

Modelling Occupant-Centric HVAC Zoning for Summer Energy Efficiency in Tokyo Office Buildings[#]

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ABSTRACT

Small and medium enterprises (SMEs) in Japan face challenges in implementing energy-efficient building operations due to limited resources, knowledge gaps, and the absence of occupant-centric management approaches. This study develops a predictive model for HVAC control tailored to SMEs, drawing on a field experiment conducted in an office building in the Nihonbashi district of Tokyo. Multiple HVAC control patterns were trialled, with systematic data collection including environmental parameters (temperature, humidity, CO₂ concentration), thermal comfort indices (PMV, PPD), and occupant survey responses. These datasets were analysed to evaluate the relationship between zoning strategies, occupant well-being, and energy consumption. Based on these observations, a preliminary optimisation framework for HVAC temperature settings and zoning was proposed to maximise thermal comfort while reducing energy demand. The findings contribute to practical pathways for SMEs to achieve both enhanced occupant well-being and improved energy performance, providing insights for wider urban decarbonisation efforts.

Keywords: HVAC Control, Temperature Zoning, Well-being, Thermal Comfort, SME

NOMENCLATURE

Abbreviations

HVAC	Heating, Ventilation and Air Conditioning
SME	Small and Medium Enterprises
PMV	Predicted Mean Vote
PPD	Predicted Percentage of Dissatisfied

1. INTRODUCTION

Small and medium enterprises (SMEs) occupy a large proportion of the office floor-area in Tokyo and

Japan more broadly, yet their contribution to national carbon-neutrality and energy-efficiency goals remains insufficiently studied. Conventional HVAC (heating, ventilation, and air-conditioning) systems in many such office buildings operate on predetermined schedules, with uniform set-points and little adaptation to real-time occupancy, spatial variability, or individual comfort preferences. In contrast, the emerging concept of occupant-centric control seeks to integrate occupant presence, preference and behaviour into the decision-logic of building systems (Ouf, Park, & Gunay, 2021).

In the context of summer cooling in Tokyo's humid climate, where energy demand for air-conditioning peaks and occupant comfort issues frequently arises, there is an opportunity to leverage zoning strategies that differentiate set-points and airflow control by zone, aligned with occupant distribution and feedback. This research therefore develops and validates an occupant-centric HVAC zoning model in a typical Tokyo SME office building. The aim is to evaluate whether adaptive zoning approaches can both reduce cooling energy consumption and maintain or improve occupant thermal comfort.

The key research questions addressed in this work concern how zoning of HVAC set-points and airflow can respond to spatial and temporal variations in occupant presence and comfort feedback, the quantifiable energy savings and comfort improvements that can be achieved through occupant-centric zoning compared to a uniform control baseline, and the feasibility of implementing such zoning strategies in conventional SME office environments without major retrofitting of smart infrastructure. To address these objectives, a field study was conducted in a Tokyo office building in which environmental and occupant questionnaire data were monitored under different control scenarios, followed by analysis of comfort and energy metrics. The main contributions of this research include a real-world field

[#] This is a paper for the 17th International Conference on Applied Energy (ICAE2025), December 8-12, 2025, Bangkok, Thailand.

trial of occupant-centric HVAC zoning in a Tokyo office, indicative evidence of energy reduction and comfort improvement resulting from zoning strategies, and a practical discussion of implementation considerations relevant to SMEs seeking to improve HVAC operations.

2. METHODOLOGY

2.1 Field Experiment

The study was conducted during the peak cooling season (July–August 2025) in an office building located in Nihonbashi, Tokyo. Two floors of the building were instrumented with environmental sensors recording at 5-minute intervals, measuring air temperature, relative humidity, and CO₂ concentration. Predicted Mean Vote (PMV) values were measured directly in each area to assess thermal comfort under different HVAC control patterns. Additional measurements included outdoor temperature and humidity obtained from nearby meteorological data, as well as floor-level electricity consumption captured through the building’s energy monitoring system. Concurrently, occupant surveys were administered weekly to collect thermal sensation, satisfaction, and perceived productivity using a 5-point Likert scale (Esterman, 2003). The spatial location of respondents was recorded to enable zone-based mapping of comfort. All environmental, energy, and survey data were synchronised for integrated analysis.

