NATIONWIDE IMPACTS OF FUTURE WEATHER ON THE ENERGY USE OF COMMERCIAL BUILDINGS

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ABSTRACT

The energy use of commercial buildings is highly dependent on the regional differences of building stock and local weather. Nationwide building energy use is often calculated using the simulation of a set of "reference" buildings using regional typical meteorological year (TMY) weather files which are combined in weightings indicative of relative prevalence in the national building stock. To understand how changes in future weather will affect building energy use, one could run the set of simulations with "future" weather files that are supposed to reflect the expected change in weather that comes from variations in global climate.

There are several ways of generating "future" weather for use in such simulations including "morphing" of current TMY weather data, generation of synthetic weather using statistics extracted from simulations of global climate, or by dynamic downscaling of future climate simulations, i.e. regional weather simulations driven by boundary conditions extracted from future climate simulations.

In this paper the authors present a comparison of energy use of commercial buildings in the US using current TMY files and of future weather files generated using dynamic downscaling of global circulation models. Future weather files are created from dynamic downscaled climate models for the years 2050 and 2090 the expected energy changes in total energy for the ASHRAE climate regions along with changes in expected heating and cooling energy for some specific buildings and cities are presented.

INTRODUCTION

Building designers have known for decades that climate and associated weather affects building energy use and that a changing climate means changing weather patterns and a change in building energy use. There have been many oversimplified generalizations about these changes such as “buildings will use more energy” or “more cooling will be required”. There have been a number of studies looking at regional impacts of climate change on building energy use in different regions of the world, typically with a focus on homes, but relatively little looking at the effects on a large variety of commercial building types over large range of climate zones such as found across the United States.

When data from a regional climate model dynamic downscaling of global climate models over the entire United States came available, there was a great opportunity to use those data to look into nationwide effects of climate change on commercial building energy use. This paper describes conversion of the dynamic downscaled global climate models into weather data suitable for building energy simulation and application of those weather data to estimate the energy use of commercial buildings convert those data into weather files suitable for building energy simulation and investigate the change in energy use of commercial buildings across the U.S. The study includes ASHRAE climate zones 2A – 8 (excepting 6B) and most of the standard reference buildings typically used for energy code analysis and nationwide impacts of energy efficiency measures. The results of the study are somewhat limited however because the analysis only used one GCM and did not refine the set of buildings any finer than the standard set of DOE reference buildings.

SIMULATION METHODOLOGY

The simulation methodology has two distinct steps: generation of future weather files at specific locations across the U.S. followed by building energy simulation and analysis.

Future Weather File Generation

Researchers have developed a multitude of ways to estimate future weather files to understand the impacts of climate change on building energy use. Most of these start with long term future global climate data estimated with one or more Global Circulation Models (GCMs).

The “Morphing” method, as described by Troup and Fannon (2016) and Dickinson and Brannon (2016) takes a current TMY weather file for the location of interest and will *shift* and *scale* the TMY data in order for the monthly average values of several weather data variables to match the average values obtained by the GCM for a number of variables including:

- max, min, and mean daily temperatures
- relative humidity
- solar irradiance
- wind speed
- air pressure
- total precipitation

While a morphed weather file does have a realistic temporal variation of weather variables, the morphing procedure does not necessarily maintain the proper physical relationships between variables. The atmosphere is a highly nonlinear coupled system and a series of linear transformations applied to variables will not maintain those non-linear relations. Furthermore, expected changes of intensity, duration, and frequency of weather events such as heat waves, cold waves, clouds, and precipitation will not be reflected in the morphed files because the temporal variation follows that of the weather of today.

An alternative to morphing is the use of a stochastic weather generator that is “tuned” to match the spatial and temporal averages predicted in future by a GCM. It is not clear that this method provides any distinct advantage over the morphing technique since, again, the non-linear relations between atmospheric variables are not necessarily maintained because the statistical inputs that feed the stochastic generator come from current weather which represents a different macro state of the atmosphere. It is also unclear if the stochastic method will properly generate the expected variation in intensity, duration, and frequency of weather events.

