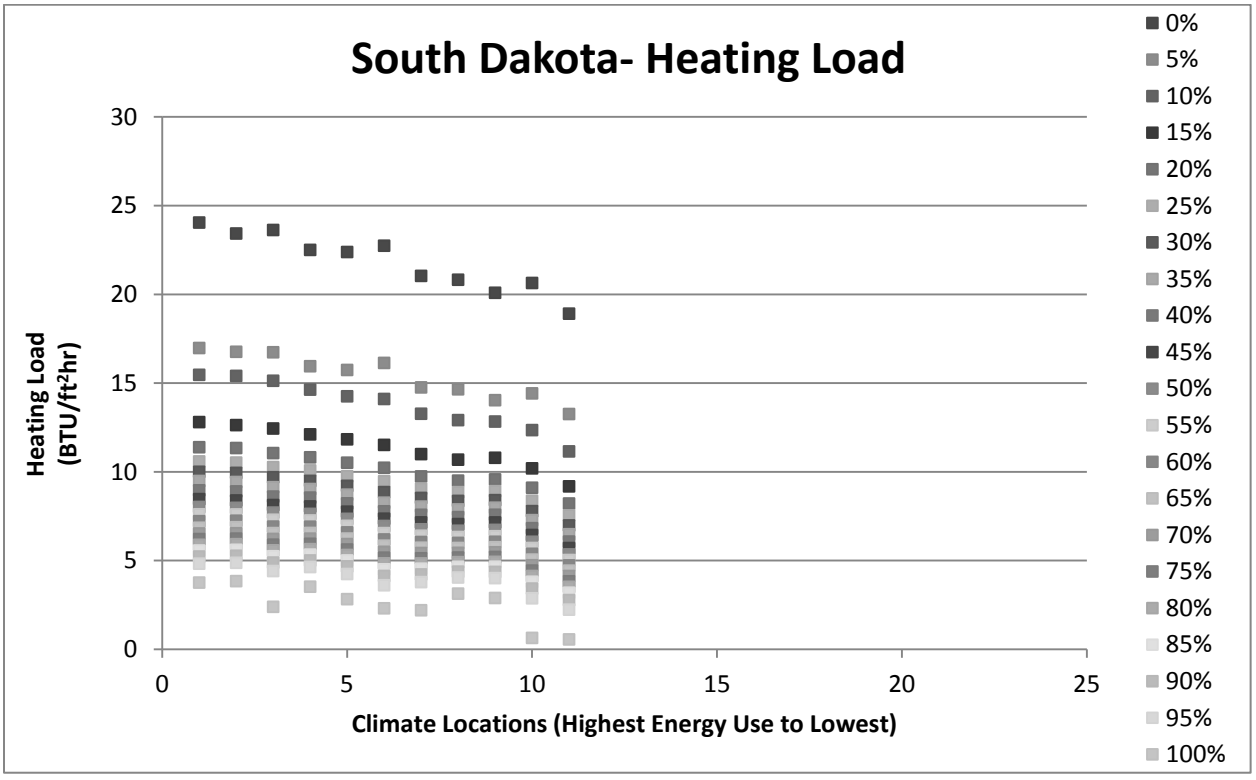

South Carolina- Heating Demand
Annual Heating Demand kBTU/ft²yr
Climate Locations (Highest Energy Use to Lowest)
0
5
10
15
20
25
0
2
4
6
8
10
12
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

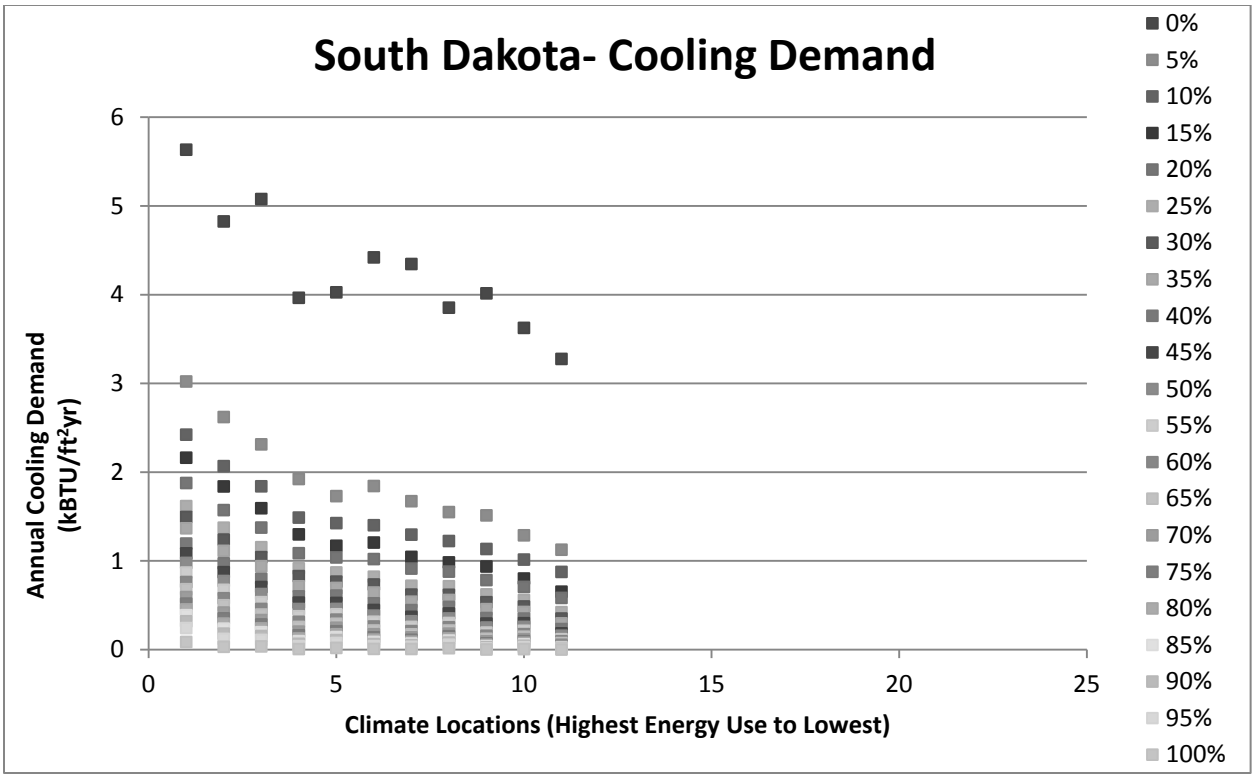

South Carolina- Heating Load
Heating Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0
2
4
6
8
10
12
14
0
2
4
6
8
10
12
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

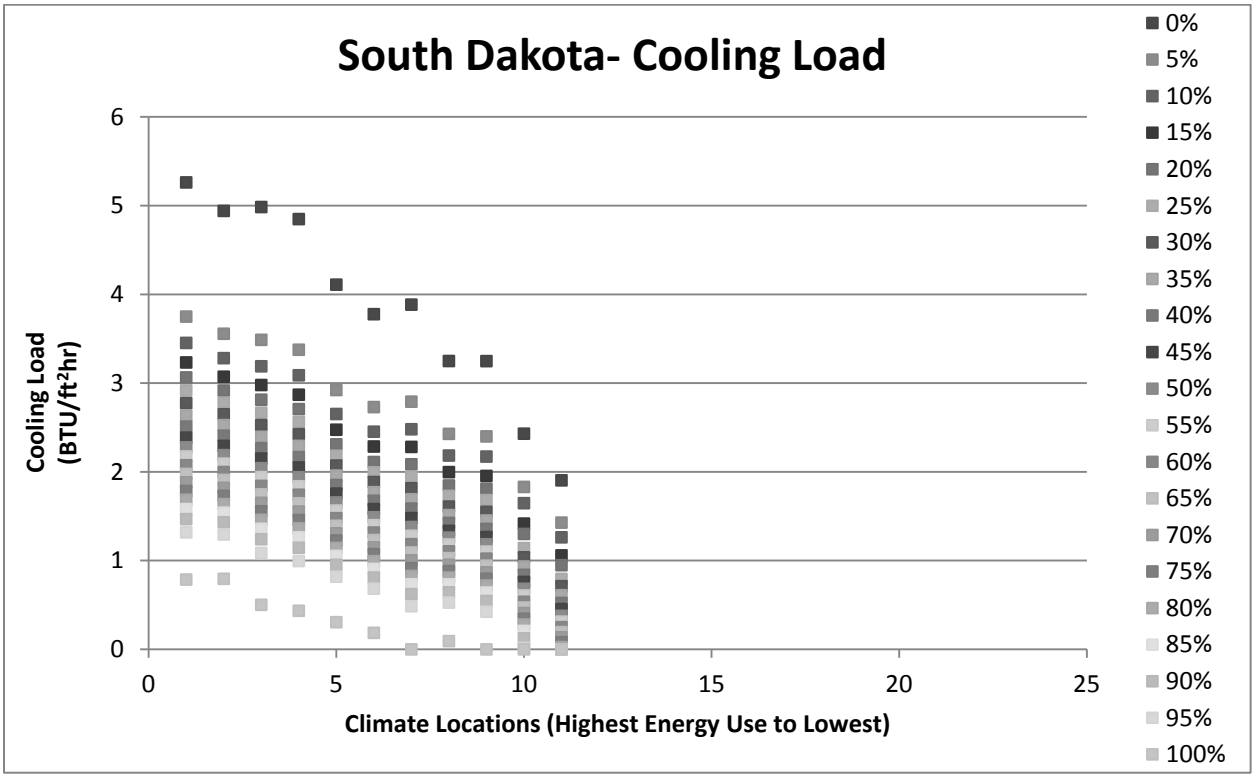

South Carolina- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

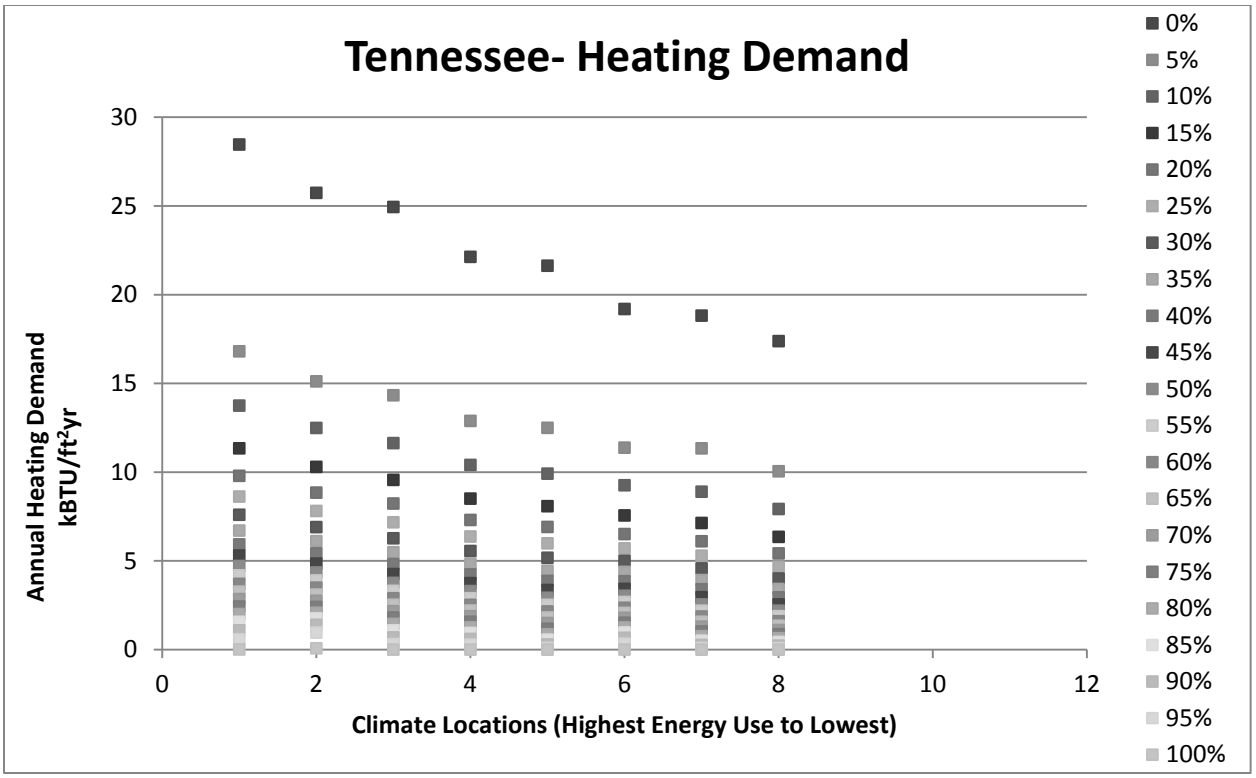

South Carolina- Cooling Load
Cooling Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

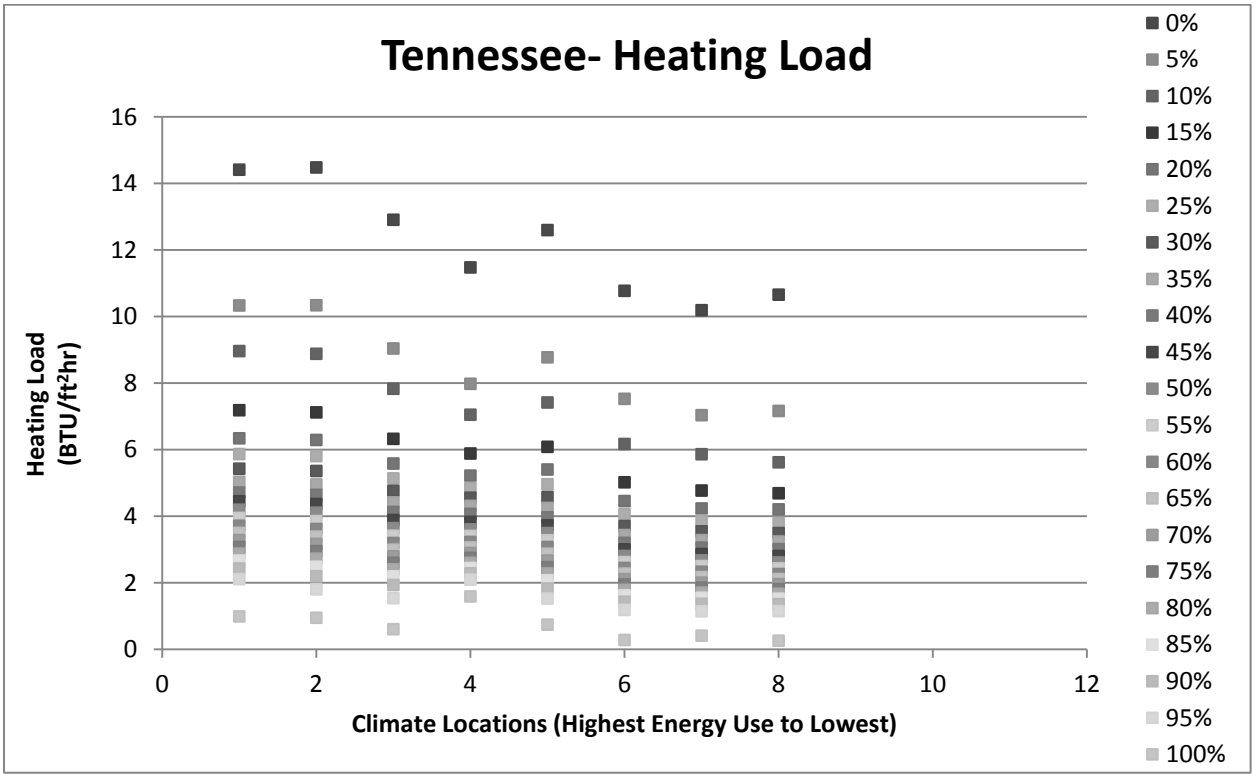

South Dakota- Heating Demand
Annual Heating Demand kBTU/ft²yr
70
60
50
40
30
20
10
0
0
5
10
15
20
25
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

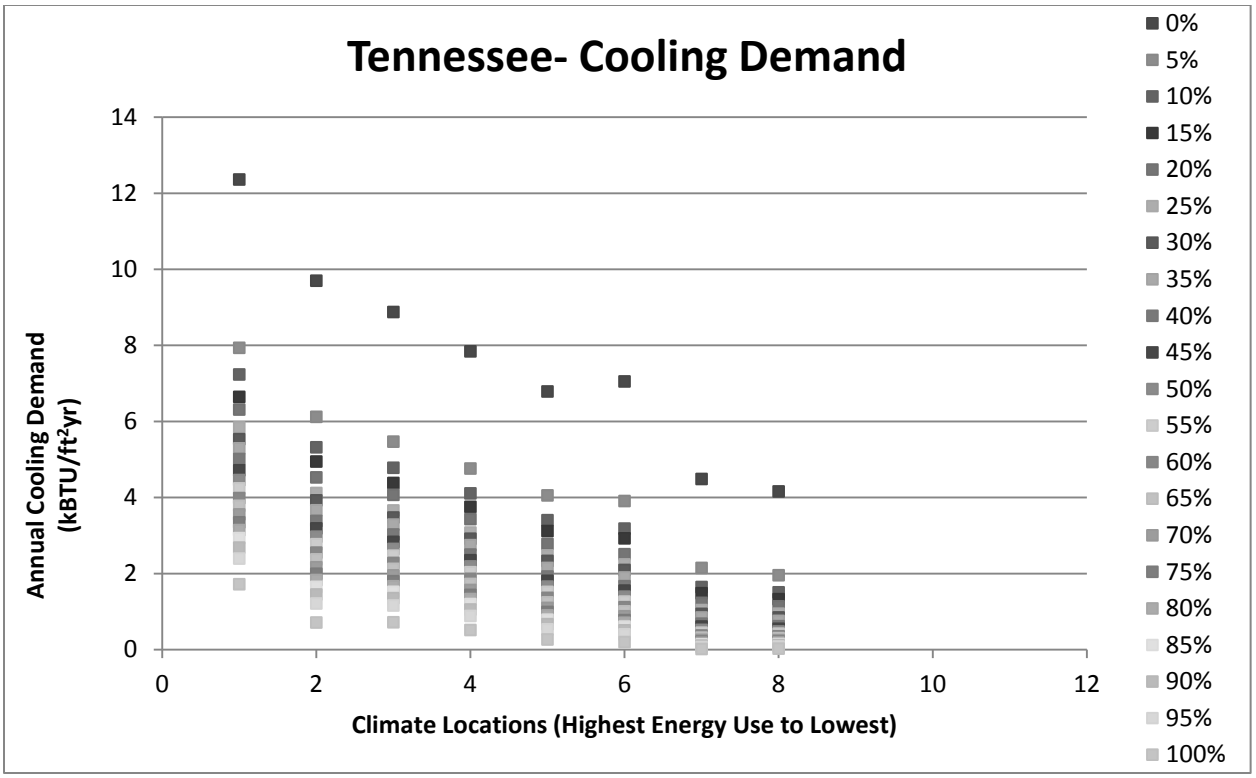

South Dakota- Heating Load
Heating Load (BTU/ft²hr)
30
25
20
15
10
5
0
0
5
10
15
20
25
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

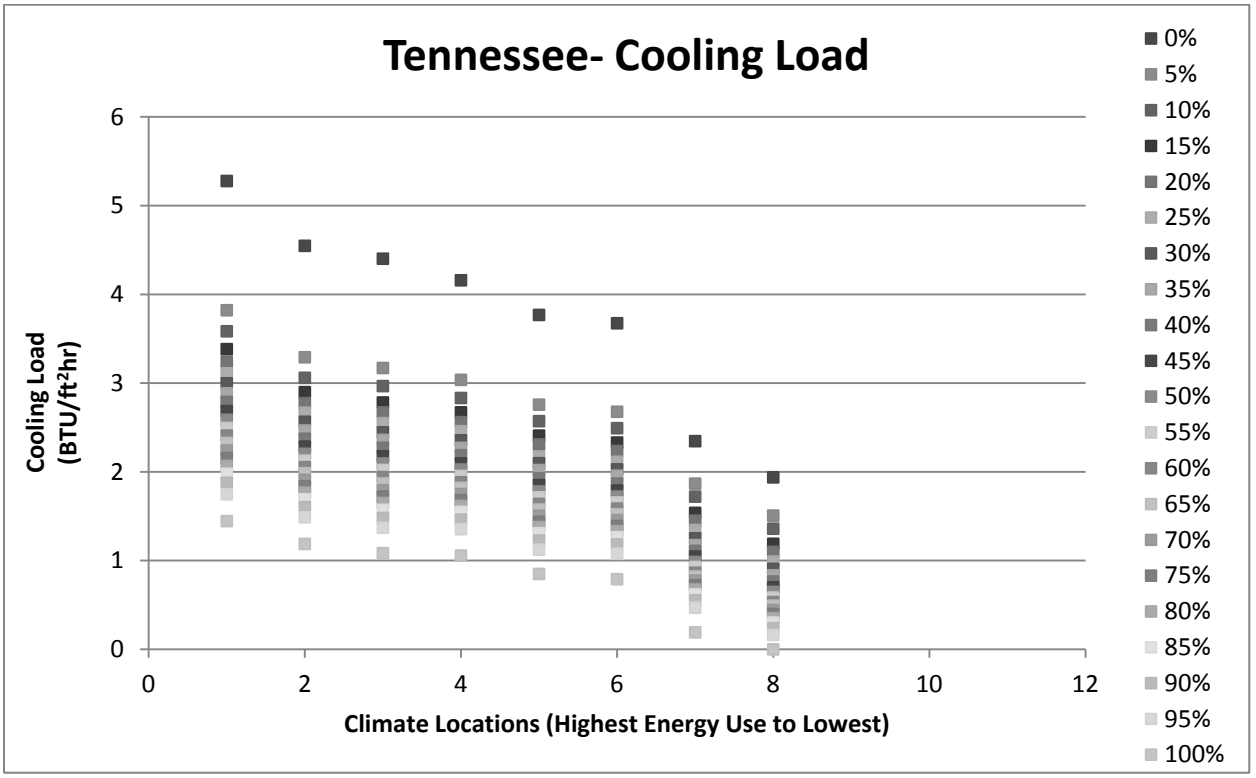

South Dakota- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
Climate Locations (Highest Energy Use to Lowest)
0
1
2
3
4
5
6
0
5
10
15
20
25
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

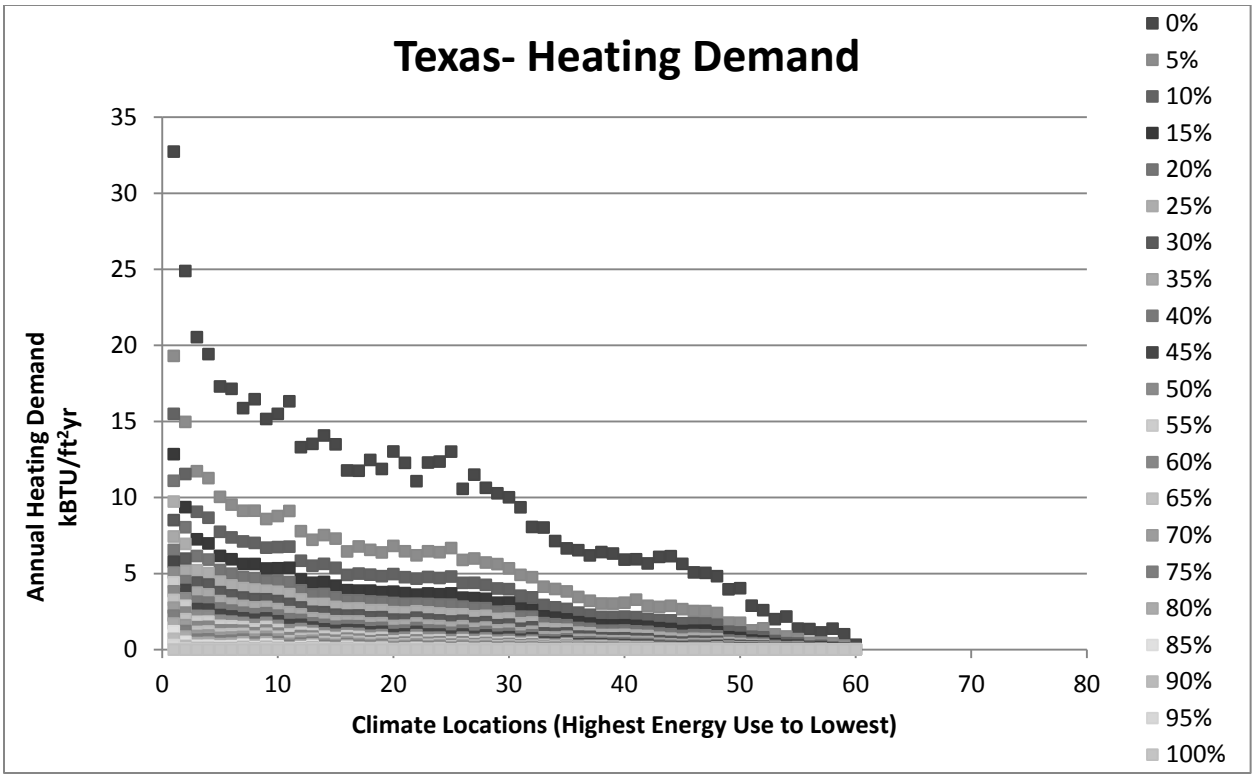

South Dakota- Cooling Load
Cooling Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0
1
2
3
4
5
6
0
5
10
15
20
25
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

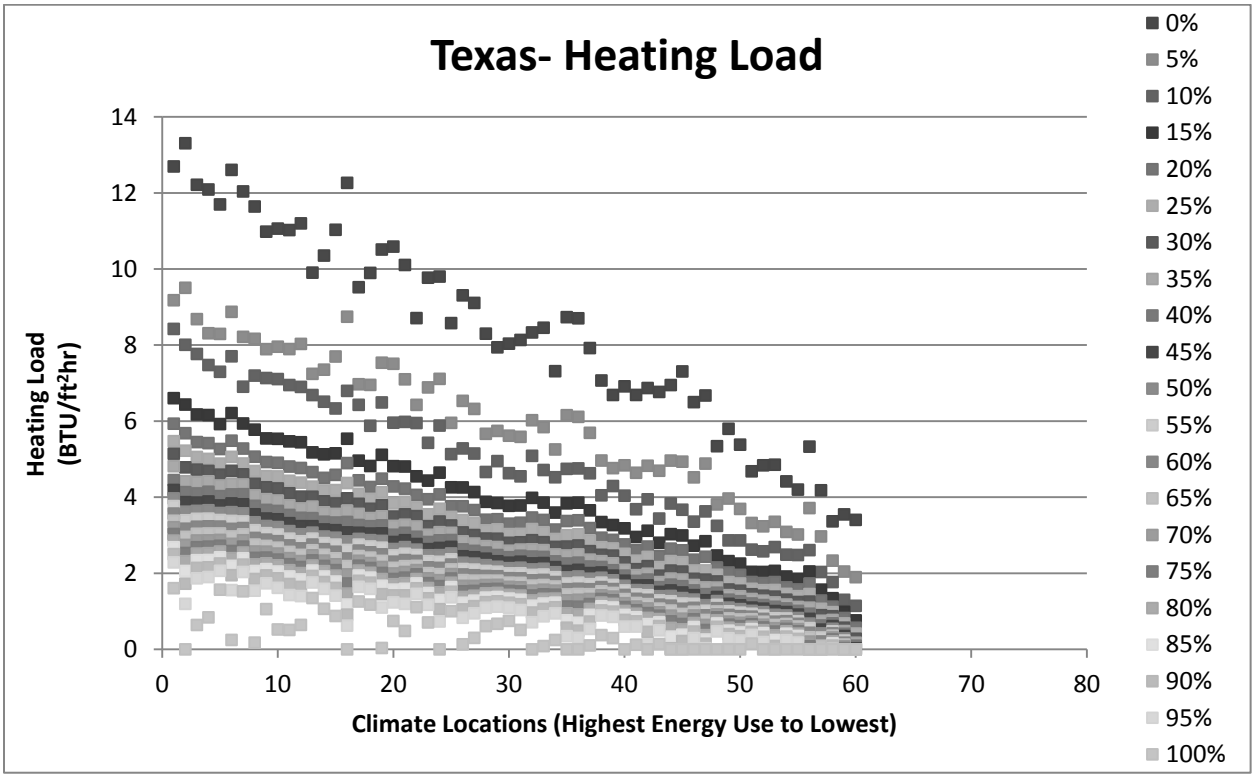

Tennessee- Heating Demand
Annual Heating Demand kBTU/ft²yr
Climate Locations (Highest Energy Use to Lowest)
0
5
10
15
20
25
30
0
2
4
6
8
10
12
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

