

Use of NARCCAP Data to Develop a “Typical Meteorological Year” to Incorporate Climate Change into Building Design

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Introduction

Typical climate conditions for the 20th century may not provide the full range of temperature, precipitation and humidity extremes that likely will be encountered for the built environment of the 21st century. The conventional practice in the engineering community for incorporating climate data into building design is to use the “Typical Meteorological Year” (TMY), a site-specific database of typical hourly values of climate developed by Wilcox and Marion based on observed conditions from the National Solar Radiation Data Base and meteorological data for 1976-2005 from NCDC. Based on future scenario climates for the period 2040-2070 produced by eight global/regional climate models, *future typical meteorological year* (FTMY) data sets were developed for Mason City, IA and basic energy calculations were conducted in Energy Plus for the US DOE commercial reference buildings. Our results show that the increase in energy consumption due to projected climate change at this location results primarily from an increase in ambient humidity in summer. Therefore, the largest energy cost for maintaining desired levels of health and comfort in the future at this location will be attributed to managing higher ambient humidity levels.

Data and Methodology

A total of nine variables are evaluated in this study – total sky cover, dry-bulb temperature, dew-point temperature, relative humidity, absolute humidity, pressure, wind speed, wind direction, and precipitation.

We first assess whether the TMY data for our selected site (Mason City, Iowa) are, indeed, “typical” compared to observations. We computed monthly and hourly averages of each variable using the current TMY3 data set and compared them to the 1976 to 2005 base period of observations using NCDC data. (Results not shown revealed that the differences were generally quite small – less than the monthly standard deviation in all months and all variables except relative humidity, pressure, and precipitation).

Next we use reanalysis-driven runs of five NARCCAP regional climate models to evaluate their skill in reproducing TMY3 data. Data were compared with the TMY3 months through both monthly and 3-hourly averages. Comparing data in this way clearly shows the bias structure for each model.

We then use NARCCAP data to evaluate monthly climate change in seven meteorological variables used in building design. The significance of these changes is assessed by comparison to interannual variability of the current climate at the selected site. Four NARCCAP global climate models (GCMs) and five regional climate models (RCMs) were used, represented by each model's closest grid point to Mason City.

