SIMULATION-BASED WEATHER NORMALIZATION APPROACH TO STUDY THE IMPACT OF WEATHER ON ENERGY USE OF BUILDINGS IN THE U.S.

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ABSTRACT

Weather normalization is a crucial step in building energy rating and retrofit measurements. Accounting for the impacts of weather on energy use of commercial buildings is a rigorous challenge because of the complexity and diversity in the operation, the mechanical systems, and the use-types available. This paper documents preliminary results of an effort to determine a set of weather adjustment coefficients that can be used to isolate the impacts of weather on energy use of buildings in 1020 weather location sites available in the U.S. The U.S. Department of Energy (DOE) commercial reference building models are adopted as hypothetical models with standard operations to deliver consistency in modeling. The correlation between building envelope design, heating, ventilation and air conditioning (HVAC) system design and properties for different building types and the change in heating and cooling energy consumption caused by variations in weather is examined.

INTRODUCTION

In the United States, the buildings sector accounted for about 41% of primary energy consumption in 2010 (D&R International, Ltd., 2012). Understanding energy use in commercial buildings is complicated because there are many factors that affect building energy use, such as variations in building use-types including mixed-use buildings, various types and sizes of mechanical systems supplying building heating and cooling demand, unpredictable weather impacts, and different building ownership and operational choices. There have been more efforts in recent years to evaluate energy use in commercial buildings as a first step to reduce energy consumption and carbon emissions. One of these efforts that has recently drawn global attention is building energy performance rating. Evaluation of the building energy efficiency in contexts of both asset rating (i.e., buildings as-designed or as-built) and portfolio or operational rating (i.e., buildings as-operated) has been growing. Energy rating can provide better understanding and more specific information on building energy use and comparative energy efficiency levels of buildings. A scoring or certification system would also encourage building owners to increase energy efficiency of their buildings by being compared to their 'peer groups.'

An unbiased and reliable scoring system to evaluate energy performance of buildings should be developed through standard measurements. However, there are challenges impacting the widespread adoption and employment of a standardized energy performance evaluation and scoring system. First, a standard rating system should be free of bias. To achieve that, the system should be capable of reducing, if not eliminating, factors that affect the fairness of the energy rating across regions and use-types. These factors include, but are not limited to, a standard energy modeling methodology, acceptable and reliable benchmark models, and appropriate normalization technique to account for building size, operating schedule, and weather variations. Weather normalization is fundamental for building energy rating and is the most challenging factor to adjust energy use for. The research objective of this work is to test the feasibility of using a simulation-based weather adjustment method to account for effects of weather on energy use of commercial buildings in the U.S.

This paper presents a brief outline of the simulation-based weather normalization approach developed and tested. The first section is a literature review on weather normalization methods currently used to adjust energy consumption of buildings and limitations of these techniques. Next, the simulation-based approach examined in this paper is presented. The Data Analysis and Results section covers an investigation of energy use of different types of buildings and their response to weather in different climate zones in the U.S. Finally, the weather normalization approach developed is tested on a set of buildings and results are discussed.

BACKGROUND

In this section, existing methods that address weather normalization are reviewed. Weather normalization is the procedure undertaken to adjust modelled or measured energy use of buildings to a hypothetical common scale, i.e., a "normal" weather condition. This has traditionally been important to utilities for regulating rates and more recently for other objectives such as retrofit measurements and energy rating. Most utility and energy service companies have developed and utilized an energy use normalization method to measure and evaluate building energy performance independent of variations and fluctuations in weather. For most applications in the energy industry, this has mostly been done to adjust building energy use over a period of time, e.g., from the current year to the previous year. Therefore, the variations in weather have been adjusted for the same location and the same building specifications with weather as the only variable. On the other hand, applications such as asset evaluation and energy rating require fair comparison of buildings energy performance in different climate regions and locations. Therefore, weather changes should be corrected not in regard to time (i.e., seasonally or annually), but across different locations. In this paper, the terms ‘temporal’ weather normalization and ‘spatial’ weather normalization have been employed to distinguish normalization across time from that of location.