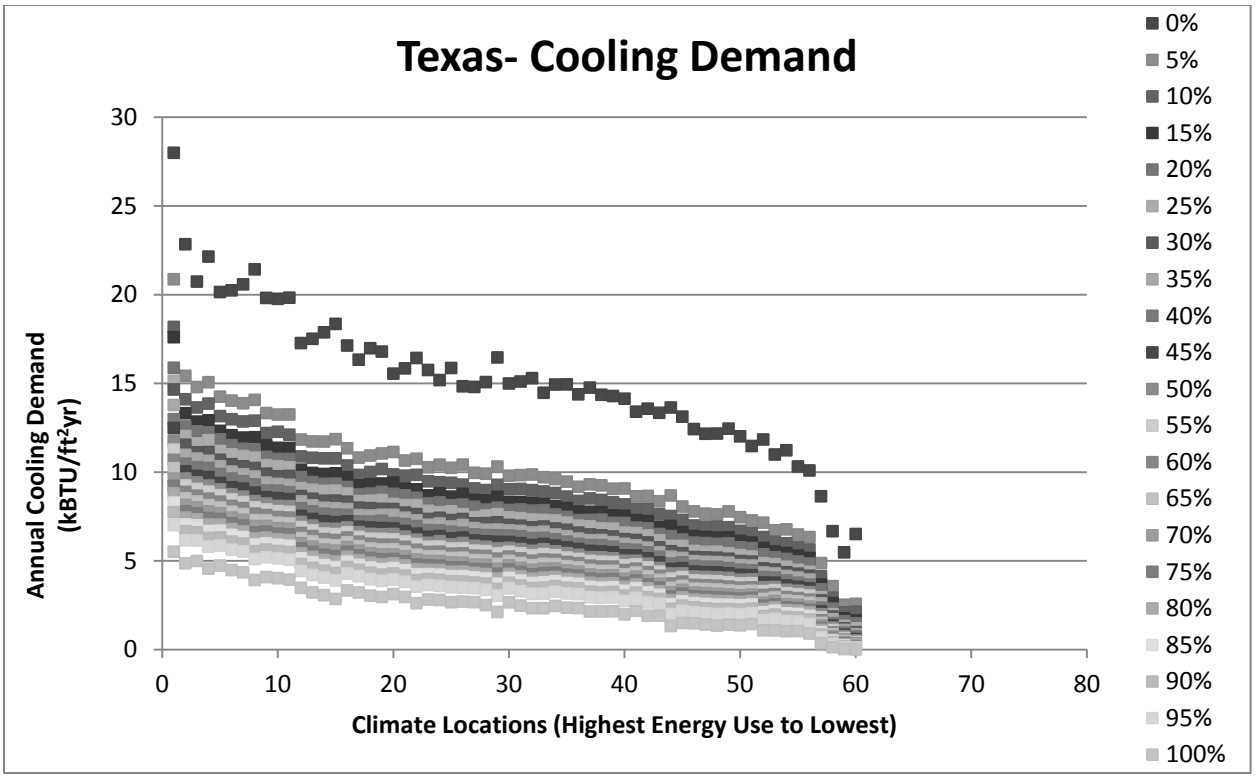

Tennessee- Heating Load
Heating Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0
2
4
6
8
10
12
14
16
0
2
4
6
8
10
12
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

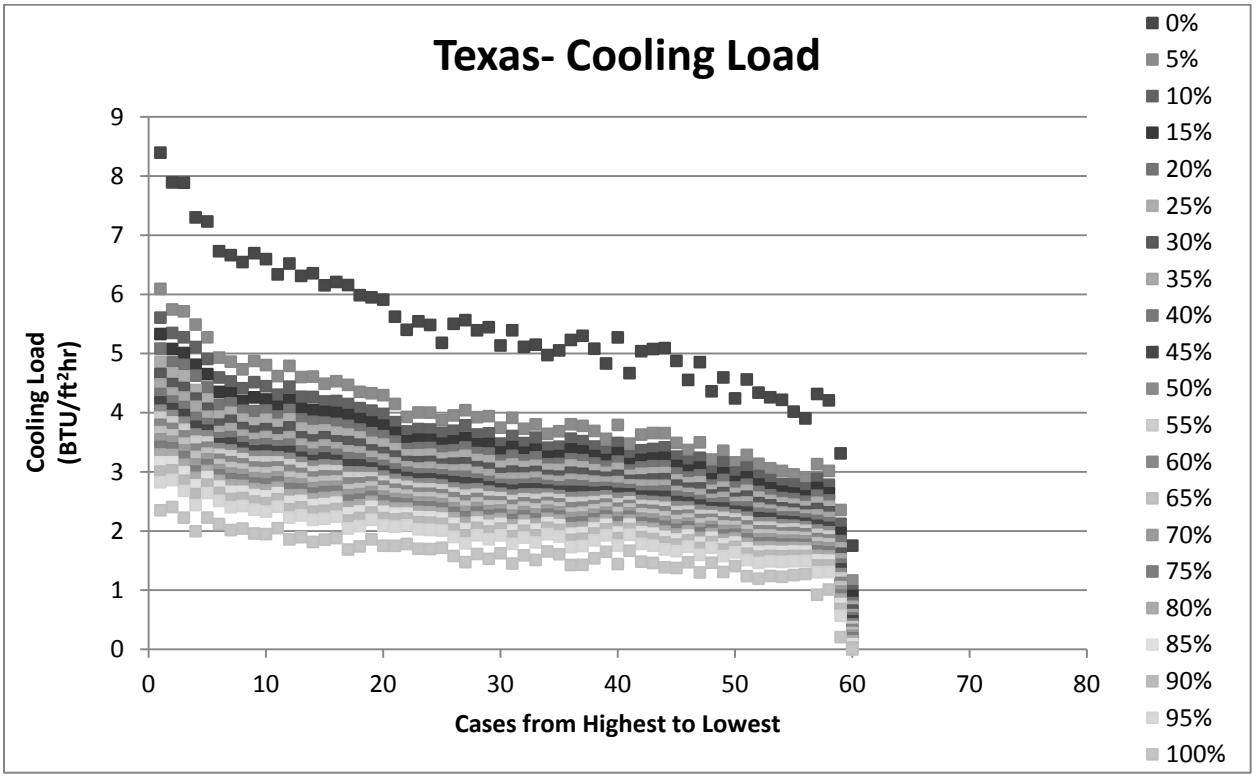

Tennessee- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
Climate Locations (Highest Energy Use to Lowest)
0
2
4
6
8
10
12
14
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

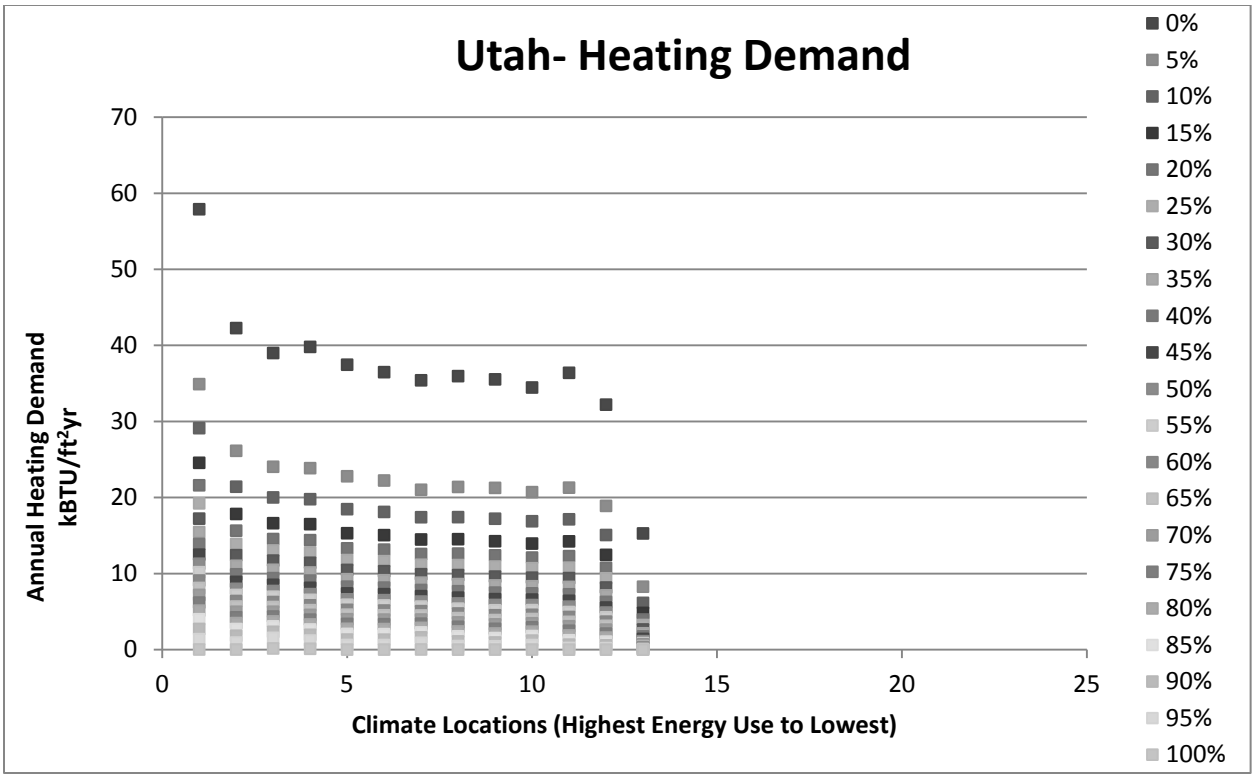

Tennessee- Cooling Load
Cooling Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0
1
2
3
4
5
6
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

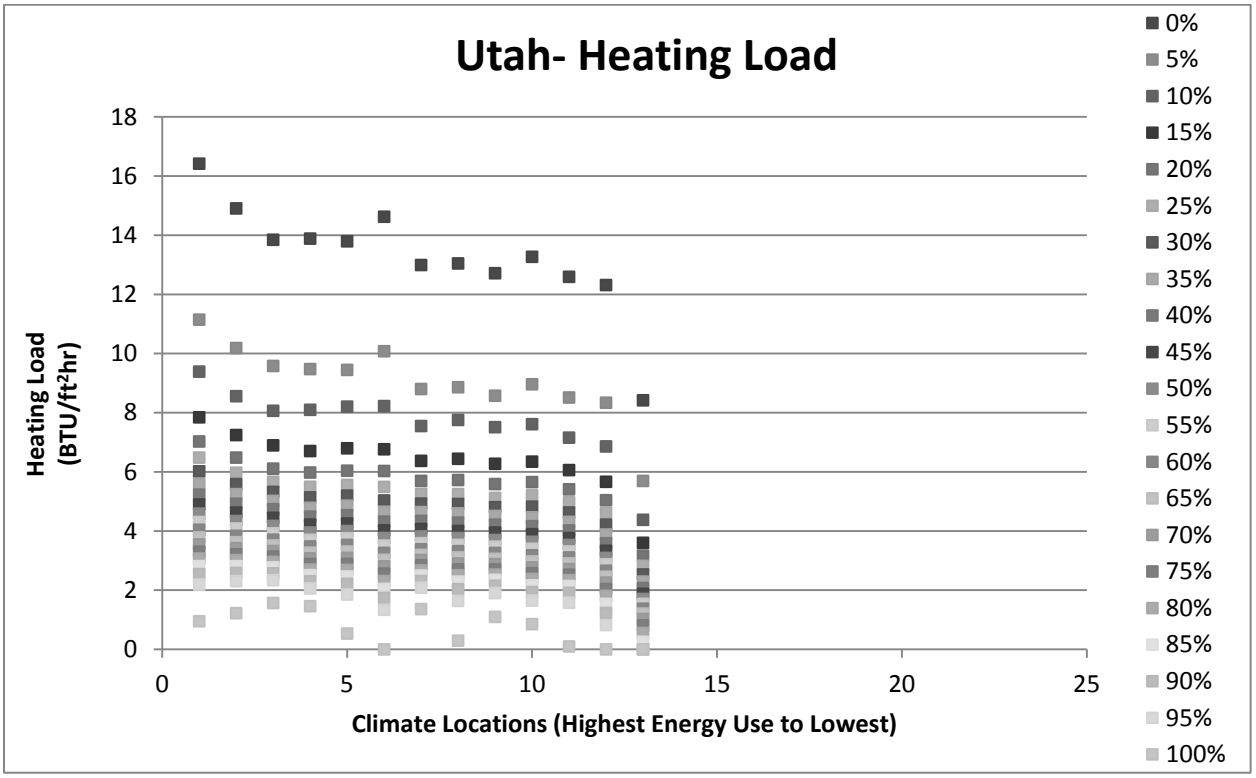

Texas- Heating Demand
Annual Heating Demand kBTU/ft²yr
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

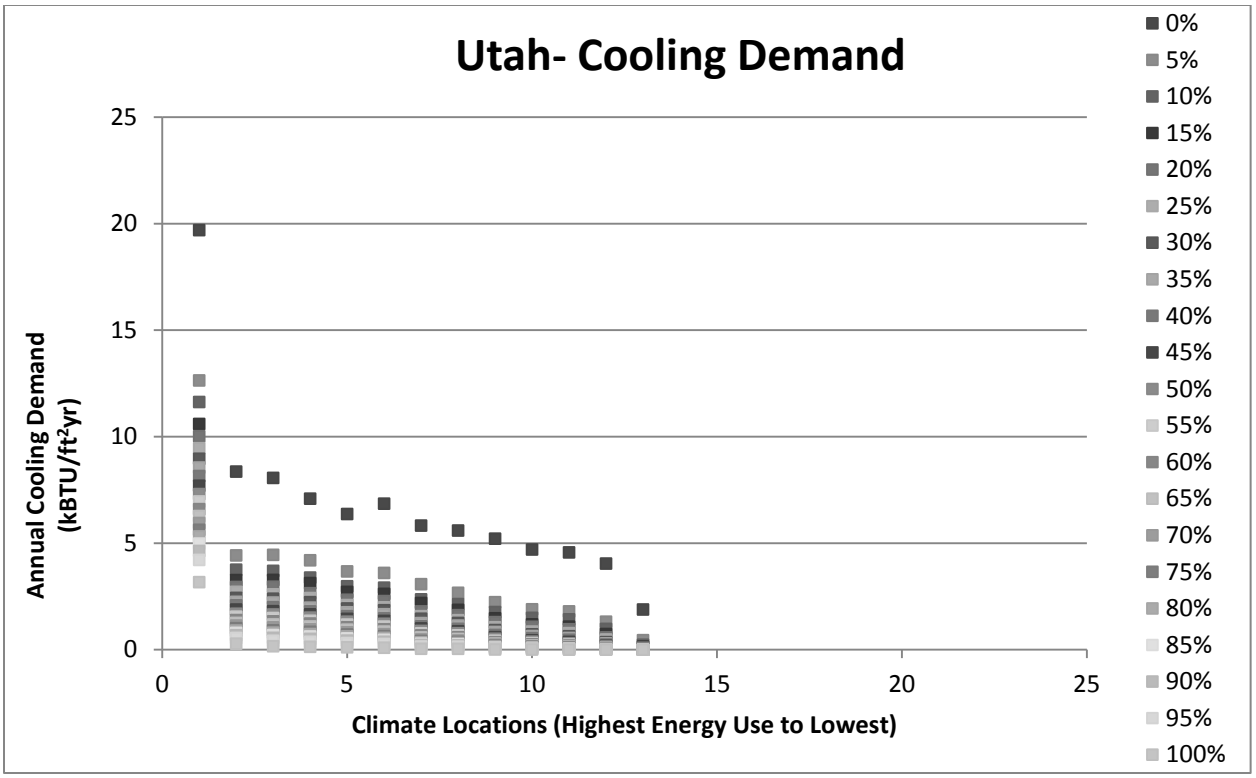

Texas- Heating Load
Heating Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

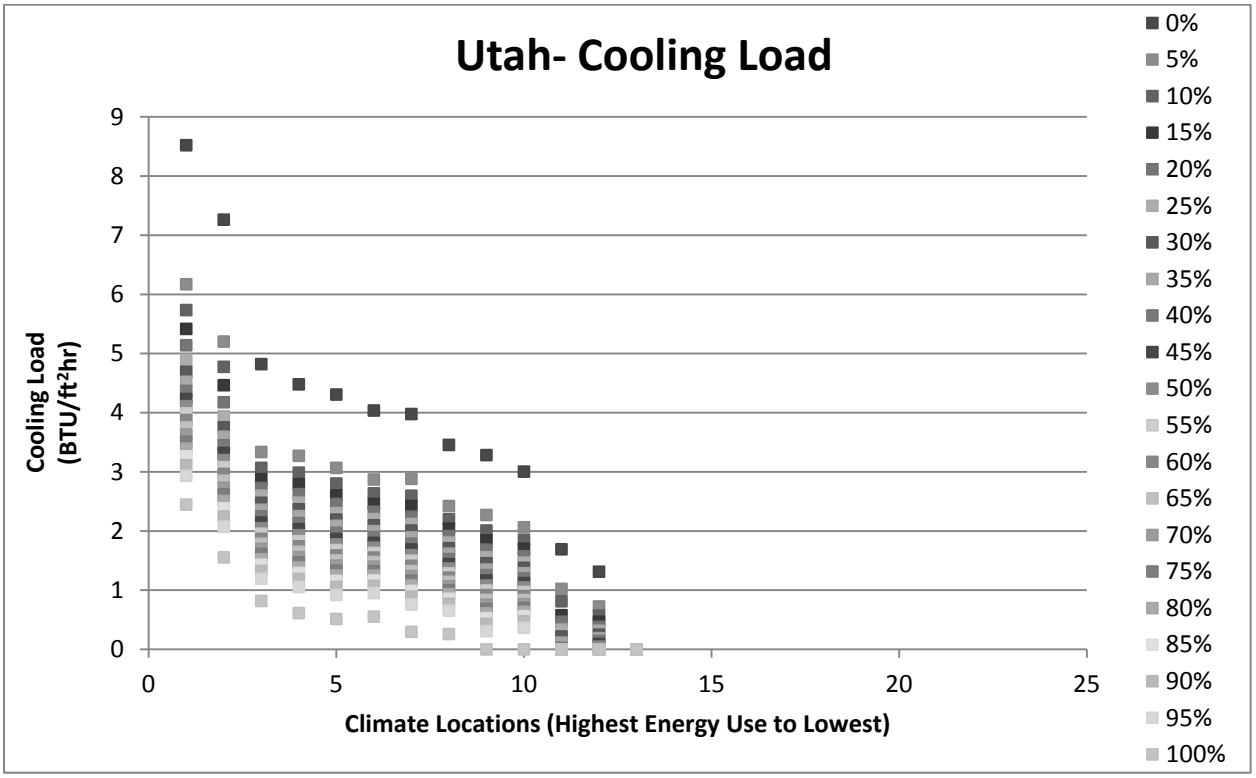

Texas- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

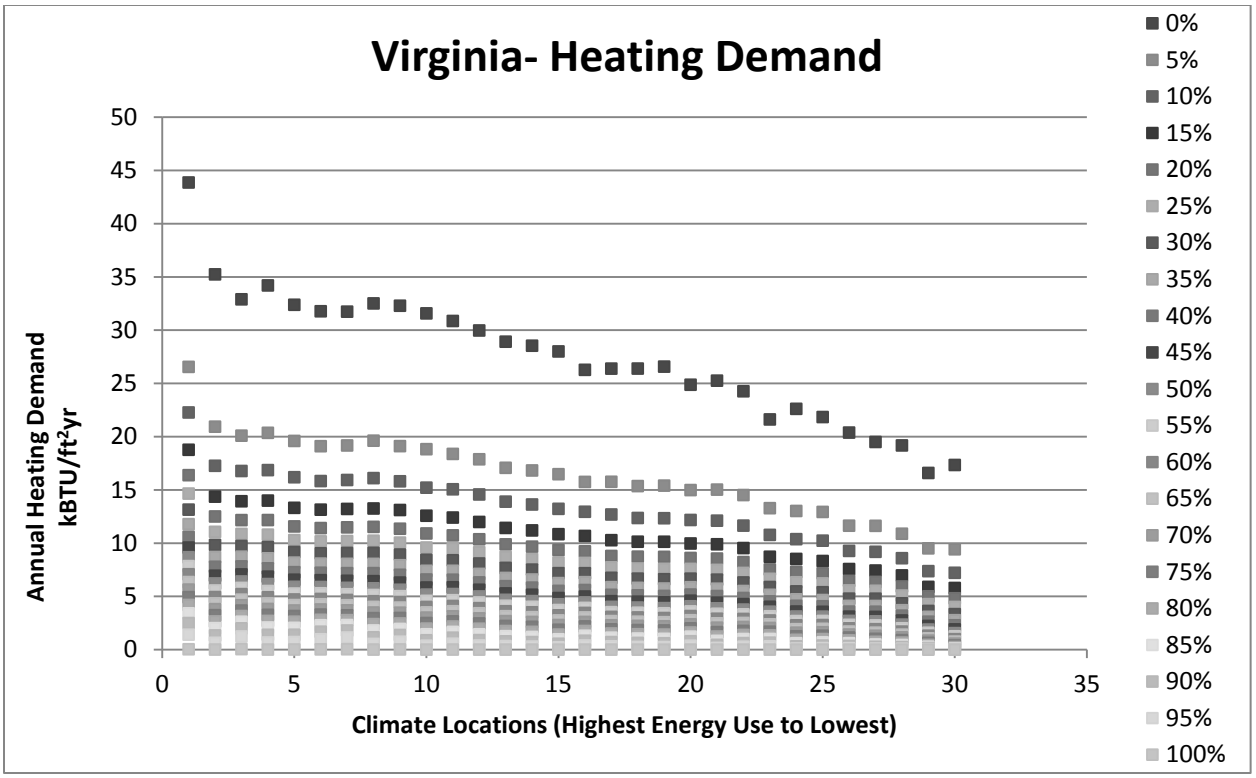

Texas- Cooling Load
Cooling Load (BTU/ft²hr)
Cases from Highest to Lowest
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

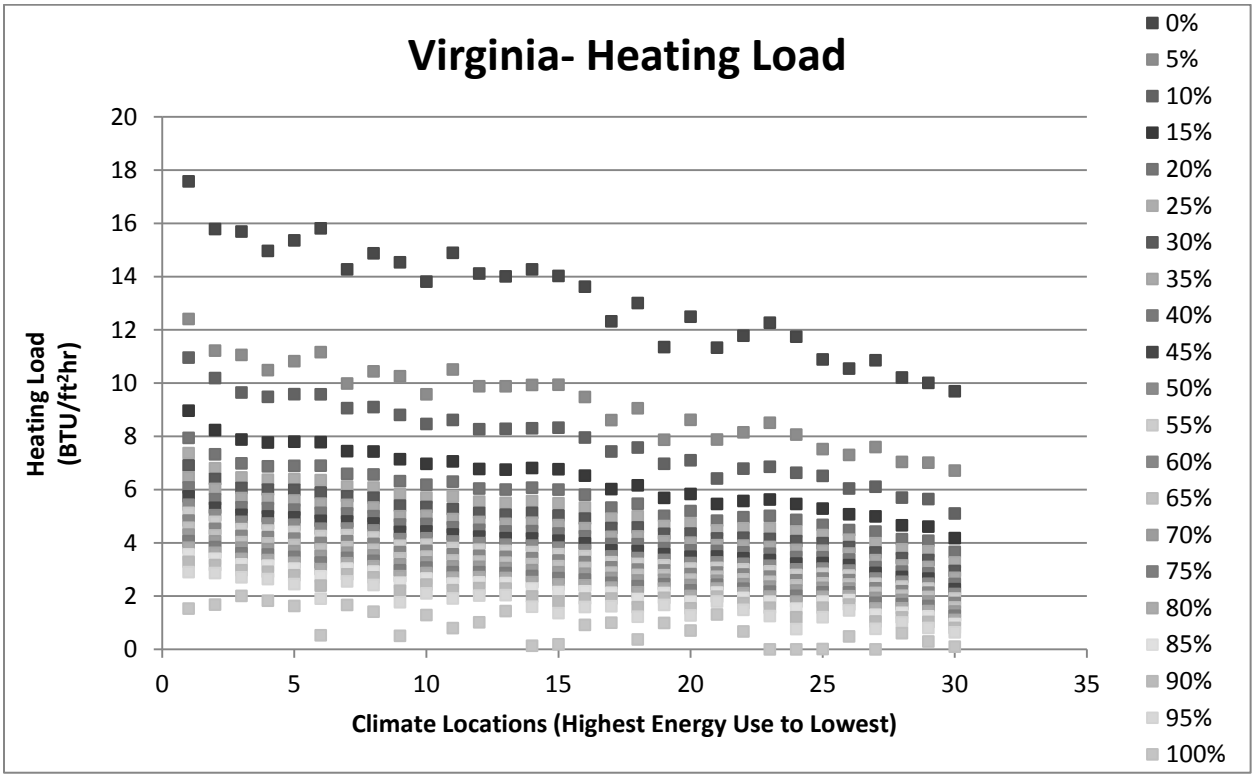

Utah- Heating Demand
Annual Heating Demand kBTU/ft²yr
70
60
50
40
30
20
10
0
0
5
10
15
20
25
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

