

## MANUAL VS. AUTOMATED WINDOW BLINDS: ANALYSIS OF ENERGY USE BASED ON CLIMATE SCENARIOS

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**ABSTRACT:** Windows in buildings impact energy usage for temperature control through solar heat gain and enable natural light to reduce reliance on artificial lighting. Balancing solar heat gain and daylight utilization is a challenge, which can be addressed by employing automated or manual blind systems to manage daylight and enhance user comfort and energy efficiency. Additionally, accurate weather forecasts are essential for predicting energy-efficient strategies through individual building energy simulations, as weather conditions synergistically interact with occupant behavior to influence energy consumption patterns. This research aims to assess the energy consumption associated with manual and automated internal window blinds in medium-sized office buildings situated within two distinct and significant climate zones in the United States, considering both present and future climate change scenarios based on the IPCC report (RCP 4.5 - 8.5). Employing a simulation-based methodology, the study unveiled varying effectiveness levels of diverse window blind configurations contingent on the specific climate zones (e.g., 4A Mixed-Humid, 2B Hot-Dry). In different climate zones, on-site energy consumption alterations for heating and cooling become evident as temperatures escalate in the forthcoming years. Using simulation as the method and comparing RCP 4.5 and 8.5 scenarios reveals that automated blinds—a more efficient choice than manual blinds—significantly reduces cooling energy consumption, particularly under RCP 8.5 in a 4A Mixed-Humid zone. Rising temperatures in Climate Zone 2B Hot-Dry are a factor in increased energy requirements for cooling and decreased energy requirements for heating due to climate change. This study provides enlightening insights into the potential benefits of diverse window-covering strategies concerning energy conservation within varied climatic contexts for the future.

**KEYWORDS:** window blinds, manual and automated Blinds, building energy use, climate scenarios.

## INTRODUCTION

Approximately one-quarter to three-quarters of global energy consumption is attributed to the building and construction sector (Abergel, Dean, and Dulac 2017). This sector's substantial energy demand stems from various activities, with heating, cooling, ventilation, and air conditioning (HVAC) systems constituting a significant portion of this consumption (Zhan and Chong 2021). Therefore, managing energy efficiency in building systems is crucial for reducing overall energy consumption and associated costs, presenting a critical area for sustainability efforts. HVAC systems are essential for maintaining comfortable indoor environments, yet they are major energy consumers. As the global climate continues to change, the demand for these systems is expected to increase, further emphasizing the need for efficient energy management practices.

Windows serve a dual purpose: they allow natural light and solar radiation to enter a building, which can positively and negatively affect the building and its occupants. The advantage of natural lighting is that it reduces the electricity required for artificial lighting, thereby decreasing the energy usage of lighting systems (Lomanowski and Wright 2009). However, windows are also a primary source of heat accumulation due to their significant contribution to solar heat gain.

Previous research on both automated and manual blind systems in workplace environments has underscored the importance of effective daylight management for user comfort and energy conservation (Meerbeek et al. 2016). Users have the capability to influence their building surroundings, and interactions with internal blinds can significantly impact the utilization of daylight (Bavaresco and Ghisi 2018). Nevertheless, a prevailing challenge lies in the predominant use of manually operated shade systems, which require occupants themselves to make adjustments. Studies indicate that, in such cases, shading devices are often not positioned optimally to balance natural light exposure while mitigating solar heat gains (Kim and Park 2012). Moreover, a case study by Nezamdoost, Van Den Wymelenberg, and Mahic (2018) has shown that automated controls do not demonstrate more significant enhancements in daylight or annual energy savings when compared to manual controls. However, some unique research results have shown that in most situations people manually raise the blinds within 15 minutes of when they were automatically lowered, suggesting a low acceptance of automatic blind adjustments (Meerbeek et al. 2016). Thus, there remains a contentious debate regarding the disparities between manual and automated blind systems in terms of annual energy consumption and their consequential effects.

Along with the building dynamics, weather plays a crucial role, and the heat and CO<sub>2</sub> emissions from building appliances and occupants, along with their temperature, lighting, and air quality preferences, add further complexity. The impact of climate change on the energy consumption of residential and commercial buildings has been investigated through various approaches. These approaches fall into three broad categories: global/regional energy modeling, observation-based regression/prediction, and individual building energy simulation (Huang and Gurney 2016). Hence, the principal goal of the research is to integrate weather forecasts into individual building energy simulations, specifically within a mid-sized office building situated in two distinct and significant climate zones in the United States (4A Mixed-Humid, 2B Hot-Dry). The study will comprehensively assess and compare the efficiency of manual and automated blinds, considering present conditions and future climate change scenarios based on the IPCC report (RCP 4.5 - 8.5) (IPCC 2014). The overarching objective is to pinpoint future strategies that are energy-efficient, with careful consideration given to the patterns of occupant interaction.

