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INVESTING IN WELL-BEING IN A CHALLENGING FUTURE

Quantifying the influence of the adaptive comfort model slope in cooling energy consumption in present and future scenarios

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Abstract

Understanding how people adapt to indoor temperature conditions is crucial to designing places that both improve occupant well-being and achieve energy efficiency goals. The premise behind adaptive setpoint temperatures is that people would adjust to mechanically conditioned spaces by acting as though they were naturally ventilated. Thus far, the potential energy savings of adaptive setpoints have been compared with PMV-based setpoints or building operating strategies based on regional and global comfort models. But there is an absence of a more comprehensive viewpoint that goes beyond certain models and environments. In order to comprehend the adaptive comfort model's influence on energy usage, this research looks at its slope. The Department of Energy (DOE) small office building prototype is fitted with adaptive setpoint temperatures using the Adaptive-Comfort-Control-Implemented Model (ACCIM) tool, while the parametric analysis is carried out using the Building and Energy Systems Optimization and Surrogate-modelling (BESOS) tool. In light of the fact that climate change is anticipated to cause people to adapt to rising temperatures, the Shared Socioeconomic Pathways (SSP) scenario SSP5-8.5 for 2080 is taken into consideration. The results show that increasing the slope of the adaptive comfort model significantly reduces cooling energy consumption, with higher gradients achieving greater savings. Notably, the optimal gradient range of 0.15 to 0.3 achieves substantial energy savings of 18% to 25% for each interval. Moreover, higher gradients, such as 0.8, can achieve energy savings up to 79% in the present scenario and 86% in the future scenario. These findings highlight the potential of adaptive comfort models to enhance energy efficiency in buildings, suggesting it is key to steering the industry towards more energy-efficient standards and achieving climate goals through both mitigation and adaptation measures.

Keywords

Adaptive setpoint temperatures, adaptive comfort, slope, energy-saving, climate change

Introduction

Understanding and forecasting how people will react to changing temperatures is becoming more and more important as a result of climate change, especially in the areas of building design and energy management. Conventional thermal comfort models, such as the Adaptive Comfort

Model and the Predicted Mean Vote (PMV) (Fanger, 1967), have given important insights into how people perceive and adapt to indoor climates. However, because they frequently rely on historical data, they might not fully take into account the dynamic nature of future climate scenarios (Jentsch et al., 2008).
Buildings will have a greater difficulty keeping occupants comfortable in more severe and changeable situations than they have in the past due to climate change. In order to ensure both occupant well-being and energy efficiency, while addressing the growing danger of energy poverty, it is necessary to develop adaptive thermal comfort models that can react flexibly to these changing conditions (Kwok & Rajkovich, 2010), achieving besides an acceptable indoor environmental quality (Cordero et al., 2024). Incorporating long-term adaptation mechanisms that occupants may develop in response to sustained temperature fluctuations is crucial for these models, in addition to acute thermal reactions (Pino-Mejías et al., 2018).
According to adaptive thermal comfort, people' perceptions of comfort in buildings are impacted by their prior experiences with various temperature conditions as well as contextual circumstances. Accordingly, interior comfort levels vary according to previous temperature exposures, going up during warm or hot seasons and down during cool or cold ones. In contrast to what the conventional Fanger heat-balance model (PMV/PPD) predicts, occupants may be comfortable in a greater range of interior temperatures due to physiological, behavioural, and psychological adaption mechanisms (de Dear & Brager, 1998).

Adaptive comfort models were first introduced by de Dear and Brager in 1998 (de Dear & Brager, 1998). These models concentrated on naturally ventilated areas and how they might adjust to outside temperatures. This restricted their use to settings without mechanical air conditioning or heating systems, as first outlined in 2004 by ASHRAE Standard 55 (ASHRAE Standard 55-2004 Thermal Environmental Conditions for Human Occupancy, 2004). Adaptive comfort models were further investigated in later research, mostly conducted in domestic settings without air conditioning (Nguyen et al., 2012; Rijal et al., 2019). But in 2020, Parkinson et al. (Parkinson et al., 2020) looked again at similar models with the ASHRAE Global Thermal Comfort Database II (Földváry Ličina et al., 2018), and they found an adaptive model that worked for all kinds of buildings when mean internal temperature took the place of external temperature as the independent variable. Based on observations of occupants' adaptability to interior thermal environments—whether naturally ventilated or air-conditioned—adaptive setpoint temperatures have been improved in recent research (Parkinson et al., 2020; Yun et al., 2016). This facilitates the establishment of adaptive setpoints and the wider use of adaptive thermal comfort concepts in air-conditioned rooms.