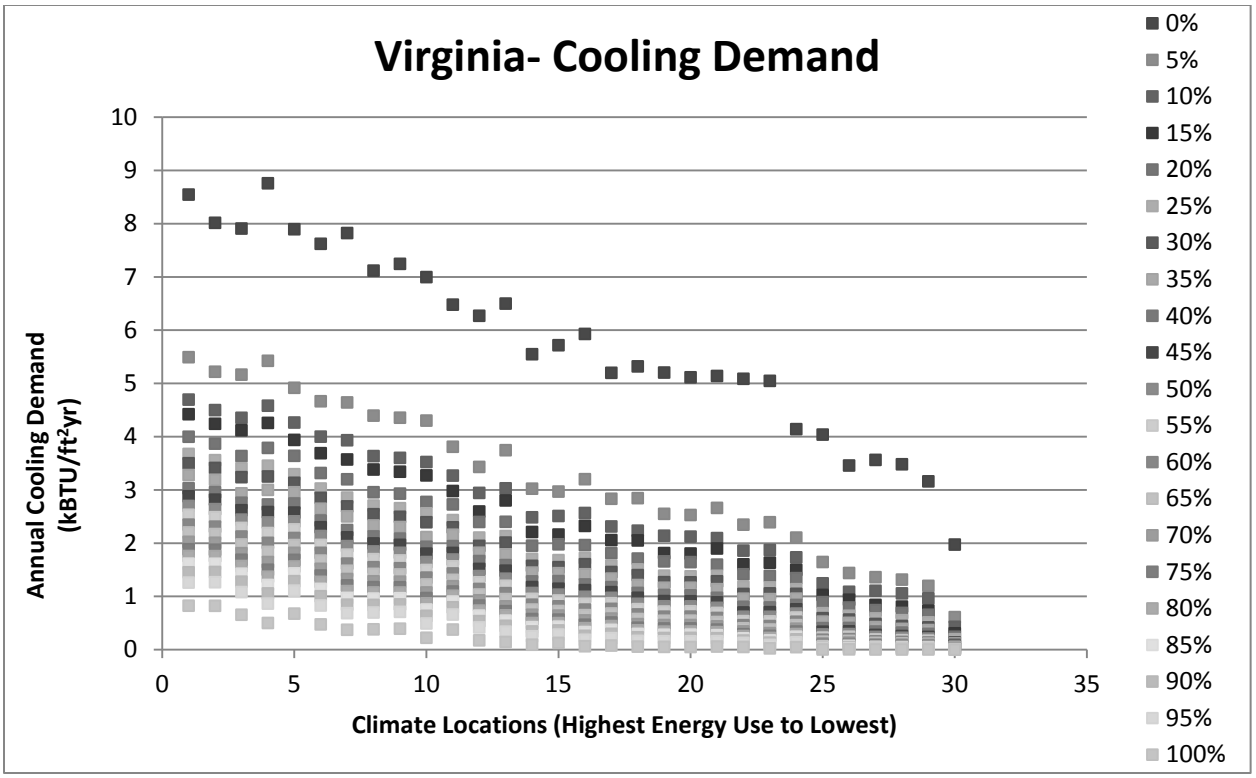

Utah- Heating Load
Heating Load (BTU/ft²hr)
18
16
14
12
10
8
6
4
2
0
0
5
10
15
20
25
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

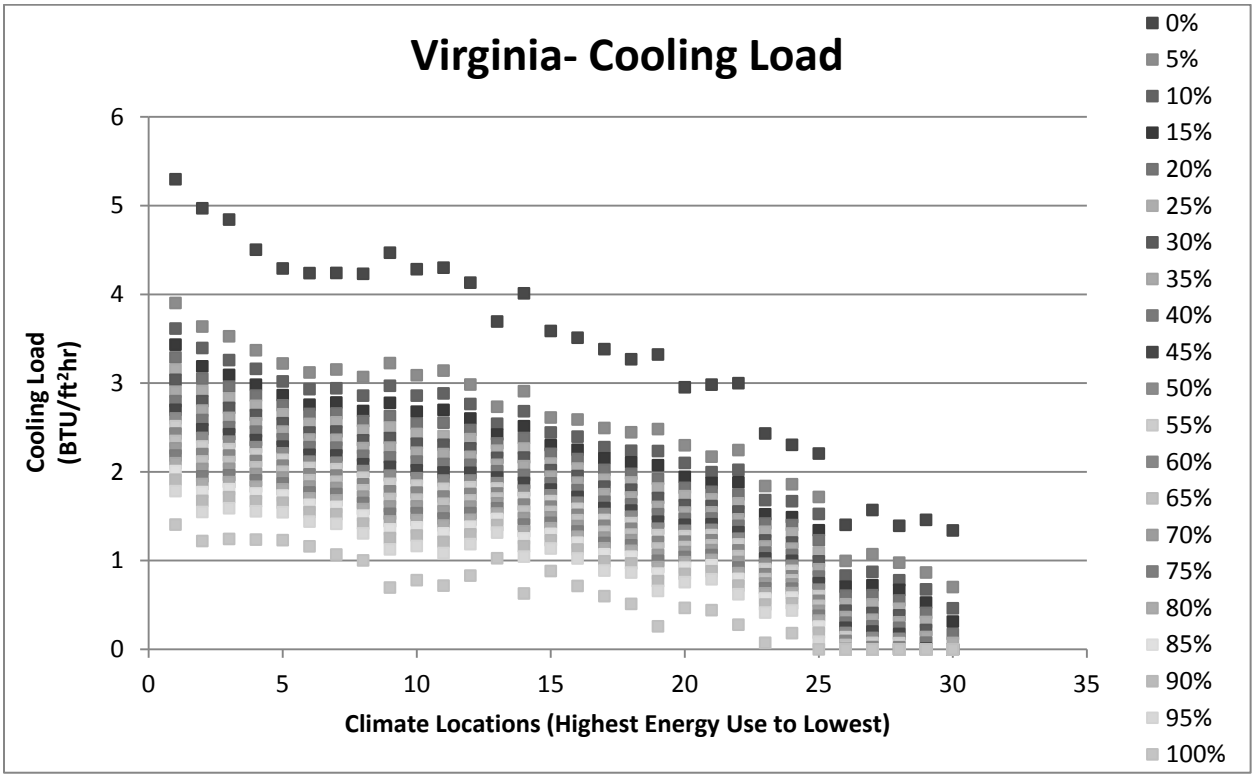

Utah- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
Climate Locations (Highest Energy Use to Lowest)
0
5
10
15
20
25
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

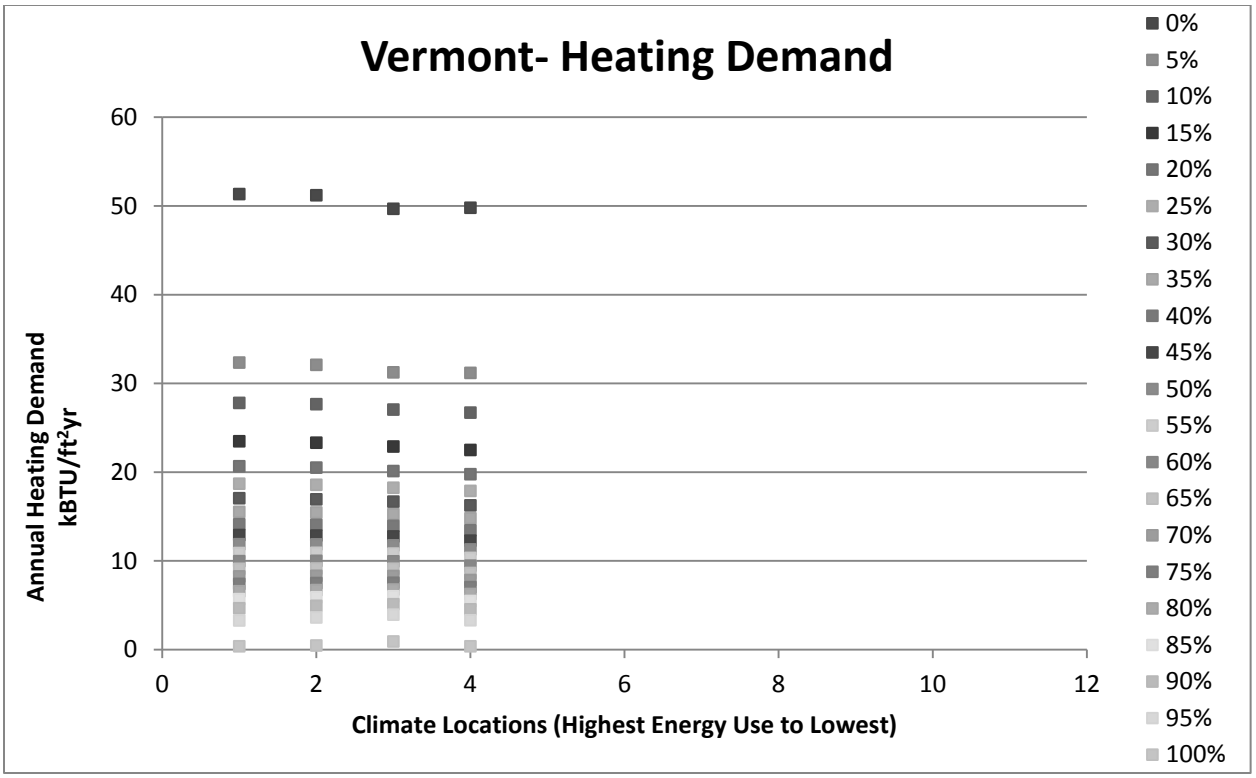

Utah- Cooling Load
Cooling Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0
1
2
3
4
5
6
7
8
9
0
5
10
15
20
25
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

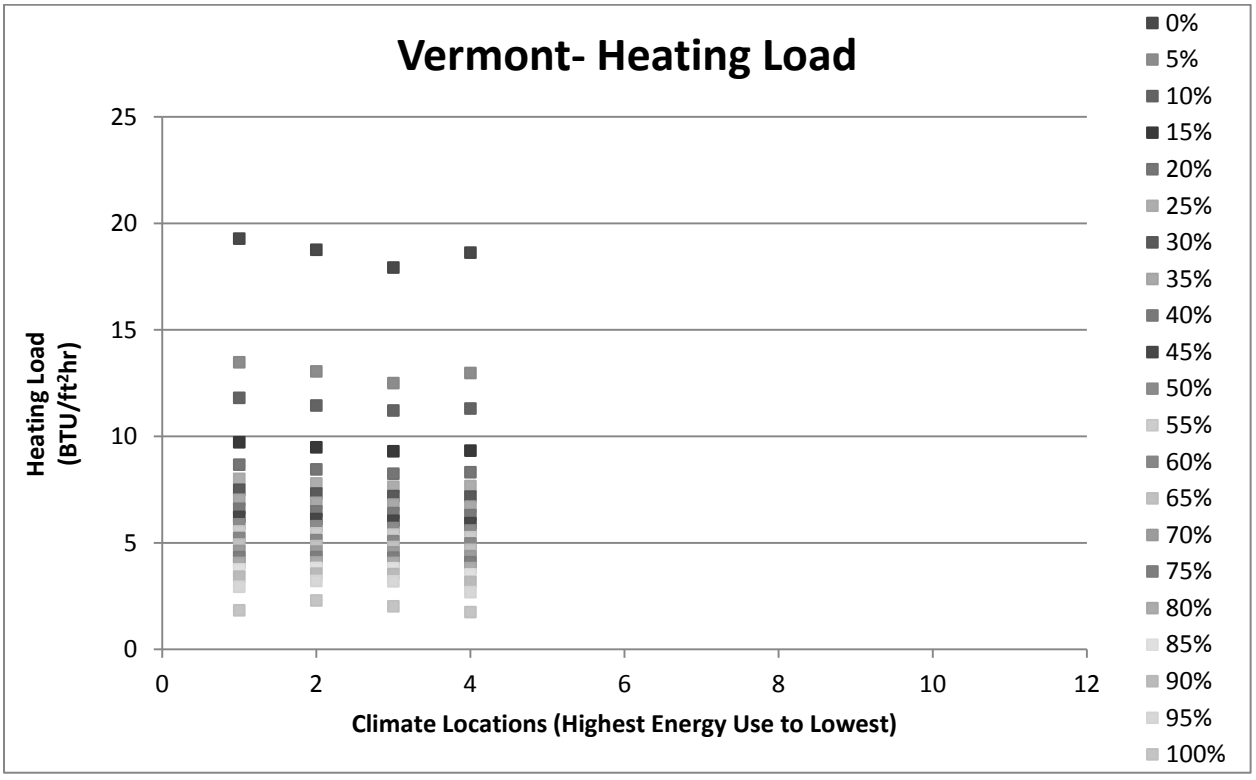

Virginia- Heating Demand
Annual Heating Demand kBTU/ft²yr
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

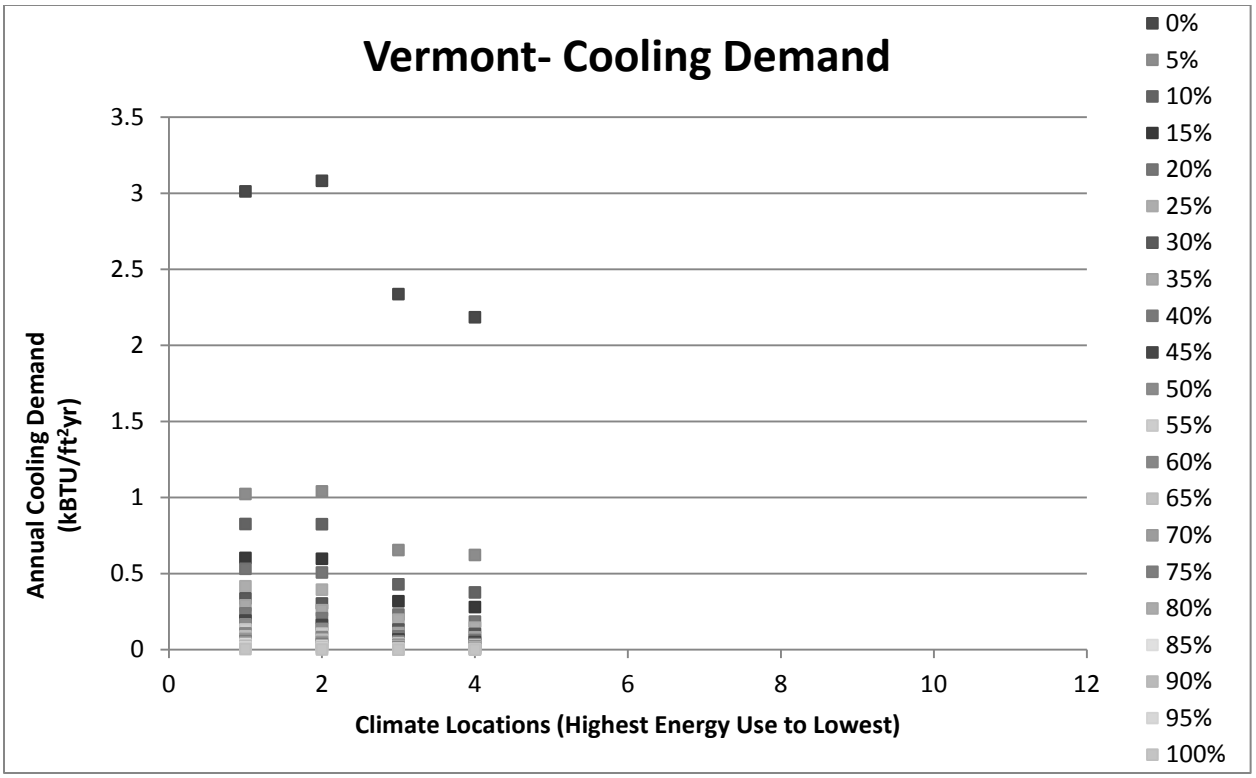

Virginia- Heating Load
Heating Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

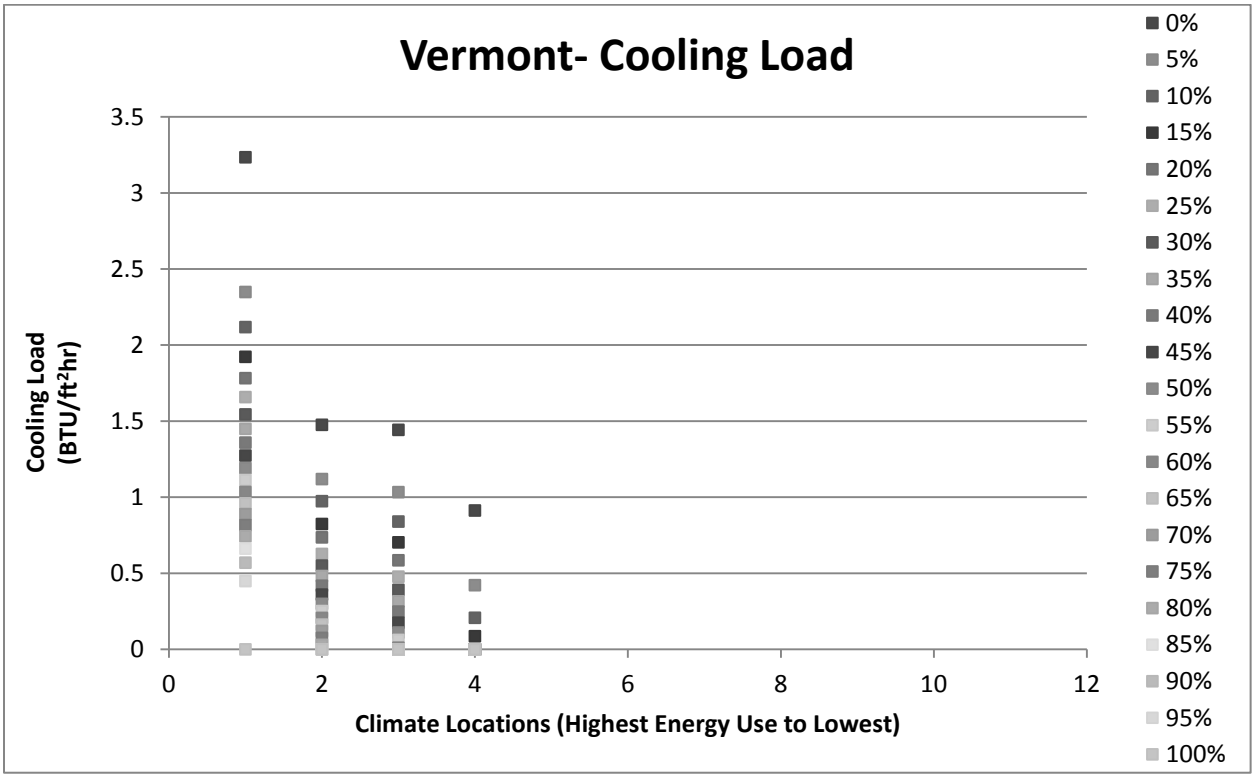

Virginia- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

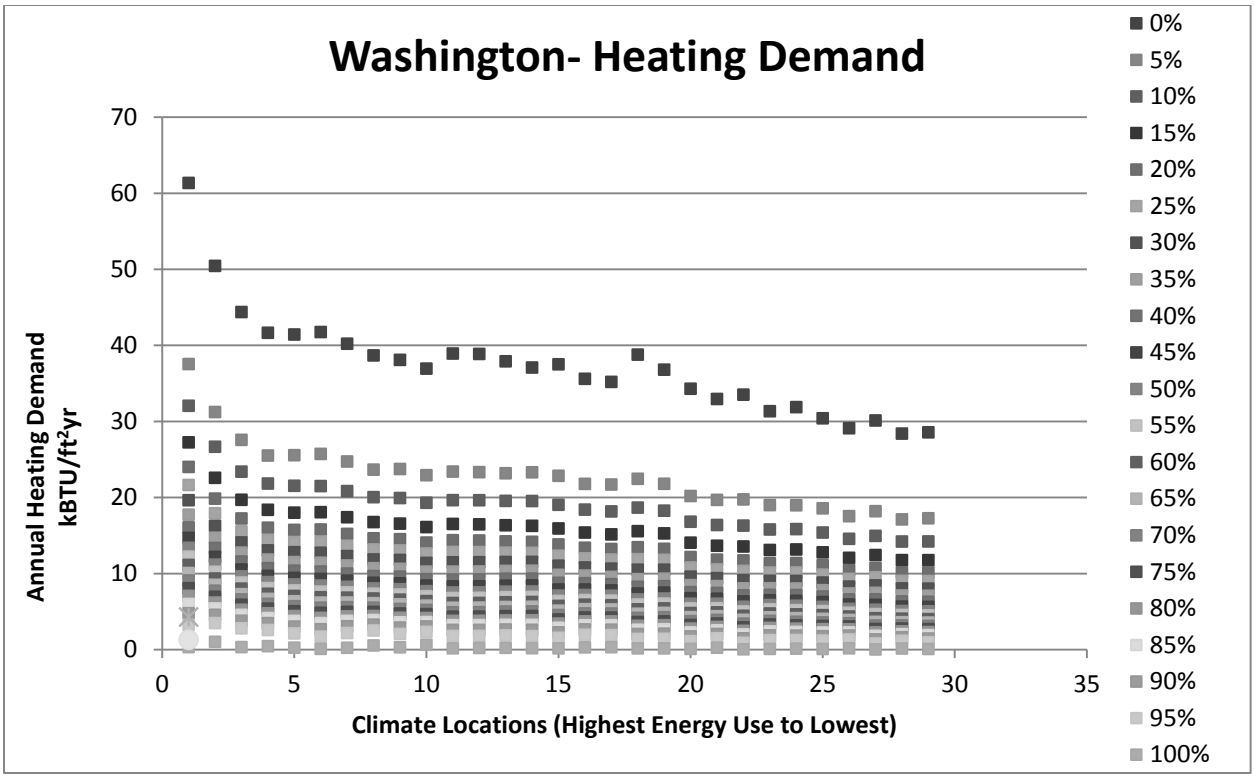

Virginia- Cooling Load
Cooling Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

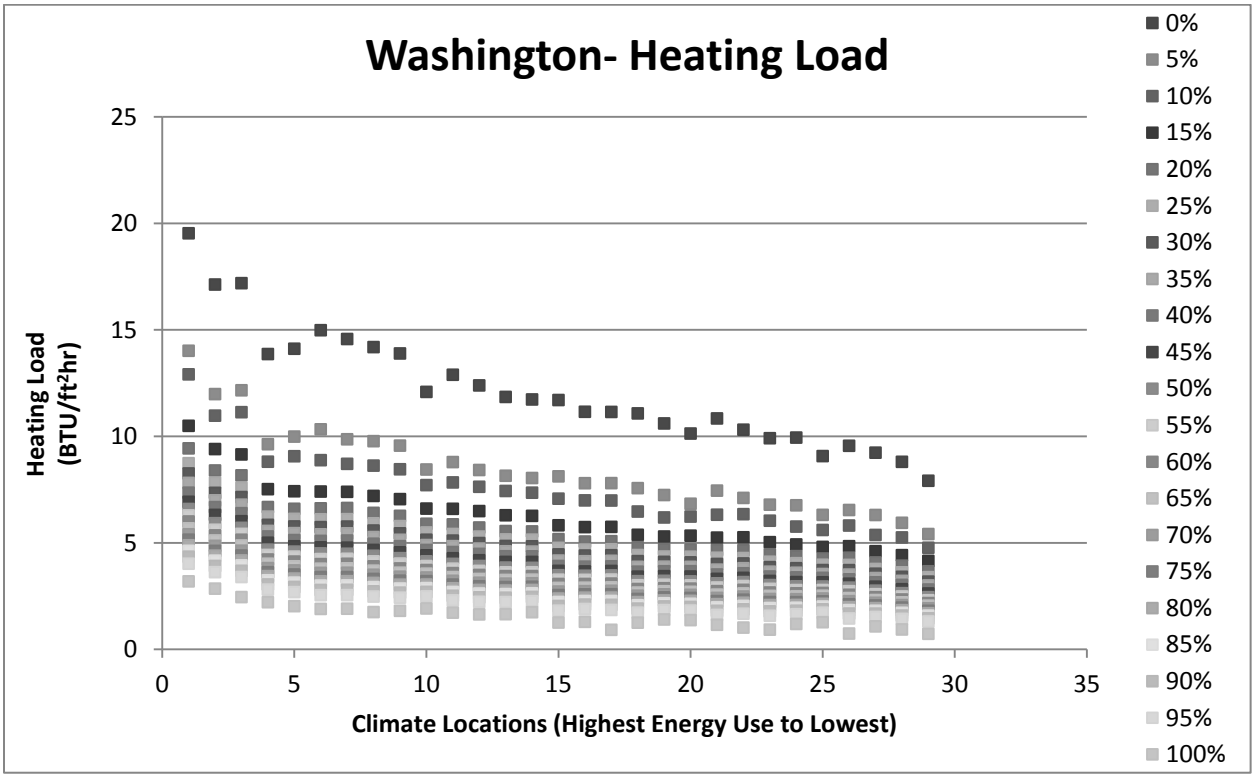

Vermont- Heating Demand
Annual Heating Demand kBTU/ft²yr
0
10
20
30
40
50
60
0
2
4
6
8
10
12
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

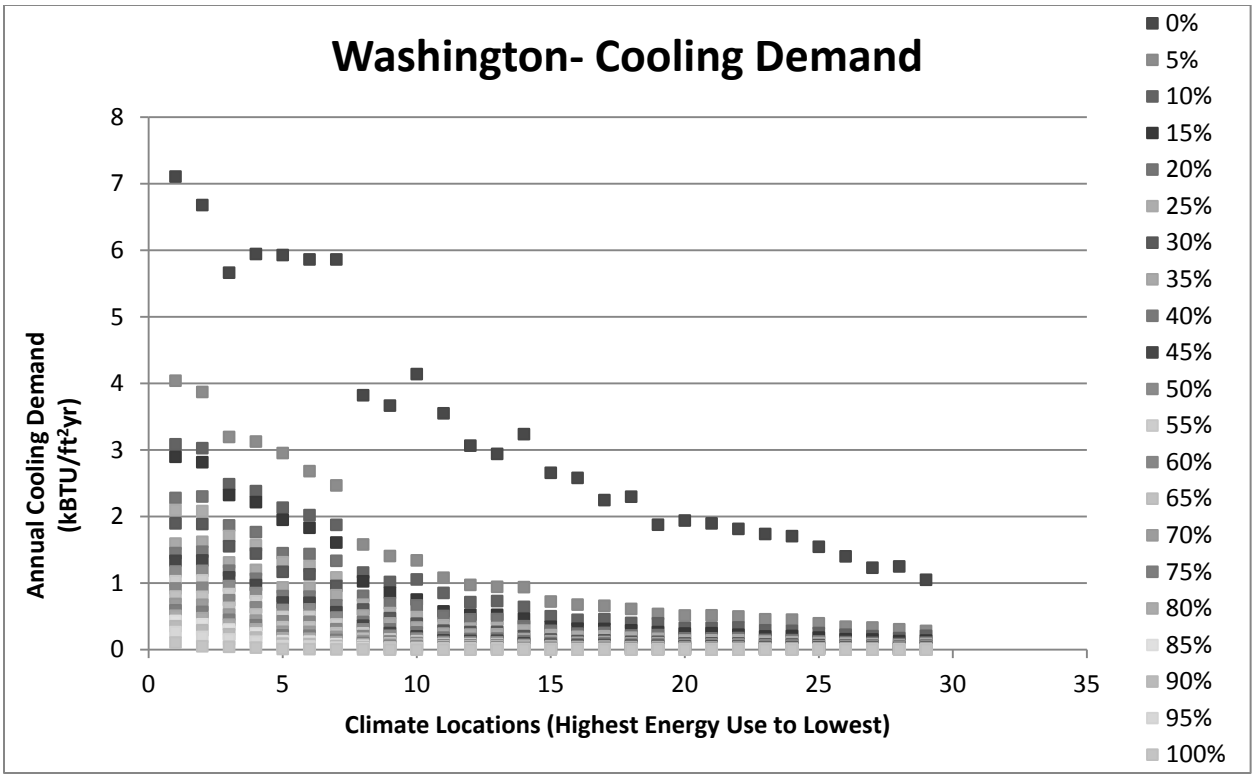

Vermont- Heating Load
Heating Load (BTU/ft²hr)
0
5
10
15
20
25
0
2
4
6
8
10
12
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

