



Projected climate data for building design: barriers to use

POLICY ANALYSIS

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ABSTRACT

Building professionals' use of historical weather data in performance analysis and design is an insufficient response to the impacts of a changing climate. Existing standards, laws and conventions in the US (and elsewhere) reinforce the use of typical weather files derived from historical data. Although projected climate data are readily available from reliable sources, significant barriers prevent adoption. These include a lack of consensus on the *methodology* for creating climate data for buildings based on climate models; a lack of a publicly available *platform* for providing climate projections for use in a *format* suitable for building analysis; a lack of consensus on a *standardized framework* for communicating results of simulation with long-term climate data projections; and *liability concerns* with using projection data. A coordinated response to these challenges is necessary across building design disciplines to ensure widespread adoption. Professional institutions, codes and standards organizations, and national governments have a key role to ensure that buildings created today are fit for climatic conditions in 20, 50, and 100 years' time.

POLICY RELEVANCE

Codes and standards for buildings and infrastructure need rethinking to account for adaptation to climate change, including the protection of real estate investments. Concerted action from professional and standards-setting bodies is required to standardize and make available projected climate data that can be used for building design and analysis. The use of these data and resultant analyses must be standardized in an industry-wide, sanctioned framework to address concerns around liability, misuse and transparency.

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1. INTRODUCTION

Architects and engineers have long viewed climate change impacts as potential problems of the future. However, the impacts of climate change are already present. This changing reality within which buildings will operate must inform the design process. Changes in climate that have already occurred—and will plausibly occur in the near future—must be accounted for when designing for climate change adaptation and mitigation.

Current standard practices in the US and several other parts of the world are insufficient to address the reality of climate change and its impact on human health and the environment. Although the subject is complex and any data will include uncertainties, sufficient data are now available for professionals to be able to take scientifically defensible, repeatable, and rigorous actions based on projected climatic data. Some jurisdictions around the world, e.g. the UK, have introduced legislation and guidance mandating the use of projected climate data in analysis.

Given the widespread and accelerating impacts of climate change on building performance, building owners, occupants, and designers will be at risk. Lack of confidence in the data available, whether due to uncertainties in modeling the underlying natural mechanisms or the social and economic (anthropogenic) factors, is often cited as a reason for not using projected climate data. While this reticence is understandable, the lack of absolute certainty in projected climatic data should not be a barrier to action in the built environment.

2. THE PROBLEM WITH ‘TYPICAL’

The climate has already changed in a way that is measurable in engineering metrics (Owen 2021, ch. 14, sect. 6; Crawley & Lawrie 2021), and is changing faster than the scientific community had anticipated (Wuebbles *et al.* 2017a; Loeb *et al.* 2021). Using average climate data from the past three decades has been generally considered a sufficient representation of a climate (Owen 2021, ch. 14, sect. 6) and approximately the ideal length of record used to create climate ‘normals’. However, in a time of rapid change, these historical data poorly characterize the diversity of weather conditions that a building will experience in a changing climate during its lifetime (Rastogi & Khan 2022). This is likely to result in buildings that will fail to realize their life-cycle goals for greenhouse gas (GHG) emissions from operations due to changes in the nature of dominant peak and average load types, e.g. unequal reduction of heating load and increase in cooling loads (Yang *et al.* 2021). These buildings may also fail to maintain indoor comfort and air quality, especially those that use natural ventilation, mixed-mode ventilation, and passive systems. Building and heating, ventilation and air-conditioning (HVAC) systems that are already over-designed may not suffer the same issues, but might instead incur higher operational costs, use more energy, and emit more GHGs due to higher utilization. Other changes such as those to ambient air temperature and relative humidity may shift a structure’s actual heating and/or cooling loads beyond the design loads of its HVAC system. This could lead not only to considerable HVAC performance issues, but also to unintended changes, e.g. condensation, which can threaten the longevity of the structural system (Owen 2021, ch. 36).

Various typical or reference year weather files are publicly available around the world and have become the primary resource for building design teams to analyze a building design’s operational characteristics. In the US, the Typical Meteorological Year (TMY) dataset produced by the National Renewable Energy Laboratory (NREL) serves this purpose. The intended use of this dataset is to represent typical or reference values of specific weather parameters (e.g. solar radiation, air temperature, and wind speeds) for comparative simulations of the performance of different systems and designs at a specific location. Datasets such as TMY reflect ‘typical’ or median weather conditions for a given location over a past multiyear period of historical record and are therefore not suited for designing for future climatic conditions or extreme weather events.