A very computationally intensive alternative to morphing or stochastic weather generation is the method called Regional Climate Model (RCM) dynamic downscaling. In this method, a GCM run is used to estimate the long term climate state throughout a large region, but those data are used to act as boundary conditions for the running of a smaller scaled regional weather model (such as the Weather Research and Forecasting Model (WRF) (Powers *et al.* 2017). Future weather files are then extracted from specific locations in the RCM output. The combination of GCM and RCM can easily require weeks of computing time on even the world’s largest supercomputers. However, since this method actually models the coupled non-linear thermodynamics and fluid mechanics of the atmosphere, it can produce both the large scale and small scale spatial and temporal variations expected of future weather and will generate the expected variations in intensity, duration, and frequency of weather events.

A good comparison of the tradeoffs between the different methods of generating future weather can be found in the reviews by Herrera et al. (2017) and Moazami et al. (2017 and 2019).

For this study, the authors obtained data generated by the dynamic downscaling method using WRF on a 12 km grid. Details of the study are described in Zobel et al. (2017). The data used here were taken specifically from the Representative Concentration Pathway (RCP) 8.5 runs driven by the Community Climate System Model 4 (CCSM4) GCM. The RCM model was calibrated to local weather over the years 1995-2004 and then driven by GCM for the years 2045-2054 and 2085-2094. Unfortunately, the original purpose of the data was to look at climate induced changes in intensity, duration, and frequency of weather events and so the simulation results were saved for every 3 hours instead of every hour to save storage space. Even so, the set of data files for the two-decades of weather over the full 12 km grid exceeds 10 TB for just one RCP. The uncertainty in the results from running just one RCM with just one GCM are likely large and it would be better to use data from multiple RCM runs using different GCM as boundary conditions, but the required computing effort makes this impractical in general. As the data from running RCMs based on additional GCMs come available, the results presented here will be updated and expanded.

Weather data for the years 2045 and 2090 were extracted from the simulation grids at the ASHRAE 90.1-2016 representative locations shown in Table 1 cities representing the 15 ASHRAE climate zones across the continental US and Alaska.

Climate zone 1A, represented by Honolulu, was dropped from the analysis because dynamic downscaling data for the Honolulu region was not yet available. Climate zone 6B, represented by Great Falls, was dropped from the analysis because of some building model errors that occurred during the energy simulation portion of the project. The extracted weather data were then converted from 3hr values to hourly values using cubic spline interpolation and finally converted into standard EPW files using the EnergyPlus Weather Converter program.

Note that these data are single year future meteorological year (FMY) weather files and not “future” TMY (FTMY) files created from multiple years of FMY data. The use of FTMY files would be preferred but at the time of this analysis, the authors had not yet created the software to analyze multiple years of FMY to generate FTMY. The current ASHRAE TMY3 files were used for generating the energy use in 2016 used as a comparison point for energy use in the future.

Table 1: Climate Locations Used in Energy Simulations

CLIMATE ZONE	MOISTURE REGIME	WEATHER LOCATION
2A	Moist	Tampa, FL
2B	Dry	Tucson, AZ
3A	Moist	Atlanta, GA
3B	Dry	El Paso, TX
3C	Marine	San Diego, CA
4A	Moist	New York, NY
4B	Dry	Albuquerque, NM
4C	Marine	Seattle, WA
5A	Moist	Buffalo, NY
5B	Dry	Denver, CO
5C	Marine	Port Angeles, WA
6A	Moist	Rochester, MN
7	N/A	International Falls, MN
8	N/A	Fairbanks, AK

For the comparative analysis done in this study, the differences between the results obtained with morphed, stochastic, or dynamic downscaled FMY files is likely quite small since the quantity of interest is annual energy consumption. However, if one were trying to use the weather files for sizing equipment, computing unmet hours, or looking at the timing and value of peak loads, the differences between the simulation results is expected to be more significant.

Building Energy Simulation and Analysis

For the analysis shown here the authors used the methodology employed for ANSI/ASHRAE/IES 90.1 savings analysis as described by Liu, Rosenberg, and Athalye (2017) using EnergyPlus V9.1 (EnergyPlus) for building energy simulations and used a subset of the ANSI/ASHRAE/IES Standard 90.1 Prototype Buildings as developed by Pacific Northwest National Lab (PNNL 2019). The files were converted from EnergyPlus V8.0 to V9.1 using the EnergyPlus IDF convertor included with EnergyPlus. The hospital and outpatient healthcare facilities were excluded from the study because of model errors that occurred during the conversion process from V8.0 to V9.1. A finer breakdown of the building stock, including both finer regional variations and building type variations would be preferred but such a characterization of the building stock was not yet available when this analysis was made.

