

Understanding the Impact of Meteorological Parameters in Building Design: A Review

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Abstract. Meteorological conditions intensely influence building performance, particularly energy use, thermal comfort, and thermal behaviour. Fluctuations in air temperature, relative humidity, solar radiation, wind, and precipitation can affect energy demand and indoor conditions, while conventional weather datasets may not fully capture extreme climatic conditions. This review examines how meteorological conditions and weather-data representation influence building performance. It reviews different approaches for developing weather data, including interpolation, statistical and dynamical downscaling, and weather-data generation. Methods for identifying extreme events, such as threshold-based approaches, anomaly detection, and Extreme Value Theory, are also discussed in relation to building-performance assessment. The reviewed studies show that meteorological parameters can affect energy demand, thermal performance, and thermal comfort, while extreme events such as heatwaves can increase overheating and place additional stress on buildings. Typical Meteorological Year datasets are useful for representing typical climate conditions, whereas Representative Meteorological Year datasets can better capture unusual and extreme conditions and help assess peak loads, thermal stress, natural ventilation, and outdoor comfort. The review also highlights the importance of suitable performance indicators and future heatwave weather files for understanding building response under changing climatic conditions. Overall, appropriate representation of meteorological conditions is important for reliable building-performance assessment and for developing climate-responsive designs.

Keywords: Meteorological conditions, Weather data, Building performance, Extreme weather, Climate change

1. Introduction

Buildings are increasingly influenced by changing environmental conditions, which can affect their energy use, thermal comfort, durability, and overall performance. As a result, building design needs to respond to local climatic conditions and consider environmental factors that may influence buildings throughout their service life. Building performance is shaped by several factors, including weather conditions, building materials, occupancy schedules, and building openings [1]. Among these, meteorological conditions are particularly important because variations in temperature, relative humidity, solar radiation, wind, and precipitation can affect energy use, thermal comfort, and building design [2]. Respectively, the occupant behavior and occupancy patterns also influence internal heat gains and building energy use, which can contribute to differences between predicted and actual energy consumption. At the same time, changes in weather conditions can alter building energy use, particularly through variations in temperature, relative humidity, and solar radiation [3]. Building performance can vary from what is expected because climate conditions are not always predictable. Moreover, using weather data that represent both local conditions and possible future changes is important for assessing building energy use and thermal performance over its service life [4]. Tarkhan et al. [5] investigated that conventional weather data may not fully reflect the conditions buildings

experience throughout their service life. Although Typical Meteorological Year (TMY) files are widely used in building simulations, they mainly represent typical weather and may not capture extreme events or changes in climate. Considering these variations can provide a more realistic understanding of building energy and thermal performance and support better climate-responsive design. As the impact of meteorological parameters was studied in crops in Himachal Pradesh [6-8], the impact of the same in buildings is yet to be studied in various states of India. In addition, the effects of individual meteorological parameters on building performance and their role in building design are still not fully clear. Therefore, this review examines how temperature, relative humidity, solar radiation, wind, and precipitation affect building energy performance, thermal comfort, and design. It also discusses climate-responsive design strategies and the need for representative weather data for reliable building-performance assessment. Table 1 shows the relationship between meteorological parameters, their key impacts, and their implications for building design. Figure 1 shows the flow chart of literature search, study selection, classification of reviewed studies, and assessment of their implications for building performance.

Table 1. Key impacts of meteorological parameters on building design and performance

Meteorological parameter	Key impact	Building implication
Temperature	Heating and cooling demand	Air conditioning, heating and ventilation system, and energy-efficient envelope
Relative humidity	Thermal comfort and moisture conditions	Indoor comfort, moisture control and material selection
Solar radiation	Daylight availability and solar heat gain	Glazing design, building orientation, and shading
Wind	Heat transfer and natural ventilation	Natural ventilation strategies, building orientation and openings
Precipitation	Water management and moisture exposure	Weather-resistant building envelope and drainage design

