Selection of Appropriate Weather Files for Building Energy Simulation

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ABSTRACT

Proper selection of weather data is an important component of evaluating energy efficiency through the use of building energy simulation. However, it is often difficult to determine an appropriate set of weather files and proportional weighting to represent a large region, such as in the analysis of building energy codes, regulations or demand side management (DSM) programs.

The Department of Energy (DOE) has presented a method to address this problem (Briggs et al. 2003). Appropriate weather files are assigned in a two step process by (1) linking populated places to National Oceanic and Atmospheric Administration (NOAA) weather data, and (2) selecting appropriate weather files based on the ‘equivalent latitude miles.’ When this method is applied to a region, it can provide population based weighting. This metric appears to have significant potential for improving the selection of weather files by taking into account the effects of heating degree days (HDD), cooling degree days (CDD), distance, and elevation.

This paper evaluates the error associated with the second step of this process compared to a simple distance only weather file selection method and a method based on HDD and CDD, using savings from weather-sensitive upgrades as the basis for comparison. Upgrade savings are calculated with known weather data for a number of base locations. Savings are then calculated for the location indicated as most similar by each method. The difference in energy efficiency savings between the base and proxy locations is analyzed to determine the potential error of each method.

Introduction

Proper selection of weather data is an important component of evaluating energy efficiency through the use of building energy simulation. In particular, regional studies such as analysis of codes, regulations or utility Demand Side Management (DSM) studies require the selection and proportional weighting of a set of weather locations to represent a large area. While local knowledge can sometimes aid in the selection of appropriate weather data for a specific site, this is not always sufficient or known.

The simplest method to address this problem would be to select weather locations based on distance alone. While straightforward, the method ignores known weather statistics. In their paper “Climate Classification for Building Energy Codes and Standards,” Robert S. Briggs et al. (Briggs et al. 2003) present a method that includes consideration of elevation, heating degree days (HDD) and cooling degree days (CDD) in addition to distance.

This paper evaluates the effectiveness of the equivalent latitude miles method proposed by Briggs et al., using energy savings from several typical energy efficiency upgrades as a means for evaluation. Absolute and percent error for a representative data set are shown, and are compared to a simple distance-only method and to a method utilizing HDD, CDD, and distance.

Equivalent Latitude Miles Method

In this method, weighting factors for a discrete set of weather locations are created by connecting population data to weather locations in a two step process. The first step links United States Geological Survey data of populated places to basic weather data from the National Oceanic and Atmospheric Administration (NOAA) based on distance and elevation. Next full weather data for energy simulation, in the form of the second edition Typical Meteorological Year (TMY2) weather files, is mapped to the NOAA data using the 'equivalent latitude miles.'

The equivalent latitude miles (ELM) metric was developed by performing a regression on various pairs of weather locations. The resulting equation uses heating degree days (HDD), cooling degree days (CDD) and elevation differences between a base location and possible nearby weather file locations to calculate the equivalent latitude miles. This value is added to the actual distance. When the elevation difference between the NOAA location and the closest available TMY2 file is less than 300 feet, the closest location is used. Otherwise, the weather location with the lowest sum of actual and ELM distance is selected as the "proxy location". The equation provided by Briggs et al. is shown in Equation 1.

Equation 1 - Equivalent Latitude Distance (Briggs et al. 2003)

$$d_{equiv} = I + \alpha \times \Delta HDD + \beta \times \Delta CDD + \gamma \times \Delta Elev$$

Where

d_{equiv} = equivalent latitude distance (miles)
ΔHDD = difference in heating degree-days (base 65F)
ΔCDD = difference in heating degree-days (base 65F)
$\Delta Elev$ = difference in elevation (feet)
I = -6.8938
α = 0.1061
β = -0.0149
γ = -0.0718

This paper examines whether this Equivalent Latitude Miles metric performs better than the distance-only method in the context of building energy efficiency analysis. The primary purpose for using energy simulation for buildings is to understand the impact of energy consuming technologies on a building's performance. For this reason, the energy savings from a weather-sensitive technology upgrade were seen to be an appropriate method for evaluating this method of weather file selection. The specific evaluation criteria was whether the proxy location selected by the ELM method provided similar energy savings to what could be expected at the actual location.