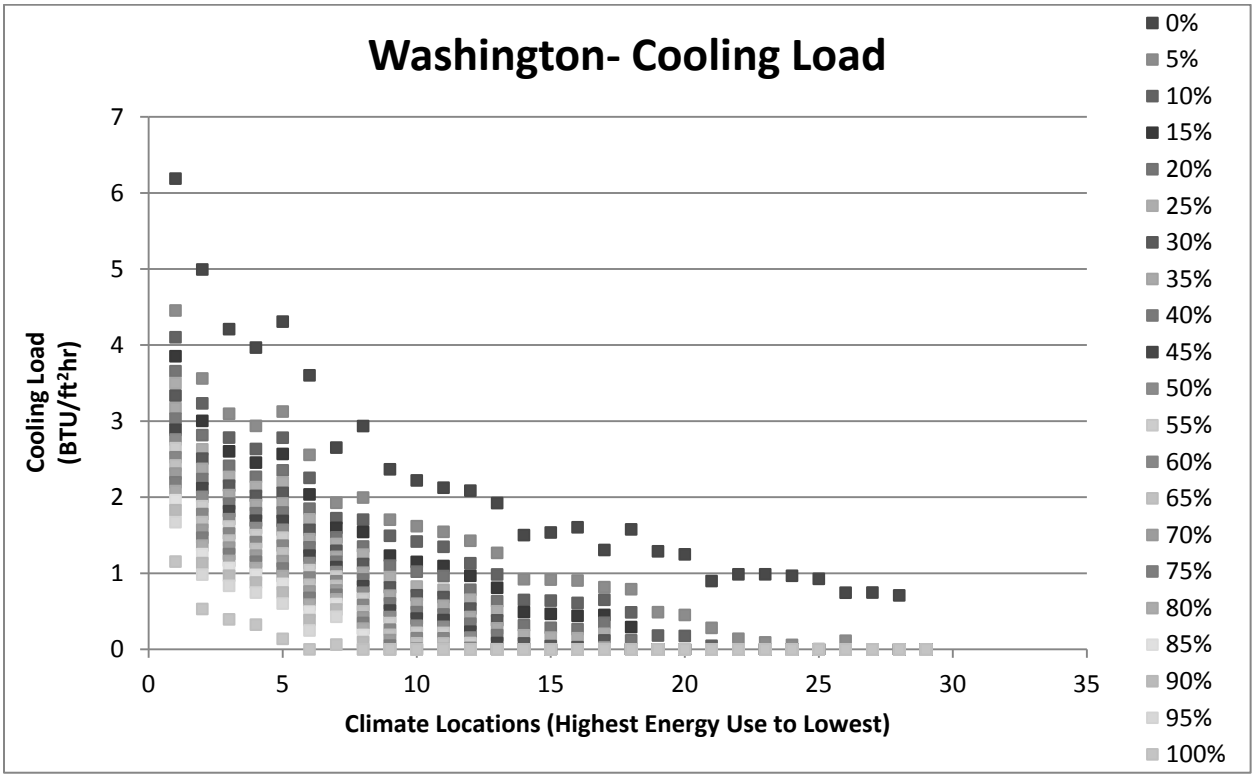

Vermont- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
3.5
3
2.5
2
1.5
1
0.5
0
0
2
4
6
8
10
12
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

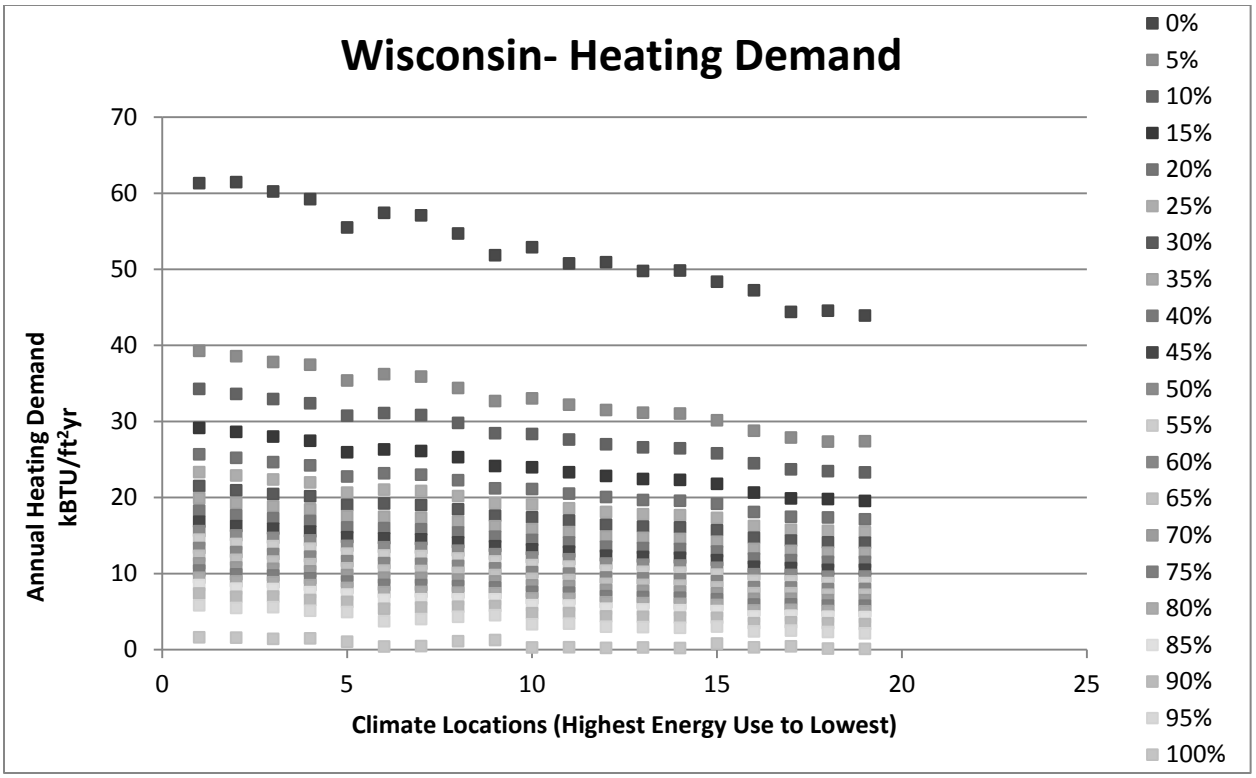

Vermont- Cooling Load
Cooling Load (BTU/ft²hr)
3.5
3
2.5
2
1.5
1
0.5
0
0
2
4
6
8
10
12
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

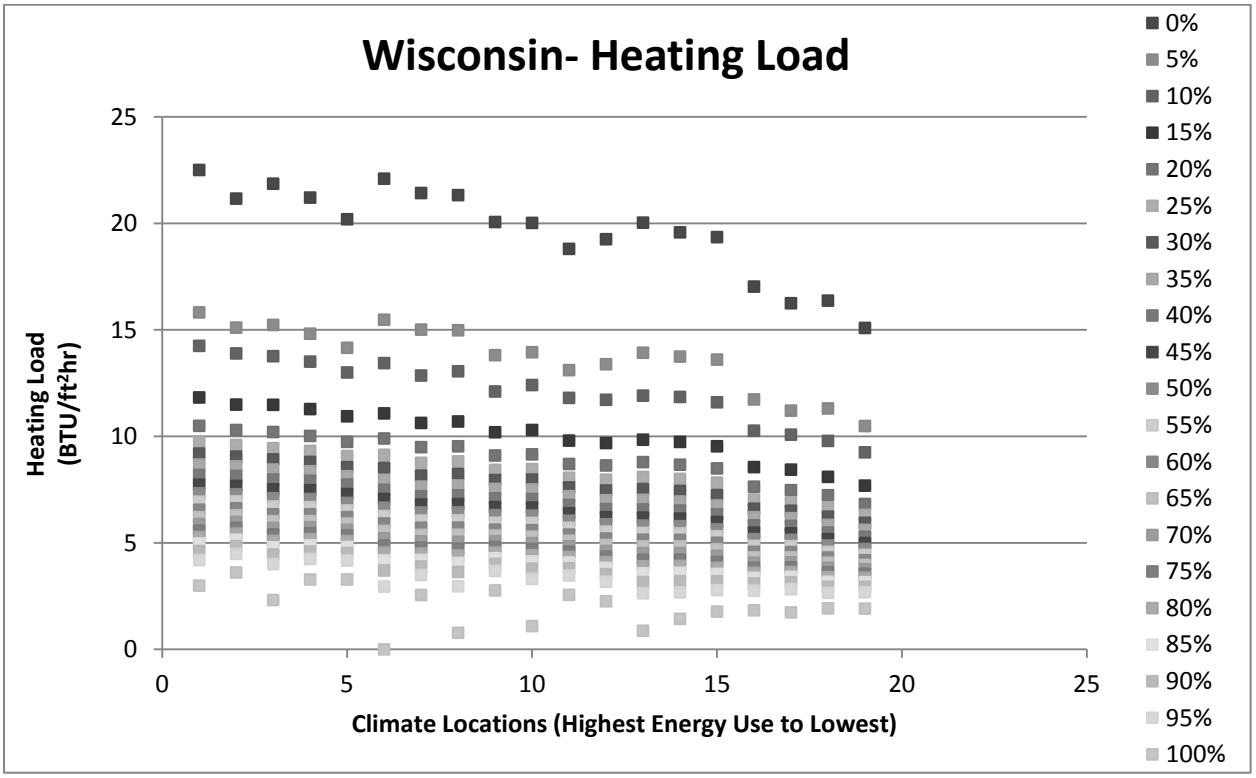

Washington- Heating Demand
Annual Heating Demand kBTU/ft²yr
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
35
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

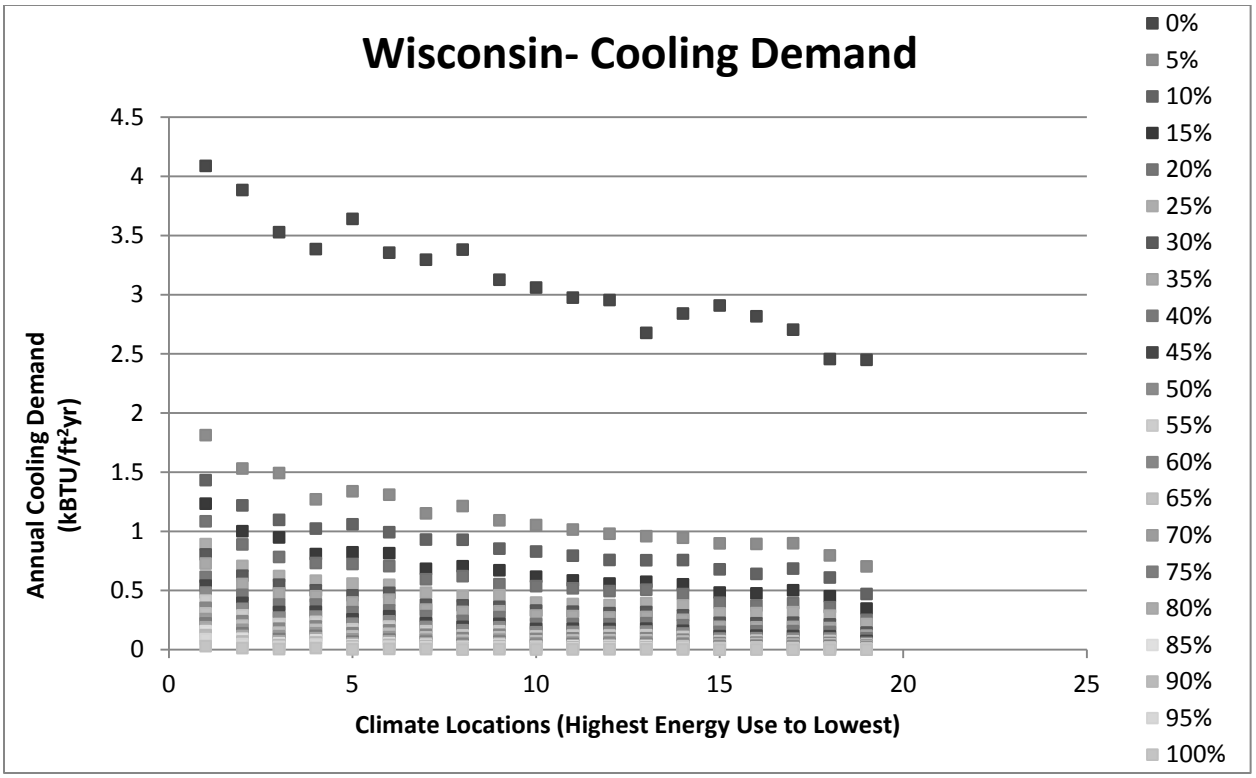

Washington- Heating Load
Heating Load (BTU/ft²hr)
25
20
15
10
5
0
0
5
10
15
20
25
30
35
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

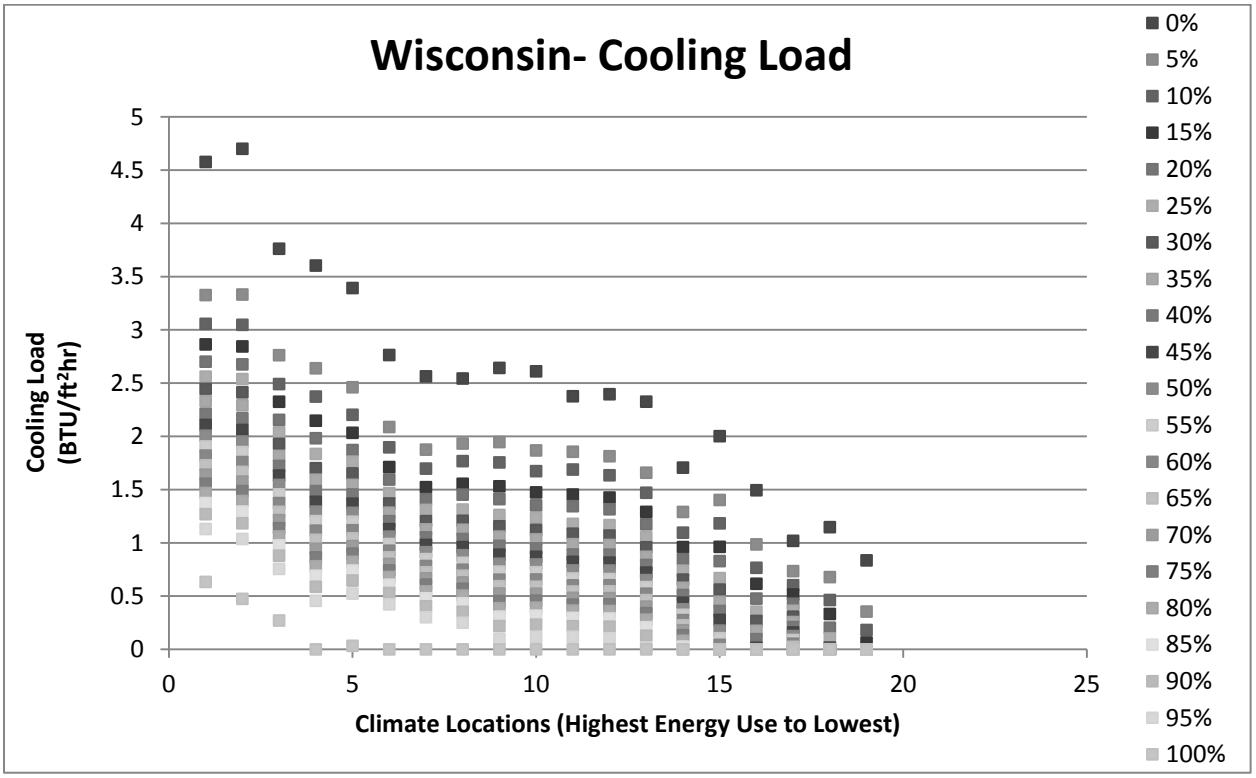

Washington- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

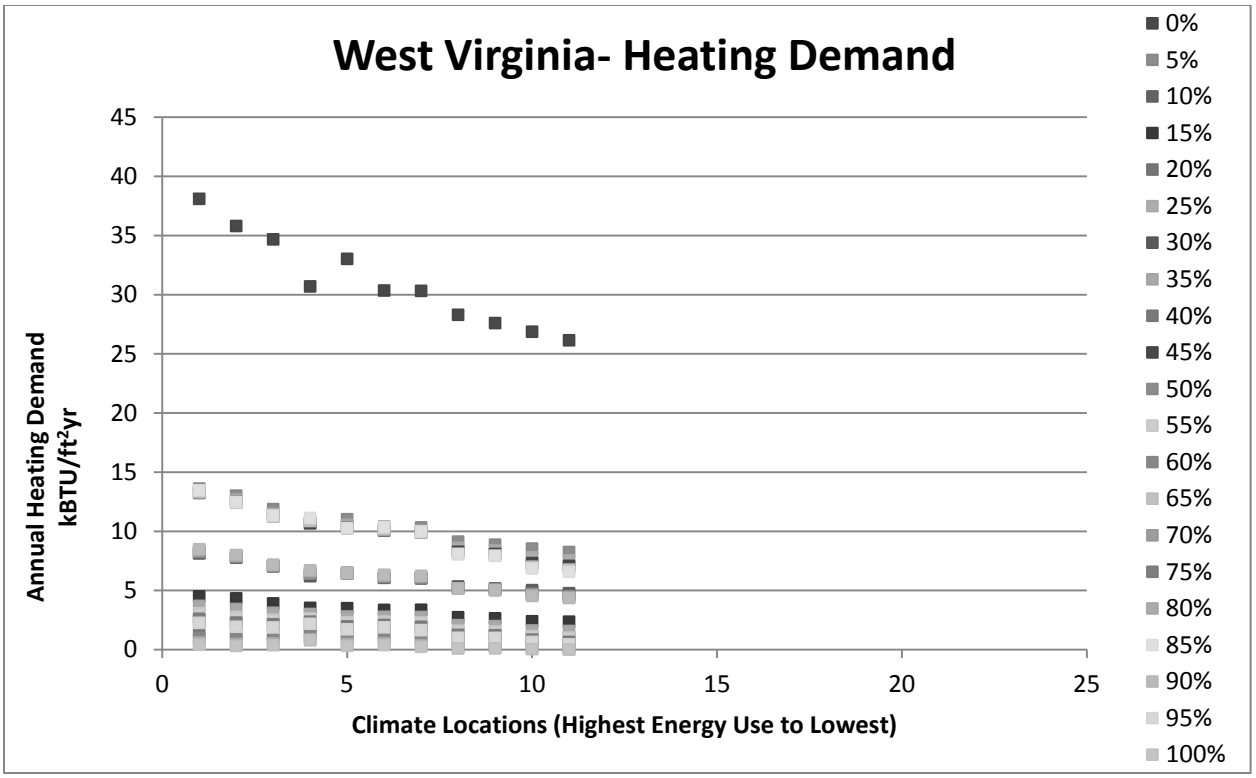

Washington- Cooling Load
Cooling Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

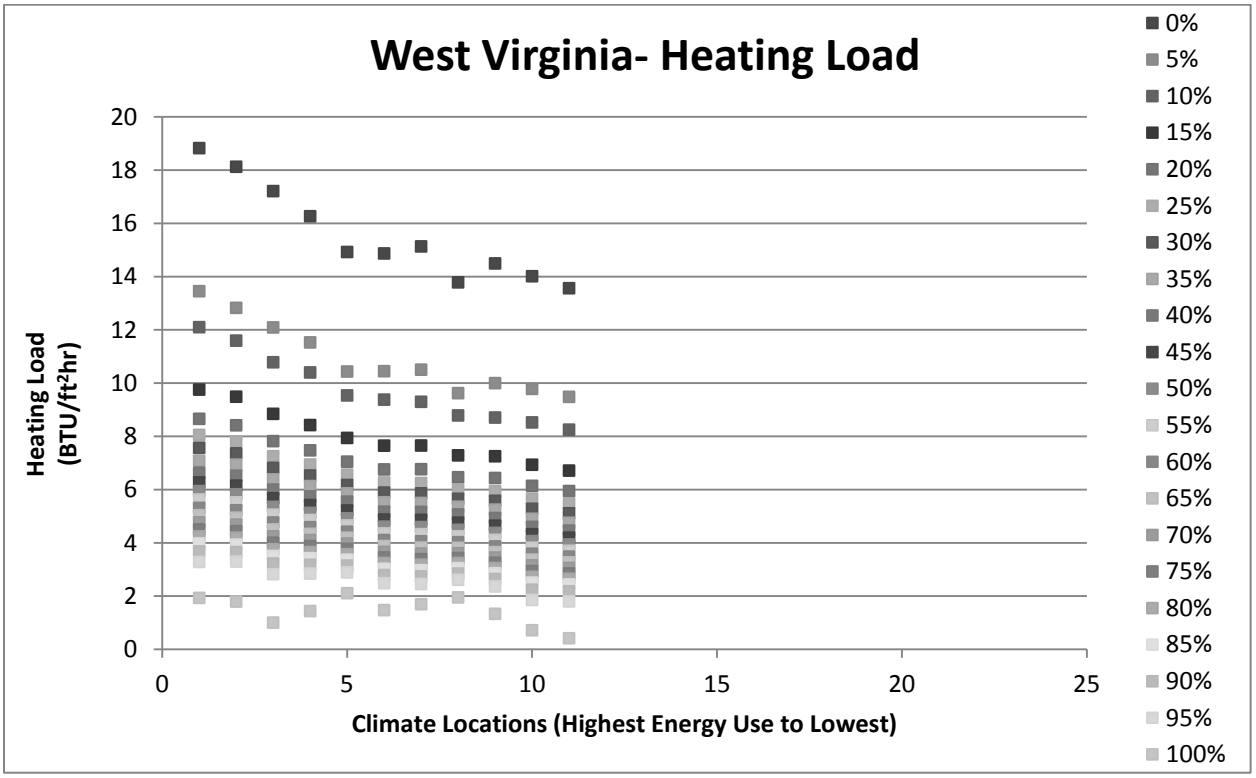

Wisconsin- Heating Demand
Annual Heating Demand kBTU/ft²yr
70
60
50
40
30
20
10
0
0
5
10
15
20
25
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

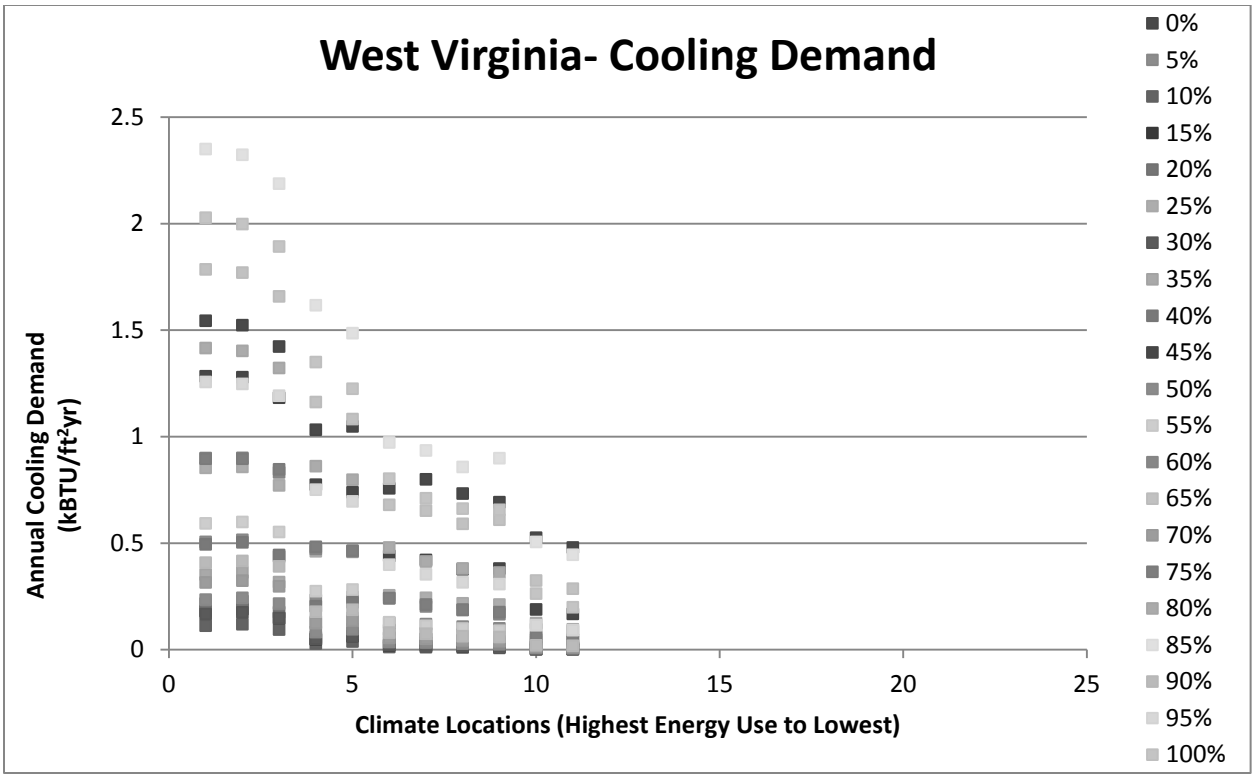

Wisconsin- Heating Load
Heating Load (BTU/ft²hr)
25
20
15
10
5
0
0
5
10
15
20
25
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

