

National Oceanic and Atmospheric Administration
U.S. Department of Commerce

Typical Meteorological Year in Cold Regions

For Architects and Engineers

Authors:
Eugene Wahl, Lindsey Vogelmann, Zachary Paganini, Adriana Formby-Fernandez, Morgan Taing, Audrey McSain, Bridget Smith, Margaret Coates

Executive Summary

Changing climate patterns across the United States (U.S.) occur at different magnitudes and have different impacts depending on the region. For cold weather regions, like the Northern Plains, Upper Midwest, Northern Rockies, Northeast, the high mountain regions of the American West, and Alaska, the impacts on changing temperature patterns and rainfall amounts can lead to failures in infrastructure and the built environment. The National Oceanic and Atmospheric Administration (NOAA) is working to promote climate resilience by connecting major U.S. industries with NOAA products, services, and actionable weather and climate data.

Through collaboration with the architecture and engineering (A&E) industry, NOAA has developed a new tool that combines historical hourly weather data and future projections into an hourly dataset of "typical" meteorological values. Practitioners can use the Typical Meteorological Year (TMY) product to gain insight into how future changing weather changes could impact current built infrastructure.

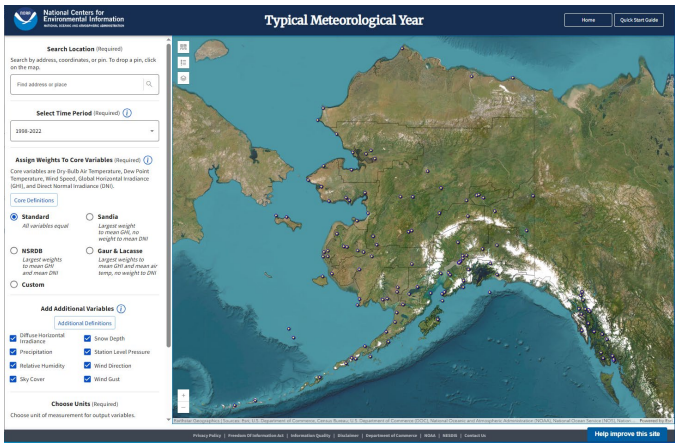


Figure 1. Screenshot of the TMY product interface.

This paper provides an overview of the TMY product, and highlights its use in cold weather regions. Practitioners in the cold weather engineering field provided insight into challenges and opportunities for using TMY to make more resilient design decisions. This paper touches on the application of TMY for:

- Building energy balance design
- Solar energy site planning
- Power grid design
- Specific challenges in Alaska

The case study on Alaska discusses the specific climatic challenges that are experienced in Alaska, such as permafrost thaw, coastal erosion from delayed sea ice formation, and a sparse weather station network. Specific features in TMY are highlighted for their applicability to these challenges.

This paper provides users with an understanding of the value of using TMY for cold weather engineering applications. The information in this document is aimed at explaining the changing climate conditions to practitioners in the A&E industry to enhance their understanding of what may be expected in the future for cold weather regions. This information can be used to introduce topics of resilience into conversations with clients and stakeholders on projects facing these challenges.

Introduction

The National Oceanic and Atmospheric Administration (NOAA) helps industries answer their most pressing questions about environmental information to better assess risks and opportunities, make climate-smart investments, and build a more resilient future. To further this impact, NOAA's direct engagement with industries allows the agency to deliver modernized products and services that enable partners to build adaptation in the face of weather and climate extremes.

Since 2021, NCEI has conducted several user engagement events with the architecture and engineering (A&E) sector to deepen its understanding of user needs, especially from members of the American Society of Civil Engineers (ASCE) and the American Institute of Architects (AIA). NOAA aims to understand sector needs and iteratively develop products that improve the industry's understanding of current and future conditions to support their decision-making and design processes. One of the new NOAA products codeveloped with the A&E sector is the Typical Meteorological Year (TMY) product, which supplies current and future "typical" weather conditions to inform building design and energy system site planning.[1]

This report highlights the A&E sector's critical data needs in cold climate regions of the contiguous U.S. (CONUS) and Alaska and how TMY can help meet these needs.

Projected Changes in Cold Regions' Weather and Climate

The cold climate regions of the U.S. include the Northern Plains, Upper Midwest, Northern Rockies, Northeast, the high mountain regions of the American West, and Alaska. Cold season weather in these regions includes:

- Extended periods of sub-freezing (and even sub-0 Fahrenheit) temperatures associated with outbreaks of Arctic air.
- Extreme temperature swings—annual to sub-seasonal, and even daily—ranges of cold and hot.
- Seasonal to permanent snow and ice conditions.
- Seasonal and permanent below-ground freezing, largely in Alaska.
- Strong changes in solar radiation over the year, especially in Alaska.

These characteristics are expected to continue as the century progresses, with important trends.[2]

- Existing "Arctic amplification", where the Arctic region warms about twice as fast as the mid latitudes, is expected to continue in Alaska, especially in large portions of the Interior and north of the Alaska Range.
- From a seasonal perspective, winter temperatures in the mid latitudes (including the CONUS) have been rising twice as fast as summer temperatures.[3] In Alaska, this seasonal difference is even stronger, with temperatures warming nearly 2.5 times more in winter than in summer statewide during the second half of the 20th century.[4] These trends are expected to continue.

[1] NOAA. 2026. "Typical Meteorological Year (TMY)." National Oceanic and Atmospheric Administration. June 8, 2026. https://www.ncei.noaa.gov/products/typical-meteorological-year.
[2] Material in this section is drawn primarily from the U.S. Fifth National Climate Assessment. A.R. Crimmins et al. "USGCRP 2023: Fifth National Climate Assessment." U.S. Global Change Research Program. https://doi.org/10.7930/NCA5.2023. Citations to other sources are noted where they occur.
[3] Deke Arndt. 2015. "Climate change rule of thumb: cold 'things' warming faster than warm things." Climate.gov. June 7, 2026. https://www.climate.gov/news-features/blogs/beyond-data/climate-change-rule-thumb-cold-things-warming-faster-warm-things.
[4] Alaska Climate Research Center. 2026. "Climate Change in Alaska." The Alaska State Climate Center. June 7, 2026. https://akclimate.org/climate-change-in-alaska/.

- In areas where 24-hour temperature ranges remain below freezing for long periods during cold seasons, these freezing periods are expected to shorten, increasing the occurrence of freeze-thaw cycles. In areas like the Midwest and Great Lakes region that already experience many daily freeze-thaw events, frequency of these cycles are projected to continue to decrease as nighttime temperatures remain above freezing more often[5]. Freeze-thaw cycles may increase in some places due more to the effects of reduced snow cover than the direct impact of temperature changes.
- The Great Lakes, notably Lakes Superior and Huron, are expected to experience significantly reduced ice thickness and duration, increasing lake-effect snow.
- More precipitation is projected to occur as rain rather than snow with important spatial variability. Where it occurs, this change is expected to increase the potential for damaging freezing rain in relatively colder locations that now typically receive only snow, and decrease the potential where freezing rain now tends to occur.
- The role of rain-on-snow meltwater episodes in local hydrological extremes is expected to decrease in the CONUS Northeast and Upper Midwest and increase in the Northern Rockies, again with important spatial variability.[6]
- Hail events are anticipated to increase in the Upper Great Plains, both in terms of event frequency and length of the hail season. Hail size is also projected to increase.
- Delayed autumn freeze-up of sea ice allows coastal waters to remain open and absorbent to solar radiation much later into the cold season, reducing sea ice extent and allowing storm waves to impact coastal areas.