Weather normalization is a crucial task for comparing measured or calculated energy data in a wide range of energy conservation applications (e.g., measuring retrofits). The Energy Performance of Buildings Directive (EPBD) has identified normalization and weather correction procedures as critical areas related to energy and asset rating of buildings that should be given special attention (Thomsen & Wittchen, 2011). The same document states that “a correct and European-wide harmonized approach for the climate normalization for both heating and cooling would simplify the intercomparison of national requirements, as well as the use of measured energy rating” (Thomsen & Wittchen, 2011). Review of asset rating, scoring and labelling efforts such as the Massachusetts MPG Rating for Commercial Buildings (Massachusetts Department of Energy Resources, 2010), ASHRAE Building Energy Labelling Program (BEQ) (ABEL, 2009), and California Energy Commission (CEC) (Itron, 2006) also indicates that there is no standard method for weather correction and adjustment to normalize calculated energy data in the U.S.

The literature indicates that currently more research exists in adjusting energy consumption of residential buildings in regard to weather rather than for commercial buildings. These efforts are better tested and documented although none has been adopted as a standardized approach. The following sections describe current normalization methods. These include the degree-day methods, the modified utilization factor (MUF) method, and the climate severity index (CSI) method (Akander et al., 2005). These methods are described in the following sections, and their limitations as well as their applicability for weather normalization in commercial buildings are discussed.

Degree-Days Methods

The most common and widely used method to isolate the effects of weather changes on buildings energy performance is the heating and cooling degree-day (HDD, CDD) method. Degree-days represent the total positive or negative difference between a base temperature and the average daily outdoor dry-bulb temperature for a given period of time (ASHRAE, 2009). In the U.S., the base temperature has been specified as 18.3°C. Kissock et al. (2004), describe different methods to calculate degree-days such as the variable-base degree-day (VBDD) method, which finds the base temperature that provides the best statistical fit between energy consumption and the number of variable-base degree-days in each energy use period. Other methods employed for this purpose include linear, change-point linear, and combined multiple linear regressions (Kissock et al., 2004).

A ratio-based method using HDD and CDD is the oldest and most common weather normalization technique used. This technique is described by the U.S. Energy Information Administration (EIA) as adjusting the major fuel (e.g. gas) used for heating by multiplying energy used by an HDD factor that is obtained by dividing the normal number of HDD in a location by the specific number in a particular year (EIA, 1995). The same procedure is applicable to adjust cooling load using the major fuel used for cooling (e.g. electricity) and a CDD factor.

The drawback of such a ratio-based weather normalization approach is that it relies on major fuel used for heating and cooling to disaggregate load. Therefore, it does not address disaggregation of base-load energy consumption, which in this case refers to non-weather-sensitive energy use (e.g., lighting) that should be isolated from normalized energy use. Hence, this method can be correctly used only if heating and cooling loads as well as base-load energy consumption are reliably disaggregated from total consumption.

A linear regression analysis method using degree-days is adopted to capture limitations of ratio-based normalization technique. In this method, the weather normalization is accomplished by developing a building energy use regression model that correlates historical energy use data (i.e., dependent variable) with degree-days (i.e., independent variables). The linear regression equation of energy consumption on degree-days to disaggregate load is:

$$\textit{Predicted Energy Use} = \alpha + \beta \times x \qquad (1)$$

where:

α = intercept (MJ), the non-weather-sensitive component

β = consumption slope (MJ/DD), the weather-sensitive component, which shows estimation of energy consumed on each degree-day.

The success of regression of energy use on degree-days is measured by the R value (i.e., coefficient of determination), which indicates how 'good' the correlation is between dependent and independent variables. Therefore, it is used to determine the dependence of energy use on degree-days. For instance, an R of one indicates perfect correlation and suggests that the independent variable (degree-days in this case) was a good factor to normalize energy use against. On the other hand, an R closer to zero indicates that the independent variable selected is insignificant and other causal or confounding factors exist.