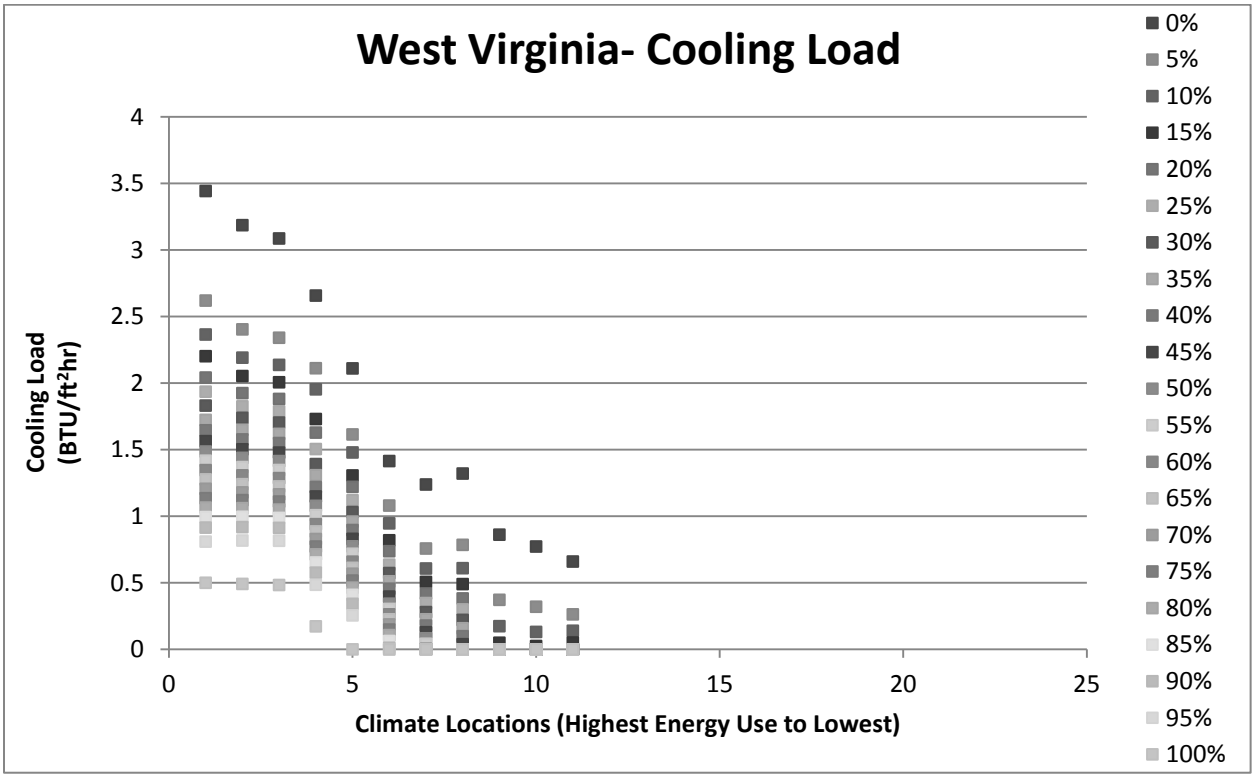

Wisconsin- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

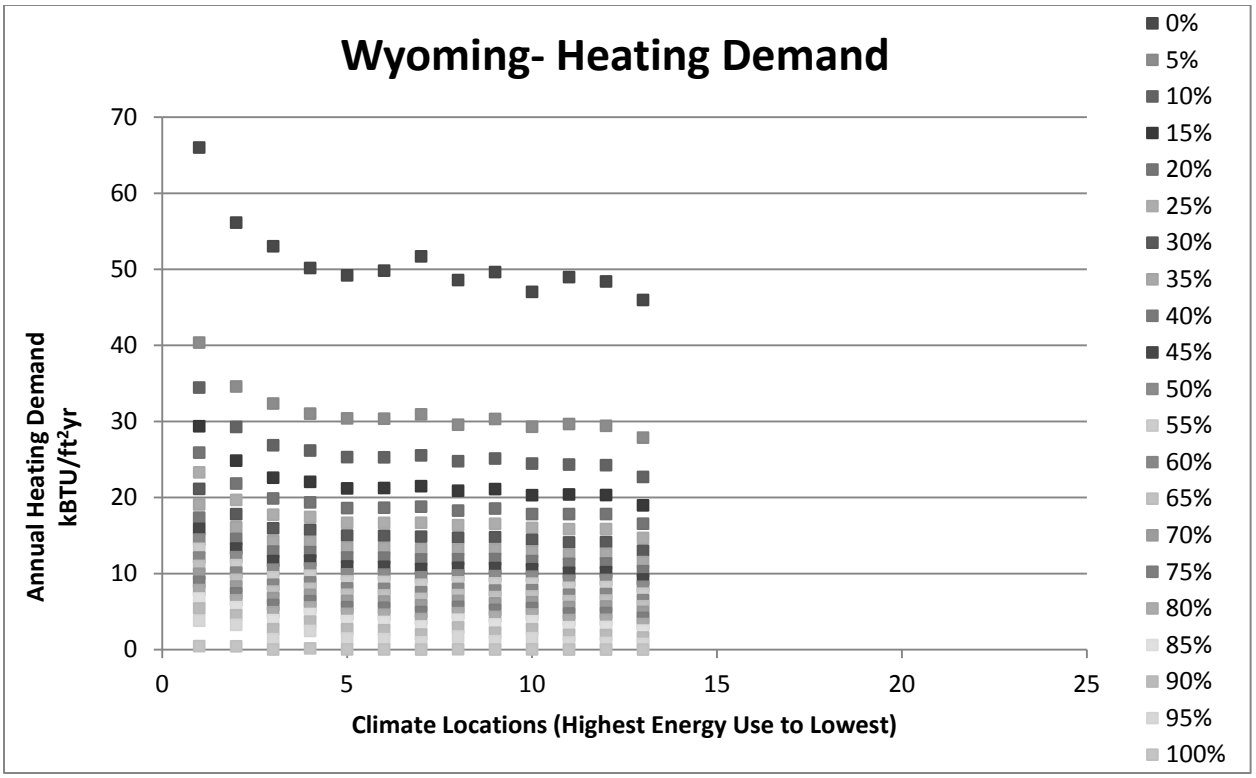

Wisconsin- Cooling Load
Cooling Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

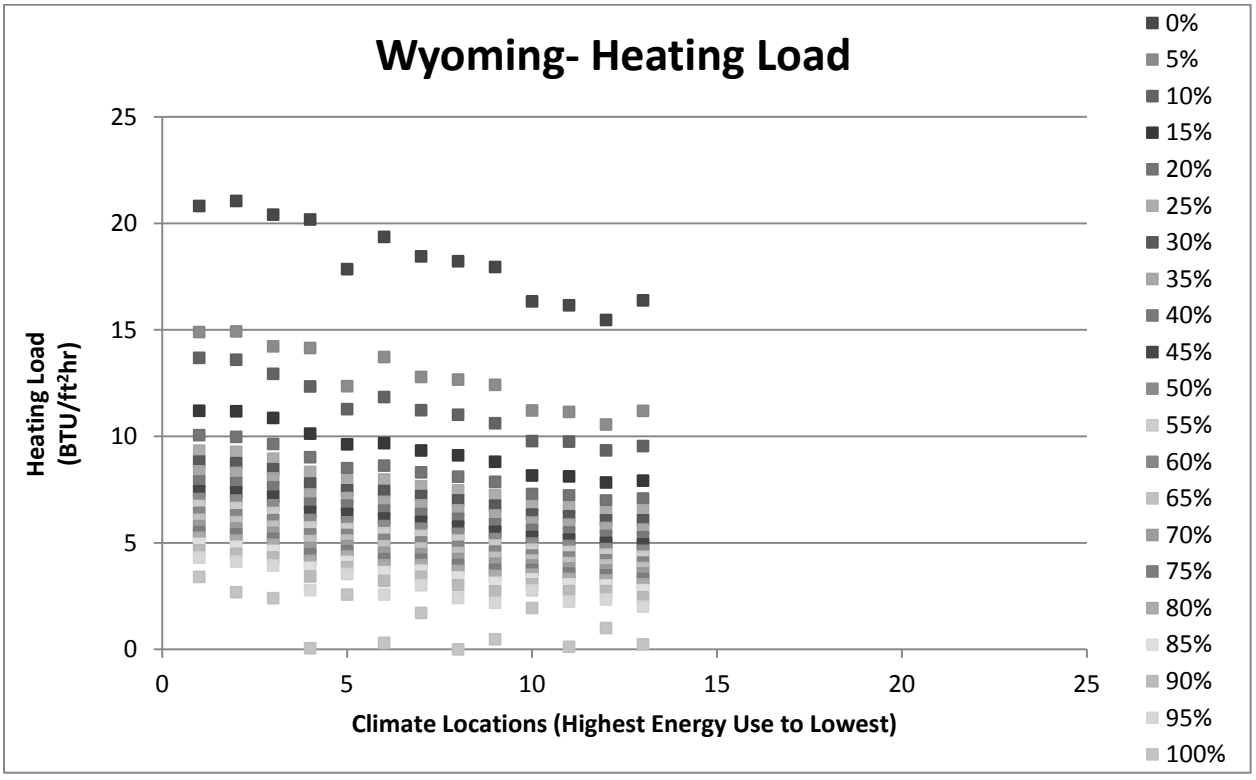

West Virginia- Heating Demand
Annual Heating Demand kBTU/ft²yr
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

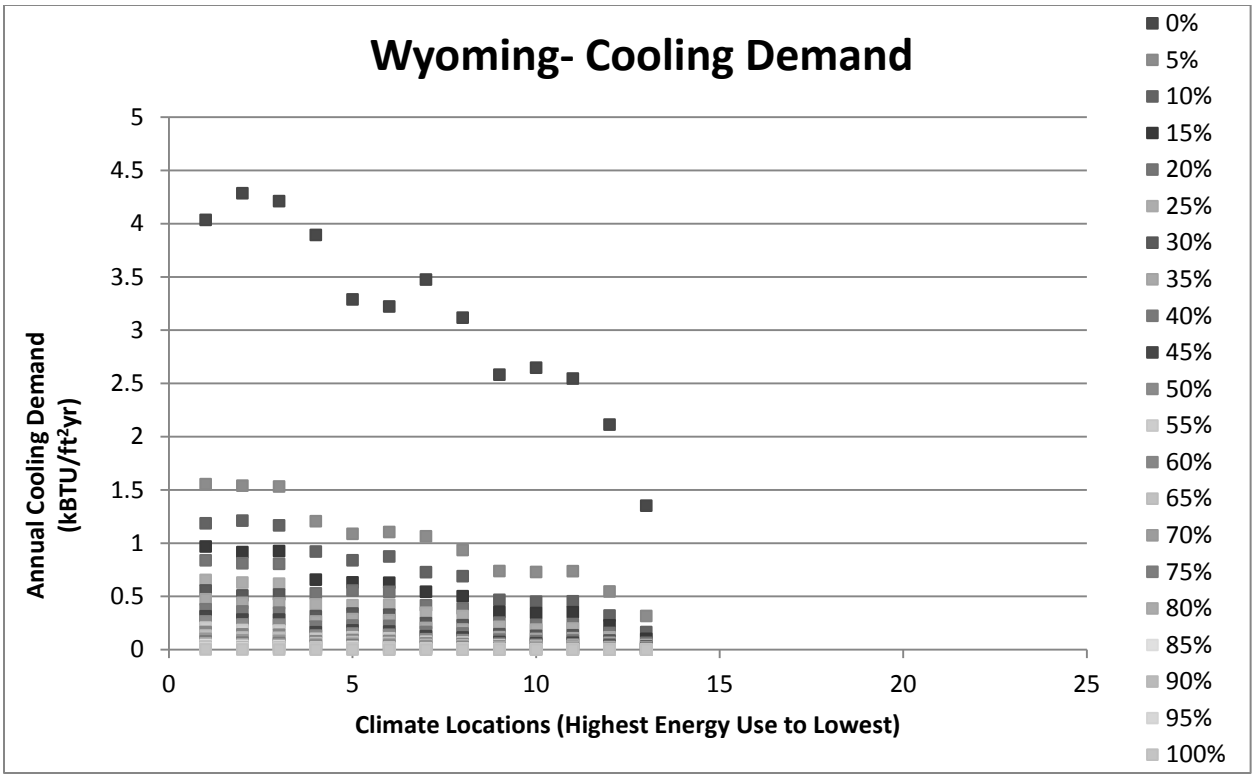

West Virginia- Heating Load
Heating Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

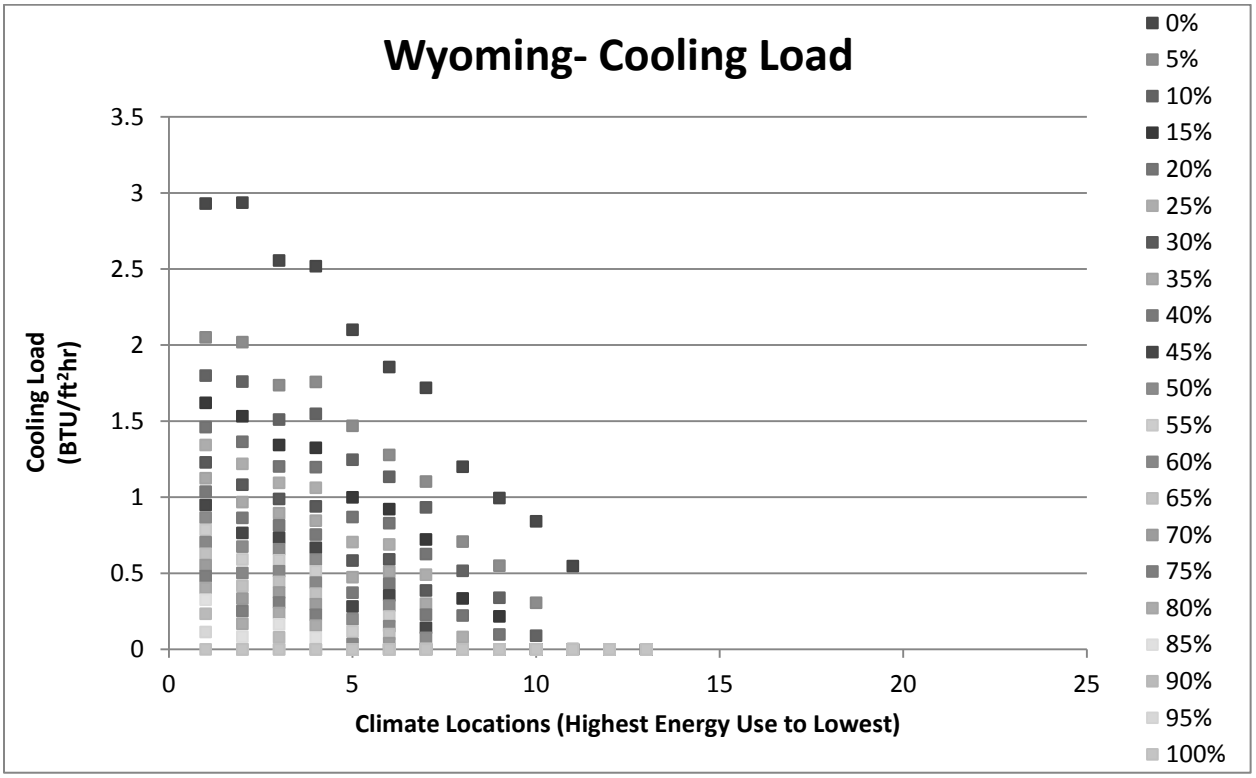

West Virginia- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
2.5
2
1.5
1
0.5
0
0
5
10
15
20
25
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%


West Virginia- Cooling Load
Cooling Load (BTU/ft²hr)
4
3.5
3
2.5
2
1.5
1
0.5
0
0
5
10
15
20
25
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%


Wyoming- Heating Demand
Annual Heating Demand kBTU/ft²yr
70
60
50
40
30
20
10
0
0
5
10
15
20
25
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%


Wyoming- Heating Load
Heating Load (BTU/ft²hr)
25
20
15
10
5
0
0
5
10
15
20
25
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%


Wyoming- Cooling Demand
Annual Cooling Demand (kBTU/ft²yr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%


Wyoming- Cooling Load
Cooling Load (BTU/ft²hr)
Climate Locations (Highest Energy Use to Lowest)
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%

Appendix F: Values Per Location from Chapter 4

Location	Heating Demand	Heating Load	Cooling Demand	Cooling Load
ANNISTON METROPOLITAN AP AL	0.0789	1.0232	0.3914	0.8236
AUBURN-OPELIKA APT AL	0.0386	1.3358	0.3237	0.3632
BIRMINGHAM MUNICIPAL AP AL	0.0331	0.2410	1.1605	1.0901
DOTHAN MUNICIPAL AP AL	0.0038	0.0000	2.0613	1.2383
MUSCLE SHOALS REGIONAL AP AL	0.0980	1.7083	0.6017	1.1709
MONTGOMERY DANNELLY FIELD AL	0.0101	0.0000	1.5822	1.5159
MOBILE REGIONAL AP AL	0.0033	0.0000	2.3216	1.3836
MOBILE DOWNTOWN AP AL	0.0007	0.0000	2.3819	1.5372
MAXWELL AFB AL	0.0118	0.0000	2.0377	1.4821
HUNTSVILLE INTL/JONES FIELD AL	0.0868	1.1711	0.6459	1.1952
GADSEN MUNI (AWOS) AL	0.4295	1.0296	0.2617	0.8009
CAIRNS FIELD FORT RUCKER AL	0.0065	0.7316	1.1265	1.2421
TUSCALOOSA MUNICIPAL AP AL	0.0619	0.6155	1.1363	1.0956
TROY AF AL	0.0221	0.8512	1.1981	1.1882
YAKUTAT STATE ARPT AK	5.2472	2.6268	0.0000	0.0000
WRANGELL AK	3.5925	3.3939	0.0000	0.0000
WHITTIER AK	5.8529	2.5416	0.0000	0.0000
VALDEZ PIONEER FIEL AK	6.5774	3.2265	0.0000	0.0000
VALDEZ WSO AK	6.1221	2.8927	0.0000	0.0000
DUTCH HARBOR AK	6.4419	2.9447	0.0000	0.0000
UNALAKLEET FIELD AK	9.1031	6.0969	0.0000	0.0000
TOGIAC VILLAGE AWOS AK	6.1228	4.0230	0.0000	0.0000
TANANA RALPH M CALHOUN MEM AP AK	12.9703	7.2795	0.0000	0.0000
TALKEETNA STATE ARPT AK	7.8882	4.9359	0.0000	0.0000
ST PAUL ISLAND ARPT AK	6.8561	3.1260	0.0000	0.0000
SOLDOTNA AK	5.1610	3.6622	0.0000	0.0000
SLEETMUTE AK	8.5932	6.4166	0.0125	0.7936
SKAGWAY AIRPORT AK	4.8107	3.5791	0.0000	0.0000
SITKA JAPONSKI AP AK	2.8384	1.7178	0.0000	0.0000
SHISHMAREF (AWOS) AK	12.9830	5.8088	0.0000	0.0000
SHEMYA AFB AK	7.4045	2.7863	0.0000	0.0000
SEWARD AK	5.2096	2.9301	0.0000	0.0000
SELAWIK AK	14.0794	7.5767	0.0000	0.0000
SAVOONGA AK	10.9925	4.7636	0.0000	0.0000
SAND POINT AK	4.2501	1.5117	0.0000	0.0000
SAINT MARY`S (AWOS) AK	7.8170	4.6347	0.0000	0.0000
PORT HEIDEN AK	5.7940	3.5404	0.0000	0.0000
POINT HOPE (AWOS) AK	13.5163	5.3191	0.0000	0.0000
PETERSBURG AK	5.1150	3.1474	0.0000	0.0000

PALMER MUNICIPAL AK	5.6501	3.9932	0.0000	0.0000
NORTHWAY AIRPORT AK	15.4915	7.3510	0.0000	0.0000
NOME MUNICIPAL ARPT AK	10.9807	4.7566	0.0000	0.0000
NENANA MUNICIPAL AP AK	10.5531	6.6716	0.0000	0.0000
MINCHUMINA AK	11.7267	7.5631	0.0000	0.0000
MIDDLETON ISLAND AUT AK	3.7147	2.2288	0.0000	0.0000
MEKORYUK AK	8.2072	4.3237	0.0000	0.0000
MCGRATH ARPT AK	12.8140	6.6039	0.0000	0.0000
KOTZEBUE RALPH WEIN MEMORIAL AK	14.5593	6.1845	0.0000	0.0000
KODIAK AIRPORT AK	3.6804	2.2993	0.0000	0.0000
KING SALMON ARPT AK	6.7793	3.3110	0.0000	0.0000
KETCHIKAN INTL AP AK	3.7638	2.2016	0.0000	0.0000
KENAI MUNICIPAL AP AK	5.7420	3.3353	0.0000	0.0000
KAKE SEAPLANE BASE AK	4.4660	3.1524	0.0000	0.0000
JUNEAU INT ARPT AK	4.9280	2.8728	0.0000	0.0000
ILIAMNA ARPT AK	4.6693	3.7472	0.0000	0.0000
HYDABURG SEAPLANE AK	2.5883	2.6588	1.3433	0.0000
HUSLIA AK	12.1512	7.4074	0.0000	0.0000
HOOPER BAY AK	7.7391	3.9970	0.0000	0.0000
HOONAH AK	4.2548	2.9818	0.0000	0.0000
HOMER ARPT AK	5.1968	3.0309	0.0000	0.0000
HEALY RIVER AIRPORT AK	8.8634	5.4029	0.0000	0.0000
HAYES RIVER AK	7.8604	4.3649	0.0000	0.0000
GUSTAVUS AK	3.4893	4.1786	0.0000	0.0000
GULKANA INTERMEDIATE FIELD AK	11.4807	6.0418	0.0000	0.0000
GAMBELL AK	11.8780	4.7174	0.0000	0.0000
FORT YUKON AK	15.2238	6.7844	0.0000	0.0000
FAIRBANKS INTL ARPT AK	12.5000	5.8496	0.0000	0.0000
EMMONAK AK	9.1930	5.4110	0.0000	0.0000
FAIRBANKS/EIELSON A AK	10.9431	5.6933	0.0000	0.0000
DILLINGHAM (AMOS) AK	7.4433	4.7422	0.0000	0.0000
DEADHORSE AK	21.9438	7.5338	0.0000	0.0000
CORDOVA AK	5.9242	3.1371	0.0000	0.0000
COLD BAY ARPT AK	5.2273	2.5856	0.0000	0.0000
CHULITNA AK	8.5474	4.1197	0.0000	0.0000
BIRCHWOOD AK	4.9526	4.1125	0.0000	0.0000
BIG RIVER LAKE AK	7.2778	3.8937	0.0000	0.0000
BIG DELTA ALLEN AAF AK	10.9315	5.3619	0.0000	0.0000
BETTLES FIELD AK	15.1019	6.5684	0.0000	0.0000
BETHEL AIRPORT AK	8.2501	3.8999	0.0000	0.0000
BARROW W POST-W ROGERS ARPT [NSA - ARM] AK	22.9923	6.5967	0.0000	0.0000
ANVIK AK	8.5033	4.5193	0.0000	0.0000

ANNETTE ISLAND AP AK	2.6341	1.8421	0.0000	0.0000
ANIAK AIRPORT AK	7.0819	4.9914	0.0000	0.0000
ANCHORAGE MERRILL FIELD AK	6.7600	3.4901	0.0000	0.0000
LAKE HOOD SEAPLANE AK	5.2854	3.7032	0.0000	0.0000
ANCHORAGE/ELMENDORF AK	6.3927	3.9694	0.0000	0.0000
ANCHORAGE INTL AP AK	7.3863	3.9022	0.0000	0.0000
ANAKTUVUK PASS AK	16.0894	7.7362	0.0000	0.0000
AMBLER AK	13.5287	7.7362	0.0000	0.0000
ADAK NAS AK	5.0492	2.2494	0.0000	0.0000
YUMA MCAS AZ	0.0000	0.0000	7.4631	3.2757
YUMA INTL ARPT AZ	0.0000	0.0000	7.7423	3.2295
WINSLOW MUNICIPAL AP AZ	0.0528	0.0000	0.1638	0.7089
TUCSON INTERNATIONAL AP AZ	0.0000	0.0000	3.5432	2.1245
SHOW LOW MUNICIPAL AZ	0.0535	1.7740	0.0137	0.0000
SCOTTSDALE MUNI AZ	0.0000	0.0000	7.5466	3.3747
SAFFORD (AMOS) AZ	0.0004	0.0000	2.8826	1.9974
PRESCOTT LOVE FIELD AZ	0.0473	0.5815	0.0412	0.1587
PHOENIX SKY HARBOR INTL AP AZ	0.0000	0.0000	8.5244	3.2781
DEER VALLEY/PHOENIX AZ	0.0000	0.0000	7.5626	3.1856
PAGE MUNI (AMOS) AZ	0.0277	0.2941	1.3997	1.5629
LUKE AFB AZ	0.0000	0.0000	7.0592	3.5054
KINGMAN (AMOS) AZ	0.0060	0.2747	2.5955	2.1115
GRAND CANYON NATL P AZ	0.3315	1.4244	0.0000	0.0000
FLAGSTAFF PULLIAM ARPT AZ	0.3155	2.1120	0.0000	0.0000
DOUGLAS BISBEE-DOUGLAS INTL A AZ	0.0014	0.0000	0.5163	1.2704
DAVIS MONTHAN AFB AZ	0.0000	0.0000	4.4946	2.5399
CASA GRANDA (AWOS) AZ	0.0000	0.0000	6.1627	2.9371
WALNUT RIDGE (AWOS) AR	0.1183	0.5907	0.7729	1.1216
TEXARKANA WEBB FIELD AR	0.1433	1.1963	2.6887	2.0286
STUTTGART (AWOS) AR	0.0324	1.0698	1.6640	1.4395
SPRINGDALE MUNI AR	0.5413	2.0697	0.7965	1.4110
SILOAM SPRING(AWOS) AR	0.1082	1.2734	0.7578	1.5022
ROGERS (AWOS) AR	0.1429	1.9061	1.0612	1.4266
PINE BLUFF FAA AP AR	0.4108	1.6739	2.4066	1.9738
LITTLE ROCK ADAMS FIELD AR	0.0762	1.5689	1.7116	1.5917
LITTLE ROCK AFB AR	0.3400	1.4829	1.0568	1.5912
JONESBORO MUNI AR	0.5850	1.8206	1.0413	1.4203
HARRISON FAA AP AR	0.2020	2.0209	0.7584	1.3245
FORT SMITH REGIONAL AP AR	0.1060	1.3013	1.2918	1.3734
FLIPPIN (AWOS) AR	0.1135	0.9272	0.5804	1.2725
FAYETTEVILLE DRAKE FIELD AR	0.1153	1.4444	1.1734	1.6544
EL DORADO GOODWIN FIELD AR	0.1347	1.2467	2.3688	1.9157

BENTONVILLE (AWOS) AR	0.1437	1.1054	0.7921	1.0248
BATESVILLE (AWOS) AR	0.0954	1.2383	0.4339	1.1373
YUBA CO CA	0.0412	0.9354	0.0807	0.9245
VISALIA MUNI (AWOS) CA	0.0639	1.0389	0.4329	1.5223
VAN NUYS AIRPORT CA	0.0000	0.0000	0.1188	1.0493
UKIAH MUNICIPAL AP CA	0.0229	0.8324	0.0140	0.0000
TWENTYNINE PALMS CA	0.0000	0.0000	4.8803	2.6594
TRUCKEE-TAHOE CA	1.5355	2.2011	0.0000	0.0000
STOCKTON METROPOLITAN ARPT CA	0.0469	0.4642	0.0241	0.8007
SOUTH LAKE TAHOE CA	1.3803	1.9475	0.0000	0.0000
SANTA ROSA (AWOS) CA	0.0468	0.2024	0.0018	0.0000
SANTA MONICA MUNI CA	0.0000	0.0000	0.0151	0.0000
SANTA MARIA PUBLIC ARPT CA	0.0022	0.0000	0.0015	0.0000
SANTA BARBARA MUNICIPAL AP CA	0.0008	0.0873	0.0054	0.0000
SANTA ANA JOHN WAYNE AP CA	0.0000	0.0000	0.0239	0.0000
SANDBERG CA	0.0086	0.3827	0.1819	0.9499
SAN LUIS CO RGNL CA	0.0023	0.1817	0.0024	0.0000
SAN JOSE INTL AP CA	0.0067	0.1424	0.0091	0.0000
SAN FRANCISCO INTL AP CA	0.0072	0.1044	0.0023	0.0000
SAN DIEGO NORTH ISLAND NAS CA	0.0000	0.0000	0.0241	0.0000
SAN DIEGO/MONTGOMER CA	0.0000	0.0000	0.0423	0.2417
SAN DIEGO MIRAMAR NAS CA	0.0000	0.0000	0.0398	0.2858
SAN DIEGO LINDBERGH FIELD CA	0.0000	0.0000	0.1199	0.0709
SALINAS MUNICIPAL AP CA	0.0070	0.0000	0.0022	0.0000
SACRAMENTO METROPOLITAN AP CA	0.0423	0.8443	0.0406	0.9419
SACRAMENTO EXECUTIVE ARPT CA	0.0361	0.7364	0.0360	0.1752
RIVERSIDE MUNI CA	0.0000	0.0000	0.0880	0.7981
REDDING MUNICIPAL ARPT CA	0.0388	0.8769	0.6036	1.2421
RED BLUFF MUNICIPAL ARPT CA	0.0243	0.9043	0.8619	1.7323
PORTERVILLE (AWOS) CA	0.0154	0.4909	0.4133	1.5086
POINT MUGU NF CA	0.0000	0.0000	0.0064	0.0000
PASO ROBLES MUNICIPAL ARPT CA	0.0069	0.0000	0.0097	0.1516
PALMDALE AIRPORT CA	0.0036	0.0000	0.9755	1.4354
PALM SPRINGS THERMAL AP CA	0.0000	0.0000	6.2387	3.0147
PALM SPRINGS INTL CA	0.0000	0.0000	7.5036	3.2073
OXNARD AIRPORT CA	0.0000	0.0000	0.0203	0.0000
OAKLAND METROPOLITAN ARPT CA	0.0095	0.1789	0.0030	0.0000
NEEDLES AIRPORT CA	0.0000	0.0000	8.7789	3.4265
NAPA CO. AIRPORT CA	0.0410	0.9356	0.0026	0.0000
MOUNTAIN VIEW MOFFETT FLD NAS CA	0.0219	0.2521	0.0219	0.0000
MONTEREY NAF CA	0.0036	0.0000	0.0036	0.0000
MONTAGUE SISKIYOU COUNTY AP CA	0.1828	0.5932	0.1828	0.0000