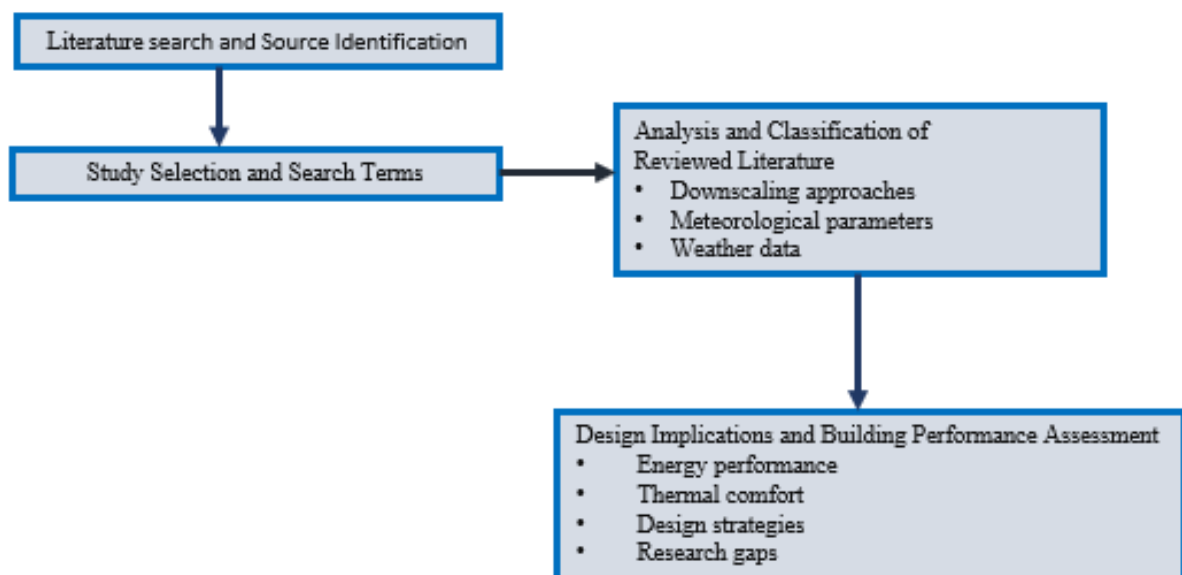


Fig. 1. Literature classification framework and Review methodology

2. Materials and Methodology

The literature search focused on studies examining how meteorological conditions affect building performance. Relevant studies were identified through academic databases and scholarly sources using keywords that were related to building energy performance, thermal comfort, climate-responsive design, and weather data. Studies examining the effects of weather conditions on building performance, thermal comfort, and design were included for further review. The search included terms such as temperature, relative humidity, solar radiation, wind, precipitation, climate change, extreme weather, TMY, and future weather data. Studies were included when they examined how meteorological conditions affect building energy use, design, thermal comfort, and thermal performance. Research on climate-responsive strategies and the use of historical, representative, or future weather data for building-performance assessment was also considered. The reviewed studies were grouped according to the meteorological parameters they examined and their effects on building performance. These included air temperature, relative humidity, solar radiation, wind speed, precipitation, typical and observed weather data, future conditions, and extreme weather events. They were also grouped by outcomes such as heating and cooling demand, energy consumption, peak loads, thermal comfort, energy efficiency, and building design. This classification helps compare the effects of different meteorological parameters and understand their relevance to climate-responsive building design. The analytical framework brings together the reviewed studies by looking at how different meteorological factors affect building performance.

3. Results and Discussion

Meteorological Data and Representation

Reliable meteorological data are significant for accurate building-performance modelling because local meteorological variations impact thermal comfort, heating and cooling needs, and overall building performance. Different methods, including interpolation, statistical downscaling, and weather-data generation, are used to develop weather data for building-scale applications and to represent present, future, and extreme climate conditions [9]. Statistical downscaling is particularly useful for converting coarse climate projections into higher-resolution data suitable for building-performance studies. Qi et al. [10] highlighted the value of downscaling, multi-year climate projections, and urban microclimate analysis for improving building-performance simulations under a changing climate. It also showed that considering different spatial and temporal scales is important for more reliable climate-resilient building design and assessment.

Dynamical downscaling uses regional climate models to convert coarse global climate data into higher-resolution regional and local information. In building-performance studies, it is used to generate future weather data from climate projections and assess how buildings may perform under changing climate conditions. Recent studies have explored how different future weather-data methods, including dynamical downscaling, affect energy use, peak loads, overheating, and thermal resilience. These approaches can provide useful climate information for climate-responsive and heat-resilient building design [11].

Spatial downscaling converts coarse climate-model data into more detailed weather information for building-performance assessment. Future weather datasets consider emissions scenarios, climate models, and downscaling methods. Dynamical downscaling can provide finer-resolution data and better represent local and regional climate conditions [12].

Future weather data are important for building energy simulation (BES) and for understanding building performance under changing climate conditions. General circulation models (GCMs) provide future climate projections, but their resolution may not be suitable for building-scale studies. Temporal downscaling helps convert these projections into weather data at a resolution suitable for building-performance simulations. Statistical downscaling methods can also generate higher-resolution future weather data from climate-model projections. Overall, the reviewed studies highlight the role of temporal downscaling in preparing future weather data and assessing building performance under different climate conditions [13]. Different building

applications may require different types of weather data. Table 2 summarizes the weather data and key meteorological variables commonly used for different building-performance applications.

