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Building Energy Modeling and Resilient Department of Defense Installations: Accounting for Climate Change

Jennifer L. Bewley
Zachary M. Berzolla

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INSTITUTE FOR DEFENSE ANALYSES
730 East Glebe Road
Alexandria, Virginia 22305-3086

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For More Information

Jennifer L. Bewley, Project Leader
jbewley@ida.org, 703-845-2390

Leonard J. Buckley, Director, Science and Technology Division
lbuckley@ida.org, 703-578-2800

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Executive Summary

As the Department of Defense (DoD) pursues climate change mitigation and adaptation efforts per the 2021 Climate Adaptation Plan, substantial resources will need to be invested into its portfolio of 300,000 buildings across installations worldwide. The DoD has already begun to take action, with over $3.2 billion in Energy Savings Performance Contracts (ESPCs) awarded to companies to carry out energy efficiency projects for the DoD, with another $1 billion currently in development. Building energy models (BEMs) have been widely adopted to help design new buildings or retrofit old ones to be more resilient, use less energy, and reduce emissions. However, current best practices in BEM do not yet fully incorporate climate change into simulations, and those that do often rely on outdated or untested models. Some BEM practitioners across the private sector and government are incorporating ensemble global climate models (GCMs) using statistical downscaling into their BEMs, but methods and reproducibility are lacking and extreme weather is rarely, if ever, accounted for. BEM practitioners would benefit from a standardized, widely available dataset and best practices to incorporate climate change into the field more widely and to better evaluate buildings against resiliency and efficiency criteria for the future. This report, sponsored by the Environmental Security Technology Certification Program (ESTCP), highlights the current approaches and challenges in accounting for climate change in BEMs that are relevant to DoD buildings and infrastructure. To close, the IDA team suggests a synergistic pathway that combines state-of-the-art science with ESPCs to create more resilient installations.

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1. Introduction

Climate change is becoming one of the defining challenges of the 21st century. The Department of Defense's (DoD) Climate Risk Analysis states that "without adaptation and resilience measures, climate hazards, particularly when combined with other stressors, are likely to contribute to political, economic, and social instability around the world" (DoD Office of the Under Secretary for Policy (Strategy, Plans, and Capabilities) 2021). In light of this challenge, the DoD developed a Climate Adaptation Plan, setting forth the requirement that the DoD must be able to "operate under changing climate conditions, preserving operational capability and enhancing and protecting the natural and man-made systems essential to the Department's success" (Department of Defense, Office of the Under Secretary of Defense (Acquisition and Sustainment) 2021). Meeting this lofty ambition for the DoD's more than 500 installations around the world will require a focus on energy security and climate resilience built on the best available climate science (Department of Defense, Office of the Under Secretary of Defense for Acquisition, Technology and Logistics 2018).

Buildings are a major component of DoD installations, and building energy models (BEMs) are a key tool when evaluating for energy security and resilience. BEMs use physics-based heat and mass flow equations applied to building geometries of interest to simulate yearly energy consumption and equipment sizing (See Section 3) (Crawley et al. 2001). By incorporating data about how the climate will change in the future, BEMs can be used to ensure new buildings and building retrofit projects will meet the needs of the occupants in the future, leading to cost savings down the road (Gholami Rostam and Abbasi 2021). Additionally, buildings are a place of refuge from extreme weather events such as storms, heat waves, and cold snaps. Extreme weather events have caused billions of dollars of damage to U.S. installations around the country in the last 5 years (Department of Defense, Office of the Under Secretary for Policy (Strategy, Plans, and Capabilities) 2021). As more extreme weather events impact installations, BEMs can help ensure that the buildings and their systems are designed to handle these extremes (Baniassadi, Heusinger, and Sailor 2018). One of the key tools to promote energy efficiency, energy security, and resilience for the DoD's buildings are Energy Savings Performance Contracts (ESPCs). ESPCs engage a private contractor called an Energy Services Company (ESCO) to implement energy conservation measures (ECMs) for installations to attain the DoD's energy goals (Department of Energy n.d.).[1] The DoD has already leveraged ESPCs for over $3.2 billion in projects, with another $1 billion expected to be implemented in fiscal year 2023 (FY23) (Department of Defense 2022). One of the major benefits of using an ESPC is that the ESCO pays for all upfront costs and takes on the financial risk if the ECMs underperform (Department of Energy n.d.). While the ESCO will take the financial hit if the ECMs are not engineered to account for climate change, the DoD installation will be left dealing with the resilience impacts. It is therefore critical for both the ESCO and the installation's resilience goals that the ECMs are designed with climate change in mind. This report, sponsored by the Environmental Security Technology Certification Program (ESTCP), provides key background information on accounting for climate change in BEMs and identifies developmental needs for these models to meet the requirements of a changing world.