MODESTO CITY-COUNTY AP CA	0.0460	0.7936	0.0460	1.3850
MERCED/MACREADY FLD CA	0.0416	0.8040	0.0416	0.9814
MARCH AFB CA	0.0018	0.2498	0.0018	0.8078
LOS ANGELES INTL ARPT CA	0.0000	0.0000	0.0000	0.0000
LONG BEACH DAUGHERTY FLD CA	0.0000	0.0000	0.0000	0.0000
LOMPOC (AWOS) CA	0.0022	0.0000	0.0022	0.0000
LIVERMORE MUNICIPAL CA	0.0394	0.3710	0.0394	0.0916
LEMOORE REEVES NAS CA	0.1078	1.2897	0.1078	1.1460
LANCASTER GEN WM FOX FIELD CA	0.0056	0.0000	0.0056	1.3550
IMPERIAL CA	0.0000	0.0000	0.0000	2.7874
HAYWARD AIR TERM CA	0.0085	0.1898	0.0085	0.0000
JACK NORTHROP FLD H CA	0.0000	0.0000	0.0000	0.1007
FULLERTON MUNICIPAL CA	0.0000	0.0000	0.0000	0.6138
FRESNO YOSEMITE INTL AP CA	0.0340	0.6721	0.0340	1.4588
TRAVIS FIELD AFB CA	0.0312	0.6078	0.0312	0.4005
EDWARDS AFB CA	0.0128	0.4390	0.0128	1.2488
CRESCENT CITY FAA AI CA	0.0765	0.7205	0.0765	0.0000
CONCORD CONCORD-BUCHANAN FIEL CA	0.0391	0.5123	0.0391	0.3430
CHULA VISTA BROWN FIELD NAAS CA	0.0000	0.0000	0.0000	0.1204
CHINO AIRPORT CA	0.0000	0.2109	0.0000	0.2703
CHINA LAKE NAF CA	0.0184	0.2348	0.0184	2.2371
CARLSBAD/PALOMAR CA	0.0000	0.0000	0.0000	0.0000
CAMP PENDLETON MCAS CA	0.0000	0.0000	0.0000	0.0000
CAMARILLO (AWOS) CA	0.0005	0.0000	0.0005	0.0000
BURBANK-GLENDALE-PASSADENA AP CA	0.0000	0.0000	0.0000	1.1846
BLYTHE RIVERSIDE CO ARPT CA	0.0000	0.0000	0.0000	3.4742
BLUE CANYON AP CA	0.2529	1.5085	0.2529	0.1072
BISHOP AIRPORT CA	0.0406	0.2234	0.0406	0.3251
BEALE AFB CA	0.0352	0.8061	0.0352	1.7213
DAGGETT BARSTOW-DAGGETT AP CA	0.0017	0.0000	0.0017	2.7587
BAKERSFIELD MEADOWS FIELD CA	0.0076	0.4138	0.0076	1.6944
ARCATA AIRPORT CA	0.0943	0.5258	0.0943	0.0000
ALTURAS CA	0.3204	2.3726	0.3204	0.0000
TRINIDAD LAS ANIMAS COUNTY AP CO	0.1212	1.5393	0.0174	0.0000
RIFLE/GARFIELD RGNL CO	1.3586	2.5323	0.0073	0.0000
PUEBLO MEMORIAL AP CO	0.1756	0.8295	0.0452	0.1196
MONTROSE CO. ARPT CO	1.0585	1.4817	0.0112	0.0000
LIMON CO	0.3424	2.6997	0.0025	0.0000
LEADVILLE/LAKE CO. CO	1.9708	2.6796	0.0000	0.0000
LAMAR MUNICIPAL CO	0.3215	2.1438	0.1076	0.8132
LA JUNTA MUNICIPAL AP CO	0.7126	1.8058	0.1770	0.8284
HAYDEN/YAMPA (AWOS) CO	2.1545	3.1075	0.0015	0.0000

GUNNISON CO. (AWOS) CO	2.8511	3.4061	0.0000	0.0000
GRAND JUNCTION WALKER FIELD CO	0.1988	0.6109	0.1364	0.5125
DENVER/CENTENNIAL [GOLDEN - NREL] CO	0.3630	3.0414	0.0090	0.0000
FORT COLLINS (AWOS) CO	0.3248	3.1118	0.0125	0.1122
EAGLE COUNTY AP CO	1.7792	3.0554	0.0000	0.0000
DURANGO/LA PLATA CO CO	0.3852	2.0490	0.0025	0.0000
DENVER INTL AP CO	0.1983	1.8488	0.0231	0.0000
CRAIG-MOFFAT CO	2.7071	2.9336	0.0000	0.0000
CORTEZ/MONTEZUMA CO CO	0.1886	1.6425	0.0045	0.0000
COLORADO SPRINGS MUNI AP CO	1.4942	1.9322	0.0041	0.0000
BROOMFIELD/JEFFCO [BOULDER - SURFRAD] CO	0.2379	1.5417	0.0108	0.0000
AURORA BUCKLEY FIELD ANGB CO	0.2050	2.2986	0.0125	0.0000
ASPEN PITKIN CO SAR CO	1.3157	2.7147	0.0000	0.0000
ALAMOSA SAN LUIS VALLEY RGNL CO	1.7730	1.6482	0.0000	0.0000
OXFORD (AWOS) CT	1.2999	1.7818	0.0235	0.5460
NEW HAVEN TWEED AIRPORT CT	1.2391	2.3463	0.0265	0.1813
HARTFORD BRAINARD FD CT	1.2171	1.9751	0.0073	0.1280
HARTFORD BRADLEY INTL AP CT	1.1776	1.8972	0.0248	0.4000
GROTON NEW LONDON AP CT	1.1015	1.9280	0.0125	0.0000
DANBURY MUNICIPAL CT	1.0825	2.6858	0.0163	0.3836
BRIDGEPORT SIKORSKY MEMORIAL CT	0.9185	1.7429	0.0540	0.4120
WILMINGTON NEW CASTLE CNTY AP DE	0.8055	0.9038	0.1557	0.6295
DOVER AFB DE	0.1401	1.5106	0.1260	0.8293
WHITING FIELD NAAS FL	0.0018	0.0000	1.6616	1.4307
WEST PALM BEACH INTL ARPT FL	0.0000	0.0000	5.2316	1.6172
VERO BEACH MUNICIPAL ARPT FL	0.0000	0.0000	4.0751	1.4182
VALPARAISO ELGIN AFB FL	0.0031	0.0000	2.2887	1.4349
TYNDALL AFB FL	0.0012	0.0000	2.2032	1.2058
TAMPA INTERNATIONAL AP FL	0.0000	0.0000	4.1116	1.6947
TALLAHASSEE REGIONAL AP [ISIS] FL	0.0009	0.0000	1.8471	1.5143
ST PETERSBURG CLEAR FL	0.0000	0.0000	6.6298	2.2619
ST PETERSBURG ALBERT WHITTED FL	0.0000	0.0000	0.0000	2.1694
SOUTHWEST FLORIDA I FL	0.0000	0.0000	0.0000	1.2888
SARASOTA BRADENTON FL	0.0000	0.0000	0.0000	1.6683
PENSACOLA FOREST SHERMAN NAS FL	0.0007	0.1033	0.0000	1.6753
PENSACOLA REGIONAL AP FL	0.0003	0.0829	0.0000	1.4086
PANAMA CITY BAY CO FL	0.0000	0.0000	0.0000	1.7410
ORLANDO SANFORD AIRPORT FL	0.0000	0.0000	0.0000	1.6486
ORLANDO INTL ARPT FL	0.0000	0.0000	0.0000	1.4311
ORLANDO EXECUTIVE AP FL	0.0000	0.0000	0.0000	1.6166
OCALA MUNI (AWOS) FL	0.0000	0.0000	0.0000	1.4824
NASA SHUTTLE FCLTY FL	0.0000	0.0000	0.0000	1.4476

NAPLES MUNICIPAL FL	0.0000	0.0000	0.0000	1.4686
MIAMI/OPA LOCKA FL	0.0000	0.0000	0.0000	2.3934
MIAMI/KENDALL-TAMIA FL	0.0000	0.0000	0.0000	1.4272
MIAMI INTL AP FL	0.0000	0.0000	0.0000	1.8142
MELBOURNE REGIONAL AP FL	0.0000	0.0000	0.0000	1.4069
MAYPORT NS FL	0.0000	0.0000	0.0000	1.6136
MARATHON AIRPORT FL	0.0000	0.0000	0.0000	2.6754
MACDILL AFB FL	0.0000	0.0000	0.0000	2.2303
LAKELAND LINDER RGN FL	0.0000	0.0000	0.0000	1.7370
KEY WEST NAS FL	0.0000	0.0000	0.0000	2.4109
KEY WEST INTL ARPT FL	0.0000	0.0000	0.0000	2.0338
JACKSONVILLE/CRAIG FL	0.0000	0.0000	0.0000	1.7582
JACKSONVILLE NAS FL	0.0000	0.0000	0.0000	1.7404
JACKSONVILLE INTL ARPT FL	0.0003	0.1525	0.0000	1.2979
HOMESTEAD AFB FL	0.0000	0.0000	0.0000	1.7690
GAINESVILLE REGIONAL AP FL	0.0000	0.0000	0.0000	1.5867
VALPARAISO HURLBURT FL	0.0015	0.0000	0.0000	1.5310
ST LUCIE CO INTL FL	0.0000	0.0000	0.0000	1.4451
FORT MYERS PAGE FIELD FL	0.0000	0.0000	0.0000	1.5917
FORT LAUDERDALE HOLLYWOOD INT FL	0.0000	0.0000	0.0000	1.8452
FORT LAUDERDALE FL	0.0000	0.0000	0.0000	1.8647
DAYTONA BEACH INTL AP FL	0.0000	0.0000	0.0000	1.3415
CRESTVIEW BOB SIKES AP FL	0.0013	0.0000	0.0000	1.3395
WARNER ROBINS AFB GA	0.0524	0.9090	1.1314	1.4522
MOODY AFB/VALDOSTA GA	0.0020	0.0000	1.7486	1.3886
VALDOSTA WB AIRPORT GA	0.0008	0.2160	2.1087	1.7746
HUNTER AAF GA	0.0069	0.2816	1.9275	1.3522
SAVANNAH INTL AP GA	0.0028	1.0920	2.3278	1.5755
ROME R B RUSSELL AP GA	0.0590	1.2481	0.7696	0.8309
MARIETTA DOBBINS AFB GA	0.1933	1.4007	0.5327	1.0327
MACON MIDDLE GA REGIONAL AP GA	0.0140	0.3665	1.4416	1.6027
FULTON CO ARPT BROW GA	0.0514	0.8858	0.8428	1.5858
FORT BENNING LAWSON GA	0.0588	0.7687	0.4629	0.7239
DEKALB PEACHTREE GA	0.1072	1.3014	0.9406	1.7170
COLUMBUS METROPOLITAN ARPT GA	0.0129	0.1103	2.3658	1.8564
BRUNSWICK MALCOLM MCKINNON AP GA	0.0000	0.1879	2.7145	1.5056
BRUNSWICK GOLDEN IS GA	0.0015	0.1751	2.5258	1.4158
AUGUSTA BUSH FIELD GA	0.0150	0.2536	1.0431	0.9754
ATLANTA HARTSFIELD INTL AP GA	0.0364	1.2468	1.0486	1.2506
ATHENS BEN EPPS AP GA	0.0401	1.2361	0.8663	1.1737
ALMA BACON COUNTY AP GA	0.0032	0.1328	1.4866	1.5908
ALBANY DOUGHERTY COUNTY AP GA	0.0011	0.3226	1.8163	1.2110

MOLOKAI (AMOS) HI	0.0000	0.0000	5.8236	1.2619
LIHUE AIRPORT HI	0.0000	0.0000	3.9293	1.0973
LANAI HI	0.0000	0.0000	0.6223	0.0902
KONA INTL AT KEAHOL HI	0.0000	0.0000	9.6635	1.7005
KAPALUA HI	0.0000	0.0000	7.6264	1.4758
KANEOHE BAY MCAS HI	0.0000	0.0000	10.1140	1.7182
KAHULUI AIRPORT HI	0.0000	0.0000	4.4377	1.0538
HONOLULU INTL ARPT HI	0.0000	0.0000	6.3724	1.5536
HILO INTERNATIONAL AP HI	0.0000	0.0000	1.3309	0.5005
BARBERS POINT NAS HI	0.0000	0.0000	7.8090	1.7889
JOSLIN FLD MAGIC VA [TWIN FALLS - UO] ID	0.6010	2.3488	0.0288	0.0000
SODA SPRINGS/TIGERT ID	2.1394	2.7965	0.0000	0.0000
SALMON/LEMHI (AWOS) ID	1.9600	1.9416	0.0015	0.0000
POCATELLO REGIONAL AP ID	1.5354	2.5605	0.0032	0.0000
MOUNTAIN HOME AFB ID	0.9708	2.2054	0.0245	0.1343
MALAD CITY ID	1.3767	1.8484	0.0072	0.0000
LEWISTON NEZ PERCE CNTY AP ID	1.2062	1.7674	0.0862	0.7844
IDAHO FALLS FANNING FIELD ID	2.8258	3.1415	0.0000	0.0000
HAILEY/FRIEDMAN MEM ID	2.4070	1.9082	0.0239	0.1285
COEUR D`ALENE(AWOS) ID	1.8814	2.6274	0.0059	0.0000
CALDWELL (AWOS) ID	0.8028	2.2446	0.0233	0.1023
BURLEY MUNICIPAL ARPT ID	0.9309	2.2474	0.0144	0.0000
BOISE AIR TERMINAL [UO] ID	0.9057	1.6386	0.0229	0.5151
CHICAGO/WAUKEGAN IL	1.9923	3.0089	0.0080	0.1242
UNIV OF ILLINOIS WI [BONDVILLE - SURFRAD] IL	1.4826	3.3876	0.1834	1.2827
STERLING ROCKFALLS IL	2.0697	4.5430	0.0367	0.5636
SPRINGFIELD CAPITAL AP IL	1.0463	2.1299	0.1710	0.9399
ROCKFORD GREATER ROCKFORD AP IL	2.3075	1.9531	0.0229	0.3870
QUINCY MUNI BALDWIN FLD IL	1.0015	2.1466	0.0976	0.5716
PEORIA GREATER PEORIA AP IL	1.3532	2.2157	0.0374	0.5674
MOUNT VERNON (AWOS) IL	0.8960	1.7347	0.1814	0.6132
MOLINE QUAD CITY INTL AP IL	1.4363	1.5864	0.0808	0.9016
MARION REGIONAL IL	0.8141	1.2101	0.5100	1.2189
W. CHICAGO/DU PAGE IL	1.3473	2.4272	0.0331	0.5703
DECATUR IL	1.1355	2.3487	0.2563	0.8119
CHICAGO OHARE INTL AP IL	1.6659	2.1996	0.0621	0.7376
CHICAGO MIDWAY AP IL	1.4607	2.6214	0.3285	1.2173
SOUTHERN ILLINOIS IL	0.1210	2.2251	0.5004	1.3167
CAHOKIA/ST. LOUIS IL	0.6805	1.9662	0.5756	1.4201
CENTRAL ILLINOIS RG IL	2.4155	2.7892	0.0585	0.6342
BELLEVILLE SCOTT AFB IL	1.0286	2.4853	0.2489	1.0754
AURORA MUNICIPAL IL	3.0041	3.6153	0.0133	0.2996

TERRE HAUTE HULMAN IN	1.8053	2.8415	0.4763	1.2047
SOUTH BEND MICHIANA RGNL AP IN	1.6952	1.7707	0.1123	1.2211
MONROE CO IN	1.4648	2.8292	0.1071	0.4913
LAFAYETTE PURDUE UNIV AP IN	2.2065	2.9680	0.0906	1.0177
INDIANAPOLIS INTL AP IN	1.2671	1.6736	0.1174	0.9629
HUNTINGBURG IN	0.1661	1.8060	0.2175	0.7532
GRISSOM ARB IN	1.8185	2.6400	0.0325	0.4244
FORT WAYNE INTL AP IN	2.0793	2.3161	0.0237	0.4995
EVANSVILLE REGIONAL AP IN	0.6742	2.2748	0.4389	1.2063
DELAWARE CO JOHNSON IN	1.5560	1.9101	0.0411	0.5600
WEBSTER CITY IA	2.2410	2.9142	0.2817	0.2817
WATERLOO MUNICIPAL AP IA	2.1683	2.8784	0.0217	0.0217
WASHINGTON IA	1.9175	2.6800	0.0368	0.0368
STORM LAKE IA	2.6020	3.2225	0.0687	0.0687
SPENCER IA	4.8625	4.0144	0.0081	0.0081
SIOUX CITY SIOUX GATEWAY AP IA	1.7433	2.3538	0.1259	0.1259
SHENANDOAH MUNI IA	1.1335	1.6895	0.2417	0.2417
SHELDON IA	2.4927	3.3125	0.0237	0.0237
RED OAK IA	1.2192	2.3076	0.1328	0.1328
OTTUMWA INDUSTRIAL AP IA	2.7899	3.5852	0.1085	0.1085
ORANGE CITY IA	2.6150	3.0433	0.0480	0.0480
OELWEN IA	2.2915	2.8508	0.0215	0.0215
NEWTON MUNI IA	2.3959	4.1581	0.0308	0.0308
MUSCATINE IA	1.7029	2.8943	0.0546	0.0546
MONTICELLO MUNI IA	2.8659	3.8099	0.0304	0.0304
MASON CITY MUNICIPAL ARPT IA	2.7726	3.5926	0.0242	0.0242
LE MARS IA	1.8307	2.8684	0.1286	0.1286
KNOXVILLE IA	1.4147	2.8625	0.3731	0.3731
KEOKUK MUNI IA	0.9287	2.0028	0.2714	0.2714
FORT MADISON IA	0.9596	2.0452	0.1561	0.1561
FORT DODGE (AWOS) IA	2.3953	3.4943	0.0391	0.0391
FAIR FIELD IA	1.5049	2.7791	0.1010	0.1010
ESTHERVILLE MUNI IA	4.1887	3.7197	0.0390	0.0390
DUBUQUE REGIONAL AP IA	2.5867	3.3097	0.0138	0.0138
DES MOINES INTL AP IA	1.3981	2.0087	0.1557	0.1557
DENISON IA	1.9762	3.6938	0.1194	0.1194
DECORAH IA	1.6282	2.8154	0.0988	0.0988
CRESTON IA	1.5515	3.5087	0.0926	0.0926
COUNCIL BLUFFS IA	1.5884	2.5453	0.0650	0.0650
CLINTON MUNI (AWOS) IA	3.0181	3.5738	0.0807	0.0807
CLARINDA IA	1.1793	2.7939	0.2261	0.2261
CHARLES CITY IA	3.1623	4.9871	0.0297	0.0297

CHARITON IA	1.4735	1.9396	0.3320	0.3320
CEDAR RAPIDS MUNICIPAL AP IA	3.8030	3.8211	0.0123	0.0123
CARROLL IA	1.9392	3.1539	0.1312	0.1312
BURLINGTON MUNICIPAL AP IA	1.5897	2.5491	0.6134	0.6134
BOONE MUNI IA	2.5712	3.1217	0.1074	0.1074
ATLANTIC IA	2.5479	3.6553	0.0675	0.0675
ALGONA IA	2.8646	3.7456	0.0374	0.0374
WICHITA MID-CONTINENT AP KS	0.1446	1.7255	0.6408	1.6164
MCCONNELL AFB KS	0.2014	1.7561	0.9084	1.6078
WICHITA/COL. JABARA KS	0.7097	2.0992	0.8152	1.5422
TOPEKA MUNICIPAL AP KS	0.1757	1.3871	0.3124	1.4998
TOPEKA FORBES FIELD KS	0.1913	1.4825	0.2503	1.2018
SALINA MUNICIPAL AP KS	0.1871	2.3700	1.1115	1.5948
RUSSELL MUNICIPAL AP KS	0.1419	1.9583	0.4773	1.6153
OLATHE JOHNSON CO INDUSTRIAL KS	0.6544	1.5397	0.5581	1.1463
OLATHE/JOHNSON CO. KS	0.7679	1.9506	0.6026	1.2046
NEWTON (AWOS) KS	0.6655	1.6685	0.4871	1.3582
MANHATTAN RGNL KS	0.2308	2.2335	0.9159	1.5614
LIBERAL MUNI KS	0.1824	2.1065	0.2828	1.2144
HUTCHINSON MUNICIPAL AP KS	0.1292	1.7567	0.4593	1.3457
HILL CITY MUNICIPAL AP KS	0.1824	1.4162	0.1996	1.4787
HAYS MUNI (AWOS) KS	0.2454	0.8684	0.6279	1.4568
GREAT BEND (AWOS) KS	0.2723	2.0376	0.2838	1.2621
GOODLAND RENNER FIELD KS	0.2715	1.6628	0.0144	0.3218
GARDEN CITY MUNICIPAL AP KS	0.2135	2.1313	0.0814	0.5615
FORT RILEY MARSHALL AAF KS	0.2075	1.8232	0.5846	1.1905
EMPORIA MUNICIPAL AP KS	1.6187	2.6169	0.3975	1.4153
DODGE CITY REGIONAL AP KS	0.2160	1.2257	0.4155	1.5239
CONCORDIA BLOSSER MUNI AP KS	0.2236	2.0894	0.7790	1.8916
CHANUTE MARTIN JOHNSON AP KS	1.0616	2.4772	1.1731	1.3503
SOMERSET(AWOS) KY	0.6175	1.7219	0.1879	0.5707
PADUCAH BARKLEY REGIONAL AP KY	0.4754	1.5767	0.4924	1.2508
LOUISVILLE STANDIFORD FIELD KY	0.9086	1.1138	0.2975	1.1674
LOUISVILLE BOWMAN FIELD KY	0.6386	1.7572	0.2593	1.0170
LONDON-CORBIN AP KY	0.9546	2.1095	0.0995	0.4815
LEXINGTON BLUEGRASS AP KY	0.8920	1.8601	0.1554	0.6526
JACKSON JULIAN CARROLL AP KY	0.5022	1.7121	0.1193	0.4709
HENDERSON CITY KY	0.8361	2.0003	0.0463	0.3197
FORT KNOX GODMAN AAF KY	0.8916	2.6541	0.2544	0.9135
FORT CAMPBELL AAF KY	0.9275	2.0318	1.0169	1.1516
CINCINNATI NORTHERN KY AP KY	1.0241	1.8373	0.0533	0.4235
BOWLING GREEN WARREN CO AP KY	1.1258	2.2679	0.3588	0.9438

SHREVEPORT REGIONAL ARPT LA	0.0206	1.0902	2.2445	1.7090
SHREVEPORT DOWNTOWN LA	0.0251	1.0626	2.8320	1.7696
PATTERSON MEMORIAL LA	0.0000	0.1432	3.6799	1.8052
NEW ORLEANS LAKEFRONT AP LA	0.0000	0.4461	4.3048	1.9134
NEW ORLEANS ALVIN CALLENDER F LA	0.0000	0.0000	3.3592	1.6557
NEW ORLEANS INTL ARPT LA	0.0011	0.0000	3.3984	1.8433
NEW IBERIA NAAS LA	0.0019	0.0000	2.6753	1.5043
MONROE REGIONAL AP LA	0.0325	0.7703	1.8478	1.5845
LAKE CHARLES REGIONAL ARPT LA	0.0025	0.0000	2.7018	1.4053
LAKE CHARLES WB AIRP LA	0.0149	0.9606	2.8235	1.7569
LAFAYETTE REGIONAL AP LA	0.0005	0.1791	2.6721	1.5270
HOUMA-TERREBONNE LA	0.0000	0.2633	3.4052	1.5762
FORT POLK AAF LA	0.0236	1.2764	1.6798	1.2119
BATON ROUGE RYAN ARPT LA	0.0030	0.6897	2.0254	1.7791
BARKSDALE AFB LA	0.0333	1.4557	1.5813	1.3967
ALEXANDRIA ESLER REGIONAL AP LA	0.0039	0.2722	1.7168	1.4241
ENGLAND AFB LA	0.0020	0.4285	1.7564	1.2411
WISCASSET ME	2.2461	3.2395	0.0073	0.0000
WATERVILLE (AWOS) ME	2.5805	3.1761	0.0080	0.0000
SANFORD MUNI (AWOS) ME	1.8430	1.9576	0.0029	0.0000
ROCKLAND/KNOX(AWOS) ME	2.0389	2.6047	0.0024	0.0000
PRESQUE ISLE MUNICIP ME	4.0411	4.4235	0.0020	0.0000
PORTLAND INTL JETPORT ME	1.7053	2.1262	0.0056	0.1744
MILLINOCKET MUNICIPAL AP ME	3.3151	3.1218	0.0031	0.0000
HOULTON INTL ARPT ME	5.3972	3.3707	0.0000	0.0000
NORTHERN AROOSTOOK ME	4.2605	3.1335	0.0000	0.0000
CARIBOU MUNICIPAL ARPT ME	4.3334	2.7723	0.0012	0.0000
BAR HARBOR (AWOS) ME	2.3645	2.2779	0.0007	0.0000
BANGOR INTERNATIONAL AP ME	2.5481	2.6106	0.0154	0.0921
AUGUSTA AIRPORT ME	3.0131	3.0914	0.0069	0.0000
AUBURN-LEWISTON ME	1.9742	2.5824	0.0047	0.0000
SALISBURY WICOMICO CO AP MD	0.1187	1.2541	0.2598	0.8692
PATUXENT RIVER NAS MD	0.0978	1.4216	0.7042	1.1711
HAGERSTOWN RGNL RIC MD	0.8217	2.1463	0.1571	0.8012
BALTIMORE BLT-WASHNGTN INT MD	0.6618	1.1995	0.3321	1.1345
ANDREWS AFB MD	0.2240	1.8125	0.1138	0.7598
WORCHESTER REGIONAL ARPT MA	1.5904	1.9019	0.0099	0.0000
WESTFIELD BARNES MUNI AP MA	1.6213	2.6788	0.0097	0.0000
PROVINCETOWN (AWOS) MA	1.0368	1.9146	0.0236	0.1159
PLYMOUTH MUNICIPAL MA	1.1898	2.4127	0.0083	0.0000
OTIS ANGB MA	1.1964	1.5194	0.0253	0.1343
NORWOOD MEMORIAL MA	1.1271	2.3064	0.0208	0.0969