Results

Model Evaluation

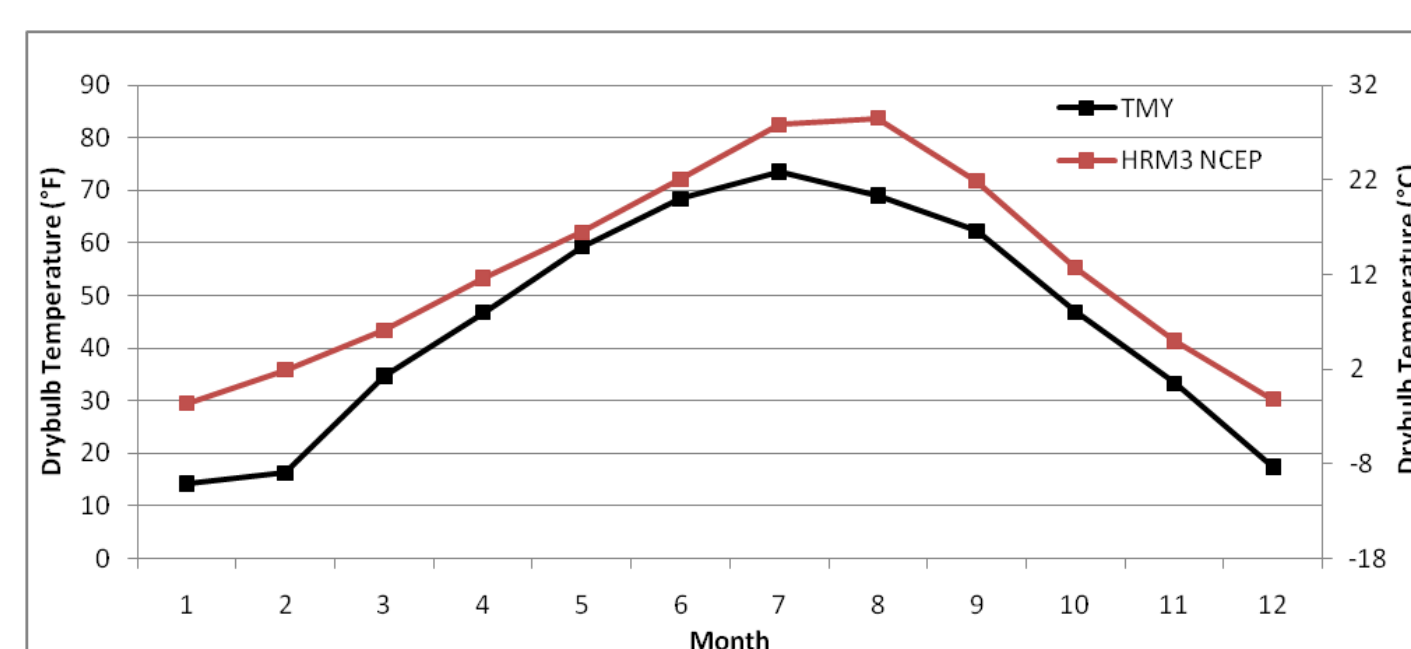


Figure 1: Comparison of TMY3 and HRM3-NCEP average monthly dry-bulb temperature for Mason City, IA. The Comparison shows a consistent warm bias in the dry-bulb temperature for the HRM3 regional climate model.

Model Projected Change

Model (Mason City, Iowa)	Totcid (tenths)	Drybulb (°F / K)	Dewpoint (°F / K)	Rhum (%)	Ahum (g cm ⁻³)	Pressure (in Hg / mbar)	Wspd (mph / m s ⁻¹)	Wdir (degrees)	Precip Total (in / mm)
CRCM-CCSM	-0.03	5.18 / 2.88	5.67 / 3.15	2.05	1.49	0.014 / 0.48	-0.09 / -0.04	-6.51	0.93 / 23.55
CRCM-CGCM3	-0.11	5.85 / 3.25	4.54 / 2.52	-2.15	1.20	0.003 / 0.09	-0.04 / -0.02	-4.33	0.61 / 15.60
HRM3-HadCM3	-0.25	4.80 / 2.67	3.37 / 1.87	-2.84	0.92	-0.022 / -0.73	-0.02 / -0.01	15.72	3.47 / 88.02
MM51-CCSM	N/A	3.67 / 2.04	4.15 / 2.30	1.12	1.02	0.013 / 0.45	-0.10 / -0.04	-4.20	4.61 / 117.16
RCM3-CGCM3	N/A	4.61 / 2.56	4.27 / 2.37	-0.04	1.07	0.004 / 0.14	-0.17 / -0.08	-6.48	2.38 / 60.53
RCM3-GFDL	N/A	4.01 / 2.23	3.70 / 2.05	-0.05	0.88	0.015 / 0.51	-0.08 / -0.04	1.84	2.38 / 60.36
WRFG-CCSM	0.16	4.87 / 2.71	5.19 / 2.88	1.19	1.03	0.020 / 0.68	-0.18 / -0.08	-3.58	2.96 / 75.18
WRFG-CGCM3	N/A	3.22 / 1.79	3.98 / 1.84	1.84	0.96	0.010 / 0.34	0.14 / 0.06	-0.57	1.45 / 36.75
Mean projected change	-0.06*	4.52 / 2.51	4.36 / 2.42	-0.10	1.09	0.007 / 0.25	-0.07 / -0.03	-1.01	2.35 / 59.64
SD of models' change	0.17*	0.85 / 0.47	0.76 / 0.42	1.80	0.19	0.013 / 0.44	0.10 / 0.05	7.33	1.34 / 34.06
SD of 20 th C obs	0.83	1.66 / 0.92	2.11 / 1.17	3.21	0.42	0.016 / 0.54	0.54 / 0.24	14.80	6.70 / 170.10