The problem with a historical record of finite length (5, 10, 30 years) is that while the probability of covering plausible values increases with the length of record, a changing climate can make such characterizations much less useful. For example, the TMY3 files for North America released in 2008

were derived from the time periods 1976–2005 or 1991–2005 (Wilcox & Marion 2008). A building designed using these in 2008 would have missed the five highest average global air temperature years on record: 2014–18, *i.e.* four out of the first 10 years of the building’s life. As ‘typical’ files deliberately exclude extremes, the now-reasonable extremes seen in these years would not be reflected in an updated typical year. Although a TMY file created in 2018 would include the hotter years in its base data, shifting the median year to be hotter, it would not include sub-yearly extremes, except by chance. One approach to correct this is to use past data for an estimate of reasonable extremes, such as the Chartered Institution of Building Service Engineers (CIBSE) Design Summer Years (DSY), available for 14 locations in the UK. These address a specific concern (summer overheating) by enforcing the use of a plausible extreme condition for testing. Such an approach is a good starting point for the development of special files that extend the concept of reference files for meaningful, enforceable design outcomes such as preventing overheating or ensuring passive survivability during power loss.

The concept of ‘typical’ years is embedded in building performance analysis and performance analysis-aided design. It is an intuitive concept to check how a building design or system compares with an alternative against typical weather data. Several recent studies have extended the concept of a year of typical *historical* data to create typical data for future decades (Owen 2021, ch. 36). The most popular techniques involve the use of *morphing* (Belcher et al. 2005; Crawley 2008; Eames 2016) or *stochastic generation* (Rastogi 2016; Grantham et al. 2018). These techniques to create future estimates of weather time series do not enforce the use of typical historical data and can instead be used to generate as many samples as are required to fully characterize possible future climate trajectories.

To make the outputs of climate models available to building performance modelers work in the US, a systematic effort to create and maintain weather files for simulation is required, such as that maintained by CIBSE for the UK (www.cibse.org/weatherdata). To be effective, these files require endorsement by a professional body—*e.g.* American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) or American Institute of Architects (AIA)—and made widely and publicly available.

3. DESIGN FOR UNCERTAIN CONDITIONS

A good building is designed to meet current needs at the time of its construction, but also accommodates future technological and cultural shifts as well as the changing needs of tenants and owners. The designer is not absolved of the need to plan for the different plausible scenarios under which a building may be operated. Most designers build adaptability, modularity, expandability, and flexibility into a building’s capacity or functions in order to provide clients with the possibilities to grow and change as they use the building over time. This culture of robust and flexible design must also be extended to designing for a changing climate. This requires a significant cultural shift from current US design practices where designs are expected to be tested only against typical, historical climatic conditions.

A changing climate will not only change the ‘typical’ performance of a building, by shifting average temperatures or relative humidity, for example, but also how frequently a building must operate under atypical, potentially extreme conditions. For example, while the definition of a heatwave depends on location and prevailing climate, it is generally understood to mean an extreme and, more importantly, unusual episode. A building owner or manager can be expected to counter an episodic heatwave by using the maximum capacity of systems or using administrative measures such as reducing occupancy. However, if the distribution of temperature shifts due to a changing climate, then the probability of the same heatwave increases, and the unusual episodes may become normal. Mechanical equipment will likely reach maximum capacity more frequently than planned, or the building may suffer loss of function more often, possibly even ‘typically’ every summer.

High-resolution climate projections have been freely available from US government websites and international collaborations for some time now, e.g. CORDEX (cordex.org), Cal-Adapt (cal-adapt.org), and CMIP5 projections (gdo-dcp.ucllnl.org). However, the outputs of climate models are not formatted to a resolution, scale, or format usable in architectural or engineering design and analysis tools. Since projected data are modeled, the uncertainties of forecasting are likely to impede their use by design professionals, especially if climate projection data are less accessible. Suitable projected data for the US and elsewhere must, therefore, be created and maintained by a trusted organization (e.g. an industry body).

The four primary technical and policy barriers to broad adoption of climate data projections are as follows:

- *Lack of consensus on the methodology for creating climate data for buildings*

A variety of climate models estimate the extent and impacts of future climate change, which are summarized in publications such as the *ASHRAE Handbook—Fundamentals* (Owen 2021, ch. 36) and the National Climate Assessment (Wuebbles et al. 2017b). These models can vary widely in their projections since many aspects of the global climate system and trajectories of influential factors such as economic activity cannot be known exactly. A range of representative scenarios based on different magnitudes of equivalent GHG emissions, the representative concentration pathways (RCPs) (van Vuuren et al. 2011), offer a foundation for projecting climate change plausibly. The ranges of projections offered by the various RCPs, however, do not offer an effective solution for the building design industry. Building design teams cannot be expected to be conversant with the nuanced interpretation of varying and uncertain future projections, and their impact on climate normals. If the building design industry is expected to use climate projection data, there needs to be consensus regarding the acceptable methods and conditions for systematically projecting climate data using specific pathways. Such a set of methods may be developed through a systematic analysis of existing techniques, the impact of data produced using them on design, and their applicability to design decision-making.