NORTH ADAMS MA	1.6616	2.4053	0.0027	0.0000
NEW BEDFORD RGNL MA	0.8728	1.7539	0.0414	0.8518
NANTUCKET MEMORIAL AP MA	0.8734	1.8097	0.0147	0.0000
MARTHAS VINEYARD MA	1.0923	1.9559	0.0112	0.0000
LAWRENCE MUNI MA	1.5398	2.6496	0.0066	0.0770
CHICOPEE FALLS WESTO MA	1.7232	2.1736	0.0088	0.3351
BOSTON LOGAN INT ARPT MA	1.1185	1.4624	0.1037	1.1631
BEVERLY MUNI MA	1.4214	2.1898	0.0232	0.6128
BARNSTABLE MUNI BOA MA	1.1236	1.9131	0.0084	0.0675
TRAVERSE CITY CHERRY CAPITAL MI	3.3686	0.0098	0.0098	0.0000
ST.CLAIR COUNTY INT MI	1.9626	0.0186	0.0186	0.3700
SAULT STE MARIE SANDERSON FIE MI	4.0442	0.0013	0.0013	0.0000
SAGINAW TRI CITY INTL AP MI	2.4574	0.0153	0.0153	0.0000
PELLSTON EMMET COUNTY AP MI	3.7936	0.0128	0.0128	0.1582
OSCODA WURTSMITH AFB MI	1.8818	0.0078	0.0078	0.2931
OAKLAND CO INTL MI	2.1144	0.0408	0.0408	0.7222
MUSKEGON COUNTY ARPT MI	2.9242	0.0088	0.0088	0.1131
MOUNT CLEMENS SELFRIDGE FLD MI	1.3000	0.0154	0.0154	0.4116
MENOMINEE (AWOS) MI	3.0210	0.0101	0.0101	0.0000
MANISTEE (AWOS) MI	3.0329	0.0114	0.0114	0.2200
LANSING CAPITAL CITY ARPT MI	2.5402	0.0097	0.0097	0.3112
KALAMAZOO BATTLE CR MI	2.2078	0.0250	0.0250	0.0827
JACKSON REYNOLDS FIELD MI	2.5552	0.0117	0.0117	0.0777
IRONWOOD (AWOS) MI	4.1609	0.0067	0.0067	0.0000
IRON MOUNTAIN FORD MI	4.2017	0.0051	0.0051	0.0000
HOWELL MI	1.7973	0.0377	0.0377	0.5092
HOUGHTON LAKE ROSCOMMON MI	3.7595	0.0039	0.0039	0.0000
HANCOCK HOUGHTON CO AP MI	5.2846	0.0048	0.0048	0.0000
GRAND RAPIDS KENT COUNTY INT MI	2.7436	0.0175	0.0175	0.4459
FLINT BISHOP INTL ARPT MI	2.6234	0.0072	0.0072	0.1758
ESCANABA (AWOS) MI	3.5263	0.0011	0.0011	0.0000
DETROIT WILLOW RUN AP MI	2.5984	0.0363	0.0363	0.5758
DETROIT CITY AIRPORT MI	2.1812	0.1010	0.1010	0.9481
DETROIT METROPOLITAN ARPT MI	1.9529	0.0220	0.0220	0.3444
CHIPPEWA CO INTL MI	3.5003	0.0000	0.0000	0.0000
CADILLAC WEXFORD CO AP MI	2.2838	0.0051	0.0051	0.1018
BENTON HARBOR ROSS MI	3.0020	0.1454	0.1454	1.4270
BATTLE CREEK KELLOGG AP MI	2.2059	0.0236	0.0236	0.0892
ANN ARBOR MUNICIPAL MI	2.0312	0.0093	0.0093	0.0000
ALPENA COUNTY REGIONAL AP MI	3.0964	0.0019	0.0019	0.0000
WORTHINGTON (AWOS) MN	3.7067	3.9877	0.0275	0.0000
WINONA MUNI (AWOS) MN	3.5744	3.4175	0.0164	0.7222

WILLMAR MN	3.1803	4.1886	0.0268	0.6684
WHEATON NDB (AWOS) MN	5.3420	3.9626	0.0143	0.6279
TWO HARBORS MN	4.4241	3.3671	0.0038	0.1871
THIEF RIVER(AWOS) MN	5.0141	4.4067	0.0071	0.0000
ST PAUL DOWNTOWN AP MN	4.0362	4.0137	0.0283	0.8632
ST CLOUD REGIONAL ARPT MN	3.5775	2.9154	0.0072	0.0000
SOUTH ST PAUL MUNI MN	3.0487	3.2437	0.0219	0.4159
SILVER BAY MN	4.0640	4.3931	0.0000	0.0000
ROSEAU MUNI (AWOS) MN	5.1225	3.3681	0.0013	0.0000
ROCHESTER INTERNATIONAL ARPT MN	3.3346	3.7159	0.0101	0.0000
REDWOOD FALLS MUNI MN	4.6172	4.0057	0.0148	0.5336
RED WING MN	3.1203	3.7956	0.0323	0.4779
PIPESTONE (AWOS) MN	4.8861	4.6706	0.0160	0.3500
PARK RAPIDS MUNICIPAL AP MN	5.2117	3.7577	0.0048	0.0000
OWATONNA (AWOS) MN	3.3870	4.9802	0.0215	0.1026
ORR MN	5.8060	4.6579	0.0000	0.0000
NEW ULM MUNI (AWOS) MN	2.9146	3.2899	0.0298	0.8256
MORRIS MUNI (AWOS) MN	3.6827	3.7378	0.0055	0.0000
MORA MUNI (AWOS) MN	4.4161	4.6250	0.0122	0.1078
MINNEAPOLIS-ST PAUL INT ARP MN	2.5160	3.5245	0.0593	0.8473
MINNEAPOLIS CRYSTAL MN	3.8057	3.7791	0.0094	0.1038
MARSHALL RYAN(AWOS) MN	2.8711	3.8587	0.0148	0.2496
MANKATO(AWOS) MN	3.4739	3.5554	0.0157	0.4645
LITTLE FALLS (AWOS) MN	4.2973	4.2424	0.0116	0.1920
LITCHFIELD MUNI MN	4.1177	4.2241	0.0201	0.2625
INTERNATIONAL FALLS INTL AP MN	5.5513	3.6752	0.0034	0.0000
HUTCHINSON (AWOS) MN	3.3747	2.9642	0.0330	0.5884
HIBBING CHISHOLM-HIBBING AP MN	5.4780	3.5623	0.0017	0.0000
HALLOCK MN	5.6759	4.0833	0.0059	0.0000
GRAND RAPIDS(AWOS) MN	4.5873	3.6565	0.0024	0.0000
GLENWOOD (ASOS) MN	3.3159	3.4701	0.0238	0.1103
FOSSTON(AWOS) MN	5.7223	4.8504	0.0028	0.0000
FERGUS FALLS(AWOS) MN	3.5958	3.7703	0.0416	0.2756
FARIBAULT MUNI AWOS MN	3.1894	3.6558	0.0171	0.0000
FAIRMONT MUNI(AWOS) MN	2.4677	3.4527	0.0258	0.2358
EVELETH MUNI (AWOS) MN	4.8759	3.6211	0.0050	0.0000
ELY MUNI MN	5.2485	4.7000	0.0000	0.0000
FLYING CLOUD MN	3.4828	3.2642	0.1268	0.8660
DULUTH INTERNATIONAL ARPT MN	4.2421	2.8805	0.0022	0.0000
DETROIT LAKES(AWOS) MN	4.2302	3.7142	0.0172	0.1044
CROOKSTON MUNI FLD MN	4.4657	3.4706	0.0049	0.0000
CRANE LAKE (AWOS) MN	5.0958	4.1572	0.0011	0.0000

CLOQUET (AWOS) MN	4.3137	3.2457	0.0021	0.0000
CAMBRIDGE MUNI MN	3.9748	4.4311	0.0154	0.0000
BRAINERD WIELAND MN	4.6101	4.5354	0.0065	0.0946
BENSON MUNI MN	4.2695	3.8095	0.0189	0.4966
BEMIDJI MUNICIPAL MN	4.2225	3.6158	0.0053	0.0000
BAUDETTE INTERNATIONAL AP MN	4.7031	3.0614	0.0019	0.0000
AUSTIN MUNI MN	3.6522	3.3899	0.0149	0.0000
ALBERT LEA (AWOS) MN	2.6334	2.9870	0.0673	0.6023
AITKIN NDB(AWOS) MN	3.9378	4.1940	0.0021	0.0000
ALEXANDRIA MUNICIPAL AP MN	5.1648	4.7273	0.0241	0.3901
TUPELO C D LEMONS ARPT MS	0.2732	1.8640	1.4650	1.6655
NATCHEZ/HARDY(AWOS) MS	0.0042	1.1109	1.2268	1.2526
MERIDIAN KEY FIELD MS	0.0210	0.1288	1.1378	1.2032
MERIDIAN NAAS MS	0.0118	0.6614	1.1552	1.8086
MCCOMB PIKE COUNTY AP MS	0.0056	0.9645	1.7476	1.1949
JACKSON INTERNATIONAL AP MS	0.0192	0.3614	1.7132	1.3237
HATTIESBURG LAUREL MS	0.0410	0.6667	0.8073	1.1201
GULFPORT BILOXI INT MS	0.0005	0.0000	2.9313	1.5777
GREENWOOD LEFLORE ARPT MS	0.0246	0.5186	1.3381	1.4289
GREENVILLE MUNICIPAL MS	0.0141	1.1791	2.1235	1.7269
GOLDEN TRI(AWOS) MS	0.1777	1.2573	0.8361	1.0247
COLUMBUS AFB MS	0.1094	1.2950	1.5200	1.3656
KEESLER AFB MS	0.0025	0.1958	2.9538	1.5665
WHITEMAN AFB MO	0.8160	1.9991	0.2307	1.0933
ST LOUIS SPIRIT OF ST LOUIS A MO	0.6649	1.8206	0.3834	1.2342
ST LOUIS LAMBERT INT ARPT MO	0.8218	1.8083	0.8559	1.6501
ST JOSEPH ROSECRANS MEMORIAL MO	0.7696	2.1644	0.5858	1.2005
SPRINGFIELD REGIONAL ARPT MO	0.1024	1.3218	0.2790	1.0337
VICHY ROLLA NATL ARPT MO	0.7621	1.9759	0.1233	0.9570
POPLAR BLUFF(AMOS) MO	0.5338	1.2841	0.8572	1.3567
KIRKSVILLE REGIONAL AP MO	2.1336	2.7789	0.1543	0.8292
KANSAS CITY INT ARPT MO	0.8995	1.3754	0.3119	1.4313
KANSAS CITY DOWNTOWN AP MO	0.1412	1.7012	1.7653	2.0656
KAISER MEM (AWOS) MO	0.7662	2.0131	0.5195	1.5097
JOPLIN MUNICIPAL AP MO	0.4919	1.7770	1.5852	1.7838
JEFFERSON CITY MEM MO	0.7105	1.9304	0.5479	1.0103
FARMINGTON MO	0.1840	2.2646	0.3571	0.7206
COLUMBIA REGIONAL AIRPORT MO	0.9193	2.2042	0.2308	1.1859
CAPE GIRARDEAU MUNICIPAL AP MO	0.7870	2.3363	0.2806	0.7398
WOLF POINT INTL FORT PECK MT	4.0969	3.2776	0.0000	0.0000
SIDNEY-RICHLAND MT	5.6164	4.3871	0.0116	0.1042
MISSOULA INTERNATIONAL AP MT	2.5535	2.4466	0.0016	0.0000

MILES CITY MUNICIPAL ARPT MT	2.0507	3.1988	0.0403	0.8810
LIVINGSTON MISSION FIELD MT	1.2020	3.6775	0.0023	0.0000
LEWISTOWN MUNICIPAL ARPT MT	1.7424	2.7243	0.0000	0.0000
KALISPELL GLACIER PK INT AR MT	3.1995	2.6474	0.0009	0.0000
HELENA REGIONAL AIRPORT MT	1.7346	2.3407	0.0026	0.0000
HAVRE CITY-COUNTY AP MT	2.2548	3.9937	0.0053	0.0000
GREAT FALLS INTL ARPT MT	1.9471	4.5764	0.0045	0.0000
GLENDIVE(AWOS) MT	4.2357	3.7806	0.0226	0.1688
GLASGOW INTL ARPT MT	3.0055	4.0973	0.0168	0.1126
CUT BANK MUNI AP MT	1.8062	4.0425	0.0000	0.0000
BUTTE BERT MOONEY ARPT MT	1.7433	2.6777	0.0000	0.0000
BOZEMAN GALLATIN FIELD MT	2.3330	3.2780	0.0014	0.0000
BILLINGS LOGAN INT ARPT MT	1.4042	2.4451	0.0186	0.1357
VALENTINE MILLER FIELD NE	1.1538	3.5154	0.0320	0.8148
TEKAMAH (ASOS) NE	2.5474	3.4155	0.1148	0.8837
SIDNEY MUNICIPAL AP NE	1.2280	2.5450	0.0072	0.0000
SCOTTSBLUFF W B HEILIG FIELD NE	1.1945	1.9444	0.0153	0.0000
ORD/SHARP FIELD NE	1.2658	1.2838	0.0302	0.5322
O`NEILL/BAKER FIELD NE	2.9745	3.5901	0.0442	0.6414
OMAHA EPPLEY AIRFIELD NE	1.4857	2.3769	0.2707	1.1660
OMAHA WSFO NE	1.2806	1.9836	0.2022	1.0813
NORTH PLATTE REGIONAL AP NE	1.0763	2.4300	0.0159	0.4789
NORFOLK KARL STEFAN MEM ARPT NE	1.4826	2.3914	0.1279	1.1034
MCCOOK MUNICIPAL NE	0.2659	2.7639	0.1994	1.0357
LINCOLN MUNICIPAL ARPT NE	1.1285	3.4672	0.2190	1.3674
KEARNEY MUNI (AWOS) NE	0.2569	3.2405	0.0573	0.7038
IMPERIAL FAA AP NE	0.3287	1.9056	0.0548	0.7082
BREWSTER FIELD ARPT NE	0.8477	3.6550	0.0247	0.5745
HASTINGS MUNICIPAL NE	1.0541	3.0840	0.2192	0.9990
GRAND ISLAND CENTRAL NE REGIO NE	1.3850	2.2053	0.0622	0.8445
FREMONT MUNI ARPT NE	2.7241	2.8828	0.0292	0.5531
FALLS CITY/BRENNER NE	1.3233	2.6157	0.1043	1.1082
COLUMBUS MUNI NE	2.2928	3.2332	0.1285	0.9621
CHADRON MUNICIPAL AP NE	1.0769	3.5378	0.0478	0.2881
BROKEN BOW MUNI NE	1.4795	3.2157	0.0239	0.2409
BELLEVUE OFFUTT AFB NE	1.5539	3.6942	0.1379	0.8167
BEATRICE MUNICIPAL NE	0.8901	2.5621	0.3697	1.5492
ALLIANCE MUNICIPAL NE	0.2537	3.8230	0.0190	0.0000
AINSWORTH MUNICIPAL NE	0.2242	3.1543	0.0426	0.2837
WINNEMUCCA MUNICIPAL ARPT NV	0.2677	1.6798	0.0110	0.0000
TONOPAH AIRPORT NV	0.1844	1.0422	0.0363	0.2107
RENO TAHOE INTERNATIONAL AP NV	0.2598	2.0161	0.0169	0.0000

NELLIS AFB NV	0.0035	0.2588	6.3012	3.2947
MERCURY DESERT ROCK AP NV	0.0088	0.6955	2.7660	2.3985
LOVELOCK DERBY FIELD NV	0.2141	1.3903	0.0319	0.4239
LAS VEGAS MCCARRAN INTL AP NV	0.0020	0.0000	4.7343	2.8671
FALLON NAAS NV	0.1712	1.5656	0.0398	0.3816
ELY YELLAND FIELD NV	0.3278	1.3034	0.0014	0.0000
ELKO MUNICIPAL ARPT NV	1.2862	2.2825	0.0033	0.0000
PEASE INTL TRADEPOR NH	1.8447	2.4842	0.0062	0.1639
MOUNT WASHINGTON NH	7.4928	4.1215	0.0000	0.0000
MANCHESTER AIRPORT NH	1.1236	2.1922	0.0131	0.3301
LEBANON MUNICIPAL NH	2.5840	2.7808	0.0036	0.0000
LACONIA MUNI (AWOS) NH	2.0095	2.4384	0.0129	0.1016
DILLANT HOPKINS NH	1.9526	2.9502	0.0070	0.0000
CONCORD MUNICIPAL ARPT NH	2.0283	2.5276	0.0057	0.0000
BERLIN MUNICIPAL NH	3.6971	2.1884	0.0000	0.0000
TRENTON MERCER COUNTY AP NJ	0.8354	1.8695	0.3390	1.2735
TETERBORO AIRPORT NJ	0.1578	1.5168	0.0159	0.3196
NEWARK INTERNATIONAL ARPT NJ	0.9146	1.6330	0.3715	1.3965
MILLVILLE MUNICIPAL AP NJ	0.1296	1.3253	0.1182	0.8814
MCGUIRE AFB NJ	0.8418	2.1856	0.0856	0.9214
CAPE MAY CO NJ	0.1087	0.4932	0.6238	1.8120
CALDWELL ESSEX CO. NJ	0.1670	1.1718	0.0115	0.3448
BELMAR ASC NJ	0.1263	1.7024	0.1625	1.1326
ATLANTIC CITY INTL AP NJ	0.7130	0.6888	0.1057	0.8915
TUCUMCARI FAA AP NM	0.0824	0.5560	0.2074	0.8022
TRUTH OR CONSEQUENCES MUNI AP NM	0.0054	0.0000	0.5977	1.0007
TAOS MUNI APT(AWOS) NM	0.2515	0.9382	0.0000	0.0000
SIERRA BLANCA RGNL NM	0.0215	0.5947	0.0154	0.0000
ROSWELL INDUSTRIAL AIR PARK NM	0.0115	0.5950	1.0215	1.4535
LAS VEGAS MUNICIPAL ARPT NM	0.0783	0.6365	0.0028	0.0000
LAS CRUCES INTL NM	0.0177	0.3992	1.7054	1.7813
HOLLOMAN AFB NM	0.0249	0.3637	0.5427	1.2105
GALLUP SEN CLARKE FLD NM	0.1971	2.0421	0.0045	0.0000
FARMINGTON FOUR CORNERS REGL NM	0.1217	0.5945	0.0337	0.0675
DEMING MUNI NM	0.0043	0.0000	0.6245	1.2697
CLOVIS CANNON AFB NM	0.1495	2.6431	0.1583	1.1248
CLOVIS MUNI (AWOS) NM	0.0882	1.4692	0.1612	0.5254
CLAYTON MUNICIPAL AIRPARK NM	0.1069	1.6821	0.0347	0.2888
CARLSBAD CAVERN CITY AIR TERM NM	0.0180	0.3253	1.5323	1.5050
ALBUQUERQUE INTL ARPT NM	0.0530	0.6175	0.1520	0.8124
WHITE PLAINS WESTCHESTER CO A NY	0.7363	1.7797	0.0280	0.6579
WESTHAMPTON GABRESKI AP NY	0.9784	1.3537	0.0099	0.1041

WATERTOWN AP NY	3.3595	2.7031	0.0037	0.0000
UTICA ONEIDA COUNTY AP NY	2.4101	2.5010	0.0045	0.0000
SYRACUSE HANCOCK INT ARPT NY	2.0289	2.3358	0.0161	0.0000
ADIRONDACK RGNL NY	3.1034	2.9639	0.0000	0.0000
ROCHESTER GREATER ROCHESTER I NY	2.2341	2.1663	0.0092	0.2013
REPUBLIC NY	0.2559	1.3072	0.2414	1.1875
POUGHKEEPSIE DUTCHESS CO AP NY	1.0402	2.4622	0.0091	0.0000
NIAGARA FALLS AF NY	3.0684	3.0644	0.0642	0.6026
STEWART FIELD NY	1.2939	2.3590	0.0394	0.6950
NEW YORK LAGUARDIA ARPT NY	0.0906	1.4429	0.7725	1.2166
NEW YORK J F KENNEDY INT AR NY	0.8761	1.2208	0.3857	0.7285
NEW YORK CENTRAL PRK OBS BELV NY	0.7096	1.5899	0.0064	1.0846
MONTICELLO(AWOS) NY	1.8645	1.9584	0.0057	0.0000
MASSENA AP NY	2.9917	2.6096	0.0047	0.0000
JAMESTOWN (AWOS) NY	2.7701	3.0651	0.2157	0.0000
ISLIP LONG ISL MACARTHUR AP NY	0.8236	1.4738	0.0081	0.6421
GLENS FALLS AP NY	2.4343	3.4818	0.0080	0.0000
FORT DRUM WHEELER-S NY	3.5781	3.1117	0.0019	0.0000
ELMIRA CORNING REGIONAL AP NY	1.3915	1.8673	0.0187	0.0000
BUFFALO NIAGARA INTL AP NY	2.2447	2.0912	0.0079	0.0777
BINGHAMTON EDWIN A LINK FIELD NY	2.0595	2.2839	0.0174	0.0000
ALBANY COUNTY AP NY	1.8535	2.2753		0.0866
WINSTON-SALEM REYNOLDS AP NC	0.0552	1.8189	0.2802	1.0168
WILMINGTON INTERNATIONAL ARPT NC	0.0296	0.0000	1.3677	1.6060
SOUTHERN PINES AWOS NC	0.0349	1.8241	0.3721	0.7855
ROCKY MOUNT WILSON NC	0.0290	0.3575	0.2205	1.0793
RALEIGH DURHAM INTERNATIONAL NC	0.0707	0.7222	0.4477	0.9780
PITT GREENVILLE ARP NC	0.0571	1.8443	0.4364	0.9310
NEW RIVER MCAF NC	0.0258	1.3589	1.7888	1.9266
NEW BERN CRAVEN CO REGL AP NC	0.0064	0.2657	0.9968	1.1149
DARE CO RGNL NC	0.0548	1.0912	1.3757	1.6628
KINSTON STALLINGS AFB NC	0.0813	1.6343	0.9191	1.4717
JACKSONVILLE (AWOS) NC	0.0433	1.4948	0.2575	0.7809
HICKORY REGIONAL AP NC	0.0792	1.3153	0.3552	0.7729
GREENSBORO PIEDMONT TRIAD INT NC	0.1328	1.8424	0.4835	1.2224
GOLDSBORO SEYMOUR JOHNSON AFB NC	0.1029	1.6404	0.7466	1.2968
FORT BRAGG SIMMONS AAF NC	0.0345	1.1554	1.0106	1.4192
FAYETTEVILLE POPE AFB NC	0.1095	1.6385	1.0703	1.4921
FAYETTEVILLE RGNL G NC	0.0746	1.4801	0.8340	1.2476
ELIZABETH CITY COAST GUARD AI NC	0.0336	0.6838	1.2585	1.1970
CHERRY POINT MCAS NC	0.0309	1.4604	1.7446	1.7394
CHARLOTTE DOUGLAS INTL ARPT NC	0.0506	1.3276	0.9987	1.4186

CAPE HATTERAS NWS BLDG NC	0.0310	0.8613	1.7946	1.3415
ASHEVILLE REGIONAL ARPT NC	0.1383	1.3525	0.0090	0.0000
WILLISTON SLOULIN INTL AP ND	3.3893	2.5650	0.0127	0.2480
MINOT FAA AP ND	3.6680	3.5996	0.0085	0.0000
MINOT AFB ND	2.9700	3.1596	0.0054	0.0000
JAMESTOWN MUNICIPAL ARPT ND	6.0825	5.5193	0.0120	0.0000
GRAND FORKS INTERNATIONAL AP ND	6.1577	4.9236	0.0103	0.0908
GRAND FORKS AF ND	3.4459	3.5170	0.0060	0.0000
FARGO HECTOR INTERNATIONAL AP ND	4.0854	3.8094	0.0094	0.0000
DICKINSON MUNICIPAL AP ND	4.8619	4.2897	0.0120	0.0000
DEVILS LAKE(AWOS) ND	5.8745	4.4398	0.0036	0.0000
BISMARCK MUNICIPAL ARPT ND	3.2160	3.7537	0.0095	0.0000
ZANESVILLE MUNICIPAL AP OH	1.2918	1.9758	0.0058	0.0000
YOUNGSTOWN REGIONAL AIRPORT OH	2.3869	2.4442	0.0053	0.1136
TOLEDO EXPRESS AIRPORT OH	2.0644	2.5884	0.0217	0.0808
OHIO STATE UNIVERSI OH	1.0319	2.6230	0.2911	0.9048
MANSFIELD LAHM MUNICIPAL ARPT OH	2.3379	2.6774	0.0346	0.6163
FINDLAY AIRPORT OH	1.4253	2.9019	0.0146	0.0000
DAYTON INTERNATIONAL AIRPORT OH	1.5113	2.3169	0.0456	0.3000
COLUMBUS PORT COLUMBUS INTL A OH	1.3442	2.4586	0.0241	0.2106
CLEVELAND HOPKINS INTL AP OH	2.1788	2.3086	0.0510	0.5582
BURKE LAKEFRONT OH	2.1192	2.2631	0.0610	0.8353
CINCINNATI MUNICIPAL AP LUNKI OH	0.8734	1.5115	0.1203	0.8519
AKRON AKRON-CANTON REG AP OH	2.2767	2.3437	0.0195	0.4245
VANCE AFB OK	0.2107	2.7562	1.1411	1.7745
TULSA INTERNATIONAL AIRPORT OK	0.1195	1.4722	1.9592	2.0301
STILLWATER RGNL OK	0.4068	2.5697	1.7514	1.8417
PONCA CITY MUNICIPAL AP OK	0.0721	1.8021	2.8109	2.1367
OKLAHOMA CITY WILL ROGERS WOR OK	0.0684	0.8137	1.6112	1.8721
OKLAHOMA CITY WILEY OK	0.1670	2.3787	1.6194	1.7916
OKLAHOMA CITY TINKER AFB OK	0.1842	2.3331	1.6712	1.5477
MCALESTER MUNICIPAL AP OK	0.0440	2.1209	1.6795	1.7541
LAWTON MUNICIPAL OK	0.0246	0.8357	1.5299	1.5295
HOBART MUNICIPAL AP OK	0.1099	1.4489	2.4349	2.0028
GAGE AIRPORT OK	0.1160	0.8622	1.1497	1.4076
FORT SILL POST FIELD AF OK	0.0579	1.7258	2.2639	2.1063
CLINTON-SHERMAN OK	0.1434	2.1446	0.8942	1.7509
BARTLESVILLE PHILLI OK	0.1240	1.5311	0.4601	1.2298
ALTUS AFB OK	0.0486	2.3039	2.5272	2.3633
SEXTON SUMMIT OR	0.2352	1.4845	0.0051	0.0000
SALEM MCNARY FIELD OR	0.7147	1.1243	0.0047	0.0000
ROSEBURG REGIONAL AP OR	0.4260	1.4588	0.0061	0.0000