Effects of Projected Climate and Weather on Structures and Infrastructure

The following is a list of different ways in which projected changes in weather and climate in U.S. cold regions may affect structures in these areas.

- Building energy balance is the consideration of how external heat transfer and internal heat generation affect desired interior conditions within a structure. Associated effects related to wind and humidity are also considered. Projected seasonal conditions are noted below.
    - **Winter:** Higher temperatures and fewer cold snaps are expected to reduce overall energy demand for heating, noting that extreme cold events will continue to occur.
    - **Summer:** Higher temperatures and heat waves are expected to increase energy demand for cooling in the Northern Great Plains and throughout the country.
    - Winters are expected to warm more quickly than summers, amplifying warming effects on winter heating demand. Nights are expected to warm faster than days, so A&E practitioners may partially weigh design considerations towards changes in nighttime losses in winter and nighttime heat shedding in summer.
- Additional early snowmelt coupled with rain-on-snow events can overwhelm runoff infrastructure designed to accommodate the spring-melt conditions of the past.
- Road and sidewalk infrastructure will be more heavily impacted by the expansion of frozen water where freeze-thaw cycles increase—creating amplified hazards for vehicles, their occupants, and pedestrians.

[5] GLISA. 2026. “Freeze-Thaw Cycles." GLISA, the Great Lakes Climate Adaptation Partnerships Team. June 9, 2026. https://glisa.umich.edu/resources-tools/climate-impacts/freeze-thaw-cycles/.
[6] Dongyue Li et al. “The Role of Rain-on-Snow in Flooding Over the Conterminous United States.” Water Resources Research 55, (2019): 8492–8513. https://doi.org/10.1029/2019WR024950.

- There is enhanced potential for icing damage and structural failure from freezing rain where these conditions increase.[7]
- Large tracts of permanently frozen ground are anticipated to thaw completely in central and southern Alaska, resulting in collapsed land, sinkholes, and newly formed lakes. By 2100, the cumulative maintenance and replacement costs for roads, runways, pipelines, and building foundations from thawing permafrost are estimated to be in the tens of billion dollars (see note 26).

TMY Product Overview

TMY is an environmental data product designed to assist users in understanding and analyzing historical and potential future conditions. A typical meteorological year is a year's worth of hourly observational data that best represent the common, long-term climate patterns for a location while also preserving the daily and seasonal variations of weather. A key use is to adapt to and incorporate into design calculations both current and future projected meteorological conditions across the U.S., and thus TMY has much to offer engineers in meeting the design needs for cold weather regions of the CONUS and Alaska.

The TMY tool includes fundamental climate and weather variables like various temperature measurements, solar irradiance, and wind speed (Table 1). The product displays one year's worth of climatological data, chosen month-by-month from a record of many years of data. A "typical" month is selected to represent each calendar month from this dataset. Using these typical months, TMY produces an hourly dataset for a specific location, presenting solar radiation and meteorological data over a full one-year period.

The calculation of TMY uses five core climate variables. Eight additional variables are available to add to the output file, although the calculation does not take them into consideration. Tables 1 and 2 contain the variables, their definitions, and sources as found in the Technical User Guide. Input data come from NOAA's Global Historical Climatology Network hourly (GHCNh) dataset, the National Laboratory of the Rockies (NLR) National Solar Radiation Database (NSRDB), and the National Aeronautics and Space Administration (NASA) Prediction of Worldwide Energy Resources (POWER) dataset.

[7] The massive electric grid damage from freezing rain in Quebec and Ontario, Canada, in 1998 can serve as an historical analog of what will be more likely and more frequent extreme occurrences in U.S. cold regions.
Scott Whittier. 2023. "25th Anniversary of the Devastating 1998 Ice Storm in the Northeast," U.S. National Weather Service. June 6, 2026. https://www.weather.gov/btv/25th-Anniversary-of-the-Devastating-1998-Ice-Storm-in-the-Northeast.

Table 1. Core Variables in the TMY Product

Core Climate Parameters	Definition	Source
Dry-Bulb Air Temperature	2 m air temperature.	GHCNh
Dew Point Temperature	Dew point temperature.	GHCNh
Wind Speed	Wind speed.	GHCNh
Global Horizontal Irradiance	Total amount of shortwave radiation from the sun that strikes a horizontal surface on Earth.	NSRDB / POWER
Direct Normal Irradiance	Amount of total shortwave radiation from the sun that strikes a surface perpendicular to the sun.	NSRDB / POWER

Table 2. Additional Variables in the TMY Product

Additional Climate Parameters	Definition	Source
Diffuse Horizontal Irradiance	Amount of shortwave radiation from the sun that strikes a horizontal surface that has been scattered by Earth's atmosphere.	NSRDB / POWER
Total Precipitation	Total liquid precipitation that can include rain or melted snow for that hour.	GHCNh
Relative Humidity	Calculated from air temperature and dew point temperature.	Derived
Station-Level Pressure	Pressure observed at the specific elevation of the station.	GHCNh
Sky Cover	Fraction of sky with coverage.	GHCNh
Snow Depth	Depth of the snowpack on the ground.	GHCNh
Wind Direction	Direction of the wind from true north.	GHCNh
Wind Gust	Short duration (< 20 s) of peak wind speed.	GHCNh