For this analysis, the 2016 building vintage model was used for all simulations. 2016 was selected because it is a reasonable representation of buildings being designed and constructed today. While energy efficiency increases in the building design are indeed expected to occur between 2016, 2050, and 2090, using the same building design and simulation model allows us to isolate energy use changes caused by climate change. It is important to note that a large fraction of the buildings being built in 2016 will still be in service in 2050 and some will still be in service in 2090 and many of the basic building envelope components of those buildings will be largely unmodified.

For each of the years of analysis (2016, 2050, and 2090), the set of 13 buildings are simulated at all 14 locations resulting in a total of 546 simulations which take approximately 3.5 hours to run on a modern desktop computer. These simulations are run in batch fashion using the group files feature of the EnergyPlus EP-Launch program. The annual heating, cooling, fan, and total energy use are extracted from each of the EnergyPlus simulation output files using python scripts. Python scripts are then used to generate result tables and the figures shown in this paper.

To estimate the annual energy use change for the entire city, the total annual energy is added in an area weighted fashion to estimate the total energy use of the city from the selected building types. The area weighted fractions for this analysis were those found in Table 3 of the ASHRAE 90.1-2016 Energy Savings Analysis (DOE 2017) and shown in Table 2 below.

Table 2: Relative Construction Weights for Prototype Buildings for Climate Zones 2-8

	CLIMATE ZONE													
BUILDING TYPE	**2A**	**2B**	**3A**	**3B**	**3C**	**4A**	**4B**	**4C**	**5A**	**5B**	**5C**	**6A**	**7**	**8**
Large Office	0.39	0.06	0.49	0.28	0.12	1.05	0.00	0.15	0.44	0.12	0.00	0.08	0.01	0.00
Medium Office	0.85	0.29	0.83	0.72	0.14	1.16	0.04	0.19	1.00	0.35	0.01	0.21	0.02	0.01
Small Office	1.13	0.29	1.02	0.47	0.08	0.84	0.06	0.12	0.89	0.32	0.01	0.18	0.02	0.00
Stand-Alone Retail	2.33	0.51	2.57	1.25	0.19	2.44	0.13	0.41	3.36	0.79	0.02	0.69	0.06	0.01
Strip Mall	1.08	0.25	1.11	0.63	0.10	0.89	0.02	0.11	0.96	0.20	0.00	0.09	0.00	0.00
Primary School	0.99	0.16	0.96	0.45	0.05	0.87	0.03	0.09	0.82	0.23	0.00	0.12	0.02	0.00
Secondary School	1.59	0.23	1.99	0.82	0.11	1.97	0.06	0.23	2.15	0.45	0.01	0.30	0.05	0.01
Full Service Restaurant	0.11	0.02	0.12	0.05	0.01	0.12	0.01	0.01	0.13	0.03	0.00	0.02	0.00	0.00
Fast Food Restaurant	0.10	0.02	0.10	0.06	0.01	0.09	0.01	0.01	0.12	0.03	0.00	0.02	0.00	0.00
Large Hotel	0.69	0.12	0.70	0.79	0.11	0.90	0.04	0.12	0.90	0.20	0.00	0.16	0.03	0.00
Small Hotel	0.30	0.03	0.27	0.11	0.02	0.32	0.02	0.04	0.35	0.09	0.00	0.08	0.02	0.00
Warehouse	3.07	0.58	2.70	2.30	0.15	2.84	0.08	0.43	3.01	0.70	0.00	0.29	0.03	0.00
Mid-rise Apartment	1.19	0.09	0.82	0.86	0.26	1.58	0.02	0.36	1.15	0.32	0.01	0.23	0.03	0.00

RESULTS AND DISCUSSIONS

The data generated by the analysis is too large to present in total so a few selected data are presented.