- *Lack of a publicly available platform for providing climate projections in a format suitable for building analysis*

Projected climatic data must be presented as a standardized and accessible dataset in formats suitable for building design and analysis, improving uptake by removing an extra step that each user must take to incorporate these data into their workflows. This refers to the provision of data in a rectangular year-long array at a sufficient resolution for building performance simulation, containing the variables necessary for common calculations. Data available in *file formats* suitable for building performance analysis tools (e.g. Energy Plus Weather) should not be tied to the algorithm used to project the data.

Currently, climate model outputs are available from meteorological agencies—e.g. National Oceanic and Atmospheric Administration (NOAA) and the UK Met Office—and the onus of finding these data and transforming them into file(s) that can be used as inputs for building performance analysis rests entirely on the individual practitioner. Recent efforts to provide curated projected time series, such as WeatherShift™, Indra, and METEONORM, have not been widely adopted. These resources are not regularly or systematically updated by a professional body and have not been systematically compared. No standard exists to compare providers using different models and data sources, especially when black-box models are used. Neither are the datasets released and updated in a systematic and traceable manner agreed upon by all actors (Rao & Rastogi 2020).

- *Lack of consensus on a standardized framework for communicating the results of simulation with long-term climate data projections*

The use of a single ‘future typical’ file may create a false impression of certainty about future climate. Responding to the projection of higher summer loads by adding a ‘climate safety factor’ results in systems that are even more oversized than current practice,

ignores nonlinear effects and shocks due to climate change, and increases upfront capital investment in bigger systems. The inherent uncertainty of climate change projections demands the appropriate quantification of risk in projects and plans to mitigate those risks according to their severity and probability of occurrence, not multiplication by another fudge factor. Current providers of future climate projections encourage building energy modelers to optimize performance over ensembles of plausible scenarios, so buildings perform robustly under many different types of conditions. To facilitate a risk-based design approach using these ensembles, a consensus-based, standardized framework must be created to examine and communicate the results or outputs of calculations performed with these projected data. This framework would facilitate a common understanding of climate risk as it related to building design and operation and would allow for wider dissemination.

- *Liability concerns with using projection data*

A regulatory framework does not exist in the US to guide building project teams using future climate projections. As a result, there is inherent risk in making design decisions based on long-term forecasts. With risk comes liability concerns.

Greater adoption of climate projection data can therefore be facilitated by better codification of this risk. A standard or model code could alleviate the design professional's risk by standardizing and providing an institutional framework to use projected climate data in building energy simulations and building systems design based on a respective enterprise or a jurisdiction's adopted standard or model code. Legislation must direct an agency such as NOAA to create a federal set of data that models extreme weather events and trends and is suitable for specified uses, including building codes. This would partially alleviate the issues described in this paper related to the lack of standardization and codification.

5. CONCLUSIONS

To make the outputs of climate models available to building performance modelers working in the US, a systematic effort to create and maintain weather files for simulation is required, such as that maintained by CIBSE for the UK. To be effective, these files require endorsement by a professional body (e.g. ASHRAE or AIA) and should be made widely and publicly available.

The US building design industry urgently needs the standardization of methods and frameworks to produce and use climate projection data, promote the widespread availability of those data, and the codification of their use. The following actions are needed for climate data projections to be broadly and properly used by design professionals:

- A consensus on methodology to project historical data using climate models: not necessarily a single methodology, but rather guidance and a comparison of the pros and cons of a range of rigorous approaches.
- The creation of a global repository of regularly updated simulation-ready files accessible for commercial and research purposes.
- The standardization of a framework for the dissemination of climate data projections.
- A model standard using normative language that clarifies these frameworks, methodologies, and approaches through which project teams may implement climate data projections into building energy simulations.

Professional institutions, codes and standards organizations, and national governments have a key role to ensure that buildings created today are fit for climatic conditions in 20, 50, and 100 years' time. The development of a consensus is urgently needed on how professionals designing and analyzing the built environment must act, together with the norms, standards, and codes for doing so.

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COMPETING INTERESTS

As part of his duties at arbnco Ltd., Parag Rastogi made available projected climate data as a paid service to clients until 2021. That service has now ended.

