CLIMATE CHANGE AND BUILDING ENERGY CONSUMPTION: DESIGN CONSIDERATIONS FOR AN UNCERTAIN FUTURE

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Abstract

Building design and retrofit teams have historically relied on past weather data to inform the design decision-making process. With rapid climate change occurring around the globe, our buildings will likely see unprecedented weather events in the future that will impact their overall energy consumption, energy end use, and peak thermal load. Today's design teams will need to consider the impacts of rapid climate change in order to effectively inform the design decision making process. Fundamental to these decisions is the data used in climate analysis during the design process and by extension, building energy simulation and load calculations. This research first looks at Typical Meteorological Year (TMY) data which is most prevalent in practice today. As data and trend analysis shows, "typical" years are no longer the norm. To account for a greater variation in climate due to climate change, extreme Meteorological Year (XMY) data is used to demonstrate how the increasing frequency of more extreme conditions can impact the design decision-making process. This research focuses on using a multitude of climactic data sets to explore the variability of various climates in the future to enable design teams to understand how climate data variation can change key design decisions including optimal window-to-wall ratio, glazing selection, wall constructions, and more.

Keywords:

Climate change, building energy, building design, thermal load, resiliency, climate data

1 INTRODUCTION

Buildings in the US and Canada account for roughly 40% of the energy consumed and carbon emissions. Over the course of time, this has directly led to an increase in atmospheric carbon which is a significant contributor to global temperature increase. This global increase in temperature has in turn impacted the way buildings use energy and are likely to use energy in the future. Higher sustained temperatures also change (among many other considerations in building design) the optimal materials for construction of buildings, peak thermal load for heating, ventilation, and air conditioning (HVAC) sizing, and occupant thermal comfort.

While these changes in the climate are volatile and difficult to predict especially farther out into the future, recent trends show significant changes in the climate characteristics of the climate zones as defined in common industry energy standards and energy codes.