One of the most successfully used regression-based techniques for analyses of conservation measurements in residential buildings, called PRISM, was developed at Princeton University in 1985 (Fels, 1985). The Environmental Protection Agency's ENERGY STAR Portfolio Manager program (Energy Star, 2011), which is perhaps the most widely used benchmark for building energy performance in the U.S., employs a similar statistical regression approach to identify the major drivers of energy use. Here, the analysis is based on a weighted ordinary least squares regression to obtain a dependent variable (i.e. source energy use intensity), subject to various independent characteristics (e.g. building size, operation and weather). (Energy Star, 2011).

Chung et al. (2006) developed a similar benchmark for the energy efficiency of commercial buildings based on multiple regression analysis. The shortcoming of such multiple regression benchmarking is the complexity and requirement of many inputs with many technical details (e.g. building size, internal loads, and operating hours) (Chung et al., 2006). Variations of regression-based weather normalization methods such as regression change-point methods and sliding Normalized Annual Consumption analysis (Lammers et al., 2011) have been used in research and practice. Bonneville Power Administration (BPA, 2011), Hydro One (Hydro One, 2006), Pepco Holdings, Inc., (Pepco Holdings Inc, 2010), REALpac (Real Property Association of Canada, 2012), and The Brattle Group (The Brattle Group, 2012) are examples of utility firms using weather normalization methods to make adjustments for the impacts of weather on energy consumption of buildings.

Despite the popularity of degree-days-based approaches for weather normalization, these techniques have several limitations and their accuracy is not well studied. Energy use in commercial buildings is not sufficiently governed by degree-days. Degree-days are calculated based on dry-bulb temperature and that is the only weather element considered. As a result, other climatic factors such as wind speed, humidity, insolation and other forces that impact energy use in commercial buildings are eliminated (Akander et al., 2005 and Eto, 1987). Therefore, use of degree-days is more reliable for locations where solar gains and wind speed do not have significant impact on the heat balance of the building.

Furthermore, commercial buildings usually have more than one thermal zone that does not maintain constant temperature. Therefore, a steady-state equation cannot precisely represent the influence of weather on their energy use while degree-day methods assume the heat loss in buildings is linearly proportional to the indoor and outdoor temperature difference (Akander et al., 2005 and Eto, 1987). Another limitation is that degree-day methods are not capable to account for energy consumed by non-weather-sensitive end uses. Regression-based methods attempt to address this, but the low R values in these models indicate that degree-days do not have a statistically significant correlation with energy use and there are other variables that should be taken into consideration as well. In addition, Thomsen & Wittchen (2011) stated, "the error made by simply correcting the heating and cooling energy needs by degree-days increases in high performance buildings. Using simple HDD/CDD analysis can lead to errors that are larger than what you're trying to measure."

Modified Utilization Factor Method

The MUF method is defined in European Standard prEN-ISO 13790 (Hogeling & Van Dijk, 2008) and has been used in Europe to normalize energy used for space heating or cooling in residences (Akander et al., 2005). The MUF method was mainly adopted to address some limitations of degree-day methods such as ignoring the contribution of solar gain. This method is developed based on the 'utilization factor' measurement commonly used in power engineering to refer to the ratio of the maximum demand to the rated capacity of a power plant. In the MUF method, the utilization factor is defined as a measure of that chunk of the internal heat gains that is required to maintain the desired set-point temperature within the space and the remainder is considered to raise the internal temperature beyond the set-point temperature (Akander et al., 2005).

In a steady-state approach, the heat balance equation is defined as:

$$Q_{heat\ losses} = Q_{spaceheating} + Q_{appliances} + Q_{metabolic} + Q_{solar} \qquad (2)$$

The indoor temperature that is obtained over time is a result of energy that is delivered into the space, the heat-loss factor and the heat capacity of the residence. Akander et al. (2005) state that the indoor temperatures of thermal zones in the building are usually unknown and the most reliable temperature data that can be obtained during the heating season is the set-point temperature of the heating system. Therefore, this method relies on adjusting indoor temperature to the set-point temperature to calculate the actual and normalized energy delivered for space heating. This enables the use of the utilization factor for internal and solar gains in the MUF method and to make normalization of the space heating possible. The utilization factor is the η_{UF} in Eq. (3).