## 1. BACKGROUND

The way that environmental and design approaches are implemented is critical to improving occupant comfort and well-being (Sheykhmaleki et al. 2021). It is often known

that a building's indoor environmental quality has a substantial impact on people's comfort, well-being, productivity, and health (Sheykhmaleki, Yazdanfar, and Litkouhi 2023). Windows let natural light and solar radiation into a building, which impacts the structure and its occupants in both positive and negative ways. Natural light lowers the requirement for electric lighting, which lowers the energy used for illumination. Windows, however, can also lead to greater heat collection, which raises the need for air conditioning during warmer months (Lomanowski and Wright 2009). An effective daylighting design must incorporate several technologies, involve multiple disciplines, and pay close attention to detail throughout the entire design and implementation process in order to save energy and improve human pleasure (Nezamdoost, Van Den Wymelenberg, and Mahic 2018). Window coverings (also called blinds) have multiple uses and can be mounted inside, outside, or within a building's walls. Furthermore, how the blinds are positioned and operated affects how much energy the building uses.

### **1.1. PATTERN OF WINDOW BLINDS AND ENERGY CONSUMPTION OF BUILDING**

According to the findings of Laouadi (2011), altering the angle and position of blinds can lead to variations in solar heat gain for high-performance windows when compared to windows without shading, which influences the energy use of the building. The quantity and distribution of daylight entering a building, concurrently with the positioning and functioning of window blinds, all affect the various types of heat transfer through windows (Nezamdoost, Van Den Wymelenberg, and Mahic 2018). However, it's crucial to remember that when window blinds are closed, the actual energy savings are reduced. Adopting natural sunlight, or daylight-sensing lighting control, has the potential to save a significant amount of electricity. It is possible to lower peak cooling demand and overall energy usage by putting blinds outside of the thermal envelope. By reducing the waste heat that lights produce, efficient daylight-sensing control systems can help reduce the need for cooling (Van Den Wymelenberg 2012; Bavaresco and Ghisi 2018). Blind control is determined by two main systems: sensor-controlled automatic blinds and human-user interaction (i.e., manual). Van Den Wymelenberg provides guidance and data on blind use patterns in his thorough literature research, which draws conclusions from more than 50 buildings globally. The Always Open, Always Close, and Frequency of Opening patterns have the potential to impact a building's energy usage significantly. Consequently, in order to reduce errors, it is essential to properly include these patterns of usage in energy and daylighting models (Van Den Wymelenberg 2012).

Furthermore, when building automation is implemented in an office setting, residents may experience a loss of control, especially when automated systems decide what happens to the facility's environment. Based on the study of Meerbeek et al. (2016), two tests were carried out with the purpose of investigating user satisfaction and real-world use of an automated blinds system with an expressive interface. To improve users' sense of control and promote more acceptance of the automated system, this system was incorporated into a virtual window. Remarkably, the results of the study show that people seem to be interested in changing automated technologies in the built environment with their personality preferences. An automated system's perceived personality is shaped by its level of automation as well as by the way it interacts with the user. Users' impression of the system's personality and their sense of control over their interactions with it are greatly influenced by this communication style (Meerbeek et al. 2016).

### **1.2. CLIMATE SCENARIOS**

According to the findings of the Intergovernmental Panel on Climate Change (IPCC), global greenhouse gas emissions witnessed a 70% increase between 1970 and 2004, and this upward trend is expected to persist over time (Zhai and Helman 2019). The building industry contributes significantly to global warming, and climate change has a significant impact on how buildings function. Thus, it is essential to accurately estimate how buildings will react to their ever-changing surroundings (Guan, Yang, and Bell 2005).