Adaptive setpoint temperatures have been shown in several studies to have the ability to save energy:

- (i) An investigation of HVAC management techniques by Wang et al. (Wang et al., 2020) revealed adaptive setpoints that can save expenses by 14% to 54%.
- (ii) By using adaptive setpoints in a variety of climates, Sánchez-García et al. (Sánchez-García et al., 2019) were able to reduce energy use in office buildings by 52% to 63%.
- (iii) Holmes and Hacker (Holmes & Hacker, 2007) predicted large energy savings by implementing adaptive comfort concepts in UK government buildings.
- (iv) In various situations, Kramer et al. (Kramer et al., 2015) and Dhaka et al. (Dhaka et al., 2012) also observed significant energy reductions using adaptive setpoints.
- (v) Research conducted in Brazil (Sánchez-García, Bienvenido-Huertas, Rubio-Bellido, et al., 2024), Australia (Sánchez-García, Bienvenido-Huertas, Martínez-Crespo, et al., 2024), and Japan (Sánchez-García, Bienvenido-Huertas, et al., 2023) revealed

considerable energy savings utilizing adaptive setpoints in a range of building conditions, from 29% to 78%.

Adaptive setpoint temperatures may be incorporated into building energy simulations more easily with the help of software tools such as the Python software "accim" (Adaptive-Comfort-Control-Implemented Model) (Sánchez-García, 2021). The most recent and advanced technique for putting adaptive setpoints into practice and improving their usefulness in building energy management methods is the Adaptive-Comfort-Control-Implementation Script (ACCIS) computational methodology (Sánchez-García et al., 2021; Sánchez-García, Martínez-Crespo, et al., 2023).

Adaptive setpoint temperatures, which are often assessed by contrasting their energy performance with fixed setpoints derived from global or local thermal comfort models, have become significant energy-saving techniques. Nevertheless, current research frequently focuses exclusively on certain models, standards, and climates, which restricts a more comprehensive knowledge of their capabilities in a range of scenarios. This work does a parametric analysis that investigates various slopes or gradients inside adaptive thermal comfort models in order to fill this research gap. To be more precise, the baseline is the ASHRAE 55 adaptive model, and the slope is progressively changed from 0.1 to 0.8 in steps of 0.05. The aim is to evaluate the influence of these modifications on cooling demand and compare the outcomes with the reference scenario.

Methodology

Case study

The simulation for this study utilized EnergyPlus 23.1 as the engine, with the building energy model based on the Small Office Prototype 2018 IECC DOE Commercial Reference Building (U.S. Department of Energy, n.d.). This model includes six distinct thermal zones. Among these, there is a central thermal zone known as CORE_ZN, surrounded by four air-conditioned thermal zones labelled as PERIMETER_ZN_1 to PERIMETER_ZN_4 (Figure 1 (a)). These zones are located on the ground floor of the building. Additionally, there is an unconditioned attic area, as illustrated in Figure 1 (b). Thermal properties are shown in Table 1.