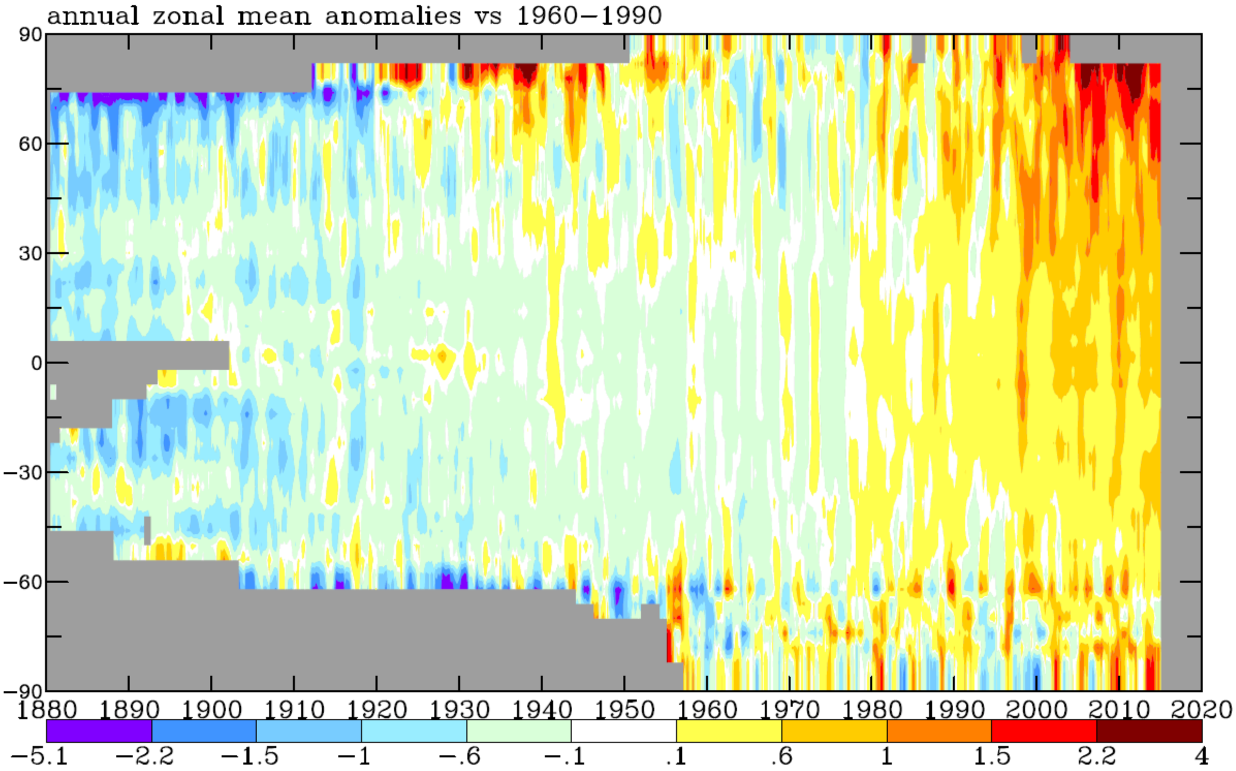

Figure 1: Average annual land surface temperature anomalies relative to a 1960-1990 average.

The earth is warming rapidly and the warming is not uniformly distributed across the globe [1]. Generally, locations that are further from the equator are seeing a more dramatic change in annual temperature. The warmest recorded years in known history have been recorded in the past 10 years. Yet none of the commonly used climate data sets in building energy simulation for compliance or for creating new codes accounts for this rapid change.

Other climate files are available. These include Annual Meteorological Year (AMY) and eXtreme Meteorological Year (XMY) data. AMY data are created for a given location by simply recording weather data on an hourly basis and compiling the data into a machine-readable format. XMY data are generated from reviewing a historic period of time and compiling either hottest or coldest hours, days, or weeks into a single file to represent 8760 hours in a year. XMY data is intended to represent an extremely hot or cold conditions over the course of a single year.

Previous research has concluded that using AMY files for annual building energy simulation is not appropriate for the design decision-making process as AMY is not representative of a larger period of time. However, that work compared previous recorded data and did not account for what scientists have shown is a rapid climate change period that has been unseen in at least the previous two millennia [1].

Going back further, research on the topic of Energy Use Intensity (EUI) in buildings as it related to climate change has been modeled since at least the 1980's. This research used a heating and cooling degree day (HDD and CDD) method to approximate the impact of assumed short-term temperature increase. While the results generally show an increase in EUI, some locations (notably northern locations that are heating dominant) showed an overall reduction in EUI. However, the demand for electrical energy increased as the need for cooling increased and the natural gas energy decreased as the need for heating decreased. This research was limited because it did not explicitly attempt to model a variety of building types so effects of occupant behavior or operational concerns related to unique building type demands [2].

In 2011, the United States Green Building Council (USBC) published a report that examined the impact on EUI in the US based on a regional approach [3]. This regional approach evaluated several different building types but lumped multiple climate zones into a single region. Hence, while this approach made recommendations to use multiple sets of climate data as it was also determined that a single climate data file was not sufficient to consider rapid climate change, the regions used are large and cross multiple climate zones. There is concern that these regions would not accurately address local concerns – especially concerns with regard to micro climate within a climate zone.

2 METHODOLOGY

In order to account for dramatic variation in climate, whole building energy models based on the US Department of Energy (DOE) reference buildings were created. There are 16 building types ranging from apartments to offices to hospitals of varying sizes, constructions, and HVAC systems among other differences. All building inputs and systems were modeled in accordance with climate zone baseline building requirements found in ASHRAE Standard 90.1-2007 using the Performance Rating Method [4].

Climate data is available in many formats and vintages. For the purposes of code compliance and/or for use with demonstrating compliance with ASHRAE Standard 90.1 or environmental rating systems such as LEED, Typical Meteorological Year (TMY) data is most commonly used. TMY data is generally used is either TMY2 or TMY3 vintages. TMY2 contains climate data for a given location from the period 1961-1990 [5]. TMY3 contains climate data for a given location from the period 1991-2005 [6]. This research also used TMY3 data from 2000-2014 (TMY15) and 2007-2014 (TMY7).

Several analyses have been undertaken demonstrating that TMY is a good statistical match for the recorded climate data in a given location over a given period of time [7]. However, matching to the past climate in the rapidly evolving climate that we are currently in may not be sufficient to properly inform design teams, code officials, and policy makers about the best course of action for the future.