$$Q_{heat\ losses}^{at\ setpoint} = Q_{spaceheating} + \eta_{UF}\,(Q_{appliances} + Q_{metabolic} + Q_{solar}) \qquad (3)$$

This normalization requires an auditor to first select an appropriate time constant for the residence at the time of audit from a prescribed set. From the audit, information is gathered for the solar apertures and their orientations. Eq. (3) is used to estimate heat losses at the prevailing temperature. A modified gain-loss ratio is calculated iteratively to find η_{UF}^{*} for the period considered.[1] The value for η_{UF}^{*} is then used in Eq. (4) to approximate heat losses if the internal temperature were equal to the set-point temperature. The heat losses are normalized with respect to the external climate for the reference year. This is carried out similarly to the ratio-based degree-day method. Using the normalized heat losses, the gain-loss ratio is again calculated to find the normalized utilization factor, $\eta_{UF}^{Normalized}$. With the normalized utilization factor and normalized heat losses, the normalized delivered space-heating energy can be estimated as shown in Eq. (4):

$$Q_{spaceheating}^{Normalized} = Q_{heat\ losses}^{setpoint} - \eta_{UF}^{Normalized}\,(Q_{appliances} + Q_{metabolic} + Q_{solar}^{Normalized}) \qquad (4)$$

The MUF method has several limitations that are magnified when normalizing energy use in commercial buildings. First, these calculations become complicated when normalizing space cooling. Currently, there is no European standard that makes use of a utilization factor to normalize cooling load (Akander et al., 2005). Another limitation is related to the lack of a central set-point temperature and data should be collected by metering or measuring temperature profiles over the course of a year. Other shortcomings include the estimation of solar gains delivered to the space and uncertainty related to the time constant required in this approach, which is assessed based on the auditor's intuition. (Akander et al., 2005).

Climate Severity Index Method

The CSI method is another approach for describing the climatic dependence of the energy requirements of a building, based on the 'severity' of different climatic conditions. CSI was first introduced and developed by Markus (1982) for different objectives such as fair assessment of retrofits and energy use of buildings in different regions. The index was developed to take into consideration several elements of weather such as air temperature, solar radiation, and wind speed. (Markus, 1982). This method was later employed in the Euroclass project. It made weather normalization possible by determining an index that relates energy consumption of buildings in different regions through a value that increases as energy use in more severe climate zones rises (Akander et al., 2005). This method requires determination of separate CSIs for heating and cooling seasons.

Steps to calculate CSI include selection of the pivot climatic condition, a set of building types common in the region, and climatic conditions covering the different climates of the region such as typical meteorological year (TMY). Computational simulations are then used to estimate the energy use of the buildings under different scenarios (e.g., different orientation, thermal properties, and so on). The CSI for each combination run in a climatic condition is then calculated and the average CSIs for all the combinations is the CSI for a sector. To cover climatic conditions different from those used in running the simulations, the calculated CSIs are correlated with the known climatic variations in other regions such as degree-days, monthly average global solar radiation, and insolation in order to find CSIs in a wider range of climatic conditions. The normalization is then carried out by multiplying the heating or cooling energy use of a building by the ratio between the reference CSI and the actual CSI (Akander et al., 2005).

The limitations of this method are that CSIs are not widely modeled and they should be further developed. Their accuracy and reliability are also not well tested and studied, especially for locations for which simulations were not performed for.

APPROACH

To determine the effect of climate on building energy use in different climatic conditions it is important to carry out the study in a controlled environment. In the approach taken, building operation and occupancy are kept constant for derivation of weather normalization coefficients in simulation-based environment. This ensures that all changes observed in energy use result solely from impacts of weather differences. These conditions cannot be kept constant in real buildings. Therefore, computerized building energy simulation models are employed to keep these conditions fixed. This simulation-based approach makes possible better understanding of the effects of weather on commercial building energy use; it can be used by researchers, practitioners, and designers to analyse simulated data as well as measured data to perform energy adjustments of commercial buildings

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[1] Details of calculations can be found in prEN ISO13790 or (Akander et al., 2005).

located in different climatic conditions. The results can also be used for other purposes such as retrofit measures and estimation of energy consumption of a building with similar characteristics in another climate zone. The method for spatial weather normalization used in this study is explained in this section.