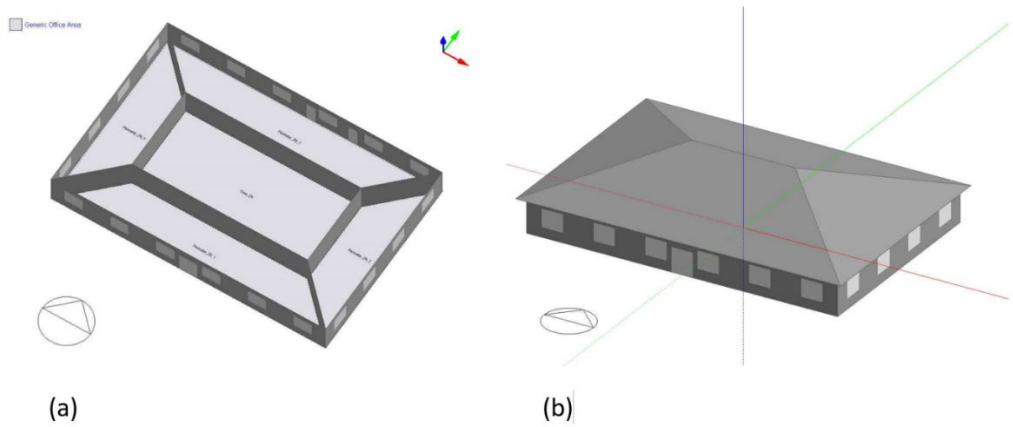


Figure 1. Small Office Prototype from the 2018 IECC DOE Commercial Reference Building. Panel (a) provides a detailed view of the thermal zones, while panel (b) presents an overall perspective of the building

Table 1. Small Office Prototype Envelope thermal properties

Envelope	U-value (W/m²·K)	SHGC
External wall	0.363368	-
Semi-exposed ceiling	0.249419	-
Ground floor	0.253742	-
Windows	2.8391	0.25

Present and future climates

The research location is Seville, which is in the Csa climatic zone (southern Spain) with pleasant winters and dry, hot summers (Rubel & Kottek, 2010). According to Figure 2, the current average monthly temperatures vary from around 10°C in January to roughly 27°C in July. In January, the lowest average monthly temperature is around 5°C, while in July, it rises to nearly 20°C. The highest average temperatures occur in January, when it is around 16°C, and in the summer, when it is approximately 36°C. The implications of climate change were explored in future scenarios, with a particular emphasis on rising temperatures, especially in areas with high temperatures. The study specifically used the SSP5-8.5 scenario for 2080, which stands for one of the Shared Socioeconomic Pathways (SSP) that the Intergovernmental Panel on Climate Change (IPCC) has identified (Jiang & O'Neill, 2017; KC & Lutz, 2017). These scenarios present narratives about anticipated changes in the twenty-first century, including socioeconomic variables, the effects of climate change, vulnerabilities, and the efficacy of sustainable policies (Jones & O'Neill, 2016).

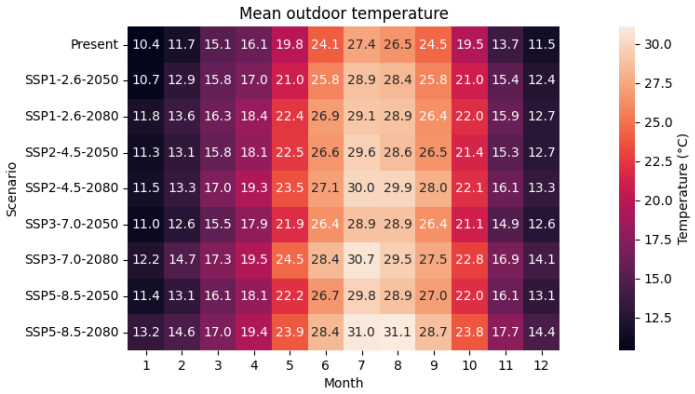


Figure 2. Mean, maximum and minimum average outdoor temperatures in Seville

Results

The adaptive comfort model's gradient, or slope, spans a wide range of values in the dataset produced by the parametric simulation, with some values as high as 0.8. Acknowledging that very high values may be viewed as unrealistic, the purpose of this research is to examine the energy implications of exceptional adaptability capabilities. As a result, the analysis concentrates on the study's greatest adaption values. It was decided to look at these extreme values because there is currently insufficient knowledge about the boundaries of human thermal adaptation, especially as these boundaries change in response to rising temperatures brought on by climate change. Therefore, it would be arbitrary to set strict boundaries in the absence of strong empirical evidence, leaving the reader to interpret the maximum adaptation capabilities.