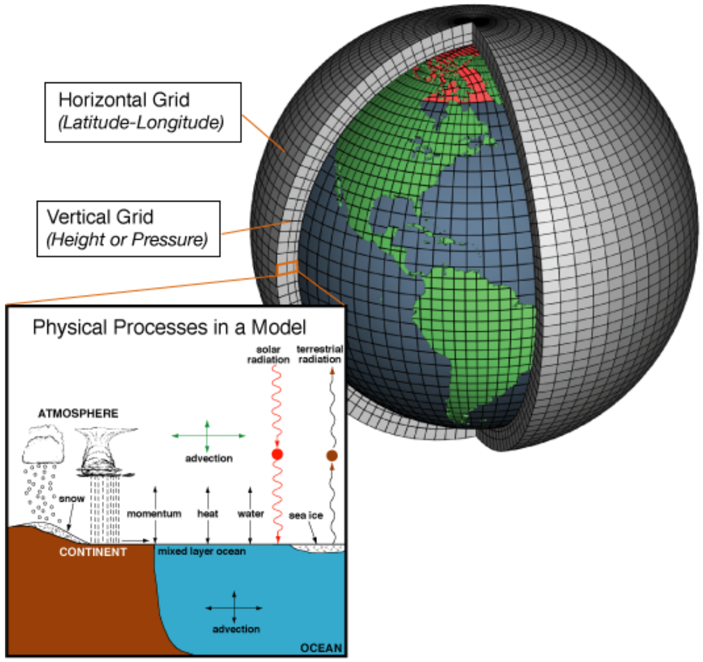
[1] For more information on ESPCs, see the Department of Energy's Federal Energy Management Program: https://www.energy.gov/eere/femp/energy-savings-performance-contracts-federal-agencies.

2. Background on Climate Change Modeling

The DoD maintains a portfolio of 300,000 buildings worldwide (Van Broekhove et al. 2012). These buildings have myriad uses from hospitals to housing to command centers to equipment maintenance. Many of these buildings are critical to sustaining DoD operations on a daily basis and therefore must stand up to the rigors of a changing climate. The impacts of climate change will vary by installation, from extreme heat or cold to stronger hurricanes or extreme drought. Understanding the impacts of climate change at a local level is thus key to devising adaptation strategies.

For decades, scientists have turned to climate modeling to project the impacts of changes in our climate at global scales. Global climate models (GCMs) have been in continuous development for decades at research institutions around the globe and provide physics-based analysis of our changing climate. Most GCMs are now simulated using grids that cover the world in 100 km x 100 km areas, as shown in Figure 1 (Kotamarthi et al. 2017). The simulations provide outputs of the climate physics equations for each of these grids around the world. The Coupled Model Intercomparison Project (CMIP) is a global organization run by the World Climate Research Program, which creates standard ensembles of GCMs—run with common input and output parameters—that are currently the state of the art in the field of climate modeling (Copernicus Programme 2021). Ensemble models combine the outputs of multiple GCMs together to create climate projections that naturally de-emphasize outliers (Kreienkamp et al. 2012). A new CMIP version is released every few years, with the most recent version, CMIP6, released in 2016. The GCMs and their outputs are publicly available online.[2]

[2] Either from CMIP directly or via a National Oceanic and Atmospheric Administration viewer: https://psl.noaa.gov/ipcc/cmip6/.