Full weather data for simulation is not available at each of the 4775 NOAA weather sites. In order to test the ELM method, full annual weather data was needed for both the original and proxy location. The more recent third edition Typical Meteorological Year (TMY3) annual weather data, based on recorded weather from 1991-2005, provides greater geographical coverage with 1020 US locations as compared to the 239 in the TMY2 set (BTP 2009). For this reason, both original and proxy locations were selected from the TMY3 data set. Energy savings from an efficiency upgrade were determined at the original location via simulation. Next savings were determined at the next-best TMY3 weather location selected by the distance-only and ELM methods (the “proxy location”) and then compared to savings at the actual location.

Comparison to Distance Only Method

The Equivalent Latitude Miles method was intended to improve upon a distance-only method of selecting appropriate weather files, acknowledging that HDD, CDD, and elevation will also play a role in determining energy consumption. To evaluate the ELM method results were compared to the distance-only method to determine if it does indeed represent an improvement over the simpler method.

This analysis uses the savings from three energy efficiency measures (EEMs) as the basis of comparison. These included (1) a furnace upgrade from an efficiency of 75 AFUE to 85 AFUE, (2) an 11.6 EER to 12.3 EER air conditioner upgrade and (3) a 25% increase in wall insulation. The inclusion of these three measures allowed for the evaluation of the metric in upgrades that affect heating, cooling, and a measure with trade-offs between both heating and cooling.

Energy simulations were performed using the Department of Energy’s Commercial Reference Buildings Version 1.2_4.0 (NZECBI 2009), using the EnergyPlus (BTP 2010) simulation engine. The medium office building was chosen because it is a common building type in the commercial sector; each location was simulated using the benchmark EnergyPlus input file with the appropriate climate zone characteristics for that location; however, the design day data was changed to match the weather file used. The HVAC systems in the building was autosized by EnergyPlus. These files provide complete EnergyPlus input data of typical commercial buildings in the United States and allows for greater transparency and consistency in the evaluation.

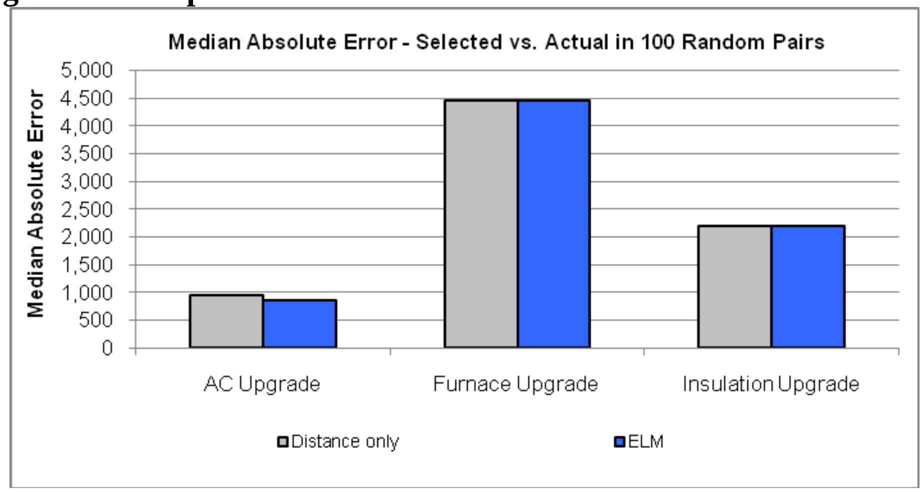
100 base locations were randomly chosen from the available TMY3 weather locations in the continental US. For each of these base locations, the distance-only and equivalent latitude proxy locations were found by selecting the top ranked TMY3 location using each method. The actual distances between the base city and all other cities in the TMY3 data set were calculated based on the latitude and longitude of the locations. Latitude, longitude and elevation were extracted from the statistical (STAT) files accompanying the TMY3 files. HDD and CDD, with a base temperature of 65 degrees Fahrenheit, were also extracted from the STAT files. For the equivalent latitude metric, the absolute distance was added to the equivalent latitude miles, calculated using Equation 1 above. Three examples are shown in Table 1 below. In 86 out of the 100 of the cases the equivalent latitude miles and distance-only methods selected the same proxy location.