Figure 1 shows a plot of the fractional increase in total heating and cooling energy from 2016 to 2050 and 2016 to 2090. In the heating dominated climate zones: 6, 7, and 8, one can see a significant decrease in energy use because the increase in cooling energy is more than offset by the enormous decrease in heating energy requirements. As one can see, heating and cooling energy decreases of over 40% will occur by 2050 and over 50% by 2060. In contrast, the hotter regions will have energy increase. What is most interesting is that Zone 2A, which is coastal and moist, has a larger increase in energy use than Zone 2B which is dry. Temperatures are not expected to rise as much in Zone 2A but humidity levels with and thus the larger energy increase in 2A than 2B can likely be attributed to humidity levels. Similarly, Zone 3C, which is Marine, has larger energy use increases than either 3B or 3A.

Another interesting note is that Zones 4 and 5 show energy increases in 2050 but smaller increases or even decreases by 2090. A further analysis of the climate itself is necessary to understand the causes of those changes. Figures 2 and 3 (wide width at the end of this paper) show the heating, cooling, and fan energy for the different building types in zone 2A (Tampa) and Zone 8 (Fairbanks).

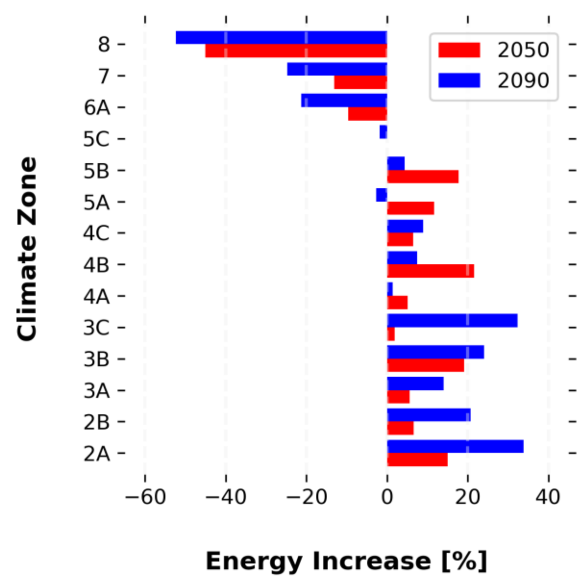

Figure 1: Change in heating and cooling energy use due to climate change in years 2050 and 2090 for most of the ASHRAE climate zones.

Figures 2 and 3show the heating, cooling, and fan energy for the different building types in zone 2A (Tampa) and Zone 8 (Fairbanks). The fan energy is virtually unchanged but as expected, the total energy increase in Tampa is dominated by increased cooling energy while the total energy decease in Fairbanks is dominated by cooling energy decrease and these trends hold for all building types. These plots show the actual energy use rather than a percent change to help the reader to understand the overall scale of energy use in the different building types for a given climate.

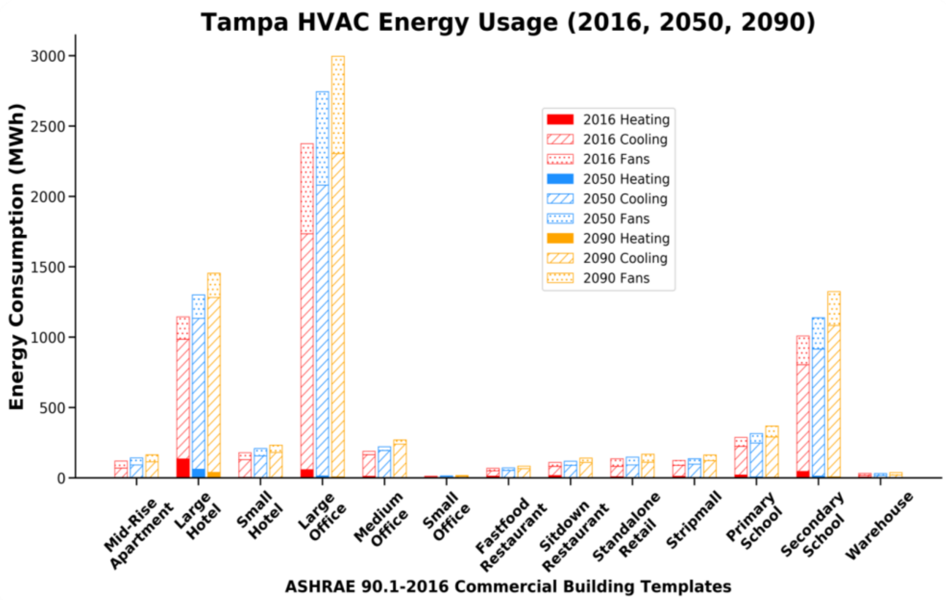

Figure 2: Heating, cooling, and fan annual energy use for several building types in Tampa, FL, a hot and humid climate.