Source: NOAA public domain.

Figure 1. Example of GCM grids overlaid on the globe. Note that each grid cell covers areas bigger than some states. Each grid cell will be used to calculate the results of several different physical processes.

GCMs allow scientists to run future scenarios that can provide projections of climate change given different anthropogenic emissions pathways. The emissions pathways are a human construction, devised to reflect different policy and emissions reduction outcomes at a global scale. Each generation of GCM uses different emissions pathways with ever evolving definitions, but they generally range from business-as-usual (unrestricted growth and development without regard to emissions) to rapid decarbonization brought on by systemic changes in growth and low-carbon technology development and deployment.[3] The exact pathways the world follows will likely fall somewhere between the different scenarios that are simulated, but they provide a useful envelope of possible outcomes that lead to differing impacts for countries around the world. While useful for assessing state-level impacts in the United States, the 100 km x 100 km scale of GCMs does not accurately predict impacts at the DoD installation level.

[3] Common pathway definitions include the Special Report on Emissions Scenarios (SRES) from the Third and Fourth Intergovernmental Panel on Climate Change (IPCC) Report, here: https://www.ipcc.ch/site/assets/uploads/2018/03/sres-en.pdf; Representative Concentration Pathway (RCP) from the Fifth Report, here: https://ar5-syr.ipcc.ch/topic_futurechanges.php; and Shared Socioeconomic Pathways (SSP) from the Sixth Report here: https://unfccc.int/sites/default/files/part1_iiasa_rogelj_ssp_poster.pdf.

To provide more detailed climate impact assessments at an installation scale, the climate modeling community has developed several methods to downscale GCM results. The two major downscaling approaches are empirical statistical downscaling (ESD or SD) and dynamic downscaling (DD). DD usually produces regional climate models (RCMs) that can provide modeling outputs at a 1 km x 1 km grid resolution (Lanzante et al. 2018). RCMs rely on the same physics-based climate equations as a GCM, but are focused on a smaller area and constrained by boundary conditions that are usually derived from a GCM (Lanzante et al. 2018). Even with the smaller scale, RCMs are computationally intensive and have traditionally been reserved for use cases where statistical modeling will not work well and detailed simulations of interacting geophysical processes are necessary[4] (Demissie 2019). Some of the most common DD datasets and models are publicly available in the United States from the North American Coordinated Regional Downscaling Experiment (CORDEX) project.[5] ESD was developed to provide climate data at the same fine-grain scale as DD, but at a fraction of the computational effort. ESD uses historical weather data to train a model that can then be used to project future climate data at the local scale (Lanzante et al. 2018). ESD, however, is only applicable if historical climate trends hold, a principle called stationarity, which may not be the case in a climate-changed world (Lanzante et al. 2018).

Concerns about stationarity have not prevented the growth in use of ESD to provide localized climate change projections. While ESD models are often validated against RCMs, RCMs are still subject to the uncertainty inherent in their parent GCMs and these can be amplified at small scales. On the whole, neither approach is considered a "gold standard," and models and projections must be carefully evaluated to ensure they agree with historical data and expected future behaviors. To overcome this barrier, the DoD has developed the DoD Climate Assessment Tool (DCAT) to screen the top climate change hazards that threaten individual installations (Gade et al. 2020). Once the hazards with the highest exposure are identified, however, a climate scientist is often still needed to help develop resilience measures based on more detailed local climate projections (Kotamarthi et al. 2016). This is an untenable situation when trying to evaluate energy security and resilience across all of the DoD's installations because local climate projections at the resolution needed to support decision makers in resilience planning may not exist or be available in a format that is easily assimilated into the decision-making process.