Model (Atlanta, Georgia)	Totcid (tenths)	Drybulb (°F / K)	Dewpoint (°F / K)	Rhum (%)	Ahum (g cm ⁻³)	Pressure (in Hg / mbar)	Wspd (mph / m s ⁻¹)	Wdir (degrees)	Precip Total (in / mm)
CRCM-CCSM	-0.16	4.47 / 2.48	4.00 / 2.22	-0.64	1.69	0.008 / 0.26	-0.07 / -0.03	0.29	-0.95 / -24.02
CRCM-CGCM3	-0.28	4.26 / 2.37	3.64 / 2.02	-1.13	1.55	0.003 / 0.10	-0.03 / -0.01	1.30	-0.25 / -6.38
HRM3-HadCM3	-0.18	4.08 / 2.27	3.29 / 1.83	-1.67	1.48	-0.023 / -0.78	0.14 / 0.06	1.60	3.87 / 98.30
MM51-CCSM	-0.17	3.66 / 2.03	2.88 / 1.60	-1.34	1.02	0.018 / 0.60	-0.28 / -0.13	27.02	-1.38 / -35.03
RCM3-CGCM3	N/A	3.63 / 2.02	3.45 / 1.92	-0.15	1.32	0.004 / 0.14	-0.07 / -0.03	0.11	0.32 / 8.17
RCM3-GFDL	N/A	3.69 / 2.05	3.08 / 1.92	-0.82	1.07	0.091 / 3.09	-0.07 / -0.03	-23.55	0.93 / 23.61
WRFG-CCSM	-0.24	4.81 / 2.67	3.34 / 1.71	-2.15	1.01	0.014 / 0.47	-0.15 / -0.07	6.83	-1.64 / -41.75
WRFG-CGCM3	N/A	3.06 / 1.70	3.54 / 1.96	1.30	1.28	0.021 / 0.70	-0.23 / -0.10	11.24	2.52 / 63.95
Mean projected change	-0.20*	3.96 / 2.20	3.40 / 1.89	-0.83	1.28	0.017 / 0.57	-0.10 / -0.04	3.10	0.43 / 10.86
SD of models' change	0.05*	0.56 / 0.31	0.34 / 0.19	1.06	1.30	0.033 / 1.12	0.13 / 0.06	14.07	1.94 / 49.31
SD of 20 th C obs	0.41	1.23 / 0.68	1.68 / 0.93	2.48	0.48	0.019 / 0.66	0.87 / 0.39	17.04	14.92 / 379.03

Table 1: NARCCAP average projected climate change for Mason City, IA (top) and Atlanta, GA (bottom). Comparison of the bottom three rows for each variable shows that the models produce climate change values exceeding both natural variability of the 20th Century and inter-modal variability in projected climate change for dry-bulb temperature, dew-point temperature, and absolute humidity (highlighted).

Global climate models used include the Community Climate System Model (CCSM), the Third Generation Coupled Global Climate Model (CGCM3), the Hadley Centre Coupled Model version 3 (HadCM3), and the Geophysical Fluid Dynamics Laboratory GCM (GFDL). Regional climate models used include the Canadian Regional Climate Model (CRCM), the Hadley Regional Model 3 (HRM3), the PSU/NCAR Mesoscale Model (MM5), the Regional Climate Model version 3 (RCM3), and the Weather Research & Forecasting Model (WRFG).