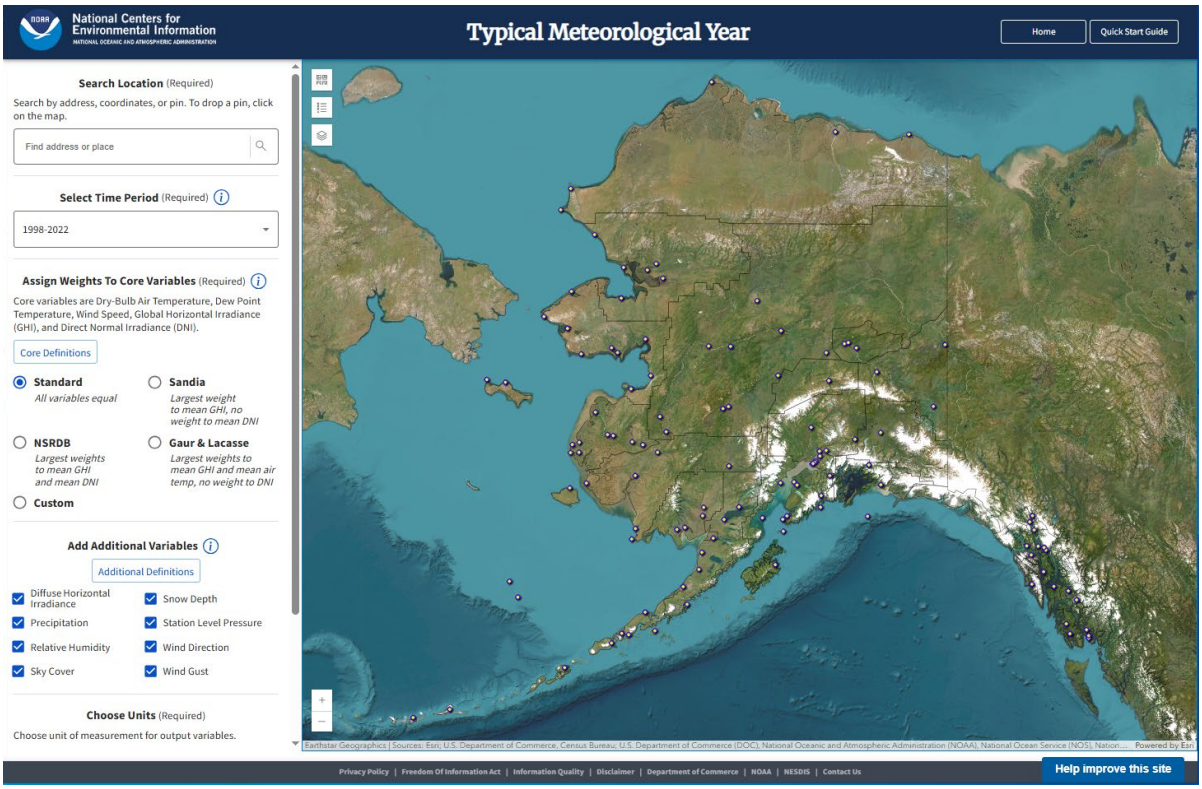


Figure 1. Screenshot of the TMY product interface.

The following is an example of how the tool constructs a typical weather year. For a weather station near the Ted Stevens Anchorage International Airport in Anchorage, Alaska (-150.0278 W, 61.1692 N), using the "Standard" weighting scheme, January 2011 has the most typical hourly meteorological and solar radiation conditions in the 25-year historical January record evaluated. In turn, February 2015 has the most typical conditions over the 25-year February record. The tool repeats the same process for the months of March through December, identifying the specific year within the historical record that is most typical for each month. The set of twelve months that this process determines becomes the TMY record for that site. Users can also select time periods through 2100 to access projected typical data based on future climate projections. NOAA's TMY is the only open-access product of its kind providing data across the U.S with this feature.

TMY obtains its location-specific weather data from a series of weather stations in the NOAA GHCNh database, where points on the map in Figure 1 indicate them in Alaska.[8] The map interface allows users to view the different stations available when selecting their location. TMY then presents data from the station closest to where users click on the map, providing information from the locations where it has actually been measured, rather than interpolations or similarly infilled gridded products. TMY also provides future projection values for each station, using the NOAA Geophysical Fluid Dynamics Laboratory SPEAR model. For more information on the methodology, see the TMY Technical User Guide.

[8] NOAA. 2026. "Global Historical Climatology Network hourly (GHCNh)." National Oceanic and Atmospheric Administration. June 8, 2026. https://www.ncei.noaa.gov/products/global-historical-climatology-network-hourly.

In addition, this tool is unique in that it allows users to tailor the TMY calculations via a user-customized weighting scheme. This feature allows users to place emphasis on certain variables to tailor the application of the output dataset for different use cases. For example, a user might place an enhanced emphasis on wind speed in relation to building energy loss considerations or compare weighting schemes across different outputs to determine appropriate design considerations that are related to particular climatic variables or time-of-year conditions (see Building Energy Balance Design below).

The Role of the A&E Sector in TMY Development

NOAA developed this TMY based on needs that members of the A&E sector expressed for a national-scope product that incorporates future projections. Throughout development, NOAA has collaborated with the sector to ensure that TMY is useful, usable, and used by industry. See Appendix B. Development of NOAA's TMY for more information.

During development, the A&E sector provided insight into many use cases for TMY data. The NOAA TMY product is especially useful for A&E because it offers a practical and dependable resource to support designing infrastructure that is energy-efficient and resilient to both current and future conditions in various climate zones across the U.S. TMY can support the sector's weather- and climate-informed decision-making in multiple ways that include, but are not limited to:

- Simulating building energy demands.
- Informing design models to evaluate the impact of future climate on infrastructure.
- Understanding annual variability in climatology for a specific location.
- Managing stormwater and other drainage systems through better understanding of the potential for landscape-scale events that can produce large volumes of runoff.

TMY data additionally can help fill data gaps in cold climate regions such as the Northern Rockies/Plains states, the far Northeast, and Alaska. "Typical" conditions from TMY can be used in outlying areas, notably in U.S. cold regions, to supplement limited observational data for the design of buildings and infrastructure, in planning and monitoring for energy grid systems, and more generally as a benchmark for the future.

TMY Resources for Cold Region Engineering Needs

Cold weather regions present particular challenges to engineers due to combinations of extreme temperatures (including extreme annual to sub-seasonal, even daily, ranges of cold and hot), related strong changes in solar radiation over the annual cycle, and seasonal-to-permanent snow and ice conditions. Designing structures and infrastructure to accommodate these conditions and function to design parameters requires taking into account a number of specific challenges. TMY data help mitigate these challenges since the product provides typical hour-by-hour values of many meteorological variables across the entire calendar year, providing the time resolution needed for seasonal to sub-daily design considerations.

The sections below explore some important applications of TMY data to cold climate engineering needs.[9]

[9] NOAA collected much of the following information from interviews with members of the A&E sector, now anonymized.

Building Energy Balance Design

In cold weather regions, structures are subject to large temperature variations throughout the year. Building energy systems must be equipped to handle these ranges, while also taking energy balance considerations and efficiency into account. Winter versus summer needs related to building energy balance can be effectively opposite in nature.

Winter:

- The amount of passive solar input during the day is an important consideration for both heating and lighting.
- Cloudy nights help maintain building interior temperature by inhibiting outgoing infrared radiation (heat).
- Active heating systems are needed to maintain usable conditions.
- Storm conditions potentially associated with cloudy winter nights would produce additional wind loss.

Summer:

- Days and even nights can be very warm or hot, creating large interior heat gain.
- Cloudy nights dampen removal of excess heat from the day by inhibiting outgoing infrared.
- In many locations, active cooling systems are necessary to maintain usable conditions.

In the face of this polarity, architects and engineers build models that use TMY data to find an optimal "sweet spot" or "sweet range" of design parameters, where they estimate the opposition of these seasonal considerations is reduced as much as possible. In dense urban environments, they additionally consider the effects of heat radiation of buildings on each other during both seasonal poles.

TMY Variables

- **Direct Normal Irradiance** relates to the passive energy input into a building through the structural skin and thus is critical in terms of environmental heating and lighting. This input varies with the lower winter to higher summer position of the sun in the sky, which differs substantially more in the northern CONUS states compared to southern states, and especially in Alaska.[10]
- **Global Horizontal Irradiance** and **Diffuse Horizontal Irradiance** are measures of indirect light and heat. These variables are also critical for environmental lighting and heating in high reflectivity, snow covered areas, especially at low direct sun angles.
- **Wind Speed** has a key impact on energy output, alongside passive infrared radiation loss. Wind affects energy loss through air entering and leaving the structure, along with enhanced transfer through convection. It also can result in heat entering a structure when the outside temperature is greater than that inside.
- **Dry Bulb Air Temperature** (ambient dry air temperature) and **Dew Point Temperature** are directly related to the conduction of heat into and out of structures, which is a key mode of direct energy transfer to and from the environment.