Table 1 - Example Base and Proxy Locations

Base Location	Distance-Only Proxy	Equivalent Latitude Proxy
Concordia Blosser Municipal Airport, KS	Fort Riley Marshall Airfield, KS	Manhattan Regional Airport, KS
Chicago Waukegan Airport, IL	Chicago O’Hare International Airport, IL	Chicago O’Hare International Airport, IL
Benson Municipal Airport, MN	Morris Municipal Airport, MN	Morris Municipal Airport, MN

Energy savings were calculated as the difference between whole building energy in one location. Error in energy savings was then calculated as the difference between the energy savings between the base and proxy locations. The 14 locations for which the ELM method selected a different location have very little impact on the error of the set. Figure 1 the median error for each of the three energy efficient measures (EEMs). The AC upgrade shows a very small decrease in error with the ELM method. The other two upgrades show no appreciable change in error.

Figure 1 – Comparison of Median Error in Distance and ELM Methods



By including a 300 foot elevation difference filter for the equivalent latitude miles equation, Briggs et al. ensured that in most cases distance alone would determine the appropriate proxy location. The few locations chosen by the equivalent latitude miles metric would have significant elevation changes and as such would be likely candidates for microclimates with the greater chance of energy differences. Although there is only a minimal impact on error in the dataset as a whole, the ELM method could be expected to reduce the number of outliers in the data.

Figure 2 to 4 on the following page show the actual error of the two methods for the 100 random locations. The results have been sorted based on the error of the distance only method, from lowest to highest. The error for the same base location using the ELM method is shown on top of the distance method. When the two methods produce the same error (i.e. when the same location is selected), the two data sets fall on top of each other. When a different location is selected with the ELM method, the resulting error falls off the distance-only line. Points above the line represent locations with error higher than the distance-only method, while points below the line represent locations with lower error.

For each of the three upgrades, the majority of the cities changed by the ELM method are in the upper half of the error range of the cities. However, these are not necessarily those with the most error that a method targeting outliers would hope to reduce. In the AC upgrade, only one of the top ten highest errors is reduced with the ELM method. Two and four out of the top ten are changed for the insulation and furnace measures, respectively; however, the error in the city with the largest error for the furnace measure actually increased with the ELM method.

Overall, it is not clear that the ELM method provides an improvement over the distance-only method, either in average error or in the reduction of outliers. From this sample, it did appear that in general the ELM method favored modification to cities with higher total error, but did not necessarily improve the energy savings estimates by changing the city. This conclusion, of course, is limited only to the randomly-sampled locations studied here. Looking specifically at locations with significant differences in elevation or analysis of a different building type may show more significant benefits of the ELM method.

Degree-Days Method

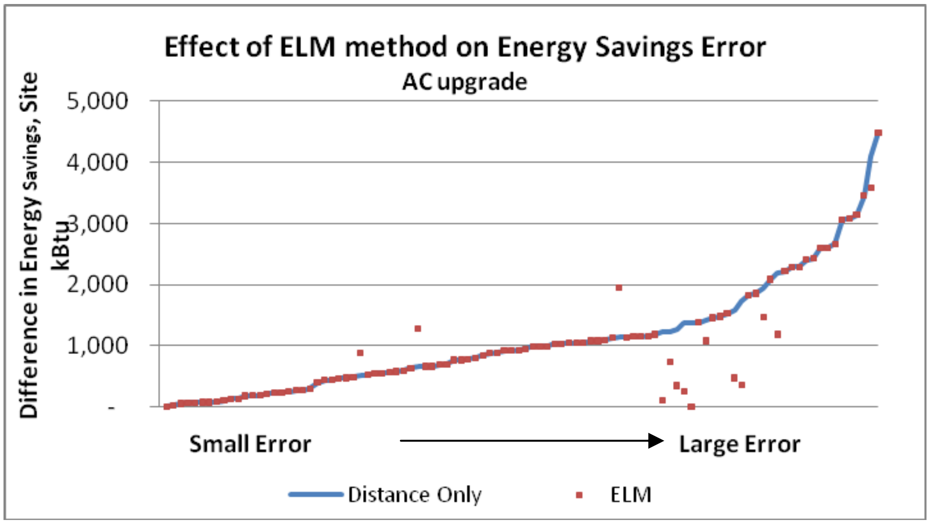
A third alternative for assigning weather file locations for energy simulation is based on finding locations that are highly similar in heating degree days (HDD) and cooling degree days (CDD). In the ELM method, distance is by far the dominant factor. It also considers the energy-influencing variables of HDD and CDD, but does so only when there is a significant elevation difference in the nearest location. The proposed method lowers the comparative influence of distance by eliminating the elevation filter. In addition, the method considers heating and cooling degree-days as being equally important, instead of weighting one more than the other. Although many other variables influence the results of building energy simulations, this method does not consider the impact of those variables in selection. This method is called the Degree Day method.