The Fifth Assessment Report (AR5), the most recent report from the IPCC, was published in 2014. It included four emissions scenarios called Representative Concentration Pathways (RCP). Some of these pathways include RCP 2.5, RCP 4.5, RCP 6.0, and RCP 8.5 (IPCC 2014; Aijazi and Brager 2018). They include two intermediate scenarios (RCP 4.5 and RCP 6.0), a scenario with high greenhouse gas (GHG) emissions (RCP 8.5), and a rigorous mitigation scenario (RCP 2.6) (IPCC 2014). An RCP defines a range of baseline and projected emissions for each emissions category through the year 2100. These estimates have been developed based on assumptions about economic activity, energy sources, population increase, and other socioeconomic aspects (Zhai and Helman 2019). Apart from accessing the future weather file and applying the climate scenarios, these pathways also include various generators for producing hourly weather data in future scenarios. Notable examples include the Climate Change World Weather Generator (CCWorldWeatherGen), the Urban Weather Generator (UWG), the Advanced Weather Generator (AWE-GEN), Meteonorm, and WeatherShift (Yassaghi and Hoque 2019). The Meteonorm software, which is utilized in this study to generate weather files, combines powerful computational methods with dependable data sources. Anywhere on Earth can provide consistent and accurate typical weather patterns according to historical time series (Meteotest 2023).

## 2. METHODOLOGY

The present investigation employs an experimental approach, utilizing whole-building performance simulation. According to Groat and Wang (2013), environmental technology studies often adopt a sequenced phasing strategy, integrating simulation and experimentation. Simulation enables one to explore potential real-world scenarios while circumventing ethical dilemmas, physical hazards, and financial burdens. Consequently, this research entails the comprehensive simulation of the entire building energy usage for a prototype of midsize office buildings (with the dimensions of 163.8 ft x 109.2 ft, or 53,600 sq. ft), employing the IESVE software. IESVE software covers all relevant factors, including energy use, thermal comfort, and lighting, ensuring accurate results. Validated against industry standards like ASHRAE 140, IESVE supports compliance with certifications such as LEED and BREEAM. Its user-friendly interface, advanced analysis features, and BIM compatibility enable precise modeling and in-depth performance optimization, making it a highly reliable tool for building energy simulation (IESVE 2022). As outlined by the US Department of Energy's Building Energy Codes Program, the mid-sized office building prototype is meticulously modeled within the IESVE software. This modeling includes the incorporation of all lighting, HVAC, internal load, and occupant schedules into the simulated mass, as illustrated in Figure 1 (DOE 2020). Figure 2 provides all the specifics on the building's dimensions, layout, orientation, and materials for its floors, walls, roof, and windows (DOE 2020).

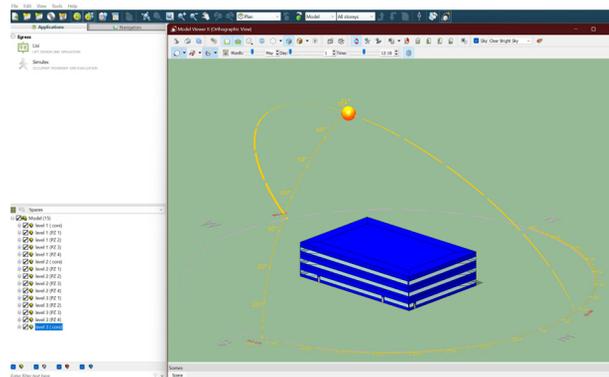


Figure 1: Modeled mid-sized office building prototype based on the US Department of Energy on IESVE software. Source: Author 2024.

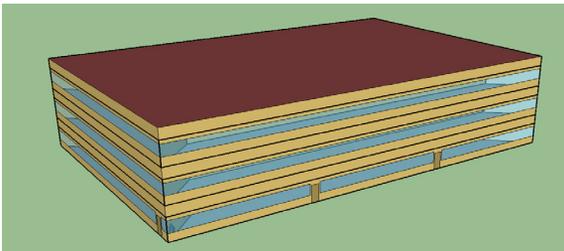
Total Floor Area (sq feet)	53,600 (163.8 ft x 109.2 ft)		Roof	
Building shape			Construction	Built-up roof: Roof membrane + roof insulation + metal decking
Aspect ratio	1.5		U-factor (Btu / h * ft <sup>2</sup> * °F)	Requirements in codes or standards
Number of floors	3		Dimensions	Based on floor area and aspect ratio
Window fraction (window-to-wall ratio)	33% (Window dimensions: 163.8 ft x 4.29 ft on the long side of the façade 109.2 ft x 4.29 ft on the short side of the façade)		Tilts and orientations	Horizontal
Window locations	Evenly distributed along four façades		Window	
Shading geometry	None		Dimensions	Based on window fraction
Azimuth	Non-directional		Glass-type	Hypothetical window
Thermal zoning	Perimeter zone depth: 15 ft.  Each floor has four perimeter zones and one core zone  Percentages of floor area: perimeter 40%, core 60%		U-factor (Btu / h * ft <sup>2</sup> * °F)	Requirements in codes or standards  Nonresidential; vertical glazing
Floor-to-floor height (feet)	13		SHGC (all)	
Floor-to-ceiling height (feet)	9 (4 ft above-ceiling plenum)		Visible transmittance	Same as the above requirements
Glazing sill height (feet)	3.35 ft (The top of the window is 7.64 ft high with 4.29 ft high glass)		Operable area	0%
<b>Exterior walls</b>				
Construction	Steel-frame walls (2X4 16IN OC) 0.4 in. Stucco+5/8 in. gypsum board + wall Insulation+5/8 in.			
U-factor (Btu / h * ft <sup>2</sup> * °F) and/or R-value (h * ft <sup>2</sup> * °F / Btu)	Requirements in codes or standards  Nonresidential; walls, above-Grade, steel-framed			
Dimensions	Based on floor area and aspect ratio			
Tilts and orientations	Vertical			