In total, 2048 building energy simulations were completed using Integrated Environment Solutions Virtual Environment (IESVE) whole building energy simulation software. Sixteen different climate files and fourteen different building types were assessed by using seven different climate files in a single location. This methodology allows for comparing older climate data to newer climate data as well as using past data to create extreme future conditions. By running multiple climate inputs design teams can get a better understanding of how a rapidly changing climate will change the performance of their designs over time from an EUI perspective as well as an energy end-use perspective.

Table of locations

Table of climate files

Table of climate zones for each climate file

3 ANALYSIS

3.1 Inputs

Inputs for the simulations were based on ASHRAE Standard 90.1-2007 Performance Rating Method (Appendix G).

3.2 Climate files as inputs

The inputs for each building type were kept consistent and only the climate data was varied. This resulted in accounting for changes in building energy use intensity (EUI) based on fluctuation in longer-term climate trends. This method assumes that the buildings would not change in construction type or usage in order to isolate the effects of a changing climate on the EUI.

3.3 Quality Assurance

Building energy simulation is a complex process with many inputs. In order to ensure the inputs were held constant IESVE features a parametric processing tool which automatically transfer all inputs except for climate data. The user has the ability to change climate data while holding all other inputs constant across simulations. This feature of the software virtually eliminates the possibility that user error would skew the results.

4 RESULTS

Significant variation in EUI is demonstrated across nearly all building types and climate zones. The largest variation in EUI is generally found in colder climate zones.

Climate Zone 1A - Miami, FL		
Building Type	EUI Variance	EUI Variance (no XMY)
Full Service Restaurant	16%	5%
Hospital	19%	7%
Large Hotel	19%	7%
Large Office	16%	8%
Medium Office	17%	9%
Outpatient	5%	3%
Primary School	14%	4%
Secondary School	6%	3%
Small Hotel	19%	7%
Small Office	19%	8%
Strip Mall	20%	8%
Warehouse	24%	10%

Table 1: EUI Variance by Building Type Climate Zone 1A

Climate Zone 2A - Houston, TX		
Building Type	EUI Variance	EUI Variance (no XMY)
Full Service Restaurant	19%	5%
Hospital	17%	4%
Large Hotel	17%	5%
Large Office	6%	3%
Medium Office	11%	6%
Outpatient	5%	2%
Primary School	22%	5%
Secondary School	16%	5%
Small Hotel	25%	6%
Small Office	18%	7%
Strip Mall	19%	6%
Warehouse	15%	6%

Table 2: EUI Variance by Building Type Climate Zone 2A

Climate Zone 2B - Phoenix, AZ		
Building Type	EUI Variance	EUI Variance (no XMY)
Full Service Restaurant	13%	2%
Hospital	7%	3%
Large Hotel	13%	3%
Large Office	4%	3%
Medium Office	13%	2%
Outpatient	9%	1%
Primary School	7%	3%
Secondary School	6%	3%
Small Hotel	8%	5%
Small Office	18%	4%
Strip Mall	17%	4%
Warehouse	13%	6%

Table 3: EUI Variance by Building Type Climate Zone 2B

Climate Zone 3A - Atlanta, GA		
Building Type	EUI Variance	EUI Variance (no XMY)
Full Service Restaurant	6%	2%
Hospital	6%	2%
Large Hotel	12%	2%
Large Office	17%	1%
Medium Office	14%	2%
Outpatient	3%	3%
Primary School	54%	8%
Secondary School	21%	5%
Small Hotel	12%	7%
Small Office	16%	4%
Strip Mall	19%	5%
Warehouse	42%	7%

Table 4: EUI Variance by Building Type Climate Zone 3A

Climate Zone 3B - Las Vegas, NV		
Building Type	EUI Variance	EUI Variance (no XMY)
Full Service Restaurant	5%	1%
Hospital	13%	0.40%
Large Hotel	5%	2%
Large Office	13%	1%
Medium Office	5%	2%
Outpatient	8%	1%
Primary School	23%	2%
Secondary School	6%	2%
Small Hotel	15%	1%
Small Office	7%	3%
Strip Mall	9%	3%
Warehouse	25%	2%