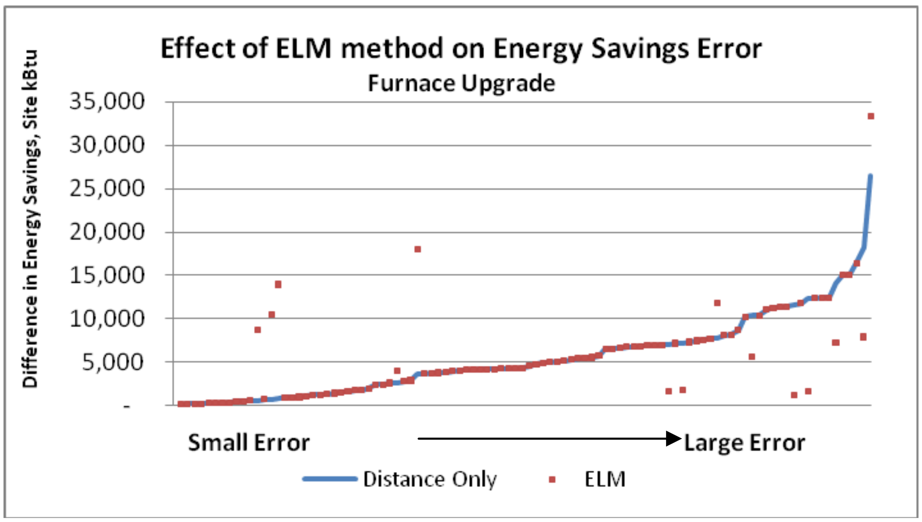
In this method, the ten nearest locations are determined. From these, the location with the closest combined sum of HDD and CDD is selected as the most representative. Several options of weighting for HDD and CDD were considered, including using regression data on building energy simulations for the medium office buildings selected for analysis of the ELM method. However, the ideal weighting of energy parameters is highly dependent on multiple variables. Heating and cooling measures will favor HDD and CDD, respectively. Additionally, building type will play a strong role in the relative importance in measures that affect heating and cooling, with CDD being less important in commercial buildings as compared to residential due to high internal gains. To avoid limiting the applicability of the method, equal weighting was seen to be the simplest solution.

Choosing from the ten nearest locations ensures the selected location is relatively near, but avoids giving too much weight to distance alone. HDD and CDD are not the only factors that influence building energy predictions, and as such distance must still be a significant criteria in weather selection. The most appropriate number of nearby cities to consider will depend on the number and distribution of locations in the data set. The authors propose that a refinement to this method could include looking at the typical distance of the set of closest locations from which the proxy location is selected. However, this analysis only seeks to show the possible impact of a method with a lower requirement for proximity.

To validate the method energy simulations were performed on each of the 100 base cities that were used to evaluate the distance-only and equivalent latitude miles methods previously. Each selected location was simulated with the AC, furnace and insulation upgrades. Figure 5 through Figure 7 show resulting absolute errors for each of the three methods. The middle line in the bars represents the median error, while the edges of the bars represent the upper and lower quartiles of the data. The upper whisker represents the highest error in the data set. The lowest error was near zero in each case. Table 2 provides a summary of these same results in both absolute and percent error.