[10] At 45 degrees North on a clear day in the northern CONUS, only 36.7 percent of full normal solar radiation will occur at solar noon on the winter solstice. At 65 degrees North, near Fairbanks, Alaska, only 2.6 percent of full normal solar radiation will occur.

Solar Energy Site Planning

TMY information is an important input in site development for solar photovoltaic arrays (PVA), enabling companies to compare performance estimates of different designs and configurations across various potential locations.[11] In cold regions farther from the equator, the lower sun angles overall and more extreme seasonal changes become key design parameters. The high reflectivity of snow cover is also a critical factor, boosting cold season electricity output that lower sun angles and shorter day lengths diminish.

TMY Variables

- **Direct Normal Irradiance** provides the fundamental component of sunlight available to strike the primary surface of a PVA. In winter, direct sunlight occurs at shallow to very shallow angles in U.S. cold regions (or not at all for periods at far northern locations). For optimal solar input in winter, and to ensure snow shedding, PVA panels need to tilt steeply to be nearly perpendicular to the sunlight. In contrast, this angle is much less for the most summer power production. Engineers use direct normal irradiance to estimate how much overall production they can gain by increasing the tilt angle to enhance winter production, while keeping in mind summer production.
- **Global Horizontal Irradiance** and **Diffuse Horizontal Irradiance** can contribute significant amounts of light to PVA in high reflectivity, snow covered areas, especially where arrays use bifacial solar panels that generate power from both sides of the panel. Along with their role in optimal capture of direct normal irradiance, steeper tilt angles open up the area behind the PVA, allowing it to capture significantly more reflected light.
- **Snow Depth** helps engineers estimate snow cover and model the reflected light hitting the rear side of bifacial panels. This effect can boost overall generation by up to fifteen percent, shorten return-on-investment periods, and help make best utilization of available space.[12]
- **Sky Cover** is mathematically tied to irradiance, however, analyzing it as a standalone variable is vital for PVA system resilience. To ensure an off-grid home or a critical facility (such as a hospital microgrid) does not lose power during high-sky-cover periods, engineers must size battery storage to bridge such events when solar generation plummets. To the extent that relatively small distances make a difference in sky cover and site location has flexibility, this variable can aid in site selection.
- **Dry Bulb Air Temperature** can be used to determine the expected extreme cold that a PVA system may experience. Very cold temperatures can cause PVA voltage in a string of panels to exceed the maximum input voltage of the system's inverter, potentially destroying the inverter.[13] Design considerations to avoid this outcome include shortening how many panels are included in a string, whose length-to-voltage relationship is temperature sensitive.[14] Similar to sky cover, where relatively small distances make a difference in temperature and site location has flexibility, this variable also can aid in site selection. On the positive side, lower dry bulb temperatures keep the PVA operating temperature cooler during sunny periods, which leads to higher overall efficiency and power output compared to hot summer days.

[11] The NOAA TMY dataset is not advised for use in determining the specific output of solar arrays, but is valuable to identify prime locations in site planning.
[12] Gaëtan Masson et al. 2023. "Trends in Photovoltaic Applications 2023." International Energy Agency, Report IEA PVPS T1-43:2023. September 24, 2026. https://iea-pvps.org/wp-content/uploads/2023/10/PVPS_Trends_Report_2023_WEB.pdf. See also note 40 and associated text regarding snow depth projections.
[13] Solis. 2022. "Solis Seminar [Episode 36]: The influence of winter on Solar PV system operation and related O&M considerations". July 12, 2026. https://www.solisinverters.com/in/documentation/The_influence_of_winter_on_Solar_PV_system_operation_and_related_O%26M_considerations_12071715.html. Photonik. 2026. "Solar String Voltage Calculator". July 12, 2026. https://www.photonik.solar/string-voltage-calculator/.
[14] National Fire Protection Association (NFPA). 2017. "National Electrical Code (NEC) Article 690.7 - Maximum Voltage." July 9, 2026. https://www.electricallicenserenewal.com/Electrical-Continuing-Education-Courses/NEC-Content.php?sectionID=377

Power Grid Design

Many CONUS electric power grids were designed focusing on summer-peak loads, due to the power draw of air conditioning. However, as a significant number of buildings adopt heat pumps in cold weather CONUS states, this behavior can shift peak load conditions to winter. Utilities can aggregate TMY data across their service territories to model future load curves and identify potential power production and distribution constraints during extended cold snaps.

TMY Variables

- **Dry Bulb Air Temperature** helps identify the temperature difference between the indoor and outdoor environment, which directly influences a heat pump's coefficient of performance and capacity.
- **Relative humidity** can help estimate the frequency and severity of icing/frosting on the heat pump evaporator coils, which reduces efficiency and triggers defrost cycles, significantly impacting peak power consumption.
- **Wind speed** is a key factor in calculating convective heat loss from the building envelope and enhancing air infiltration, increasing heating load.

A suite of additional applications to cold climate conditions identified via engagement with members of the A&E sector and through further research is presented in Table 3.

Table 3. Additional Applications for NOAA's TMY Product in Cold Regions of the U.S.

Application	Weather and Climate Issues	TMY Variables
Sequences of Cold and Wet Conditions	Sequences of combined cold and wet conditions can cause substantial freeze-thaw damage in infrastructure. Where freeze-thaw cycles are a common night-to-day occurrence, dangerous, quickly changing conditions can occur on roadways and sidewalks.	**Dry Bulb Air Temperature** A drop in the air temperature below 0°C followed by a subsequent rise above freezing is considered a standard freeze-thaw cycle. TMY hourly data can capture the likelihood of fast night-to-day cycles during, for example, a month in the late winter.
Runoff Water Management	Rapid snowmelt enhanced by rain-on-snow events can substantially affect runoff. These situations can overwhelm the design capacity of existing stormwater infrastructure, and even threaten the integrity of large reservoirs.	**Snow Depth** **Total Precipitation** **Direct Normal Irradiance** **Dry Bulb Air Temperature** Baseline estimates of late winter/early spring snow depth and associated rain precipitation, solar irradiance, and elevated temperatures can help identify likely times of enhanced risk. TMY future projections for temperature can assist in assessing additional risk from changing conditions. (See also note 40 and associated text regarding snow depth projections.)
Seasonal Natural Gas Storage Estimation	The Upper Midwest and Northeast generate large winter heating demand. Pipeline capacity cannot meet this demand, and operators rely on natural gas storage from the summer to meet the winter demand.[15]	**Dry Bulb Air Temperature** Baseline forecasting for typical conditions uses *heating degree hours*, which are determined by how much and for how long the air temperature is cooler than a specified base temperature. Dry bulb air temperature provides both the base temperature and the ongoing hourly temperature profile used in the calculation.
Controlled Environment Agriculture	Engineering considerations for heating and lighting in controlled environment agriculture (CEA) focus on optimizing plant yield and are highly specialized in cold regions. Large winter differences in temperature between inside and outside lead to high energy use indoors, especially in greenhouse-type CEA that seeks to maximize natural light input into structures that are poor at retaining heat.	**Dry Bulb Air Temperature** **Relative Humidity** Models can use air temperature and humidity to model the typical exterior conditions during cold seasons, which can then be compared to the required interior conditions of CEA, particularly for greenhouse-type applications.