Dynamical downscaling provides detailed regional climate information for building-performance assessment, but it can require considerable computational resources and depends on the resolution and setup of regional climate models. It also carries uncertainties from the global climate models used as inputs and may not fully capture local weather variations. Its performance can also differ across regions and weather variables. Therefore, validating the data and considering local climatic conditions are important when using dynamical downscaling for building-performance simulations.

Table 2. Weather-data requirements for different building performance applications.

Building application	Purpose	Suitable Weather data	Key variables
Annual energy assessment	Estimate annual energy demand	TMY/representative hourly data	Humidity, temperature, solar radiation,
Peak-load assessment	Estimate cooling/heating peaks	extreme data or Design-day	Solar radiation, temperature
Natural ventilation	Assess passive cooling potential	High-resolution/local weather data	Temperature, direction, wind speed,
Future climate assessment	Evaluate climate change impacts	Downscaled future weather data	Solar radiation, wind, humidity, temperature
Heatwave assessment	Evaluate resilience and overheating	Future heatwave weather files	Solar radiation, temperature, humidity

Extreme Weather Events and Representation

Extreme events can be identified using approaches such as threshold methods, anomaly detection, and statistical techniques like Extreme Value Theory (EVT). These methods help identify unusual climatic conditions and describe extreme weather events more effectively, supporting the development of weather datasets that better reflect conditions experienced by buildings [14]. Overall, the reviewed study shows that these approaches can improve the identification and characterization of extreme weather for building-performance assessment [5].

Extreme weather can be included in building weather datasets by considering both extreme weather years and individual events such as heatwaves. Extreme years represent periods with more severe conditions than typical years, while individual events can be described by their intensity and duration. Hence, considering extreme meteorological conditions in building datasets is important [15].

Representative Meteorological Year (RMV) and TMY datasets are mostly utilized to calculate building performance. TMY represents typical weather conditions, while RMV is intended to capture more extreme or unusual conditions. Studies propose that RMV can reflect better severe weather impacts on thermal stress, peak loads, natural ventilation, and outdoor comfort, however average energy use may not vary much [14]. Hence, TMY is recommended for typical conditions, whereas RMV is more recommended for analyzing building performance during dangerous weather conditions.

Common indicators include indoor overheating, thermal comfort, energy demand, and peak loads, along with suitable temperature thresholds. These indicators can be assessed under current and future climate scenarios to identify changes in building performance and comfort. Studies have conveyed increased overheating

ing under upcoming heatwave conditions, emphasizing the requirement for appropriate performance measuring metrics and thresholds to assess building response to both present and future extreme weather [16, 17].

4. Conclusion

This review examined how meteorological conditions and the way weather data are represented can affect building energy performance, thermal comfort, and climate-responsive design.

Meteorological conditions affect building performance. Changes in temperature, relative humidity, solar radiation, wind, and precipitation can influence energy use, thermal performance, and thermal comfort. These factors should therefore be considered when evaluating buildings and developing climate-responsive designs.

1. Reliable weather data are important for building assessment. Methods such as interpolation, statistical and dynamical downscaling, and weather-data generation can provide information at suitable spatial and temporal scales. Future weather datasets can help assess building performance under changing climate conditions, although uncertainties related to climate models, downscaling methods, and local climate variability need to be considered.
2. Extreme weather should also be considered. Threshold methods, anomaly detection, EVT, and data-driven approaches can help identify and describe extreme events. Including extreme years and events such as heatwaves can provide a better understanding of how buildings may respond to severe and future weather conditions.
3. TMY and RMY datasets have distinctive uses. TMY represents typical weather conditions, whereas RMY is more useful for unusual or extreme conditions. RMY can be particularly helpful for examining peak loads, thermal stress, natural ventilation, and outdoor comfort during severe weather.
4. Appropriate performance indicators improve building assessment. Indicators such as overheating, thermal comfort, energy demand, and peak loads, together with appropriate temperature thresholds, can help evaluate building performance under current and future climate conditions. Representative heat-wave weather files can also capture a range of future conditions while reducing the number of files needed for analysis.

In particular, the review shows that reliable building-performance assessment requires suitable weather data, consideration of both typical and extreme conditions, and appropriate performance indicators. Combining representative weather data with relevant performance metrics can provide a better understanding of building energy performance, thermal comfort, and climate-responsive design under changing climatic conditions. The assessment should be done for various locations.