This approach involves the following two preparatory steps: (i) development of weather correction coefficients and (ii) calculation of the normalized heating and cooling energy consumption.

STEP 1: Development of Weather Adjustment Coefficients

The weather adjustment coefficients are calculated using the estimated building Energy Use Intensities (EUIs)[2] of weather-sensitive components. These EUIs include energy used for space heating and cooling, heat rejection, service water heating and energy used by pumps and fans. Energy consumption for non-weather-sensitive components such as interior equipment (i.e. office equipment) and lighting is excluded from the calculation. The procedure for calculation of the weather adjustment coefficients requires having a set of building models that can be simulated in different climatic conditions, suitable weather files for each climate region, a simulation engine that can handle a large number of runs, and finally a methodology to calculate coefficients. This procedure is described in this section.

Building Models

To isolate the effect of weather on building EUI and determine a weather coefficient, an identical building must be simulated in each weather location within a climate zone. Yearly energy requirements of different types of commercial buildings were estimated using the *EnergyPlus* building energy modeling and simulation tool (Version 6.0). DOE’s commercial reference building models (DOE, 2009) developed by the National Renewable Energy Laboratory in *EnergyPlus* characterize about 70% of the commercial building stock in the U.S (Deru et al., 2011). These reference building models are only used as sample building models not intended to represent absolute energy use of any specific building or to act as targets to rate the energy performance. Rather, in this work they are adopted as hypothetical models with standard operations that meet certain minimum requirements. These models are used to provide consistency in modeling and implementation approaches across commercial buildings to demonstrate the change in energy use caused by weather variations in different climatic zones. This would enhance and facilitate comparison of energy use of buildings between different climate regions. DOE’s commercial reference building models are available with characteristics adjusted to fit requirements of different U.S. climate zones described by the International Energy Conservation Code. Input parameters for different types of building envelope assembly and thermal properties of the walls, roofs, floors, and windows vary in these models depending on the climate zone. These adjustments are made following ASHRAE Standards 90.1-2004, 62.1-2004, and 62-1999 and several other sources (Deru et al., 2011). HVAC equipment for these models is also based on ASHRAE (2004) specifications for baseline buildings. Table 1 summarizes characteristics of two of the reference building models used in this study.

Table 1
Summary of reference buildings

PROPERTIES	**LARGE OFFICE**	**SCHOOL**
Size (m^2)	46,320	19,592
Shape	Rectangular with 12 floors plus basement	E shape with two floors
Construction	2 × 4 steel-frame with gypsum board	Steel-framed
Glazing	38% of wall area	35% of wall area
Operation	9:00 – 18:00 , with some evening hours; about 40% occupancy on Saturday	8:00 – 21:00, with about 60% occupancy in summer and 20% weekends
Thermostat settings	Heating: 21ºC Cooling: 24ºC	21ºC 24ºC
Internal loads (W/m^2)	Lighting: 16.15 Plug loads: 10.76	9.69 – 15.07 4.0 – 20.0, 222 in the kitchen
Air distribution	Multi-zone variable air volume (MZ VAV)	MZ VAV and packaged single-zone air conditioner (PSZ-AC) in some zones
Cooling	Water-cooled chiller	Air-cooled chiller and PACU
Heating	Boiler	Boiler

Weather Data

Typical meteorological year TMY3s are data sets of hourly values of solar radiation and meteorological elements for a one-year period. These data sets are derived from the 1961–1990 and 1991–2005 National Solar Radiation Data Base archives. The TMY3 data set contains data for 1020 locations. These are used for simulations that are carried out for each reference building model.

Simulation Process

To accomplish the simulations, Pacific Northwest National Laboratory (PNNL) energy simulation infrastructure based on *EnergyPlus* was used to populate building models in each climate zone and to simulate them in parallel. For each reference building available, there is an IDF file that corresponds to a

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[2] Energy use per unit floor area, MJ/m^2

building type (e.g., Medium Office) and the representative city of each climate zone. To use PNNL's simulation infrastructure, this *EnergyPlus* file (i.e., IDF file) was first made into a template—a parameterized *EnergyPlus* IDF that could take weather files available in each climate zone from a CSV file. This enabled an automated process to generate all 1020 *EnergyPlus* IDF files from the original 16 reference building models available. PNNL's simulation infrastructure allows running simulations on several parallel servers by clustering (Thornton et al., 2011).