Seasonal and Diurnal Changes

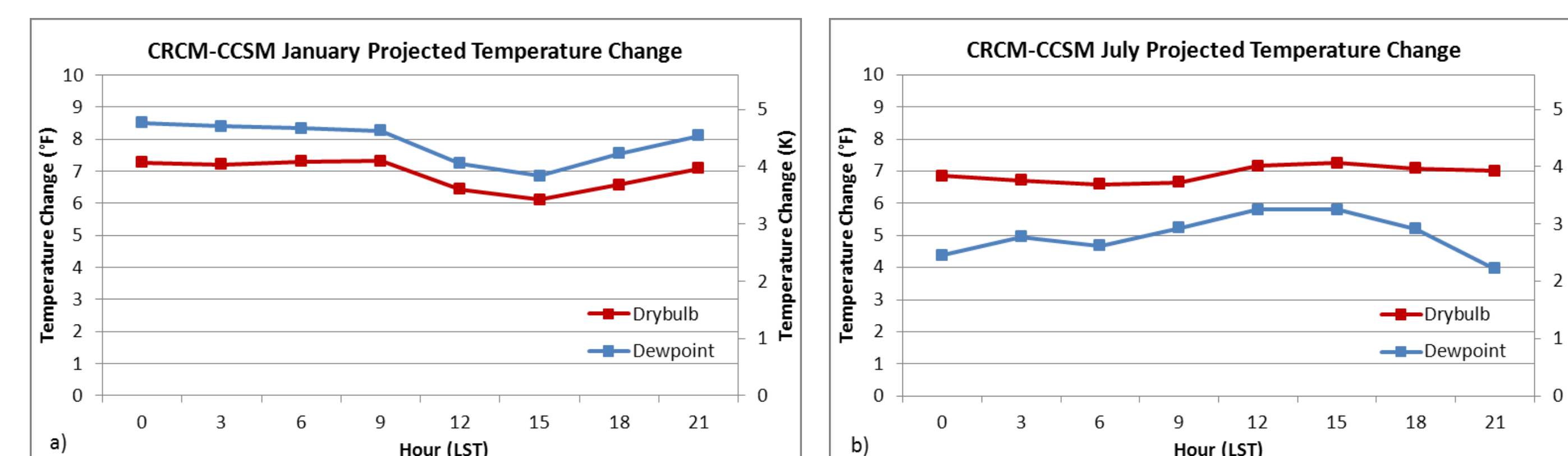


Figure 2: Seasonal changes in the diurnal patterns of temperature and humidity for the CRCM-CCSM model for Mason City, Iowa. (a) January dew-point temperatures are projected to change more than dry-bulb temperatures, increasing relative humidity. (b) July dew-point temperatures are projected to change less than dry-bulb temperatures, decreasing relative humidity. Projected July temperature changes are more than twice the standard deviation (natural variability) of the last 30 years.

References

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Impact on Building Energy Consumption

Energy performance simulations were conducted to evaluate the impact of projected changes in climate on a selection of the 16 U.S. Department of Energy (DOE) reference buildings. These reference buildings represent about 60% of the U.S. commercial building stock. For those regions having significant changes in energy consumption and patterns, future typical meteorological year data can be prepared for risk analysis of a changing climate.