[15] Natgas. 2013. "Storage of Natural Gas." NaturalGas.org. June 10, 2026. https://naturalgas.org/naturalgas/storage/.

Application	Weather and Climate Issues	TMY Variables
Seasonally and Permanently Frozen Ground	Seasonally frozen ground is an issue across U.S. cold regions. Engineers need to determine design parameters for frost-protected shallow foundations. Soil frost depths can be estimated with the air freezing index (AFI).[16] Accurate estimates of soil frost depth profiles allows for reduced construction costs and better preparedness for future climate conditions. In Alaska, eighty percent of the surface lies above permanently frozen ground, or permafrost.[17] Constructing buildings in this situation requires specialized analysis and building techniques to mitigate how disturbed or thawing permafrost can result in uneven foundation settling that puts buildings' structural integrity at risk.[18] [19]	**Dry Bulb Air Temperature** The daily maximum and minimum air temperatures for a given location can help to calculate typical AFI values in that area.[20] In Alaska, AFI values derived from projected future TMY can aid in evaluating the likelihood and potential timing of permafrost degradation.

[16] Rocky Bilota et al. "Calculation and Evaluation of an Air-Freezing Index for the 1981–2010 Climate Normals Period in the Coterminous United States." Journal of Applied Meteorology and Climatology 54, no.3 (2015): 69-76. https://doi: 10.1175/JAMC-D-14-0119.1.
[17] EPA. 2017. "Climate Impacts in Alaska," Environmental Protection Agency. November 25, 2025. https://19january2017snapshot.epa.gov/climate-impacts/climate-impacts-alaska.html.
[18] USGS. 2025. "Deep Dive: Enhancing Economic and National Security for Alaska and the Nation." U.S. Geological Survey. November 25, 2025. https://www.usgs.gov/programs/climate-adaptation-science-centers/science/deep-dive-enhancing-economic-and-national.
[19] Permafrost also occurs in the CONUS, but only in high alpine areas nearly entirely limited to the Rocky Mountains and the Sierra Nevada and Cascade Ranges in the U.S. West. Troy Péwé. "Alpine Permafrost in the Contiguous United States: A Review." Arctic and Alpine Research 15, no. 2 (1983): 145-156. DOI: 10.1080/00040851.1983.12004339.
[20] See reference in note 16 for AFI calculation methodology.

Case Study: Alaska

The following sections highlight circumstances particular to Alaska in which NOAA's TMY product can support analyses in the A&E sector. NOAA developed this following a series of four interviews with members of A&E and academic communities in Alaska in November 2025. In these interviews, the team explored how the interviewees and their institutions considered a changing climate environment in their work to provide solutions to their clients and users, and how they used meteorological data to drive these decisions.

Alaska Climate Challenges

Alaska presents significant A&E challenges due to its vast, complex terrain and extreme climatic conditions.[21] [22] The state's high latitude results in very low sun angles and no direct sunlight beyond the Arctic Circle in winter, and to extreme variations in daylight hours over the year.[23] These conditions directly impact building solar gain, thermal performance, and lighting design. Unlike the CONUS, Alaska's infrastructure must contend with deeper extreme cold, shorter construction seasons, and higher material costs due to the state's remote geography and widely dispersed population centers.

A critical design issue is changes in the permafrost that underlies eighty percent of the state.[24] Rising temperatures are causing permafrost thaw, leading to soil instability and surface subsidence that threatens the structural integrity of roads, foundations, and utilities.[25] One study estimates that permafrost thaw could cost Alaska $37-$51 billion this century in building and road losses alone.[26] Managing these risks requires specialized site analysis and materials to prevent uneven settling, along with greater labor requirements and increased transportation and on-site costs.

Interior Alaska is expected to experience hotter, drier summers. The boreal forest fire regime will intensify in turn, burning millions of acres with greater severity and removing the organic peat layer that forms a natural insulation protecting the underlying permafrost.[27]

Additionally, delayed near-shore sea ice formation leaves coastal infrastructure vulnerable to high-energy wave action and accelerated erosion, potentially necessitating the relocation of entire communities by the end of the century.

Alaska Data Challenges

The limited observational network in Alaska creates significant hurdles for engineering decision-making. Weather stations are sparse and unevenly distributed, mostly concentrated in low-elevation coastal

[21] WorldAtlas. 2026. "Maps of Alaska." WorldAtlas. November 25, 2025. https://www.worldatlas.com/maps/united-states/alaska.
[22] Peter Bieniek et al. "Climate Divisions for Alaska Based on Objective Methods." Journal of Applied Meteorology and Climatology 51, no. 7 (2012): 1276-1289. https://doi.org/10.1175/JAMC-D-11-0168.1.
[23] Henry Lee and Wendy Dewi. 2025. "Solar energy in the Arctic: A case study of northwest Alaska." Harvard Kennedy School, Belfer Center for Science and International Affairs. June 11, 2026. https://www.belfercenter.org/sites/default/files/2025-09/Lee%20Dewi_Alaska%20Solar%20Energy_20250910.pd.
From a geometric perspective, at 45 degrees North on a clear day a location in the northern CONUS states will receive only 36.7 percent of full normal solar radiation at solar noon on the winter solstice. At 65 degrees North, near Fairbanks, Alaska, only 2.6 percent of full normal solar radiation will be received.
[24] EPA. 2017. "Climate Impacts in Alaska," Environmental Protection Agency. November 25, 2025. https://19january2017snapshot.epa.gov/climate-impacts/climate-impacts-alaska.html.
[25] Tanya Spero et al. "Environmental Impacts from Projected Permafrost Thaw in Alaska: Defining Knowledge Gaps, Data Needs, and Research Priorities." Weather, Climate, and Society 17, no. 3 (2025): 325–337.
[26] Elias Manos et al. "Permafrost thaw-related infrastructure damage costs in Alaska are projected to double under medium and high emission scenarios." Communications Earth and Environment 6, art. 221 (2025). https://doi.org/10.1038/s43247-025-02191-7
[27] Pieter Beck et al. "The impacts and implications of an intensifying fire regime on Alaskan boreal forest composition and albedo." Global Change Biology 17 (2011): 2853–2866. doi: 10.1111/j.1365-2486.2011.02412.x.

areas or major river basins.[28] This pattern leaves large empirical data gaps in high-elevation and inland regions, hindering the accuracy of historical trends and extreme weather hazard documentation essential for infrastructure resilience.[29]

Furthermore, Alaska's topographically complex regions—such as the fjords and mountains of Southeast Alaska—create micro-climates that can be difficult to capture with global or regional climate models and reanalyses.[30] These limitations make it challenging for engineers to obtain accurate, local-scale weather and projected climate data, emphasizing the need for improved meteorological records and specialized datasets like TMY to inform state-specific design and standards.