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4 For example, riverine flooding often results from the confluence of several different factors governed by overlapping geophysical systems such snowmelt, ground saturation, and precipitation.

5 https://na-cordex.org/

3. Background on Building Energy Modeling

BEMs have been used by the DoD since the 1970s to calculate building energy consumption and size heating and cooling equipment (Crawley et al. 2001). EnergyPlus, developed by the Department of Energy in the 1990s, is now in widespread use as a BEM tool across the United States and other countries (Crawley et al. 2001). In order to run a BEM, EnergyPlus must have several key inputs:

- Building geometry (i.e., the shape of the building)
- Building construction (e.g., materials and thickness of walls)
- Equipment specification (e.g., for heating and cooling equipment)
- Schedules (e.g., occupancy, when computers are used)
- Weather data (Crawley et al. 2001)

EnergyPlus uses a standardized weather file format, EnergyPlus Weather (EPW), that is available for 10,000+ locations worldwide (Crawley et al. 2001). EPW files are text files with a row for the weather at each hour of each day for an entire year that include data such as:

- Dry bulb temperature
- Relative humidity
- Solar radiation (diffuse horizontal, direct normal, global horizontal, extraterrestrial horizontal, extraterrestrial direct normal)
- Wind speed and direction
- Liquid and liquid water equivalent precipitation amounts (Crawley, Hand, and Lawrie 1999)

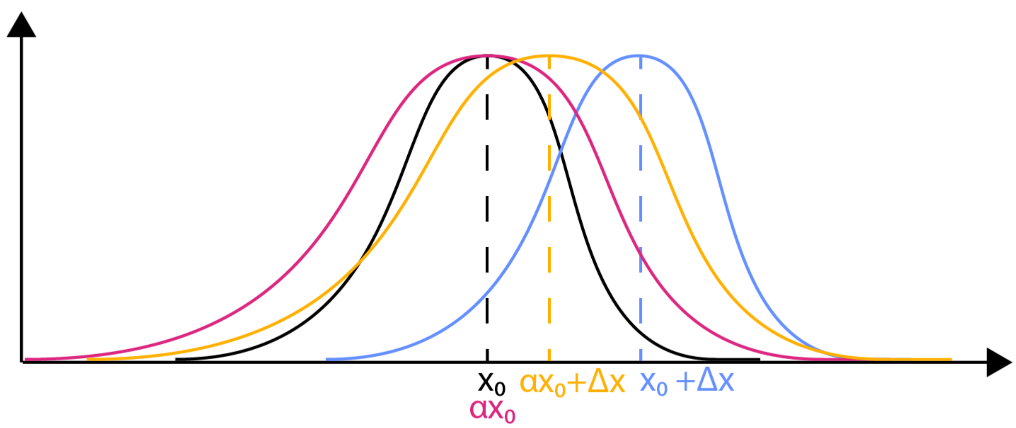
EPW files are usually created from typical meteorological year (TMY) data, which draw on 30 years of historical data to create a weather file that best represents the average weather during that period. This is accomplished by computing the mean monthly values across the key variables in the dataset, and then for each month in the TMY file selecting the month from the historical record that most closely matches the mean values (Cox et al. 2015). For example, a given TMY EPW file might use measured weather data from January 2000, February 1990, and so on. A smoothing function is applied to limit the discontinuities between months (Crawley, Hand, and Lawrie 1999). TMY data come in several formats with fixed ranges of historical weather periods included (Crawley, Hand, and Lawrie

1999). The most widespread data used today are TMY3, which use data from 1976 to 2005, but TMY data starting in 1948 and going up to 2021 are available in some areas. The use of TMY data for building simulations is built upon the assumption of stationarity in overall climate trends. If stationarity holds, the 30-year window in a TMY file captures the overall climate while allowing for some inter- and intra-year variability. While BEMs simulated with a TMY-derived EPW file have historically been shown to be sufficient to design buildings and size their heating and cooling systems, there is a need to account for climate change and extreme weather in building weather files in the face of a rapidly warming world. This is especially important when designing buildings whose lifespans are generally 50 years or longer.