Figure 2 to 4 – Error of Distance and ELM Methods in 100 Random Cities





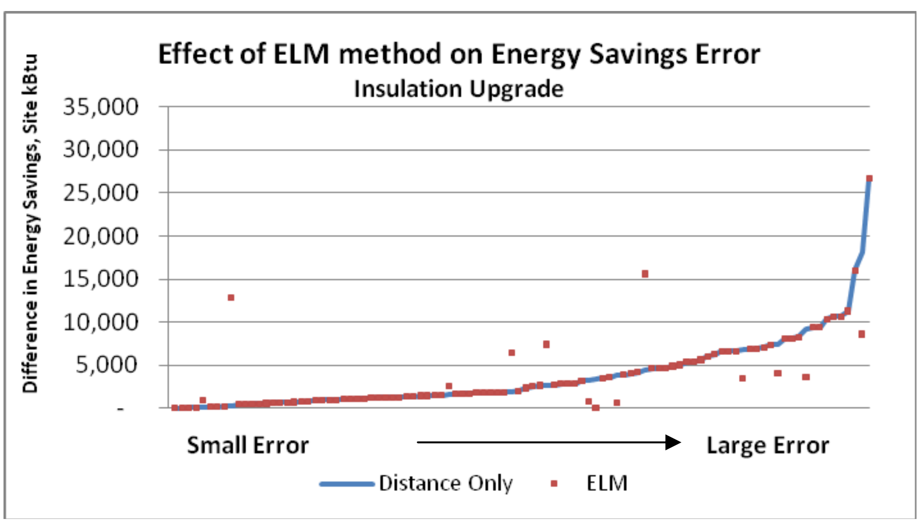


Figure 5 – Median, Upper and Lower Quartile of Energy Savings Difference

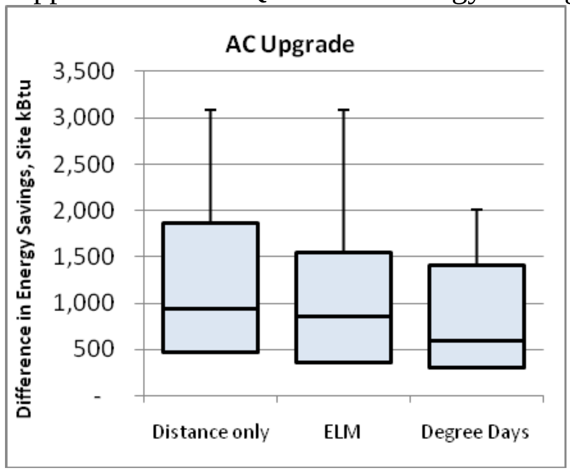


Figure 6 - Median, Upper and Lower Quartile of Energy Savings Difference

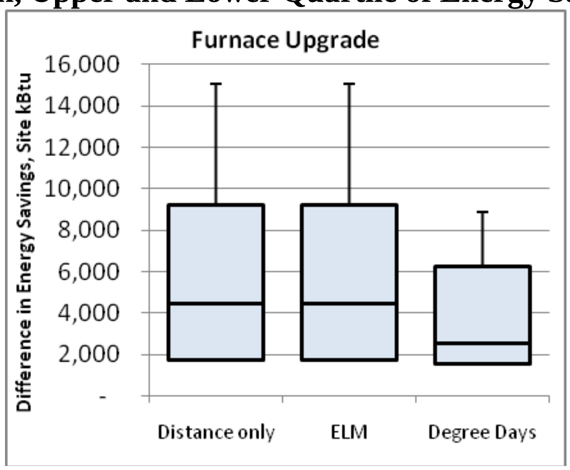


Figure 7 - Median, Upper and Lower Quartile of Energy Savings Difference

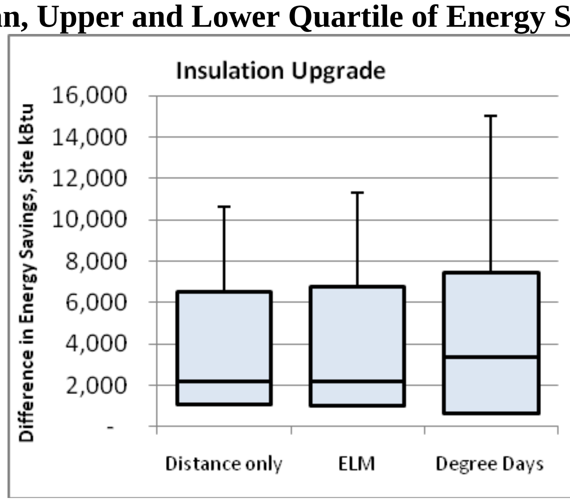


Table 2 - Error in Energy Savings for 100 Random Cities

		Energy Savings Difference (kBTU)				
		Mean	**Median**	**Min**	**Max**	**Std Dev**
AC Upgrade	**Distance-Only**	1,105	938	9	4,492	918
	Equivalent Lat.	1,025	862	9	4,492	911
	Degree Days	812	592	9	4,104	699
Furnace Upgrade	**Distance-Only**	5,608	4,455	114	26,436	4,733
	Equivalent Lat.	5,646	4,455	114	33,336	5,018
	Degree Days	3,724	2,517	0	26,436	3,820
Insulation Upgrade	**Distance-Only**	3,815	2,204	0	26,682	4,207
	Equivalent Lat.	3,854	2,204	0	26,682	4,221
	Degree Days	4,774	3,332	0	34,814	5,954

The results shown appear to favor the Degree Days method as compared to the other two methods. For the AC and Furnace upgrades, the median, upper and lower quartile results all have improved accuracy. For the insulation upgrade, results are less clear, with the lower quartile results being lower while the median and upper quartile results are both less accurate compared to the other two methods.