Figure 2: Prototype building modeling specifications, medium office. Source DOE 2020.

Drawing from the literature review findings, the primary manual configurations for window blinds comprise three options: Always Down, Always Up, and Up from 8:00 a.m. to Down after 12:00 p.m. Additionally, one automated window blind pattern was assessed, involving opening when solar radiation is below 50 W/m<sup>2</sup> and closing when it surpasses 50 W/m<sup>2</sup>. The simulation will be conducted in representative locations for four distinct climate zones: 2B Hot-Dry (Phoenix, Arizona) and 4A Mixed-Humid (New York, New York). Climate files reflecting current conditions and projections for the years 2050 and 2080 were generated using the Meteororm database. These configurations underwent testing within the IESVE model. Forty-eight simulations were conducted to collect data concerning current climate conditions and two climate change scenarios (RCP 4.5 and RCP 8.5) for the years 2050 and 2080.

### 3. RESULTS

Tables 1 and 2 represent the simulation results for individual regions using the existing weather file and two distinct climate scenarios projected for 2050 and 2080. For each anticipated scenario, a novel Energy Use Intensity (EUI) and site energy assessment (including cooling and heating) have been calculated. The energy needed for heating and cooling in future scenarios is greatly influenced by the scenario selected for the Representative Concentration Pathway (RCP). An in-depth analysis of several window blind patterns highlights the effectiveness of the automated system and the third manual pattern (raising at 8 a.m. and lowering at 12 p.m.) for the best energy savings.

Climate condition (Phoenix, AZ; 2B Hot-Dry)	Window Blinds Patterns	Site Energy		Site Energy Use Intensity (kBtu/Ft <sup>2</sup> )
		Space cooling	Heating fossil fuel	
Current weather	Always Up	17.1	7.7	47
	Always Down	15.9	8.7	47
	Up 8 a.m. and Down 12 p.m.	16.4	8.5	47
	Automated	16.3	8.6	47
Scenario 4.5 (2050 year)	Always Up	20.3	6.1	49
	Always Down	19.1	6.9	49
	Up 8 a.m. and Down 12 p.m.	19.6	6.7	49
	Automated	19.4	6.7	49
Scenario 4.5 (2080 year)	Always Up	20.5	6	49
	Always Down	19.3	6.7	48
	Up 8 a.m. and Down 12 p.m.	19.8	6.5	49
	Automated	19.6	6.6	49
Scenario 8.5 (2050 year)	Always Up	20.3	6.1	49
	Always Down	19.1	6.8	48
	Up 8 a.m. and Down 12 p.m.	19.6	6.7	49
	Automated	19.4	6.7	49
Scenario 8.5 (2080 year)	Always Up	23	4.4	51
	Always Down	21.7	4.9	50
	Up 8 a.m. and Down 12 p.m.	22.3	4.8	50
	Automated	22.1	4.8	50

Table 1: Result of simulation Window Blinds Patterns for 2B Hot-Dry (Phoenix, Arizona).