4. Accounting for Climate Change in Building Energy Modeling

The most common method used to account for climate change in building weather simulations is to "morph" existing weather files. Morphing is a form of ESD, as it uses historical weather data to project the future weather. Measured weather data for at least 30 years (the same inputs for creating the TMY file) are adjusted based on changes in a statistically downscaled GCM (Belcher, Hacker, and Powell 2005). Based on the GCM output variables for the relevant grid points, three different modifications are applied to morph the variables of interest in the historical weather data (Figure 2):

- A shift, which moves the mean, e.g., $X_0 + \Delta X$
- A stretch, which scales the mean or changes the variance, e.g., αX_0 or $\alpha\sigma^2$
- A shift and stretch, which both moves the mean and scales it, e.g., $\alpha X_0 + \Delta X$



Source: Figure adapted from Belcher, Hacker, and Powell (2005).

Figure 2. Morphing the distribution of a climate variable. In black in its original form, in blue a shift, in pink a stretch, and in orange both a stretch and shift.

Morphing leaves the weather data meteorologically consistent while reflecting climate change's effects on many of the mean monthly simulation parameters without needing detailed downscaling (Belcher, Hacker, and Powell 2005). The morphed weather file is then produced using the standard TMY approach based on input data that have been adjusted to ideally better project the future climate.

Three commonly used morphing tools in the BEM community are Weathershift,[6] CCWorldWeatherGen,[7] and Meteonorm.[8] Each tool uses a slightly different process to project local climate change from GCM outputs. The tools are often thought of as interchangeable, but each have their own strengths and weaknesses. The tools all use CMIP Version 5 (CMIP5) climate projections at a global scale to inform their morphing process.

Weathershift uses an ensemble of 14 CMIP5 GCMs and conducts bilinear interpolation between the four GCM grid cells closest to each city to produce morphed output variables (Dickinson and Brannon 2016). Simulations are conducted using both the business as usual and "moderately aggressive emissions mitigation" pathways from the Intergovernmental Panel on Climate Change's (IPCC) Fifth Assessment Report (AR5) (Dickinson and Brannon 2016). For each variable in the TMY data, a cumulative distribution function (CDF) is created and the TMY data are morphed so that the means align with the CDFs of the output variables from the GCMs (Dickinson and Brannon 2016).

CCWorldWeatherGen uses a single GCM to project future climate change, the Hadley Centre Coupled Model version 3 (HADCM3) (Moazami, Carlucci, and Geving 2017). CCWorldWeatherGen is further focused on only one climate change scenario from the IPCC Fourth Assessment Report (AR4), one that represents one of the highest emissions scenarios possible, corresponding to some regional changes but mostly business as usual. The validity of CCWorldWeatherGen's morphed results depends on how well the HADCM3 model represents the climate in that region. The original justification for using the HADCM3 model in CCWorldWeatherGen stems from CCWorldWeatherGen's development for predicting climate change in the United Kingdom (UK) and HADCM3's general alignment with historical data for the UK (Jentsch et al. 2013).

Meteonorm uses a slightly different ESD approach, specifically a stochastic weather generator that interpolates between GCM outputs using a historical climate database (Remund et al. 2010). Meteonorm uses climate change scenarios from the IPCC AR4 (Remund et al. 2010). It takes an ensemble approach, averaging the GCM results of 18 publicly available CMIP5 models to a resolution of 1 degree of latitude (Remund et al. 2010). Meteonorm includes four different IPCC warming scenarios from the AR4. These scenarios range from business as usual to "reductions in material intensity and introduction of clean and resource-efficient technologies," i.e., substantial mitigation effort (Shen 2017; Remund et al. 2010).