The primary measurements recorded from simulations are annual EUIs. This includes electricity and natural gas converted by straight unit conversion into mega joules (MJ). Energy for each end use (heating electricity and gas, cooling electricity, interior and exterior lighting, interior and exterior equipment, fans, pumps, heat rejection, service hot water electricity and gas), is recorded separately to isolate those end uses that are affected by weather. This data is used to calculate weather adjustment coefficients for each location as described below.

Calculating Coefficients

A weather coefficient is calculated for each of the 1020 weather file locations available in the U.S. An alternative is to calculate a weather coefficient only for the 16 climatic subzones. However, given the variations in energy use within a climatic subzone (as seen in Figure 1), this was found to be unsuitable. In this study, the weather normalization was achieved by adjusting the EUI of a building to a national average EUI of the same building typology. In other words the 'base' or 'reference' was taken as the 'average' EUI across all weather locations for a particular building type. To accomplish this, the weather coefficient for every specific location was obtained by dividing the EUI of each weather-sensitive component (i.e., heating, cooling, pumps and fans) by the average EUI of that component calculated for that building type in all weather locations as shown in Equations (5):

$$Coefficient^{N.heating}_{specific} = \frac{EUI^{\,heating}_{\,specific}}{EUI^{\,heating}_{\,average}} \tag{5}$$

Normalization coefficients for cooling can be determined similarly as shown in Equation (6):

$$Coefficient^{N.Cooling}_{specific} = \frac{EUI^{\,cooling}_{\,specific}}{EUI^{\,cooling}_{\,average}} \tag{6}$$

Determination of heating and cooling coefficients was performed for all building types in all weather locations. Therefore, a total of 1020 sets of coefficients were found for each type of commercial building.

STEP 2: Calculation of the Normalized EUIs

Given the modeled EUI of a candidate building in a specific location (i.e. a weather station site), an adjusted EUI can be calculated by multiplying the modeled heating and cooling EUI by the weather coefficient:

$$N.\ EUI^{N.heating}_{specific} = EUI^{heating}_{specific} * Coefficient^{N.heating}_{specific} \tag{7}$$

Normalized (or adjusted) cooling EUI is found similarly:

$$N.\ EUI^{N.cooling}_{specific} = EUI^{cooling}_{specific} * Coefficient^{N.cooling}_{specific} \tag{8}$$

Total Normalized EUI is then calculated by adding normalized heating and cooling EUIs in addition to all non-weather-sensitive loads that were not normalized.

$$N.\ EUI^{N.total}_{specific} = N.\ EUI^{N.heating}_{specific} + N.\ EUI^{N.cooling}_{specific} + EUI^{plug\ loads}_{specific} + EUI^{lighting}_{specific} + \cdots \tag{9}$$

DATA ANALYSIS AND RESULTS

While analysis of data found from building simulation models is not ground-breaking, the simulation of multiple building types in 1020 weather station sites in the U.S. presents a unique opportunity to add new knowledge to the building energy domain. These section summarizes these findings. Variations and trends in energy use of different buildings caused by diverse weather conditions in all climate zones and weather station locations available in the U.S. are isolated and studied.

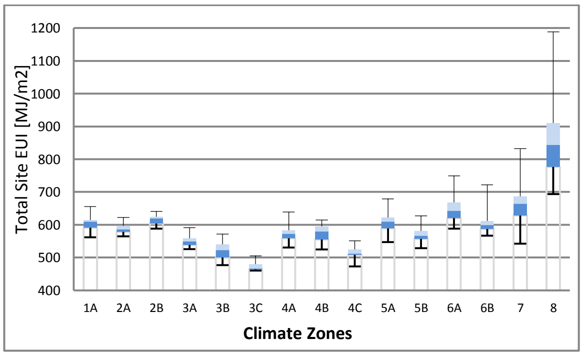

Figure 1 Total EUI variation observed across different climate zones and within each climate zone for Small Office