Climate condition (New York, NY; 4A Mixed-Humid)	Window Blinds Patterns	Site Energy		Site Energy Use Intensity (kBtu/Ft <sup>2</sup> )
		Space cooling	Heating fossil fuel	
Current weather	Always Up	6.7	28.2	55
	Always Down	6	30	56
	Up 8 a.m. and Down 12 p.m.	6.3	29.4	56
	Automated	5.9	29.9	56
Scenario 4.5 (2050 year)	Always Up	8.4	23.3	52
	Always Down	7.6	24.8	53
	Up 8 a.m. and Down 12 p.m.	8	24.3	53
	Automated	7.6	24.8	53
Scenario 4.5 (2080 year)	Always Up	9.4	21.8	52
	Always Down	8.6	23.3	53
	Up 8 a.m. and Down 12 p.m.	9	22.8	53
	Automated	8.6	23.3	53
Scenario 8.5 (2050 year)	Always Up	9	23	53
	Always Down	8.2	24.6	54
	Up 8 a.m. and Down 12 p.m.	8.6	24.1	53
	Automated	8.2	24.6	54
Scenario 8.5 (2080 year)	Always Up	11.4	18	50
	Always Down	10.5	19.4	51
	Up 8 a.m. and Down 12 p.m.	10.9	18.9	51
	Automated	10.5	19.4	51

Table 2: Result of simulation Window Blinds Patterns for 4A Mixed-Humid (New York, New York).

### 3.1. CLIMATE ZONE 2B HOT-DRY (PHOENIX, ARIZONA) DATA ANALYSIS

As per Table 1, the most effective among the three manual window blind patterns involves raising the blind from 8:00 a.m. and lowering it after 12:00 p.m. Figure 3 visually depicts the energy use intensity for space cooling, heating fossil fuel, and site energy in kBtu per square foot (kBtu/Ft<sup>2</sup>) across various scenarios and years. Analyzing this data for the specific climate zone indicates that, as temperatures are projected to increase in the future, the site energy for heating through fossil fuels is expected to decrease. In contrast, space cooling requirements will likely increase. Furthermore, the data indicates no significant outcome difference between the Automated Window Blind Pattern and the Selected Manual Pattern for this climate zone (Figure 3).

### 3.2. CLIMATE ZONE 4A MIXED-HUMID (NEW YORK, NEW YORK) DATA ANALYSIS

Despite the anticipated temperature increase in the future, as Figure 4 represents, the simulated building within the 4A Mixed-Humid climate zone is expected to undergo an increase in site energy consumption for heating through fossil fuels. In contrast, a decrease is projected in the energy demand for space cooling. Collectively, these factors lead to a reduction in the building's overall Energy Use Intensity (EUI) within this specific climate zone.

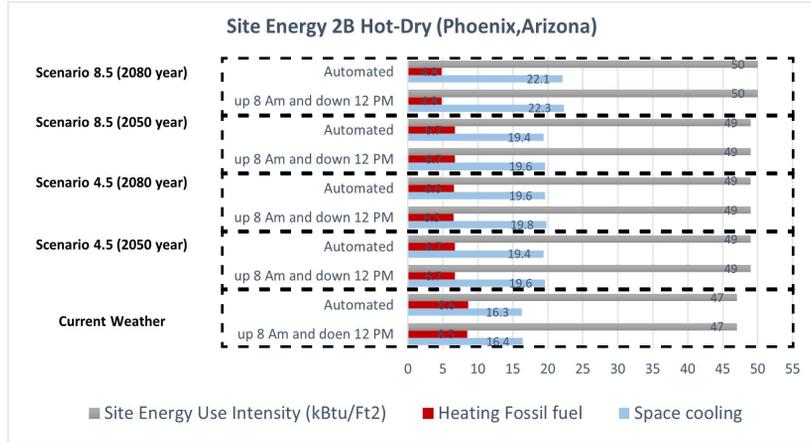


Figure 3: Site Energy for 2B Hot-Dry (Phoenix, Arizona). Source: Author 2024.

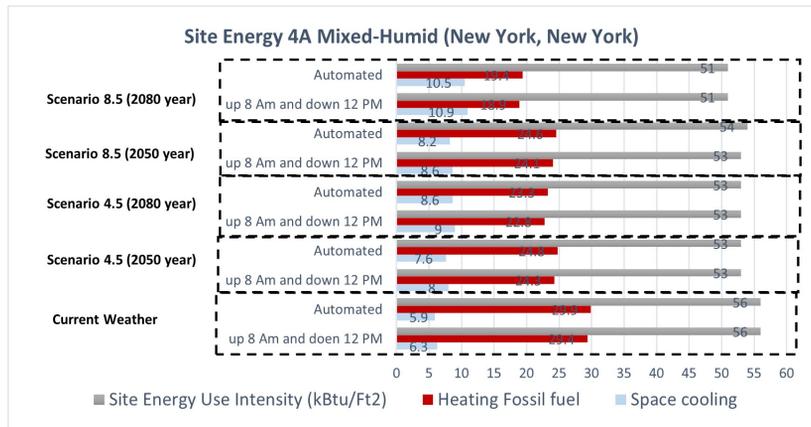


Figure 4: Site Energy for 4A Mixed-Humid (New York, New York). Source: Author 2024.