How TMY Fills Industry Needs and Data Gaps in Alaska

The fundamental added value of TMY for Alaska is that the tool uses the NASA POWER dataset to provide solar irradiance information for the region north of 60° N (Figure 2).[31] The NLR NSRDB version 3.2.2 is the primary resource for these variables in the CONUS.[32] At the time of TMY's development, NSRDB's spatial coverage in the Arctic ended at 60° N, which excludes, for example, the most densely populated region of the state near Anchorage and the northern hub of Fairbanks. To augment this, the POWER irradiance dataset provided coverage for TMY's core variables for 70 additional data stations north of 60° N. This allows users to incorporate all of the TMY variables into design modeling throughout the state.[33]

While the station-based data in NOAA's TMY does not overcome the underlying information gaps in this region, it is a tool that adds to the resources available to users dealing with scarce weather data. Among other uses, "typical" conditions from TMY can be used in rural areas of Alaska to supplement limited available observational data for design of buildings and infrastructure, in planning and monitoring for energy grid systems, and can be used to determine "typical" degree days and degree hours as benchmarks for the future.[34]

[28] Douglas Kane and Svetlana Stuefer. "Reflecting on the status of precipitation data collection in Alaska: a case study." Hydrology Research 46, no. 4 (2015): 478–493. https://doi.org/10.2166/nh.2014.023.
[29] Nathan Kettle et al. "Integrating archival analysis, observational data, and climate projections to assess extreme event impacts in Alaska." Climatic Change 163 (2020): 669–687. https://doi.org/10.1007/s10584-020-02907-y.
[30] Emily Williamson and Christopher Sergeant. "Independent validation of downscaled climate estimates from a coastal Alaska watershed using local historical weather journals." PeerJ 10, no. 9 (2021): e12055. https://doi.org/10.7717/peerj.12055. Samantha Basile et al. "To be policy-relevant, future climate research must include the noncontiguous United States." Proceedings of the National Academy of Sciences 121 (13) (2024): e2315505121. https://doi.org/10.1073/pnas.231550512.
[31] NASA POWER. 2026. "POWERing the Future of Energy, Infrastructure, and Agroclimatology." National Aeronautics and Space Administration. June 13, 2026. https://power.larc.nasa.gov/.
[32] NLR. 2025. "NSRDB: National Solar Radiation Database." National Laboratory of the Rockies. November 25, 2025. https://nsrdb.nlr.gov/.
[33] The POWER data have a significantly less granular spatial resolution of 1° latitude by 1° longitude, compared to the 4 km by 4 km resolution of the NSRDB data. Since longitudinal degrees cover increasingly smaller east-west distances moving towards the poles, this difference is reduced to an extent in Alaska compared to more southerly locations (NOAA. 2026. "What is longitude?" National Ocean Service. June 7, 2026. https://oceanservice.noaa.gov/facts/longitude.html). Each POWER grid cell at 65° N is only 49% as large as a corresponding grid cell at the equator. Nevertheless, at 70° N, in northern Alaska, a one degree grid cell is approximately 111.1 km north-south by 38.1 km east-west, while at 50° N, in southern Alaska, the same one-degree span is about 111.1 km by 71.7 km.
[34] For example, for interior design considerations a heating degree day is defined as [Base Temperature - (Daily High + Daily Low / 2) when the daily mean is below the base temperature. The base temperature is set to represent a comfortable environment for humans, such as 65 degrees Fahrenheit. NOAA. 2026. "Degree Days". National Weather Service. September 25, 2026. https://www.weather.gov/ffc/degdays.

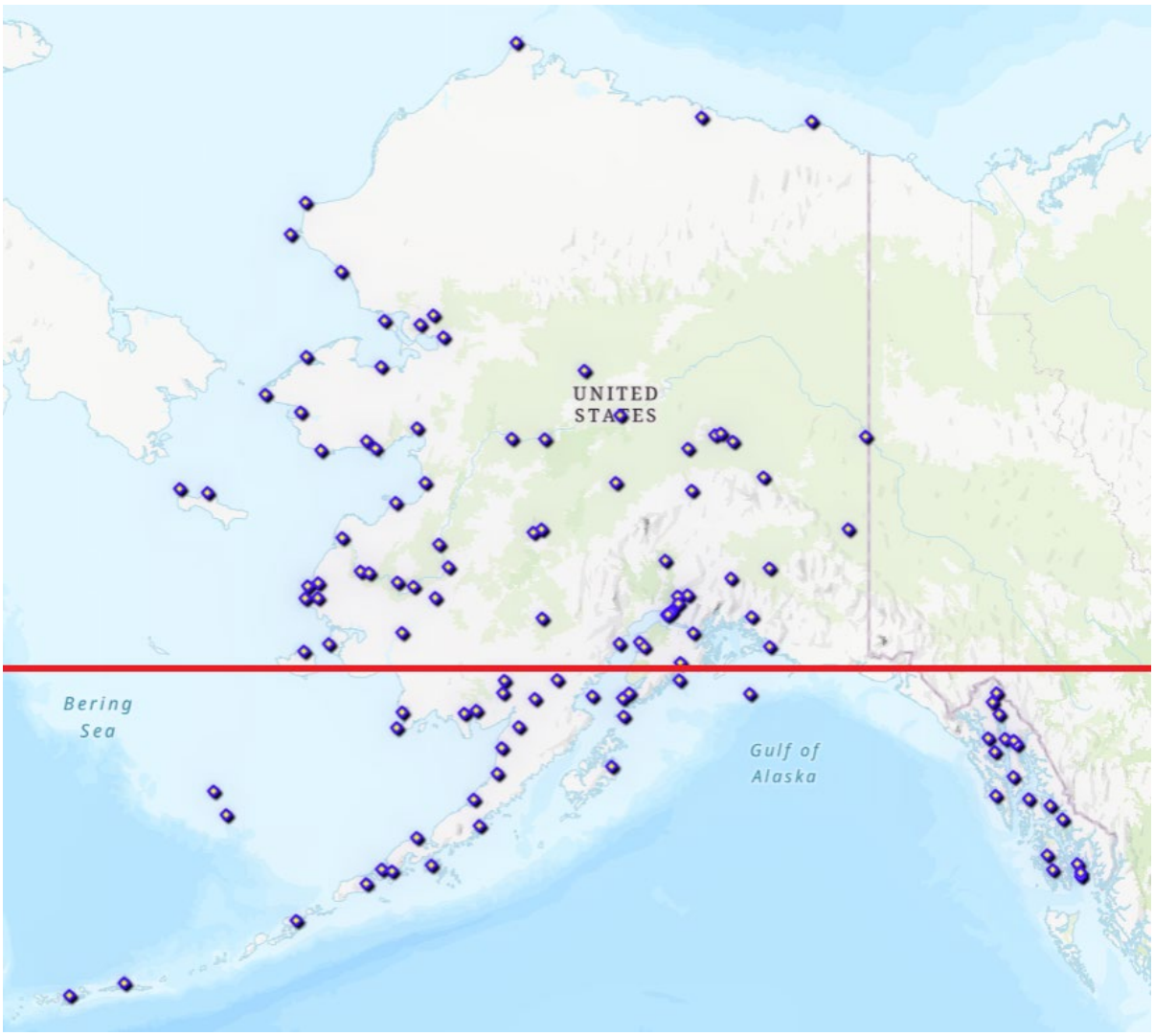


Figure 2. White dots with blue outline show weather stations in Alaska for which TMY data are available. POWER solar irradiance data allows inclusion of stations north of 60° N (red line), which is most of Alaska.