Figure 1 above shows EUIs of one building type (Small Office) in different climate zones and weather station locations in the form of a box-plot. The climate zones are shown along the x-axis from very hot and humid (1A in Florida) to subarctic (8 in Alaska). Internal loads and schedules are identical; therefore, weather is the sole cause of variation in the building EUIs observed across and within different climate zones. The difference in EUI between some climate zones, e.g. 3A (warm-humid) and 3B (dry) highlights the influence of humidity on building EUI. Larger differences in interquartile range in the coldest climate zones (e.g. 7 and 8) indicate larger differences in weather between weather station locations within these climate zones.

The simulated data confirms that different building types respond to weather differently based on the building's characteristics such as layout, envelope, and the internal loads. Figure 2 further highlights this showing the greater deviation in the EUIs of School compared to those of Large Office specifically in climate zones 7 and 8. This is because the ratio of exterior envelop to floor area is larger in School. In addition to that, School has lower insulation, longer hours of operation, and lower internal loads on average. It should be noted that the number of weather stations are not consistent in all climate zones resulting in different distance between vertical grid lines shown in Figures 2 and 3.

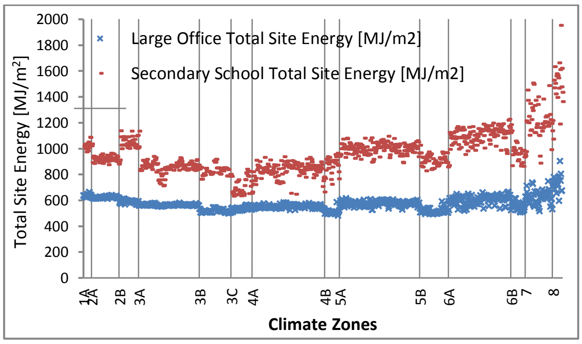

Figure 2 Total EUI variation observed across different climate zones and within each climate zone for Large Office and School

The calculated weather normalization coefficients are tested by applying them to a sample of simulated building EUIs. The result of applying weather adjustment coefficients to a set of simulated Large Office building EUIs across all climate zones are shown in Figure 3 as a dot plot. It is seen that in this case the impact of weather on EUIs is better isolated and adjusted in milder climate zones (e.g., 4A and 5A) than those with more severe weather conditions. For example, in climate zones 7 and 8, buildings in some weather locations require almost no cooling resulting in a cooling EUI that is very small compared to other climate zones. Therefore, the cooling coefficients calculated for these regions are very large leading to normalized cooling EUIs that appear skewed as seen in Figure 3. Further work is required to account for such cases.

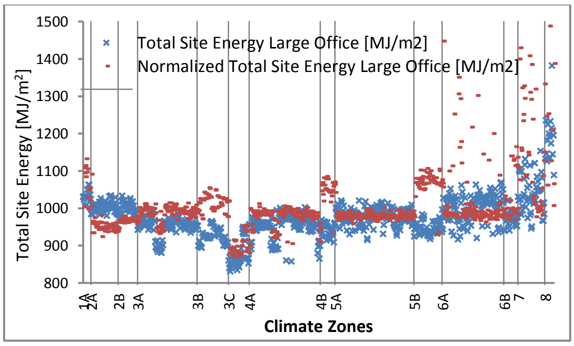

Figure 3 Results of applying weather adjustment coefficients for large office to a set of simulated building EUIs

Figure 4 shows a box-plot of normalized EUIs for the same set of buildings shown in Figure 1 (Small Office). This illustrates that EUI variation across different climate zones is minimized and the deviation between weather stations in a given climate zone is reduced. This demonstrates that employment of coefficients calculated in this work have successfully adjusted for the impact of weather on buildings energy consumption.