Table 5: EUI Variance by Building Type Climate Zone 3B

Climate Zone 3C - San Francisco, CA		
Building Type	EUI Variance	EUI Variance (no XMY)
Full Service Restaurant	5%	3%
Hospital	2%	2%
Large Hotel	9%	4%
Large Office	17%	6%
Medium Office	4%	1%
Outpatient	3%	2%
Primary School	38%	14%
Secondary School	20%	7%
Small Hotel	15%	11%
Small Office	7%	7%
Strip Mall	9%	9%
Warehouse	31%	10%

Table 6: EUI Variance by Building Type Climate Zone 3C

Climate Zone 4A - Baltimore, MD		
Building Type	EUI Variance	EUI Variance (no XMY)
Full Service Restaurant	5%	1%
Hospital	12%	4%
Large Hotel	12%	4%
Large Office	20%	5%
Medium Office	17%	3%
Outpatient	5%	1%
Primary School	58%	14%
Secondary School	48%	12%
Small Hotel	11%	1%
Small Office	20%	4%
Strip Mall	25%	5%
Warehouse	49%	14%

Table 7: EUI Variance by Building Type Climate Zone 4A

Climate Zone 4B - Albuquerque, NM		
Building Type	EUI Variance	EUI Variance (no XMY)
Full Service Restaurant	7%	2%
Hospital	30%	4%
Large Hotel	30%	4%
Large Office	21%	4%
Medium Office	17%	5%
Outpatient	11%	4%
Primary School	51%	6%
Secondary School	49%	7%
Small Hotel	42%	7%
Small Office	23%	5%
Strip Mall	35%	9%
Warehouse	59%	8%

Table 8: EUI Variance by Building Type Climate Zone 4B

Climate Zone 4C - Portland, OR		
Building Type	EUI Variance	EUI Variance (no XMY)
Full Service Restaurant	6%	2%
Hospital	23%	3%
Large Hotel	23%	3%
Large Office	22%	5%
Medium Office	22%	6%
Outpatient	9%	2%
Primary School	67%	9%
Secondary School	56%	7%
Small Hotel	23%	4%
Small Office	24%	5%
Strip Mall	33%	9%
Warehouse	63%	8%

Table 9: EUI Variance by Building Type Climate Zone 4C

Climate Zone 5A - Chicago, IL		
Building Type	EUI Variance	EUI Variance (no XMY)
Full Service Restaurant	7%	3%
Hospital	24%	8%
Large Hotel	24%	8%
Large Office	34%	9%
Medium Office	30%	9%
Outpatient	12%	4%
Primary School	63%	17%
Secondary School	60%	16%
Small Hotel	23%	6%
Small Office	33%	8%
Strip Mall	42%	11%
Warehouse	62%	16%

Table 10: EUI Variance by Building Type Climate Zone 5A

Climate Zone 5B - Boulder, CO		
Building Type	EUI Variance	EUI Variance (no XMY)
Full Service Restaurant	17%	1%
Hospital	51%	5%
Large Hotel	51%	5%
Large Office	45%	6%
Medium Office	42%	6%
Outpatient	36%	3%
Primary School	81%	10%
Secondary School	85%	9%
Small Hotel	61%	1%
Small Office	60%	7%
Strip Mall	77%	11%
Warehouse	92%	11%

Table 11: EUI Variance by Building Type Climate Zone 5B

Climate Zone 5C - Vancouver, BC		
Building Type	EUI Variance	EUI Variance (no XMY)
Full Service Restaurant	10%	2%
Hospital	24%	5%
Large Hotel	24%	5%
Large Office	24%	5%
Medium Office	23%	4%
Outpatient	11%	2%
Primary School	33%	12%
Secondary School	50%	11%
Small Hotel	27%	5%
Small Office	28%	5%
Strip Mall	41%	8%
Warehouse	57%	12%

Table 12: EUI Variance by Building Type Climate Zone 5C

Climate Zone 6A - Minneapolis, MN		
Building Type	EUI Variance	EUI Variance (no XMY)
Full Service Restaurant	12%	4%
Hospital	37%	12%
Large Hotel	37%	12%
Large Office	53%	14%
Medium Office	37%	10%
Outpatient	25%	8%
Primary School	71%	20%
Secondary School	65%	18%
Small Hotel	39%	11%
Small Office	46%	12%
Strip Mall	55%	14%
Warehouse	70%	19%