Another important aspect of TMY is that it enables users to select custom weightings for the core climate variables the product incorporates. This capacity is particularly relevant to Alaska since regional users' preferred weighting values may differ from those that are most useful in more temperate environments. For example, since Alaska has lower angles of sunlight and thus less direct solar energy input per unit of horizontal surface area, analysts may want to consider alternative weightings of the core variables to reflect this condition. Flexible weighting combinations also allow users to test and optimize for particular circumstances and locations, adding significant value for design modeling and evaluation across the state's large and variable landscape.

Because of the accelerated rates of change the Arctic is experiencing, climate projections are also particularly important to users in Alaska. The open-access nature of TMY's projection data, which is

based on the NOAA SPEAR model under the SSP 2-4.5 scenario[35], greatly enhances its value. The SPEAR model grid is incorporated into the TMY interface, and can also be accessed via ArcGIS.[36]

Highlighted Use Cases for NOAA'S TMY in Alaska[37]

Use Case 1: Engineering to Manage Thawing Permafrost

A changing snow season, future winds, and thawing permafrost will alter previous "normal" conditions and will affect engineering considerations across the state. In particular, warming permafrost can render structures such as buildings and roads unusable within a decade as the ground beneath them thaws and softens.[29] Although structures initially sit on solid, permanently frozen ground, the changeover to freeze-thaw cycles wreaks havoc on the integrity of their foundations, compromising their superstructures entirely.

Research out of the University of Alaska Fairbanks underscores rapid permafrost thaw and its effects, with a highlighted example at Point Lay, Alaska, (Figure 3).[38] Not only does this impact include structures on top of thawing permafrost; it also includes utility infrastructure underground.[39]

Engineers have expressed interest in computing the depth of seasonal freeze and thaw in the soil to help answer these questions. There are different ways to do this, but the climate variables used to identify this depth are freezing and thawing indices.[16] TMY's hourly time series of future temperatures could help engineers compute these indices, which would inform design decisions for future infrastructure and identify vulnerable existing infrastructure as the ground freezes shallower and thaws deeper. Projected snow depth is also needed to estimate the future of permafrost change. TMY's historical output provides snow depth as an additional variable in its data output, while future snow depth information can be achieved using TMY's projected precipitation and incorporating it into a snowpack model.[40]

Making roads, buildings, and other infrastructure less susceptible to the impacts of thawing permafrost requires additional materials, labor effort, transport, design work, and other factors compared to non-permafrost ground conditions. These extra measures add expense, and engineers weigh projects' potential lifetimes in relation to installation and ongoing maintenance costs. In Alaska, there are few roads to begin with, and this couples with the challenge that thawing permafrost can render existing roads unusable. Repairs are also expensive; it is especially resource-intensive to bring a work crew out to a remote location to fix a road or structure that thawing permafrost has compromised. Data from NOAA's TMY product can support modeling so engineers can better plan for the thawing that may occur during a structure's lifetime and make informed decisions that weigh these factors together.

---

[35] NOAA. 2026. "Climate Model - Surface Temperature Change: SSP2 (Middle of the Road) - 2015 - 2100". September 3, 2026. https://sos.noaa.gov/catalog/datasets/climate-model-surface-temperature-change-ssp2-middle-road-2015-2100/.
[36] NOAA. 2025. "TMY SPEAR Model Grid." National Oceanic and Atmospheric Administration. September 3, 2026. https://noaa.maps.arcgis.com/home/item.html?id=e0188706d7204b45aae872e6e33c9303#overview.
[37] NOAA collected much of the following information from interviews with members of the A&E sector in Alaska. Individual interviewees and their contributions have been anonymized.
[38] Boyce, Rod. 2025. "Research highlights rapid permafrost thaw at Point Lay, Alaska." University of Alaska Fairbanks. https://www.uaf.edu/news/research-highlights-rapid-permafrost-thaw-at-point-lay-alaska.php
[39] Reid, Robert L. 2024. "What does it take to engineer under snow and ice?" American Society of Civil Engineers Civil Engineering Source. https://www.asce.org/publications-and-news/civil-engineering-source/civil-engineering-magazine/issues/magazine-issue/article/2024/09/what-does-it-take-to-engineer-under-snow-and-ice.
[40] Physical snowpack models require radiation and boundary condition variables, along with wind direction projections, that TMY does not provide. For additional detail, see, for example, V. Vionnet et al. "The detailed snowpack scheme Crocus and its implementation in SURFEX v7.2". Geoscience. Model Development 5 (2012): 773–791. www.geosci-model-dev.net/5/773/2012/ doi:10.5194/gmd-5-773-2012.



Figure 3. Permafrost thaw in Point Lay, Alaska, showing dislocated below-ground infrastructure and exposed support pilings of buildings.[41]

Use Case 2: Electric Vehicle (EV) Modeling

The cold climates in Alaska can bring particular challenges for EV operation. One of the barriers to EV adoption is that battery performance strongly declines in cold temperatures. At the same time, the energy demands for EV cabin heating can be significantly larger than those to move the vehicle, especially in colder temperatures.[42] Modeling potential energy demand at hourly time resolution is essential when dealing with such "parasitical loads," or the power required to maintain battery and cabin heating. The projections component of TMY can be used to understand how future climate might affect the range, energy and charging needs of electric vehicles, and in turn support greater electric vehicle usage.

Researchers in the Alaska Center for Energy and Power at the University of Alaska Fairbanks are working with communities to study potential power usage and related EV usage, modeling EV performance in high latitudes and future climates. TMY is one of the inputs to their energy use models, helping to model intra-daily usage patterns by taking advantage of the hourly time resolution. Modeling potential EV usage in this way can aid the transition of electrifying transportation and could reduce the reliance on expensive fuel that needs to be flown in by aircraft in some remote locations. This could be additionally beneficial for rural communities looking for grants to improve their power grids, who can leverage

[41] University of Alaska Fairbanks photo by Benjamin Jones. Boyce, Rod. 2025. "Research highlights rapid permafrost thaw at Point Lay, Alaska." University of Alaska Fairbanks. https://www.uaf.edu/news/research-highlights-rapid-permafrost-thaw-at-point-lay-alaska.php
[42] Michelle Wilber et al. 2021. "Cold Weather Issues for Electric Vehicles (EVs) in Alaska." Alaska Center for Energy and Power. June 13, 2026. https://www.uaf.edu/acep/files/projects/Cold-Weather-Issues-for-EVs-in-Alaska.pdf.

enhanced opportunity for EV usage to show the potential positive impact of investing in solar electric capacity.

Increasing EV usage would also increase resiliency, especially in rural areas, because there is a potential to power one's house from a car in the case of a power outage. The impacts of electrifying transportation in Alaska reach beyond energy and financial cost. For example, reducing diesel and gasoline use and associated pollution-causing emissions additionally benefits the local environment and human health. Implementing electric vehicles may result in fewer vehicles that run on diesel, and therefore significantly lessen emissions.