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[6] https://www.weathershift.com/

[7] https://energy.soton.ac.uk/climate-change-world-weather-file-generator-for-world-wide-weather-data ccworldweathergen/

[8] https://meteonorm.com/en/

All three of these commonly used tools have been shown to work in their initial case studies, but none have been updated to reflect the latest IPCC scenarios or use the newest CMIP data. At this point, some of the underlying assumptions and data are from the IPCC's Third Assessment Report—released over 15 years ago—and do not reflect the latest advancements in climate science. The only tools currently using the state-of-the-art CMIP6 data are EPWShiftr[9] and the Future Weather Generator,[10] but both are not widely used and have drawbacks in their approaches. EPWShiftr is a publicly available tool in the R programming language[11] that uses the same Belcher, Hacker, and Powell (2005) morphing approach as previous tools, but it requires users to have a working knowledge of key variables in the GCMs (Jia and Chong 2021). The Future Weather Generator is a publicly available Java app, but it uses only a single GCM—EC-Earth3—to provide morphed CMIP6 results (Rodrigues, Carvalho, and Fernandes 2022). It is best practice in climate modeling to take an ensemble approach—combining the outputs of more than one GCM—when trying to project future scenarios, as a single model may not capture climatic behavior in different parts of the world well, even if they do work well for one region (Kotamarthi et al. 2016). This same issue is present in CCWorldWeatherGen, which was developed and validated in the UK, but has been applied widely. For example, Wong et al. (2011) used CCWorldWeatherGen for studies in Singapore despite the tool's design for use in the climatically very different UK. Finally, standard scientific practice in climate modeling is to provide open datasets and document all procedures used to arrive at any downscaled results (Kotamarthi et al. 2016). Most of the aforementioned tools are proprietary and lack transparency, making it hard to test the morphing methodology for reproducibility.

While dynamic downscaling has seen widespread use to provide inputs in many fields, it is rarely used in BEM. One recent study created dynamically downscaled CMIP5 GCM inputs for a BEM (Tootkaboni et al. 2021). This study compared the results of a BEM run with a future climate change file from WeatherShift, CCWorldWeatherGen, and Meteonorm, with that of the DD dataset. They found that using inputs from the three different tools created consistent BEM results and these results were generally consistent with the dynamically downscaled inputs as well, although the morphed input climate files led to greater variations (Tootkaboni et al. 2021). There is therefore some precedent for using dynamic downscaling for BEM, although Tootkaboni et al. (2021) only used a single GCM and not an ensemble. They also did not clearly describe the procedure for taking DD data and using it as a BEM input. Consequently, no one publicly available tool today provides building energy modelers with local climate change data using state-of-the-art best practices such as ensemble modeling with CMIP6 models. Finally, the morphing

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[9] https://cran.r-project.org/web/packages/epwshiftr/index.html

[10] https://adai.pt/future-weather-generator/

[11] https://www.r-project.org

approach taken by most tools does not incorporate the extremes and variability in weather that climate change is imparting as it is purely based on adjusted historical data (Belcher, Hacker, and Powell 2005). Some DD models have been designed to elucidate extremes from the GCMs, but none have been incorporated into modeling extreme weather in BEMs.

5. Accounting for Extreme Weather in Building Energy Modeling

During extreme weather events, buildings themselves are a physical form of shelter, protecting occupants and equipment from the elements as long as they are built to building codes that are appropriate for the area and the weather. Beyond physical safety, buildings can provide shelter to occupants even after a storm passes or relief from the elements in the event of a heat wave.

Taking extreme weather into account in BEM goes beyond simply morphing TMY files to account for long-term shifts in key climate variables. Climate change is leading to more frequent and intense extreme weather events that occur with variable frequency and duration (Department of Defense, Office of the Under Secretary for Policy (Strategy, Plans, and Capabilities) 2021). These overall trends are discernable in GCMs but localized impacts are frequently smoothed out by the large spatial scales involved. Downscaling provides the means to better simulate extreme weather's local impacts, but there is not yet consensus among climate scientists for a consistent simulation approach. Both ESD and DD have been used successfully in simulations of local extreme weather phenomena, but with caveats about wider applicability.