Results show the cooling energy consumption resulting from the use of a range of gradient values applied to adaptive cooling setpoint temperatures (Figure 3). These have been built using the ASHRAE 55 adaptive model equation (0.31*Trm+17.8+3.5) as a baseline and varying the

gradient value (0.31) from 0.1 to 0.8 in 0.05 intervals. Figure 4 shows an example of these adaptive cooling setpoint temperatures for gradient values 0.2, 0.4, 0.6 and 0.8. If the building was naturally ventilated, operative temperatures would exceed the upper comfort limit to a great extent. However, considering adaptive cooling setpoint temperatures have been applied considering mixed-mode, all hourly temperatures of the year remain below the upper comfort limit.

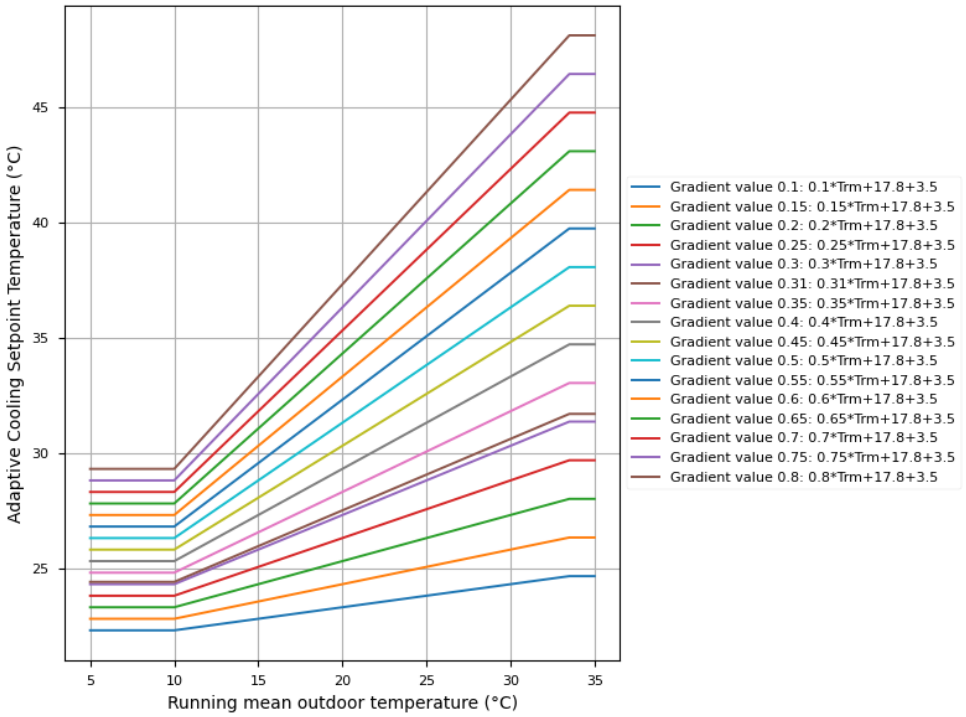


Figure 3. Adaptive cooling setpoint temperature for each gradient value

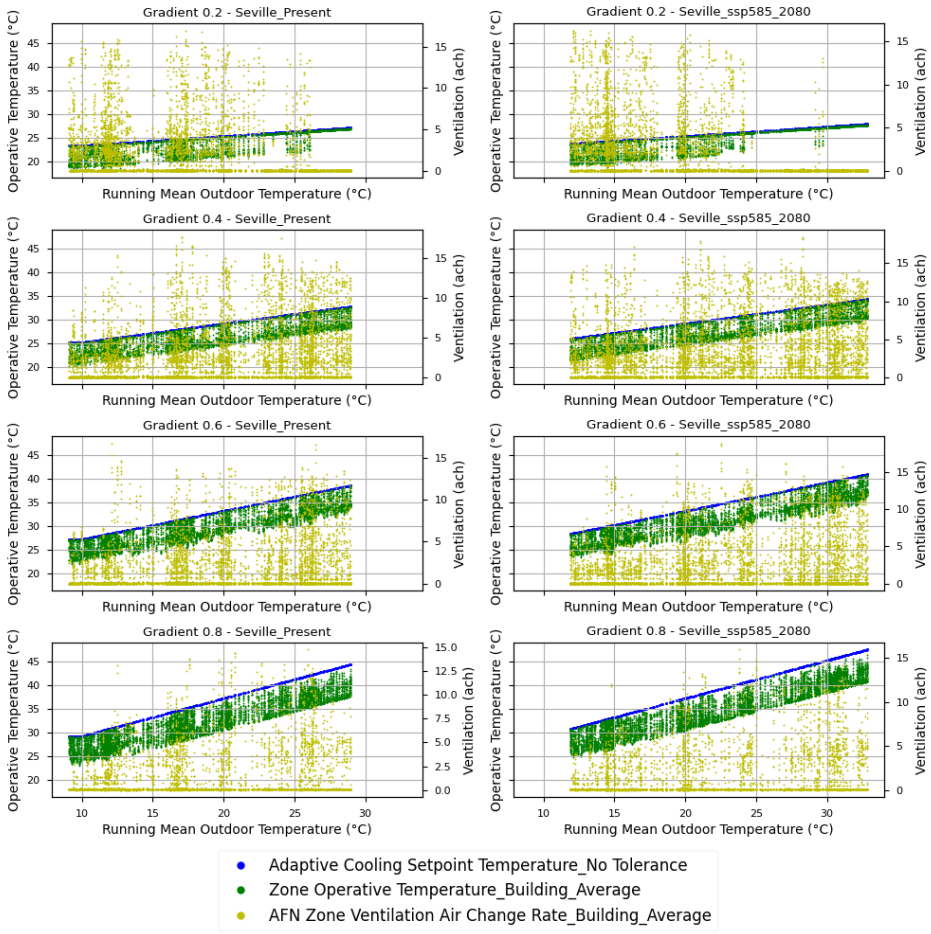


Figure 4. Adaptive comfort model for each gradient value and scenario

The results show that cooling energy consumption decreases as the gradient increases, both in present and future scenarios (Figure 5). Energy consumption in future scenario is roughly 20 kWh/m² higher than present scenario for gradient 0.1, however that difference is reduced as gradient increases until gradient takes values between 0.4 and 0.5, when cooling consumption remains slightly higher in present scenario for higher gradient values.

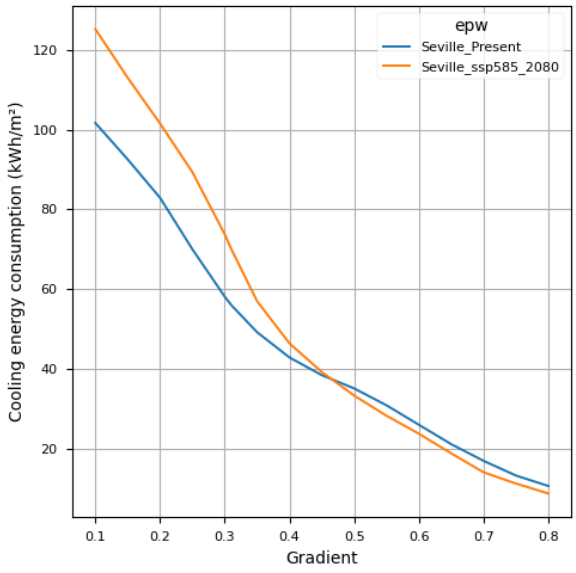