**4. DISCUSSION**

According to the simulation results, the change through the RCP 8.5 pathway is dramatically higher than the RCP 4.5 pathway. As average temperatures rise, more cooling energy will be consumed in the two US climate areas that have been chosen. Moreover, a 78% increase is anticipated in the 4A Mixed-Humid zone, which is predicted to show the greatest disparity between these two climate types (Figure 5).

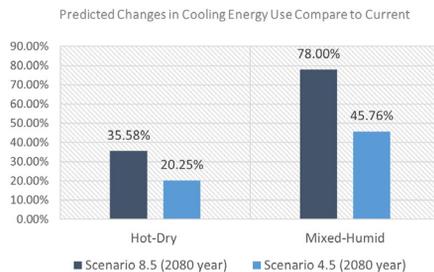


Figure 5: Summary of predicted changes in cooling energy consumption for two climate zones. Source: Author 2024.

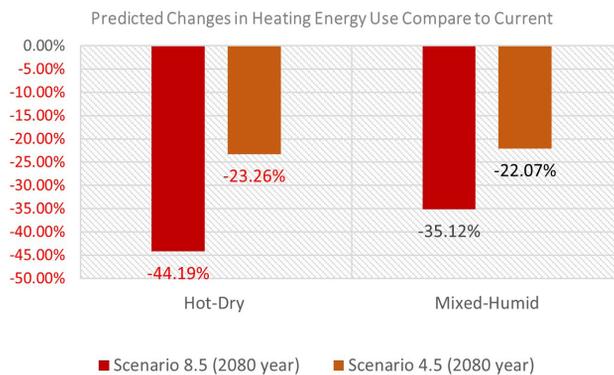


Figure 6: Summary of predicted changes in heating energy consumption for two climate zones. Source: Author 2024.

Nevertheless, as illustrated in Figure 6, a rise in temperature under both climate scenarios will decrease energy consumption for heating across all locations. The 2B Hot-Dry zone is anticipated to experience the most significant decline in heating energy usage at 44%. In contrast, the 4A Mixed-Humid zone is expected to register the highest cooling energy consumption under RCP 8.5.

## CONCLUSION

The study emphasizes how window blind arrangements are important for reducing energy use in various temperature zones. It has been shown that window blind patterns significantly impact the energy needed for space cooling and heating through simulations performed in the IESVE software for mid-sized offices located in two different climate zones under the Representative Concentration Pathway (RCP) scenarios. It is important to note that, out of all the window blind patterns evaluated, the manual way—which involves raising the blinds starting at 8:00 a.m. and lowering them after 12:00 p.m.—showed positive outcomes regarding cutting energy usage. Nonetheless, it is crucial to recognize that, as recent research shows, residents often ignore the manual window blind position adjustment. Therefore, one may claim that automated blinds may be more efficient given the almost identical results as the manual pattern and automated window blinds.

Climate change is expected to lower the demand for heating energy in climate zone 2B Hot-Dry (Phoenix, Arizona) under the 4.5 and 8.5 Representative Concentration Pathway (RCP) scenarios. Meanwhile, the rising temperatures will increase the energy needed for space conditioning. The building in climate zone 4A Mixed-Humid (New York, New York) is predicted to use more energy for space cooling and less energy for heating despite the rise in temperature, with percentages of 78% and 0.35% for RCP 8.5, respectively. Moreover, examining the differences between RCP 4.5 and 8.5 indicates that the RCP 8.5 climate change scenario is anticipated to have the most effects.

The findings demonstrate significant variability in energy consumption across different climate zones, such as the Mixed-Humid and Hot-Dry regions. While the study provides valuable insights for the specific US climate zones examined, its results may not directly translate to other geographical areas with different climate conditions. Moreover, the results note that manual window blind adjustments are often ignored by residents, which suggests that future increases in automation could impact the actual energy savings achieved. Thus, while the study provides a snapshot of current trends, its relevance will depend on ongoing technological, behavioral, and climatic changes.

## LIMITATION

In the context of this study, it is essential to recognize the importance of other aspects, including thermal and visual comfort. This study has considered several control variables, including artificial lighting, thermal profile, blind location, building construction, and controlled air conditioning. The inclusion of these variables may significantly impact the study's results. Also, future research will include the other US climate zones and these variables.

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