BEM researchers have proposed several solutions to help design buildings for extreme weather by altering the input weather file, although they are not yet widely used. The two main extreme weather file approaches used for BEMs include extreme meteorological year (XMY) and extreme reference year (ERY) (Gasparella et al. 2021). It is important to note that ERYs and XMYs are not substitutes for running BEMs with TMYs that account for climate change, they are instead meant to help design systems that can handle potential extreme weather that is otherwise outside of a typical year.

XMYs use the same time period and data as a TMY file, but the methodology instead finds the months with the highest or lowest daily values in the dataset for key parameters and chooses those months instead of the months with values closest to the mean (Gasparella et al. 2021). XMYs can also be created by focusing on a seasonal weather variable. In this approach, XMYs are split into two subclasses: XMY_1 and XMY_2. XMY_1 minimizes the winter average temperature and maximizes the summer average temperature, representing colder winters and warmer summers (Gasparella et al. 2021). XMY_2 maximizes the winter average temperature and minimizes the summer average temperature, representing warmer winters and cooler summers (Gasparella et al. 2021).

On the contrary, ERYs have been developed to simulate hot or cold years, meaning the extreme weather is felt only in either the summer or the winter (Gasparella et al. 2021). ERYs were developed by Pernigotto, Prada, and Gasparella (2020) and are denoted by h and c subscripts for hot (ERY_hs) and cold (ERY_cs) years, respectively. Pernigotto, Prada, and Gasparella (2020) found that ERY_hs can be best found by comparing parameters for dry bulb temperature and global horizontal irradiation across the reference period and picking the months when these values are statistically different from the mean. For ERY_c, they found only dry bulb temperature is needed to identify the extreme months (Pernigotto, Prada, and Gasparella 2020).

Both ERYs and XMYs result in weather files that are very different from the standard TMY files, with less than 10% of the chosen months overlapping (Gasparella et al. 2021). While this clearly shows that both approaches are effective at capturing extreme weather periods in the historical data, this does not necessarily mean they can capture future extremes well. The challenge with extreme weather files goes back to the issue of stationarity. If the climate is changing and stationarity no longer holds, using even the extremes from historical data may not accurately capture future extremes. Further research is needed to define a standardized way of incorporating climate-change-induced extreme weather into BEM simulations to promote DoD resiliency.

6. Findings and Recommendations

Climate change is already degrading the DoD's installations resulting in billions of dollars in repairs from the impacts of extreme weather (Department of Defense, Office of the Under Secretary of Defense (Acquisition and Sustainment) 2021). As climate change accelerates in the coming decades, the effects and costs will likely only increase if proactive mitigation and adaptation measures are not taken (Department of Defense, Office of the Under Secretary of Defense (Acquisition and Sustainment) 2021). A key area of focus for these efforts is the energy security and resilience of installations (Department of Defense, Office of the Under Secretary of Defense (Acquisition and Sustainment) 2021). One of the pillars of the DoD's Climate Adaptation Plan is to leverage the best available science to manage climate risk (Department of Defense, Office of the Under Secretary of Defense (Acquisition and Sustainment) 2021). The current methods used to incorporate climate change projections into BEMs, however, do not leverage the best available science. BEM practitioners currently rely on a form of ESD called morphing built on assumptions of stationarity that may not apply due to future climate change. Currently available tools also fail to use the latest CMIP data and do not always use an ensemble approach.