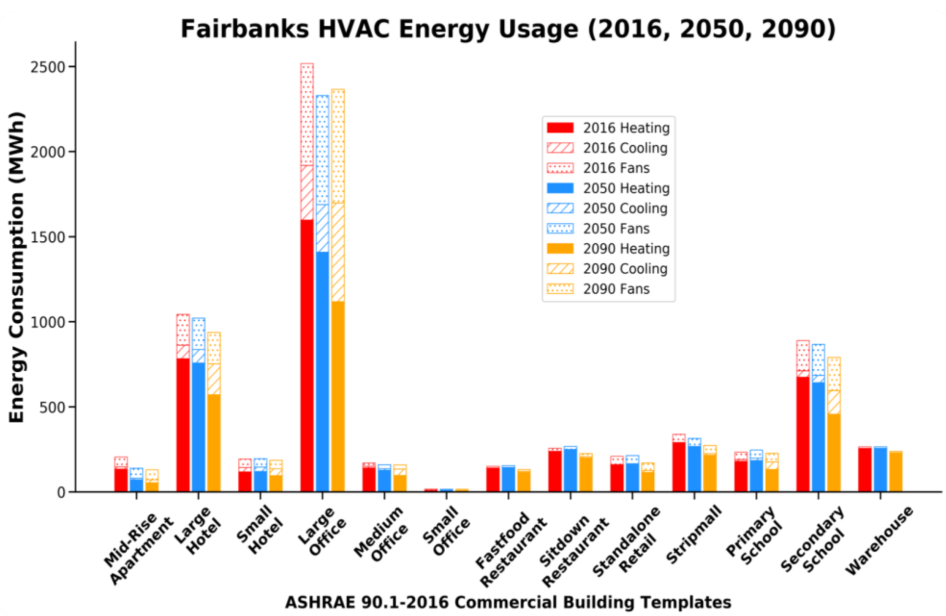

Figure 3: Heating, cooling, and fan annual energy use for several building types in Fairbanks, AK, a cold and dry climate.

Figures 4 and 5 show the heating, cooling, and fan energy for different cities for the small office building and warehouse building types. The small office is dominated by cooling energy use throughout most of the US and thus more than half the of the cities show a net increase in building energy use. In contrast, the warehouse is heating energy dominated in nearly all climates, so the warehouse is expected to have energy decreases throughout most of the U.S. These plots also show the actual energy use rather than percent change to help the reader see how the overall energy use differs by climate for the same type of building.