Overall, the equivalent latitude miles method provided a small but inconclusive improvement over the distance only method. The Degree Days method presented substantial improvement over both other methods for the simple AC and Furnace upgrades. However, for the more complex insulation upgrade, the Degree Days method resulted in increased volatility with a greater range in potential error, and this volatility presented potential for worse energy savings estimates.

In the insulation measure, the main source of the poor performance in the locations analyzed for the Degree Day method comes from the high number of outliers above 50% percent error. These outliers are shown in

Table 3 below.

The proxy locations' HDD and CDDs are within 50 of the base location on average, and no more than 120 in the worst case. Therefore, the method is working as expected by choosing locations with similar HDD and CDD. One possible reason is these heating and cooling degree-days, while similar in overall annual magnitude, may be distributed differently throughout the year. During shoulder seasons insulation can become a penalty, particular in an office building, by trapping internal gains. Additionally, other variables such as solar radiation and wind can change building heating and cooling energy despite similar HDD and CDD.

Table 3 - Insulation Savings Outliers with Degree Days Method

Base Location	CDD	HDD	Insulation Savings (kBTU)	Proxy Location	CDD	HDD	Insulation Savings (kBTU)	Percent Error
Galveston Scholes	1,761	569	14,492	Houston William P Hobby Airport	1,641	516	5,791	0%
Kelso WB Airport	45	2,530	47,847	Tacoma Narrows	74	2,607	13,033	3%
Valparaiso Elgin Air Force Base	1,340	1,081	5,156	Dothan Municipal Airport	1,352	1,109	14,900	89%
Houston William P Hobby Airport	1,641	516	5,791	Galveston Scholes	1,761	569	14,492	50%
Portland International Airport	188	2,292	45,022	Corvallis Municipal Airport	225	2,291	13,924	9%
Gulfport Biloxi International Airport	1,461	841	15,222	Pensacola Forest Sherman Airfield	1,489	814	23,212	2%
Brewster Field Airport	494	3,599	19,744	North Platte Regional Airport	465	3,615	34,748	6%
Alamosa San Luis Valley Regional Airport	28	4,674	21,223	Craig Moffat	65	4,669	32,341	2%

Conclusions

The comparison of the three methods leads to a number of conclusions. First, the Equivalent Latitude Miles method does not provide a significant advantage over the distance-only method when it comes to selecting a set of regional weather locations for building energy simulation. In terms of mean percent error in savings, the equivalent latitude method results were within 1% for each of the measures, and in the case of the furnace measure actually produced worse results. Additionally, for the locations that were changed with the ELM method, while the majority were those in the upper half of the error range they were not typically the true outliers that the elevation filter was meant to select. Considering that the Equivalent Latitude Miles method is more complicated to implement and more difficult to explain, many will find the distance-only method a better choice for regional studies using building energy simulation.

Second, the Degree Days method offers the prospect of reduced error for some measures like heating and cooling equipment efficiency. For instance, the mean percent error is reduced from 8% to 6% for the AC measure and 9% to 5% for the furnace measure when using the HDD/CDD method instead of distance-only. However, the method does provide worse savings for a wall-insulation measure, with the mean percent error going from 16% to 20%, primarily due to the risk of a small number of selections having very high percent error. Further validation is required, primarily to investigate results in other complicated measures like window U-values and SHGC coefficients, ceiling and floor insulation, and infiltration reduction.

The conclusions of this analysis only demonstrate the impact of weather file selection on a medium office building. While this may provide a good indication of how other building types may perform, significant difference in usage patterns, internal gains and other factors will change the impact of the difference in weather data. The authors suggest that further analysis could be done both in investigating the effect of building type and ways to improve the HDD/CDD method through more rigorous analysis of the relevant variables.

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