The DoD, through the ESTCP Climate Resilience focus area, could identify the best methods available today to incorporate the latest downscaled GCM projections into BEM annual weather files and develop requirements for extreme weather simulations. One promising option under development is the Climate Modeling Alliance (CliMA) project,[12] a novel GCM being developed from the ground-up by Massachusetts Institute of Technology (MIT), California Institute of Technology (Caltech), and the National Aeronautics and Space Administration's (NASA) Jet Propulsion Lab, to natively output climate projections and extreme weather threats at a local scale. Regardless of the method used, state-of-the-art climate projections will help better evaluate efforts to meet the DoD's energy security and climate resilience requirements for buildings. With a validated dataset available, the DoD can require that every ESPC first performs climate change due diligence that leverages the best available science on climate change and extreme weather hazards. This will ultimately promote better-performing ESPCs and a more resilient DoD installation enterprise. Meeting energy security and resilience goals across the DoD's buildings will be a far-reaching, multi-billion dollar undertaking in the coming years. The DoD will only achieve full potential in this effort if state-of-the-art climate change

[12] https://clima.caltech.edu/

projections are combined with the proven ability of ESPCs to fund innovative upgrades to the DoD's buildings.

7. Conclusions

As the DoD pursues climate change mitigation and adaptation efforts per the 2021 Climate Adaptation Plan, substantial resources will need to be invested into its portfolio of 300,000 buildings across installations worldwide. The DoD has already begun to act, with over $3.2 billion in ESPCs awarded to companies to carry out energy efficiency projects for the DoD, with another $1 billion currently in development. BEMs have been widely adopted to help design new buildings or retrofit old ones to be more resilient, use less energy, and reduce emissions. However, current best practices in BEM do not yet fully incorporate climate change into simulations, and those that do often rely on outdated or untested models. Some BEM practitioners across the private sector and government are incorporating ensemble GCMs using statistical downscaling into their BEMs, but methods and reproducibility are lacking and extreme weather is rarely, if ever, accounted for. BEM practitioners would benefit from a standardized, widely available dataset and best practices to incorporate climate change and extreme weather into the field more widely and to better evaluate buildings against resiliency and efficiency criteria for the future. The DoD, through ESTCP, could identify the best methods available today to incorporate the latest downscaled GCM projections into BEM annual weather files and develop requirements for extreme weather simulations. One example of a promising option under development is the CliMA project, which aspires to natively output climate projections and extreme weather threats at a local scale. Regardless of the exact climate data ultimately recommended, a synergistic pathway that combines state-of-the-art science with ESPCs to create more resilient installations is needed as the DoD moves towards achieving its energy security and resilience goals.

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13. SUPPLEMENTARY NOTES

14. ABSTRACT

As the Department of Defense (DoD) pursues climate change mitigation and adaptation efforts per the 2021 Climate Adaptation Plan, substantial resources will need to be funneled into its portfolio of 300,000 buildings across installations worldwide. The DoD has already begun to take action, with over $3.2 billion in Energy Savings Performance Contracts (ESPCs) awarded to companies to carry out energy efficiency projects for the DoD, with another $1 billion currently in development. Building energy models (BEMs) have been widely adopted to help design new buildings or retrofit old ones to be more resilient, use less energy, and reduce emissions. However, current best practices in BEM do not yet fully incorporate climate change into simulations, and those that do often rely on outdated or untested models. Some BEM practitioners across the private sector and government are incorporating ensemble general climate models (GCMs) using statistical downscaling into their BEMs, but methods and reproducibility are lacking and extreme weather is rarely, if ever, accounted for. BEM practitioners would benefit from a standardized, widely available dataset and best practices to incorporate climate change into the field more widely and to better evaluate buildings against resiliency and efficiency criteria for the future. This report highlights the current approaches and challenges in accounting for climate change in BEMs that are relevant to DoD buildings and infrastructure. To close, the IDA team suggests a synergistic pathway that combines state-of-the-art science with ESPCs to create more resilient installations.

15. SUBJECT TERMS

building energy modeling; Climate Change; climate change adaptation; climate resilience; Global Climate Model (GCM)

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