L. DeWayne Cecil, Ariane Laxo, and Daniel Overbey have no competing interests to declare.

REFERENCES

- Belcher, S. E., Hacker, J. N., & Powell, D. S.** (2005). Constructing design weather data for future climates. *Building Services Engineering Research and Technology*, 26(1), 49–61. DOI: <https://doi.org/10.1191/0143624405bt112oa>
- Crawley, D. B.** (2008). Estimating the impacts of climate change and urbanization on building performance. *Journal of Building Performance Simulation*, 1(2), 91–115. DOI: <https://doi.org/10.1080/194019401490802182079>
- Crawley, D. B., & Lawrie, L. K.** (2021). Our climate conditions are already changing—Should we care? *Building Services Engineering Research and Technology*, 014362442110042. DOI: <https://doi.org/10.1177/01436244211004279>
- Eames, M.** (2016). An update of the UKs design summer years: Probabilistic design summer years for enhanced overheating risk analysis in building design. *Building Services Engineering Research and Technology*. DOI: <https://doi.org/10.1177/0143624416631131>
- Grantham, A. P., Pudney, P. J., & Boland, J. W.** (2018). Generating synthetic sequences of global horizontal irradiation. *Solar Energy*, 162, 500–509. DOI: <https://doi.org/10.1016/j.solener.2018.01.044>
- Loeb, N. G., Johnson, G. C., Thorsen, T. J., Lyman, J. M., Rose, F. G., & Kato, S.** (2021). Satellite and ocean data reveal marked increase in Earth's heating rate. *Geophysical Research Letters*, 48(13). DOI: <https://doi.org/10.1029/2021GL093047>
- Owen, M. S.** (Ed.). (2021). *ASHRAE handbook—Fundamentals*. American Society of Heating Refrigerating and Air-Conditioning Engineers (ASHRAE).
- Rao, S., & Rastogi, P.** (2020). Towards a standard climate data model for building design and analysis. In 2020 Building Performance Analysis Conference and SimBuild co-organized by ASHRAE and IBPSA-USA (pp. 285–292). <https://www.ashrae.org/file%20library/conferences/specialty%20conferences/2020%20building%20performance/papers/d-bsc20-c034.pdf>.
- Rastogi, P.** (2016). On the sensitivity of buildings to climate: The interaction of weather and building envelopes in determining future building energy consumption (doctoral dissertation, Ecole polytechnique fédérale de Lausanne; EPFL Infoscience) (ch. 3). DOI: <https://doi.org/10.5075/epfl-thesis-6881>
- Rastogi, P., & Khan, E.** (2022). Planning for a changing climate without accurate predictions. In N. Rajkovich & S. H. Holmes (Eds.), *Climate adaptation and resilience across scales: From buildings to cities* (pp. 35–49). Routledge. DOI: <https://doi.org/10.4324/9781003030720-3>
- van Vuuren, D. P., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., Hurtt, G. C., Kram, T., Krey, V., Lamarque, J.-F., Masui, T., Meinshausen, M., Nakicenovic, N., Smith, S. J., & Rose, S. K.** (2011). The representative concentration pathways: An overview. *Climatic Change*, 109(1), 5. DOI: <https://doi.org/10.1007/s10584-011-0148-z>
- Wilcox, S., & Marion, W.** (2008). *Users' manual for TMY3 data sets*. National Renewable Energy Laboratory. <http://www.nrel.gov/docs/fy08osti/43156.pdf>. DOI: <https://doi.org/10.2172/928611>

- Wuebbles, D. J., Easterling, D. R., Hayhoe, K., Knutson, T., Kopp, R. E., Kossin, J. P., Kunkel, K. E., LeGrande, A. N., Mears, C., Sweet, W. V., Taylor, P. C., Vose, R. S., Wehner, M. F., Wuebbles, D. J., Fahey, D. W., Hibbard, K. A., Dokken, D. J., Stewart, B. C., & Maycock, T. K.** (2017a). Our globally changing climate. In *Climate science special report: Fourth National Climate Assessment*, Volume I (ch. 1). US Global Change Research Program. DOI: <https://doi.org/10.7930/J08S4N35>
- Wuebbles, D. J., Fahey, D. W., Hibbard, K. A., DeAngelo, B., Doherty, S., Hayhoe, K., Horton, R., Kossin, J. P., Taylor, P. C., Waple, A. M., & Yohe, C. P.** (2017b). *Executive summary. Climate Science Special Report: Fourth National Climate Assessment*, Volume I. US Global Change Research Program. DOI: <https://doi.org/10.7930/J0DJ5CTG>
- Yang, Y., Javanroodi, K., & Nik, V. M.** (2021). Climate change and energy performance of European residential building stocks—A comprehensive impact assessment using climate big data from the coordinated regional climate downscaling experiment. *Applied Energy*, 298, 117246. DOI: <https://doi.org/10.1016/j.apenergy.2021.117246>

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