REDMOND ROBERTS FIELD OR	1.1481	1.9997	0.0012	0.0000
PORTLAND TROUTDALE OR	0.7038	1.0921	0.0061	0.0000
PORTLAND HILLSBORO OR	0.7786	1.4080	0.0017	0.0000
PORTLAND INTERNATIONAL AP OR	0.6505	1.3114	0.0078	0.0000
PENDLETON E OR REGIONAL AP OR	1.0541	2.2913	0.0359	0.2721
NORTH BEND MUNI AIRPORT OR	0.1275	0.8363	0.0000	0.0000
MEDFORD ROGUE VALLEY INTL OR	0.6441	1.2765	0.0100	0.0000
LAKEVIEW (AWOS) OR	1.2383	2.4600	0.0017	0.0000
LA GRANDE MUNI AP OR	1.0050	1.9889	0.0018	0.0000
KLAMATH FALLS INTL OR	1.3024	1.7520	0.0016	0.0000
EUGENE MAHLON SWEET ARPT OR	0.9571	1.6012	0.0065	0.0000
CORVALLIS MUNI OR	0.5594	1.2975	0.0041	0.0000
BURNS MUNICIPAL ARPT OR	1.2537	2.0780	0.0011	0.0000
BAKER MUNICIPAL AP OR	1.1771	2.2222	0.0009	0.0000
AURORA STATE OR	0.5409	0.9895	0.0064	0.0000
ASTORIA REGIONAL AIRPORT OR	0.6689	1.0649	0.0018	0.0000
WILLOW GROVE NAS PA	0.6804	0.8429	0.0867	0.8198
WILLIAMSPORT REGIONAL AP PA	1.3475	1.8171	0.0144	0.3147
WILKES-BARRE SCRANTON INTL AP PA	1.6988	1.5987	0.0087	0.1374
WASHINGTON (AWOS) PA	1.1389	2.4042	0.0117	0.0000
STATE COLLEGE PENN STATE PA	1.4342	2.6549	0.0108	0.0000
READING SPAATZ FIELD PA	0.9108	1.5253	0.0230	0.3385
PITTSBURGH ALLEGHENY CO AP PA	1.4459	2.1084	0.0102	0.1857
PITTSBURGH INTERNATIONAL AP PA	1.5021	1.9112	0.0191	0.2530
PHILADELPHIA NE PHILADELPHIA PA	0.7729	1.9740	0.5193	1.3656
PHILADELPHIA INTERNATIONAL AP PA	0.7572	2.1142	0.2597	1.0783
LANCASTER PA	0.6267	1.9060	0.0344	0.5260
JOHNSTOWN CAMBRIA COUNTY AP PA	2.0408	2.5210	0.0150	0.0000
HARRISBURG CAPITAL CITY ARPT PA	0.9543	1.5152	0.0680	0.6335
MIDDLETOWN HARRISBURG INTL AP PA	1.6161	2.2442	0.2277	1.3180
FRANKLIN PA	2.0127	2.6710	0.0044	0.0000
ERIE INTERNATIONAL AP PA	2.5979	2.1221	0.0119	0.1087
DUBOIS FAA AP PA	2.8743	2.7925	0.0065	0.0000
BUTLER CO. (AWOS) PA	1.4098	2.3472	0.0081	0.0000
BRADFORD REGIONAL AP PA	3.2165	2.3934	0.0019	0.0000
ALTOONA BLAIR CO ARPT PA	1.1070	2.2570	0.0112	0.2133
ALLENTOWN LEHIGH VALLEY INTL PA	1.1617	1.4955	0.0210	0.2687
PROVIDENCE T F GREEN STATE AR RI	1.0308	0.8580	0.0327	0.4299
PAWTUCKET (AWOS) RI	1.3701	2.0865	0.0135	0.1004
BLOCK ISLAND STATE ARPT RI	0.9171	1.3425	0.0193	0.1610
SUMTER SHAW AFB SC	0.0669	0.9769	0.9320	1.3840
NORTH MYRTLE BEACH SC	0.0053	0.3464	2.0720	1.8631

MYRTLE BEACH AFB SC	0.0058	0.3003	2.1270	1.5564
GREER GREENV-SPARTANBRG AP SC	0.0563	1.2222	0.7793	1.1567
GREENVILLE DOWNTOWN AP SC	0.1314	1.1966	0.5590	1.2902
FLORENCE REGIONAL AP SC	0.0062	0.3713	2.2927	1.8348
COLUMBIA METRO ARPT SC	0.0278	0.7165	0.9956	1.4055
CHARLESTON INTL ARPT SC	0.0046	1.1678	2.1037	1.5223
BEAUFORT MCAS SC	0.0031	0.2703	1.6032	1.4050
ANDERSON COUNTY AP SC	0.1063	0.6797	0.7089	1.1719
CHAN GURNEY MUNI SD	2.4068	3.7202	0.1849	1.1468
WATERTOWN MUNICIPAL AP SD	5.1530	4.4577	0.0105	0.0000
SIOUX FALLS FOSS FIELD SD	2.2898	2.2353	0.0164	0.3797
RAPID CITY REGIONAL ARPT SD	1.4620	1.7248	0.0172	0.0000
PIERRE MUNICIPAL AP SD	1.8754	3.2708	0.0738	1.1599
MOBRIDGE SD	3.9792	3.7565	0.0478	0.3121
MITCHELL (AWOS) SD	2.8960	4.5179	0.0749	0.6740
HURON REGIONAL ARPT SD	2.4698	4.2493	0.0346	0.9117
ELLSWORTH AFB SD	2.1170	3.3082	0.0487	0.8318
BROOKINGS (AWOS) SD	3.4859	3.6359	0.0132	0.2674
ABERDEEN REGIONAL ARPT SD	2.8373	3.7668	0.0140	0.5343
NASHVILLE INTERNATIONAL AP TN	0.1110	1.3693	1.0079	1.3969
MEMPHIS INTERNATIONAL AP TN	0.0630	0.9067	2.1638	1.6490
KNOXVILLE MCGHEE TYSON AP TN	0.1131	0.8697	0.4287	0.9951
JACKSON MCKELLAR-SIPES REGL A TN	0.4176	1.8134	0.3076	1.0330
DYERSBURG MUNICIPAL AP TN	0.0810	1.6467	1.0486	1.2897
CROSSVILLE MEMORIAL AP TN	0.7354	1.9071	0.0522	0.3897
CHATTANOOGA LOVELL FIELD AP TN	0.0715	0.9200	0.7681	1.2675
BRISTOL TRI CITY AIRPORT TN	0.6108	1.2788	0.0370	0.0992
WINK WINKLER COUNTY AP TX	0.0029	0.6408	2.7468	2.2301
WICHITA FALLS MUNICIPAL ARPT TX	0.0233	1.1676	1.9584	2.0788
WACO REGIONAL AP TX	0.0072	0.6105	2.9042	2.1991
VICTORIA REGIONAL AP TX	0.0000	0.0000	3.5434	1.7070
TYLER POUNDS FLD TX	0.0071	0.0958	1.8490	2.1040
SAN ANTONIO STINSON TX	0.0000	0.1746	3.0240	1.8319
SAN ANTONIO KELLY FIELD AFB TX	0.0027	1.4879	3.7355	1.9275
SAN ANTONIO INTL AP TX	0.0008	0.4025	3.5591	1.8139
SAN ANGELO MATHIS FIELD TX	0.0104	0.9689	1.4639	1.6701
ROCKPORT ARANSAS CO TX	0.0000	0.0000	5.5086	1.8483
RANDOLPH AFB TX	0.0053	1.6085	2.8752	1.4015
PORT ARTHUR JEFFERSON COUNTY TX	0.0013	0.2338	3.2062	1.4134
PALACIOS MUNICIPAL AP TX	0.0021	0.9658	3.6760	1.5554
NACOGDOCHES (AWOS) TX	0.0174	0.8930	1.2328	1.6298
MINERAL WELLS MUNICIPAL AP TX	0.0352	1.2347	2.3615	2.0721

MIDLAND INTERNATIONAL AP TX	0.0068	0.8712	1.4235	1.5122
MC GREGOR (AWOS) TX	0.0294	1.0687	2.6766	1.6358
MCALLEN MILLER INTL AP TX	0.0000	0.2939	5.1530	1.9975
MARFA AP TX	0.0097	0.3010	0.0184	0.0000
LUFKIN ANGELINA CO TX	0.0040	0.7358	1.7868	1.4211
LUBBOCK INTERNATIONAL AP TX	0.0364	1.2467	0.5801	1.2203
LONGVIEW GREGG COUNTY AP TX	0.0103	0.7374	1.9106	1.9262
LAREDO INTL AP TX	0.0010	1.3351	5.4040	2.2923
KINGSVILLE TX	0.0000	0.1329	3.9084	2.0861
KILLEEN MUNI (AWOS) TX	0.0065	1.1870	2.4951	1.5618
HOUSTON WILLIAM P HOBBY AP TX	0.0000	0.0000	3.3320	1.6549
HOUSTON ELLINGTON AFB TX	0.0000	0.5230	3.2377	1.4260
HOUSTON D.W. HOOKS TX	0.0000	0.6734	2.8872	1.4845
HOUSTON BUSH INTERCONTINENTAL TX	0.0007	0.1953	3.1951	1.7967
HONDO MUNICIPAL AP TX	0.0021	0.4434	2.8759	1.3975
HARLINGEN RIO GRANDE VALLEY I TX	0.0000	0.0000	4.7808	1.8558
GREENVILLE MAJORS TX	0.0559	1.4377	1.7932	1.6543
GEORGETOWN (AWOS) TX	0.0050	1.5312	2.6981	1.6896
GALVESTON SCHOLES TX	0.0000	0.1455	6.4925	2.2953
FORT WORTH MEACHAM TX	0.0359	0.9414	3.0470	2.1304
FORT WORTH ALLIANCE TX	0.0273	1.0090	1.8473	1.6890
FORT WORTH NAS TX	0.0026	0.1965	3.0044	1.8389
FORT HOOD TX	0.0127	0.9676	3.2574	1.7893
EL PASO INTERNATIONAL AP TX	0.0020	0.0000	1.7891	1.7590
DRAUGHON MILLER CEN TX	0.0039	1.2910	2.4209	1.5842
DEL RIO LAUGHLIN AFB TX	0.0000	0.0000	5.7394	2.7112
DEL RIO TX	0.0000	0.1320	3.9845	1.9217
DALLAS REDBIRD ARPT TX	0.0028	1.1711	3.6742	2.3849
DALLAS LOVE FIELD TX	0.0046	1.4132	4.8225	2.5077
DALLAS-FORT WORTH INTL AP TX	0.0109	0.7402	3.2267	2.1494
DALLAS ADDISON ARPT TX	0.0467	1.8853	3.8337	2.6565
DALHART MUNICIPAL AP TX	0.2604	1.8376	0.0805	0.4632
COX FLD TX	0.0311	1.5022	1.3991	1.3798
COTULLA FAA AP TX	0.0000	0.0000	4.7228	2.2977
CORPUS CHRISTI NAS TX	0.0000	0.1196	5.7719	1.9006
CORPUS CHRISTI INTL ARPT TX	0.0000	0.3094	4.1227	1.6361
COLLEGE STATION EASTERWOOD FL TX	0.0005	0.3898	2.6874	1.9776
CHILDRESS MUNICIPAL AP TX	0.0363	1.2235	1.5205	1.6855
BROWNSVILLE S PADRE ISL INTL TX	0.0000	0.0000	5.2638	1.8370
AUSTIN MUELLER MUNICIPAL AP TX	0.0007	0.3613	2.6609	1.7466
CAMP MABRY TX	0.0011	0.5098	3.3884	1.9685
AMARILLO INTERNATIONAL AP TX	0.0697	1.5849	0.2501	1.1932

ALICE INTL AP TX	0.0000	0.0000	4.7161	2.2637
ABILENE DYESS AFB TX	0.0093	2.0522	3.5651	2.5209
ABILENE REGIONAL AP TX	0.0316	0.7584	1.8266	1.9976
WENDOVER USAF AUXILIARY FIELD UT	0.1823	2.0854	0.2780	0.9213
VERNAL UT	1.1316	1.9760	0.0070	0.0000
SALT LAKE CITY INT ARPT UT	0.8271	1.3289	0.2410	0.8293
SAINT GEORGE (AWOS) UT	0.0074	0.0000	3.8490	2.7632
PROVO MUNI (AWOS) UT	0.1747	1.1616	0.0182	0.1942
OGDEN HINKLEY AIRPORT UT	0.2117	1.3835	0.2047	0.8045
OGDEN HILL AFB UT	1.1276	1.8562	0.0952	0.6157
MOAB CANYONLANDS UT	0.1708	0.4911	0.3259	1.0808
HANKSVILLE UT	0.5776	1.4956	0.4430	1.9044
DELTA UT	0.8600	1.8383	0.0226	0.0000
CEDAR CITY MUNICIPAL AP UT	0.1904	0.8777	0.0099	0.2412
BRYCE CNYN FAA AP UT	1.7336	1.7897	0.0000	0.0000
BLANDING UT	0.4373	1.6495	0.0983	0.5373
SPRINGFIELD HARTNES VT	3.1277	2.7946	0.0015	2.7946
RUTLAND STATE VT	2.8180	2.9247	0.0091	2.9247
MONTPELIER AP VT	2.5245	2.6697	0.0028	2.6697
BURLINGTON INTERNATIONAL AP VT	2.5538	2.5340	0.0070	2.5340
WISE/LONESOME PINE VA	0.9167	2.2635	0.0258	0.0000
WINCHESTER RGNL VA	0.8950	2.1046	0.1919	0.9229
WASHINGTON DC DULLES INT VA	0.6990	1.3587	0.1072	0.7689
STAUNTON SHENANDOAH VA	0.1929	1.5702	0.1076	0.9957
ROANOKE REGIONAL AP VA	0.1553	1.2458	0.1071	0.3593
RICHMOND INTERNATIONAL AP VA	0.1165	0.9170	0.5598	1.4914
QUANTICO MCAS VA	0.1133	0.9726	0.3881	0.6783
PULASKI VA	0.8568	2.2032	0.0066	0.0000
OCEANA NAS VA	0.0671	0.4370	1.1237	1.4620
NORFOLK NAS VA	0.0475	0.5843	0.9463	1.4497
NORFOLK INTERNATIONAL AP VA	0.1093	0.9058	1.1106	1.3525
NEWPORT NEWS VA	0.0846	0.8332	0.7395	1.4446
MELFA ACCOMACK ARPT VA	0.0895	1.1783	0.6003	1.2297
MARTINSVILLE VA	0.1726	1.8328	0.1055	0.5142
MARION WYTHEVILLE VA	0.8953	2.3430	0.0214	0.0000
MANASSAS MUNI(AWOS) VA	0.2148	1.6217	0.0534	0.2986
LYNCHBURG REGIONAL ARPT VA	0.1432	0.4914	0.2457	0.8023
LEESBURG GODFREY VA	0.1812	1.1508	0.1549	0.6858
LANGLEY AFB VA	0.1235	0.8775	0.5865	1.3122
HOT SPRINGS INGALLS VA	1.3724	2.5093	0.0038	0.0000
HILLSVILLE VA	0.8172	2.4808	0.0110	0.0977
SHANNON ARPT VA	0.1697	1.4246	0.3280	1.0504

FRANKLIN NAAS VA	0.0173	0.4393	0.5599	1.2132
FARMVILLE VA	0.1724	1.6064	0.1219	0.9762
DAVISON AAF VA	0.1981	1.7093	0.2221	1.0800
DANVILLE FAA AP VA	0.1267	1.4834	0.7120	1.0626
CHARLOTTESVILLE FAA VA	0.1148	1.4438	0.0871	0.9366
VIRGINIA TECH ARPT VA	1.0133	1.8845	0.0230	0.0000
WASHINGTON DC REAGAN AP VA	0.1589	1.0515	0.9749	1.6646
ABINGTON VA	0.7449	2.5125	0.0971	0.5349
YAKIMA AIR TERMINAL WA	1.6837	2.2331	0.0083	0.0000
WHIDBEY ISLAND NAS WA	1.0265	1.2601	0.0000	0.0000
WENATCHEE PANGBORN WA	1.6138	2.2107	0.0626	0.3171
WALLA WALLA CITY COUNTY AP WA	1.0931	2.0736	0.0923	0.7123
TOLEDO-WINLOCK MEM WA	1.9569	2.2791	0.0000	0.0000
THE DALLES MUNICIPAL ARPT WA	0.9566	1.6688	0.0685	0.6255
TACOMA MCCHORD AFB WA	1.3602	1.5622	0.0016	0.0000
TACOMA NARROWS WA	0.9062	1.2665	0.0023	0.0000
STAMPEDE PASS WA	2.4926	2.3323	0.0000	0.0000
FELTS FLD WA	1.6354	2.0881	0.0101	0.0000
SPOKANE INTERNATIONAL AP WA	2.1180	2.3024	0.0051	0.0000
SNOHOMISH CO WA	0.8402	1.1174	0.0016	0.0000
SEATTLE-TACOMA INTL A WA	0.8892	1.3721	0.0023	0.0000
SEATTLE BOEING FIELD WA	0.8070	1.6772	0.0063	0.0000
RENTON MUNI WA	0.7039	1.5615	0.0059	0.0000
QUILLAYUTE STATE AIRPORT WA	1.1389	1.3687	0.0000	0.0000
PULLMAN/MOSCOW RGNL WA	1.2688	2.5858	0.0022	0.0000
WILLIAM R FAIRCHILD WA	1.3319	1.4561	0.0000	0.0000
PASCO WA	0.9402	2.0336	0.0364	0.0000
OLYMPIA AIRPORT WA	1.4586	1.4865	0.0013	0.0000
MOSES LAKE GRANT COUNTY AP WA	1.4636	2.0372	0.0577	0.4610
KELSO WB AP WA	0.5783	1.4618	0.0014	0.0000
HOQUIAM AP WA	0.6515	1.5759	0.0000	0.0000
HANFORD WA	1.9299	3.7376	0.1250	0.8538
GRAY AAF WA	1.3817	2.4616	0.0011	0.0000
FAIRCHILD AFB WA	2.7683	3.3314	0.0280	0.1550
EPHRATA AP FCWOS WA	1.8018	3.0815	0.1950	1.5209
BREMERTON NATIONAL WA	1.0456	1.6364	0.0000	0.0000
BELLINGHAM INTL AP WA	1.3443	1.6802	0.0009	0.0000
WHEELING OHIO COUNTY AP WV	1.4001	2.6282	0.0156	0.0000
PARKERSBURG WOOD COUNTY AP WV	1.2287	2.2180	0.0883	0.7204
MORGANTOWN HART FIELD WV	1.6615	2.8620	0.0065	0.0000
MARTINSBURG EASTERN WV REG AP WV	0.6269	1.4085	0.0338	0.3944
LEWISBURG GREENBRIE WV	1.7165	2.3181	0.0038	0.0000

HUNTINGTON TRI-STATE ARPT WV	0.7862	1.5918	0.1133	0.7214
ELKINS ELKINS-RANDOLPH CO ARP WV	1.4377	2.8084	0.0038	0.0000
HARRISON MARION RGN WV	1.3288	2.3904	0.0224	0.1645
CHARLESTON YEAGER ARPT WV	0.8007	2.3890	0.1058	0.7256
BLUEFIELD MERCER CO WV	0.5254	2.1634	0.0057	0.0000
BECKLEY RALEIGH CO MEM AP WV	1.2916	2.0641	0.0071	0.0000
WITTMAN RGNL WI	3.4584	3.8344	0.0096	0.0000
WAUSAU MUNICIPAL ARPT WI	3.8766	2.8719	0.0279	0.2908
WATERTOWN WI	1.9695	2.4130	0.0187	0.0936
STURGEON BAY WI	2.3012	2.4670	0.0135	0.0000
RICE LAKE MUNICIPAL WI	4.1425	3.8958	0.0117	0.1089
RHINELANDER ONEIDA WI	4.7208	3.3603	0.0072	0.1017
PHILLIPS PRICE CO. WI	2.9533	3.1906	0.0046	0.0000
MOSINEE CENTRAL WI WI	4.4744	3.4539	0.0045	0.0000
MINOCQUA WOODRUFF WI	4.4812	3.8053	0.0066	0.0000
MILWAUKEE MITCHELL INTL AP WI	2.2113	2.4109	0.0110	0.2920
MARSHFIELD MUNI WI	3.6090	4.1600	0.0092	0.0000
MANITOWAC MUNI AWOS WI	2.4725	3.1660	0.0052	0.1681
MADISON DANE CO REGIONAL ARPT WI	2.6455	2.4465	0.0274	0.6034
LONE ROCK FAA AP WI	1.7569	2.4550	0.0074	0.1819
LA CROSSE MUNICIPAL ARPT WI	2.2993	2.0753	0.0610	0.9790
JANESVILLE ROCK CO. WI	1.7719	2.4085	0.0029	0.0000
GREEN BAY AUSTIN STRAUBEL INT WI	2.5804	2.6909	0.0087	0.3641
EAU CLAIRE COUNTY AP WI	3.0478	2.1000	0.0271	0.8621
APPLETON OUTAGAMIE WI	1.8560	2.4975	0.0146	0.0897
WORLAND MUNICIPAL WY	1.7994	1.6825	0.0123	0.0000
SHERIDAN COUNTY ARPT WY	1.4814	1.7688	0.0066	0.0000
RIVERTON MUNICIPL AP WY	1.2427	2.6453	0.0152	0.0000
RAWLINS MUNICIPAL AP WY	0.1968	2.0134	0.0037	0.0000
LARAMIE GENERAL BREES FIELD WY	0.2958	2.4900	0.0000	0.0000
LANDER HUNT FIELD WY	1.3923	2.0660	0.0074	0.0000
JACKSON HOLE WY	2.9325	3.4265	0.0000	0.0000
ROCK SPRINGS ARPT WY	1.7173	3.6900	0.0014	0.0000
GILLETTE GILLETTE-C WY	1.3319	3.9796	0.0191	0.1036
EVANSTON BURNS FLD WY	2.3884	3.2239	0.0017	0.0000
CODY MUNI (AWOS) WY	0.3188	2.0328	0.0091	0.0000
CHEYENNE MUNICIPAL ARPT WY	0.2527	1.6769	0.0024	0.0000
CASPER NATRONA CO INTL AP WY	1.3390	1.4778	0.0045	0.0000

Glossary:

Annual Cooling Demand (ACD):

The Energy in kBTU/ft^{2}yr (or kWh/m^{2}yr) needed for cooling of the course of the year as denoted by Q_c

Annual Heating Demand (AHD):

The Energy in kBTU/ft^{2}yr (or kWh/m^{2}yr) needed for heating of the course of the year as denoted by Q_h

Building Science Corporation (BSC):

A consulting and full service architecture firm specializing in building technology, forensics, sustainability, and energy efficiency.

Challenge Home:

A successor to the Builders Challenge Program which uses requirements to ensure energy savings, comfort, health and durability of newly constructed buildings

Chi:

A point based measure of thermal transmittance

Demand:

A measure of energy use over a length of time (most typically a year)

Department of Energy (DOE):

A department of the United States Federal Government concerned with energy, both production and use, that researches and recommends policy changes for comprehensive energy policy in the United States. The DOE also developed and administrates the Energy Star, Building America, Challenge Home, and Solar Decathlon programs.

Dynamic Model:

A simulation that uses multiple boundary conditions and a small time step at which those conditions change, for instance every fifteen minutes, to simulate different time periods.

Energy Star:

A ratings program that rates both products and buildings. Homes using the Energy Star program use 15 to 30% less energy than a conventional building.

Fraunhofer Institut of Building Physics (IBP):

An institute that focuses on research, development, testing, and consulting in the various fields of building physics including energy, moisture, acoustics, and lighting.

Home Energy Rating System Index (HERS):

A scoring system that compares the energy efficiency of a home against a reference home which determines a score that is used for incentive based programs including Energy Star and Challenge Home.

Hygric Buffering:

The ability of a material or feature within a building to store or release moisture which helps moderate interior humidity levels.

Hygrothermal Analysis:

An analytical simulation measuring moisture and heat and their dual effects on a building, or more typically, on a wall assemblies performance.

Internal Heat Gain (IHG):

Gains that occur with a buildings thermal envelope due to people or equipment loads of which a portion is used to offset the heating losses to lower the Annual Heating Demand and raise the Annual Cooling Demand.

International Passive House Alliance (iPHA):

A global network built by the Passivhaus Institut to promote the Passive House Standard and increase the knowledge of passive house to professionals, the media, and the general public.

Load:

A measure of energy use at a given point of time

Passive house (passivhaus):

A type of building that uses strategies such as super insulation and airtightness to ensure low energy use

Passive House Alliance US (PHAUS):

A regional network developed by the Passive House Institute US to promote passive house as a leading mainstream market force.

Passive House Institute US (PHIUS):

A nonprofit organization founded in 2007 that provides research, consulting, national conferences, and certification programs for passive houses.

Passive House Planning Package (PHPP):

A software program developed for MS Excel that was developed by the Passivhaus Institut. The PHPP was specifically created to calculate energy demand and loads in passive houses and passive house like buildings.

Passive House Standard:

A certification program and low energy building standard developed by the Passivhaus Institut

Passivhaus Institut (PHI):

The institute that created the Passive House Standard and that is also focused on the research and development of high-efficiency energy systems

Peak Heating Load (HL):

The maximum energy load in BTU/ft^{2}hr (or W/m^2) needed for heating at the peak of the heating season as denoted by P_h

Peak Cooling Load (CL):

The maximum energy load in BTU/ft^{2}hr (or W/m^2) needed for cooling at the peak of the cooling season as denoted by P_c

PHIUS+:

A certification program that combines passive house verification with an onsite quality assurance and quality control process performed by specially trained RESNET Raters.

Primary Energy Demand (PE):

The energy produced at the power plant that is needed to supply power to the building (identical to source energy).

Psi:

A linear measure of thermal transmittance

Residential Energy Services Network (RESNET):

A not for profit, independent membership organization that developed the HERS Index and the certification standards for a HERS Rater.

R-Value:

A measure of thermal resistance

Site Energy:

The energy need to power the building as determined at the building site (in contrast to primary energy which is determined at the power plant)

Solar Heat Gain Coefficient (SHGC):

A measure of solar energy transmittance of a window or door. For passive house windows, the SHGC is measured for the glazing, not the window as a whole.

Steady State Model:

A simulation that uses one set of boundary condition, usually at one given period of time, to calculate.

THERM:

A two-dimensional heat transfer model developed at Lawrence Berkeley National Laboratory

Typical Meteorological Year 3 (TMY3):

Date sets of hourly values of meteorological elements summarized as a one year period that represents a typical condition or year.

U_{COG}:

The U-Value as tested at the center of a glazing unit

U_f:

The U-Value of a window frame

U-Value:

A measure of thermal transmittance

U_{WIN}:

The total U-Value of a window including the transmittance of the frame, the glass, the glass edge, and the installation gap.

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