Figure 5. Cooling energy consumption decrease depending on gradient

Figure 6 (a) shows the cooling energy consumption values. It ranges respectively for present and future scenarios from 101.68 and 125.21 kWh/m² for gradient 0.1 to 10.66 and 8.79 kWh/m² for gradient 0.8. To understand the extent of energy increase (negative values) or decrease (positive values), values are compared to ASHRAE 55 adaptive model slope in Figure 6 (b), which has a slope value of 0.31. When slope falls below 0.31, results show increases up to 81 and 78% when gradient takes the value 0.1 respectively for present and future scenarios. Oppositely, when the slope is increased, cooling consumption decreases until 80 and 87%, when gradient takes the value 0.8. Figure 6 (c) shows the energy saving achieved for every gradient interval. Values are higher around gradient 0.3 and 0.35, reaching 17 and 23% respectively for present and future scenarios. Then, values decrease until gradient 0.5 (9 and 15% respectively), and again increase up to 22 and 25% around 0.7-0.75 gradients. Figure 7 (a) shows the increase or decrease percentage in future scenario compared to present. Results show increase values from gradient 0.1 to gradient 0.45, ranging up to 28%. Then, between 0.45 and 0.5 takes place a turning point, and values start to decrease. However, these decrease values are low, ranging between 1.79 and 2.87 kWh/m² as shown in Figure 7 (b), and therefore significance is very limited.