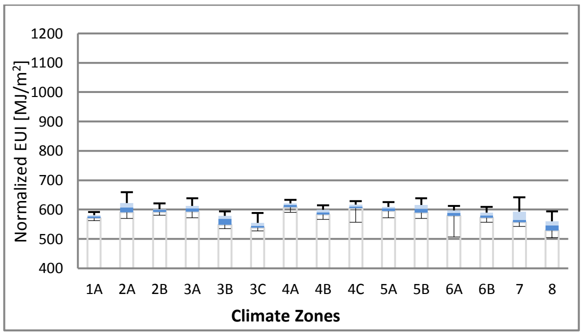

Figure 4 Results of applying weather adjustment coefficients for small office to a set of simulated building EUIs

In addition to testing the calculated weather coefficients on sample buildings, their correlation with CDD/HDD is also examined to see how they compare. Results shown in Figure 5 indicate that there is a high correlation between heating load normalization coefficients developed and HDD (R^2 = 0.9487 for School and 0.867 for Large Office). This is because heating is mainly affected by dry bulb temperature, which is used in calculation of HDDs as well. However, data is not perfectly correlated because solar gain is ignored in determination of HDD while it is considered in TMY3 weather files used in this work.

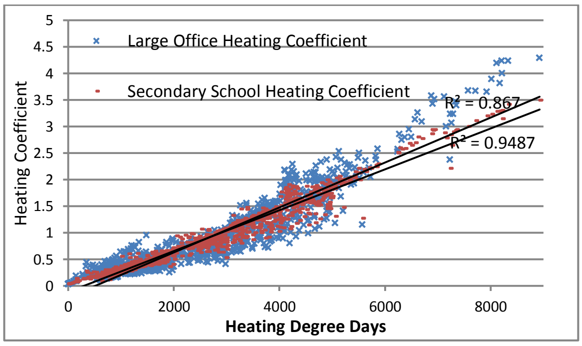

Figure 5 Correlation between heating coefficients and HDD for Large Office and School

The correlation between cooling load normalization coefficients and CDDs (shown in Figure 6) are lower (R^2 = 0.89 for School and 0.74 for Large Office) than coefficients for adjusting the heating load. This lower correlation could be caused by latent cooling load resulting from humidity not considered in CDDs.

Another reason for not having higher correlation between calculated coefficients and HDD/CDD could be the lack of wind speed data in calculation of degree-days.

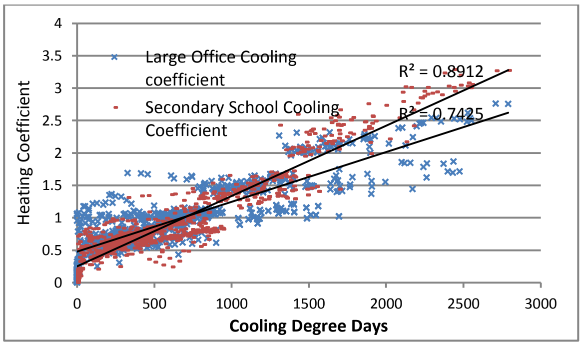

Figure 6 Correlation between cooling coefficients and CDDs for Large Office and School

CONCLUSION

Preliminary results of a study on impacts of weather on energy consumption of buildings in different weather locations in the U.S. were given. Literature was reviewed and a simulation-based weather adjustment approach was presented and its robustness was tested. Results indicate that coefficients developed can isolate and adjust for the impacts of weather in different climate zones and weather locations. However, their level of success varies in different climate zones. Reasons for this include uncertainty in modelling , uneven distribution of weather stations in different climate zones, and the approach of basic normalization to a national average.

Data generated was also compared with degree-days and results found could be used to improve regression-based normalization methods.

FUTURE WORK

The work described in this paper is part of an ongoing project; further research will be performed to test the validity of the approach explicated. Other ways to normalize a data set should be explored and compared to the results obtained in this paper. More buildings with different characteristics should be simulated to have a better sample size in each weather location for a more robust weather normalization approach. Coefficients should be organized for ease of use by a larger group of researchers and practitioners. Finally, the robustness of weather coefficients calculated should be further verified.

ACKNOWLEDGEMENT

The authors are very grateful and appreciate the assistance of Todd Taylor who constructed the cluster simulation structure in *EnergyPlus*, which allowed us to evaluate the energy use of many building typologies in hundreds of weather files in a timely fashion.

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