Conclusion

NOAA continues to help connect users to the authoritative data most useful to their work. NOAA co-developed its TMY product with members of the A&E sector to provide architects and engineers data that are necessary for safety, structural integrity, and cost-effectiveness in the face of changes to weather and climate. Across U.S. cold regions in particular, the TMY product has a wide variety of A&E applications ranging from energy planning in new buildings to mitigating compromised infrastructure with thawing permafrost, and many other use cases. In a sector whose work by its nature is to design and construct structures and infrastructure that will last and perform well into the future, publicly accessible projections like those in TMY are a valuable resource. For more information about NOAA's TMY tool, see the resources on TMY's landing page.

NOAA continuing to maintain and expand its capabilities to deliver its environmental information to the American public is key for the regular operations in industry. In A&E and industries beyond, information that users can easily find, access, understand, and use enables and fosters informed design for present and future conditions. User-oriented NOAA datasets bolster work that improves safety and solvency of the American public. Engaging with users in the A&E industry, understanding their needs, and supporting their decisions continue critical access, improve usability, and promote transparency of information.

NOAA's Industry Partnerships program connects knowledge and feedback from the A&E sector with applicable environmental data tools and services. The initiative has led to improvements in existing data tools and the co-development of new tools to support decision-making in the A&E industry. With the TMY product and beyond, NOAA maintains its commitment to supporting U.S. economic development and resilience.

Appendix A. Acronyms

Acronym	Full Term
A&E	Architecture and Engineering
AIA	American Institute of Architects
AFI	Air Freezing Index
ASCE	American Society of Civil Engineers
A&E	Architecture and Engineering
CEA	Controlled Environment Agriculture
CONUS	Contiguous United States
EV	Electric Vehicle
GHCNh	Global Historical Climatology Network hourly
GFDL	Geophysical Fluid Dynamics Laboratory
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NRL	National Laboratory of the Rockies
NSRDB	National Solar Radiation Database
POWER	Prediction of Worldwide Energy Resources
PVA	Photovoltaic Array
TMY	Typical Meteorological Year
U.S.	United States

Appendix B. Development of NOAA's TMY

The initial need for NOAA to develop a TMY product came from a listening session in 2022 with representatives from the AIA. Architects requested projected TMY values according to different climate scenarios. The 2022 Climate Data Workshop with the Northeast Regional Climate Center provided most of the starting block for this product, and participants primarily included stormwater engineers and city planners.[43] The NOAA development team began development in summer 2024 and deployed the final product in early 2026.

Co-Development Process with Users

User feedback influenced NOAA's TMY product at every step in its creation. From the first request in 2022 to the final tweak in 2026, NOAA has sought out members of industry, asked them pointed questions, listened to their inputs, and incorporated their needs into product requirements. This is in alignment with NOAA's Service Delivery Model that guides and improves NOAA's development and delivery of decision support products and services with user-feedback-oriented processes.[44]

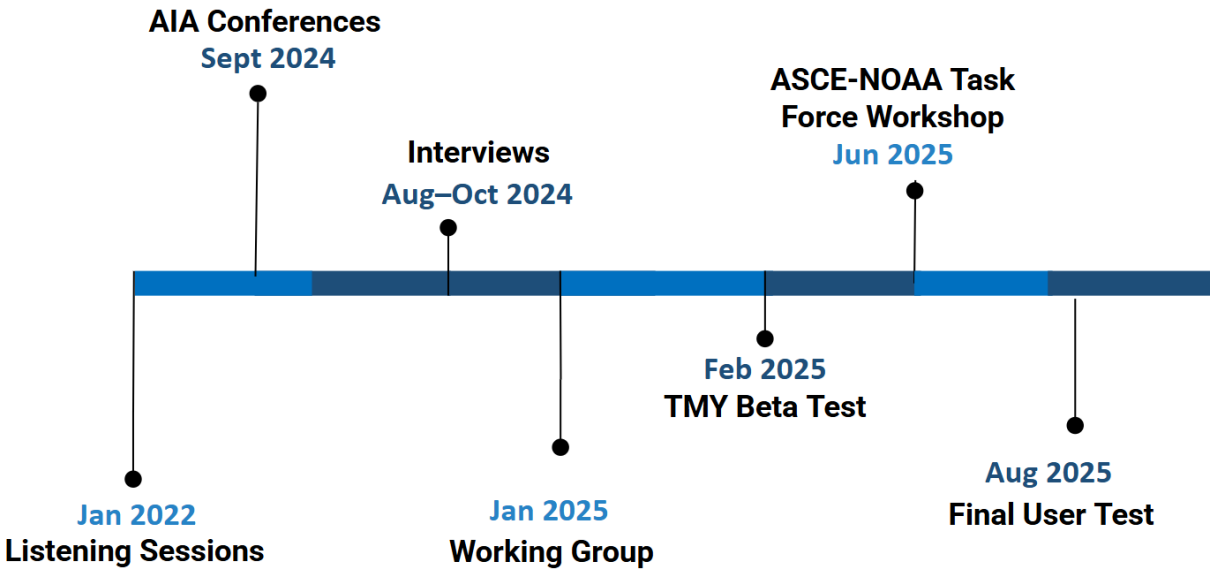


Figure 4. Timeline of engagements at which NOAA has engaged with TMY users to inform the product's development.

Engagement with the sector throughout the process provided feedback from experts and potential users that informed TMY's development. NOAA hosted and attended events to connect with users from the American Society of Heating, Refrigerating and Air-Conditioning Engineers, the Northeast Regional Climate Center, AIA members, and practicing architects during product development for targeted feedback.

In addition, NOAA conducted two demonstrations and testing sessions online. The Beta Demo in February 2025 was an opportunity for industry members to see the progress on the product and provide

[43] NRCC. 2026. "Northeast Regional Climate Center." Northeast Regional Climate Center. June 13, 2026. https://www.nrcc.cornell.edu/.
[44] NOAA Water Team. 2020."A Model of Service Delivery for the NOAA Water Initiative: A Proven Method for Integrating Decision Support and Service Delivery." National Oceanic and Atmospheric Administration, Water Initiative. June 13, 2026. https://www.noaa.gov/sites/default/files/2022-02/A-Model-of-Service-Delivery-for-the-NOAA-Water-Initiative_FINAL.pdf.

feedback that would shape the rest of its development. The Final Demo in August 2025 demonstrated an updated, near-complete TMY. The event served to show previous participants how the feedback they contributed informed the product, as well as to promote the product to new potential users.

The feedback from these sessions resulted in a more intuitive interface, increased transparency about uncertainty, guides better suited for new users, and supported file formats for compatibility with common industry uses. NOAA developers incorporated the final round of feedback into the version that is now published.

Working Together to Improve Resilience

NOAA collaborates with industry leaders to update and develop new data and observation products, including maps, interactive tools, and other datasets. By improving access to environmental data, NOAA connects decision makers with accurate, timely, and future-facing data products and services to support improved risk assessments and economic, community, and environmental resilience.

Together, we can empower safe, resilient, and cost-efficient decisions for short and long-term planning, which safeguards communities and the U.S. economy.



Contract #1305M423DNEEA0014
Professional, Scientific, and Technical Services Program (ProTech)
Satellite Domain – Small Business
Task #1332KP24F0021

Learn more at **ncei.noaa.gov/about/our-impact**

CSS
CADMUS STC BLN24 Deloitte. iSciences AECOM CASE
NCICS North Carolina Institute for Climate Studies
NSF National Science Foundation