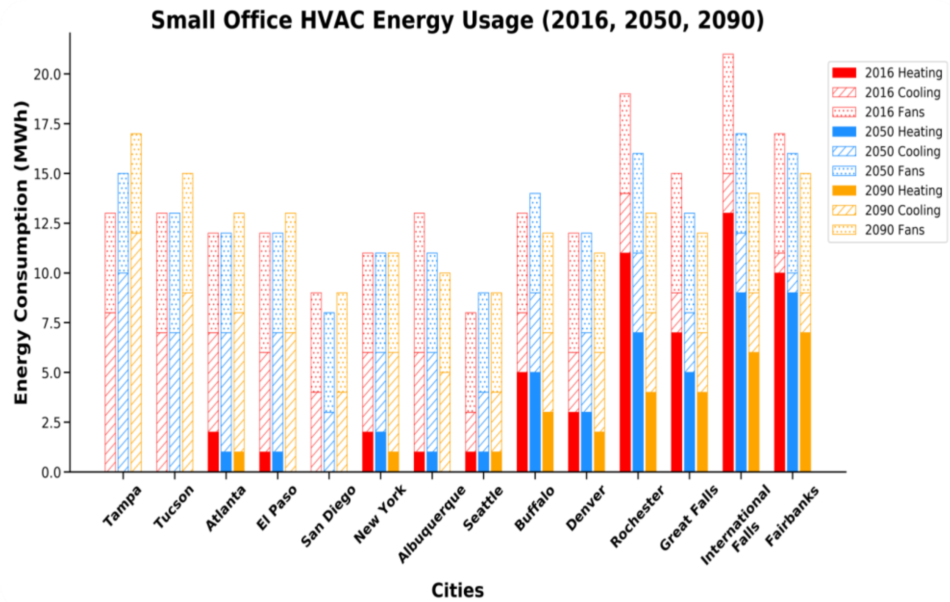

Figure 4: Heating, cooling, and fan annual energy use for small office buildings in 14 climate zones in the years 2016, 2050, and 2090.

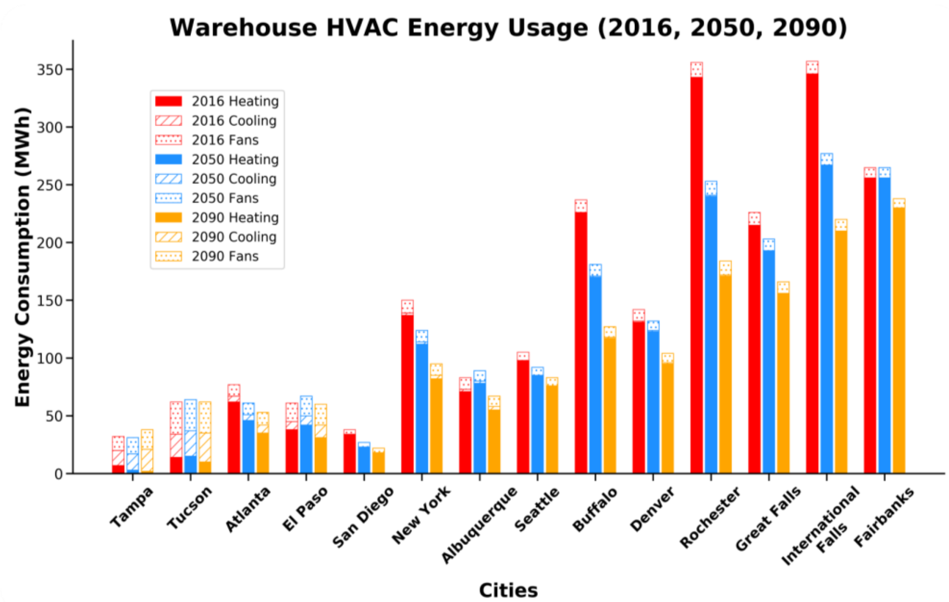

Figure 5: Heating, cooling, and fan annual energy use for small office buildings in 14 climate zones in the years 2016, 2050, and 2090

FUTURE WORK

The researchers who developed the initial 12 km grid RCM models from which the FMY files were developed have improved their models and are now running on a 4 km grid and are saving their simulation data hourly. There are plans to generate a new set of FMY files from those updated data. There are also plans to use standard methods of creating TMY files to create a "2050ish" FTMY from 2045-2054 runs and a "2090ish" FTMY from 2085-2094 runs. As the climate researchers expand their 4km RCM runs to other GCM besides CCSM4, weather files from those data will be generated.

Separate from the generation of a wider range of FMY and FTMY files, there are also plans to a much wider range of building types and characteristics using the methods being developed by NREL for their ResStock and ComStock models (NREL 2019).

The analysis presented here will be repeated using the larger set of FMY and FTMY files and the wider collection of building models. The future analysis will look more carefully at the interesting results for Zones 4 and 5 where the predicted change in energy does not make clear sense.

CONCLUSION

This paper has described recent work to estimate the changes in building energy use across the US for a large number of building types as a result of climate change. The paper describes a methodology for generating future weather climate files derived from dynamic downscaling of global climate models using a regional climate model. It then describes a methodology for evaluating regional and nationwide impacts of climate change on expected building energy use. By using the same building energy models for all years of analysis, energy use effects from climate change can be isolated.

The analysis shows that while most climate zones in the US can expect increases in energy use because the of the increases in required cooling energy exceed the decreases in required heating energy, northern climates in the US which are heating dominated are expected to have total heating and cooling energy related energy drops because the reduction in heating energy greatly exceeds the increase in cooling energy.

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