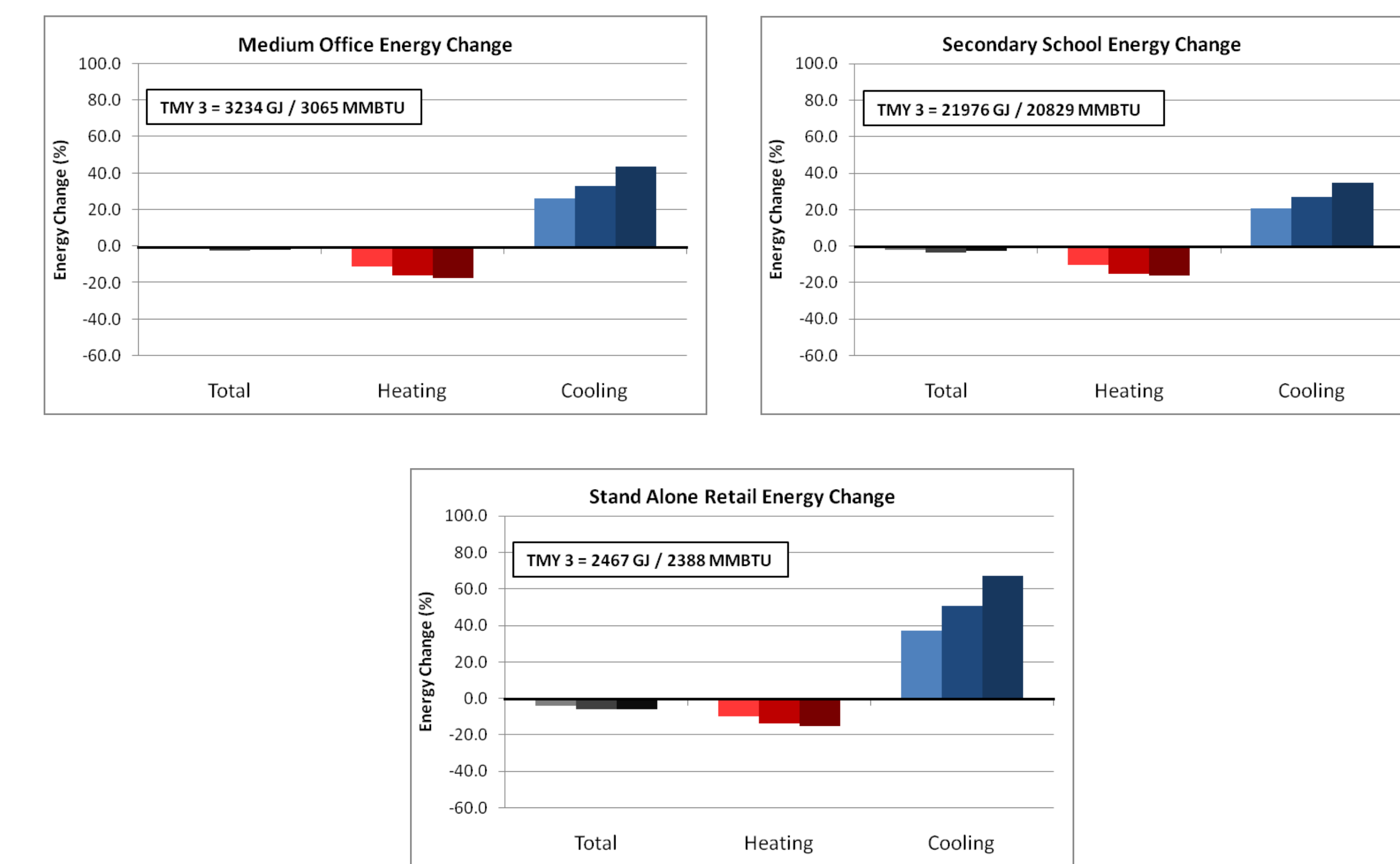


Figure 3: Percent change of energy consumption for three selected DOE reference buildings for low (WRFG-CGCM3), moderate (RCM3-CGCM3), and high (CRCM-CCSM) climate change projections for Mason City, Iowa. Total energy consumption decreases slightly, with increases in cooling consumption compensated by decreases in heating consumption.

It is informative to compare the climate change of the warm-climate city (Atlanta) with the cold-climate city (Mason City) for annual means. Temperatures and dew-point temperatures increase in both cities, but by a smaller amount at Mason City. However, absolute humidity increases by 17% more in the warm city because of the higher saturation vapor pressure in the warmer climate. This means larger increases in cooling costs can be expected in warmer climates compared to cold climates because, for instance, a 1 degree C cooling in a warm climate requires more water vapor to be removed from the air than in a cold climate.

Conclusions

- ✦ TMY3 data are representative of (except for relative humidity, pressure, and precipitation) the 30-year observed conditions.
- ✦ While each model and variable has its own unique bias structure, the NARCCAP models are generally able to reproduce the TMY3 data.
- ✦ The NARCCAP models produce significant changes in dry-bulb temperature, dew-point temperature, and absolute humidity between 20th C and mid-21st C climates.
- ✦ Additional significant changes in climate variables occur when examining model projections on seasonal and diurnal levels.
- ✦ Projections show a decrease in heating costs and an increase in cooling costs for Mason City, Iowa with total energy consumption decreasing slightly.
- ✦ Further research exploring the impacts of climate change on energy consumption for different locations is planned.