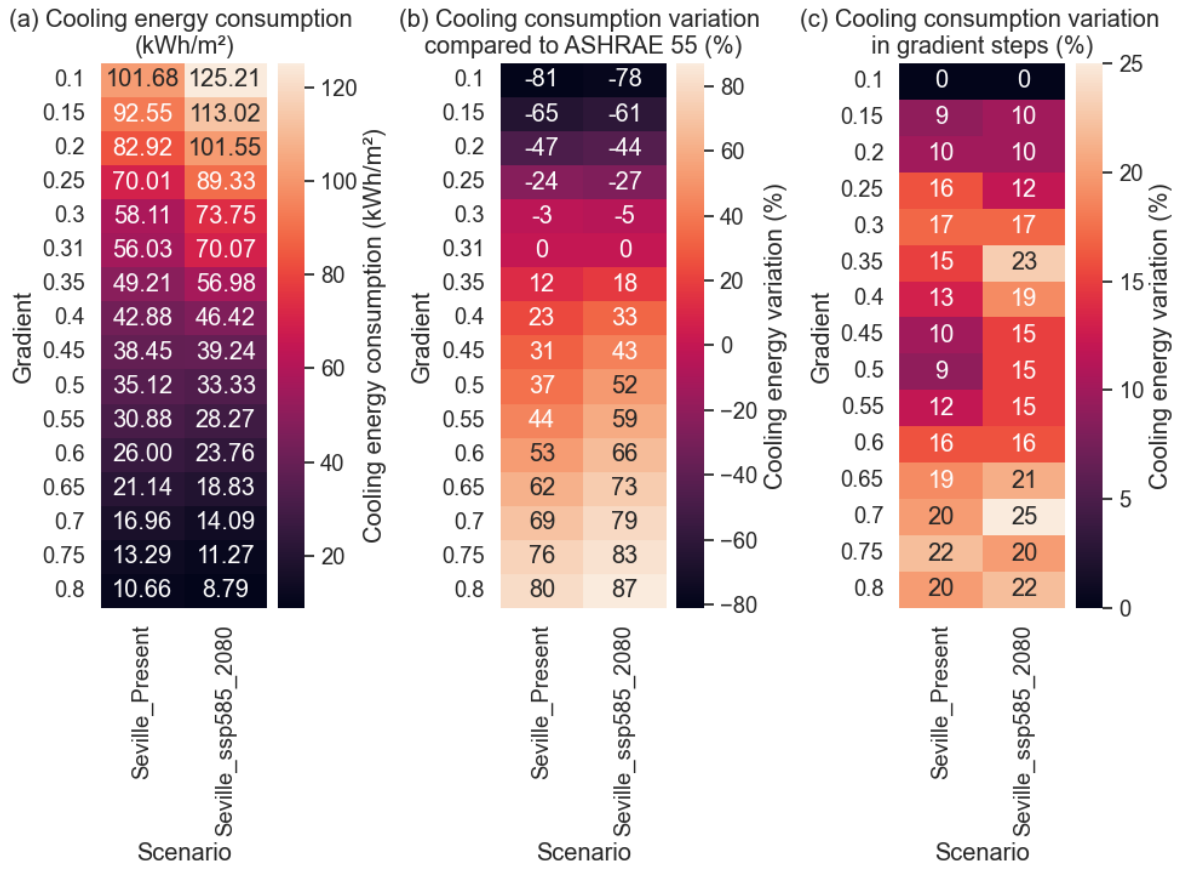


Figure 6. Cooling energy consumption variation depending on gradient and scenario