Table 13: EUI Variance by Building Type Climate Zone 6A

Climate Zone 6B - Helena, MT		
Building Type	EUI Variance	EUI Variance (no XMY)
Full Service Restaurant	22%	20%
Hospital	56%	11%
Large Hotel	56%	11%
Large Office	70%	24%
Medium Office	46%	3%
Outpatient	42%	17%
Primary School	100%	38%
Secondary School	87%	26%
Small Hotel	67%	18%
Small Office	63%	3%
Strip Mall	77%	4%
Warehouse	100%	34%

Table 14: EUI Variance by Building Type Climate Zone 6B

Climate Zone 7 - Duluth, MN		
Building Type	EUI Variance	EUI Variance (no XMY)
Full Service Restaurant	15%	5%
Hospital	39%	14%
Large Hotel	39%	14%
Large Office	35%	12%
Medium Office	46%	3%
Outpatient	50%	18%
Primary School	67%	24%
Secondary School	63%	23%
Small Hotel	40%	14%
Small Office	49%	17%
Strip Mall	56%	19%
Warehouse	64%	23%

Table 15 EUI Variance by Building Type Climate Zone 7

Climate Zone 8 - Fairbanks, AK		
Building Type	EUI Variance	EUI Variance (no XMY)
Full Service Restaurant	30%	11%
Hospital	60%	21%
Large Hotel	60%	21%
Large Office	49%	17%
Medium Office	50%	17%
Outpatient	50%	18%
Primary School	71%	25%
Secondary School	71%	25%
Small Hotel	64%	23%
Small Office	63%	21%
Strip Mall	71%	24%
Warehouse	75%	26%

Table 16: EUI Variance by Building Type Climate Zone 8

The results show a significant variation in EUI for all building types. The more extreme the climate variation the larger the variance in EUI is. XMY data results in larger variance due to the nature of the larger temperature variation in this data set. However, even varying the timeframe for TMY data generally shows significant variation in EUI.

As the window-to-wall ratio, internal gains, constructions, and other factors which would influence the EUI of the buildings was unchanged, all the variation is due only to changes in climate. When considering buildings are built often exceed or alter the parameters dramatically, the variance due to climate could be much larger. For example, a building that is 80% or 90% glass would likely be more susceptible to variation in climate data than the buildings used in this work as the window-to-wall ratio is maxed at 40%.

As computer simulation programs have evolved to incorporate genetic algorithms and approaches for “optimizing” a solution, this works demonstrates significant potential for the optimal solutions to be dramatically different in a given location simply by varying the climate data used as the input into the optimization routine.

5 CONCLUSION

Consideration of climate change in the design of new buildings and in the evaluation of retrofits is essential to optimize the performance of new and existing buildings. As the climate is likely to warm considerably, optimal window-to-wall ratios, glazing characteristics, wall construction characteristics, and HVAC equipment sizing and performance are all related to climate and weather. Sizing systems and evaluating performance of buildings based on past climate conditions is not sufficient when determining what the optimal systems are for all the building types studied in this research.

Design teams (for new and existing buildings) should consider the effects of climate change. In lieu of using climate files that are based on various future climate models, design teams can follow the recommendations of USGBC and the findings of this research to evaluate both TMY data (most recent 15 years) plus including XMY data. This combination of climate data in the design process will allow for a broader range of EUI and thermal loads to be understood in the design process. This will also help inform the building owner that climate change will play a significant role in the actual performance of the building in the future and hopefully begin to address the misunderstanding the compliance energy modeling is meant to predict actual performance.

With regard to code compliance, the significant variation creates a potential conundrum that is not readily solvable with a simple algorithm. Restricting the code to use a certain climate data set will inherently reduce the flexibility in the design of buildings to account for future climate conditions. Yet demonstrating compliance could potentially be "gamed" by design teams if selection of climate data were not regulated in some way. A balance must be struck between stringent definitions of climate data and in allowing for the necessary flexibility in designing buildings for the future.

6 ACKNOWLEDGMENTS

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7 REFERENCES

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