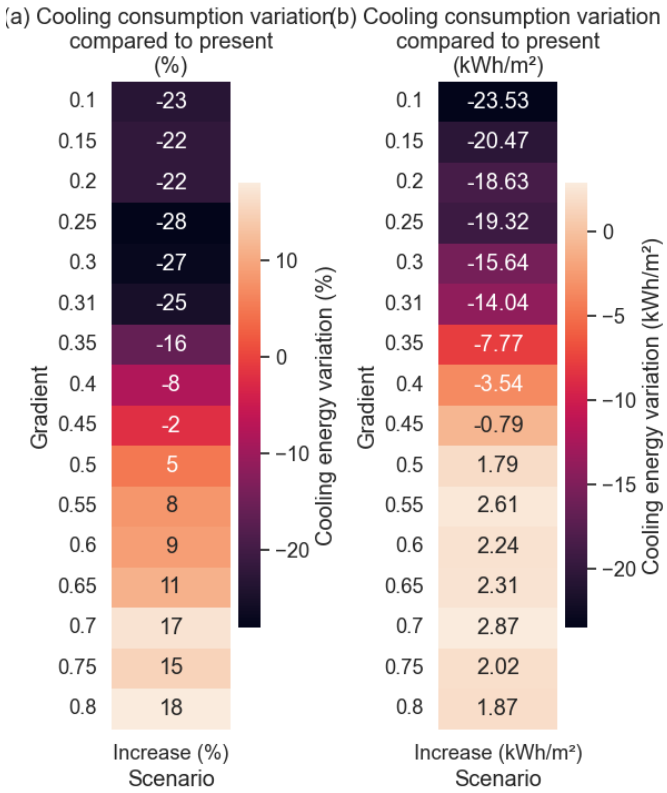


Figure 7. Cooling energy consumption variation compared to present scenario

Limitations

This research assumes that people who live in air-conditioned buildings will respond to temperature variations in a manner that is comparable to that of those who live in naturally ventilated areas. According to the adaptive comfort concept, individuals will eventually become used to the increased temperatures brought on by future climate changes, albeit this adaptation is not entirely assured. It is yet uncertain exactly how and to what degree this change will take place. Since comfort models customized for future circumstances aren't available, comfort models for present climate have been used instead. This approach can create errors and restrict our capacity to anticipate comfort in future situations since it does not take into account how people can adjust to future temperature rises brought on by climate change. However, given that it is expected the human being will be able to withstand higher temperatures, models that incorporate thermal adaptation may produce higher adaptive cooling setpoint temperatures and possibly more energy savings.

Conclusions

This study has explored the impact of the adaptive comfort model's slope on cooling energy consumption in both current and future climatic conditions. By employing the DOE small office building prototype and the ACCIM tool for adaptive setpoint temperatures, and analysing data using the BESOS (Christiaanse et al., 2022) tool, we have drawn several important conclusions:

1. The results demonstrate that increasing the gradient of the adaptive comfort model consistently reduces cooling energy consumption. This trend is evident in both present and projected future scenarios, reaching up to 80 and 87% energy savings respectively for present and future scenarios in slope 0.8.

2. The analysis reveals that the most substantial energy savings occur at gradients 0.3-0.35, with energy reductions reaching 17 and 23% for present and future scenarios, as well as gradients 0.7-0.75, reaching respectively 22 and 25%.
3. Under the SSP5-8.5 scenario for 2080, the study shows that while future energy consumption is generally higher due to increased ambient temperatures, the application of higher adaptive gradients mitigates this increase. Results show increase values from gradient 0.1 to gradient 0.45, ranging up to 28%.
4. These findings underscore the potential for adaptive comfort models to significantly enhance energy efficiency in buildings, particularly in the face of climate change. By adjusting the setpoint temperatures dynamically based on adaptive comfort principles, buildings can maintain occupant comfort while minimizing energy use.

In conclusion, adopting adaptive comfort models with appropriate gradient adjustments presents a viable strategy for reducing cooling energy consumption in buildings. Future research should focus on empirical validation of these models across diverse climatic regions and building types to further refine and optimize adaptive setpoint strategies.

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