2.2 HVAC Control Scenarios

Four HVAC control patterns were tested during the summer field experiment to examine the effects of temporal and spatial temperature zoning on occupant comfort and energy performance. The experiment was conducted on two floors of the Nihonbashi office building: the 3rd floor (fixed seating) and the 4th floor (free-address seating). Each floor was equipped with temperature sensors and operated under identical environmental conditions, differing only in the implemented HVAC control pattern.

Temperature set-points were defined as *strong* = 24 °C, *standard* = 25 °C, and *weak* = 26 °C. The four control patterns were implemented as follows: The normal pattern served as the baseline, maintaining a constant standard temperature across all zones throughout the day. The time setting pattern introduced temporal differentiation: weaker cooling was applied in the morning (08:00–10:00), stronger cooling at midday (10:00–13:00), and standard cooling during the afternoon (13:00–16:00), before returning to weaker cooling in the evening. The area setting pattern

introduced spatial zoning, with intensified cooling (*strong*) near the entrance or high-solar-gain façade areas and weaker cooling in interior zones. The time and area setting pattern combined both temporal and spatial differentiation, adjusting set-points according to the time of day while maintaining stronger cooling at the entrance and weaker cooling in interior areas.

These four patterns were selected to represent a progressive shift from uniform operation toward adaptive, occupant-centric control strategies that respond to spatial and temporal variations in heat load and occupancy. The design of these patterns was informed by previous findings on temperature zoning and occupant comfort (Kimura, Yamagata, & Takahashi, 2025). Each pattern in the present study was applied under otherwise consistent operational conditions to isolate the influence of control logic on thermal comfort and energy consumption.

2.3 Data Analysis

Sensor and survey datasets were processed using Python. Thermal comfort was evaluated via the Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) indices in accordance with ASHRAE 55. Energy-use data were obtained from hourly HVAC power logs exported from the building-management system. Statistical analyses—including analysis of variance (ANOVA) and regression modelling—were performed to assess differences in comfort and energy outcomes between control scenarios and across zones.

3. RESULTS

The results presented here are intended to provide indicative trends rather than final statistical conclusions. Preliminary analysis was conducted using data collected from the third and fourth floors of the Nihonbashi office building during July–August 2025. Each floor operated under the four HVAC control patterns described in Section 2.2, with environmental conditions, PMV values, and energy use continuously monitored.

Early observations indicate clear temporal and spatial variations in thermal comfort under different zoning configurations. PMV measurements across multiple areas showed that the time × area setting pattern maintained the most stable comfort levels throughout the day, with smaller fluctuations between zones compared to the normal and time setting conditions. The area setting pattern also contributed to reducing discomfort near the entrance and façade areas exposed to higher solar gain.

In terms of energy performance, initial examination of floor-level electricity consumption logs suggests potential reductions in cooling energy demand under both time setting and time × area setting operations. These reductions appear to correspond with periods of weaker cooling and more efficient temperature zoning, although detailed quantification is still under analysis.

Subjective survey responses collected weekly further support these tendencies. Occupants reported slightly higher satisfaction and fewer thermal complaints during the area setting and time × area setting weeks, particularly in the afternoon periods when solar load was highest. These early results collectively suggest that zoning based on both time and area can improve comfort uniformity and may contribute to moderate energy savings, although full statistical validation is ongoing.

4. DISCUSSIONS

The preliminary findings reinforce the potential of occupant-centric HVAC zoning as a practical approach to balance thermal comfort and energy efficiency in SME office buildings. The trends observed which improved PMV stability and reduced energy consumption under time and area based zoning are consistent with previous work demonstrating the benefits of adaptive thermal control (Kimura, Yamagata, & Takahashi, 2025).

From an operational perspective, the observed effects suggest that relatively simple zoning configurations, even without advanced predictive control systems, can meaningfully enhance indoor comfort conditions. Particularly, differentiating entrance or façade zones with stronger cooling appears effective for mitigating discomfort due to heat gain, while temporal modulation helps to align HVAC intensity with daily occupancy and thermal load profiles.

Further analysis will focus on quantifying statistical significance across all datasets and identifying relationships between environmental variables, subjective comfort responses, and energy performance metrics. Future discussion will also consider how these control logics can be generalised and embedded into low cost HVAC management frameworks suitable for SMEs, which often lack comprehensive building automation systems.

5. CONCLUSIONS

This study presents an ongoing empirical investigation into occupant-centric HVAC zoning strategies for SME office environments in Tokyo. Four temperature control patterns of normal, time setting, area setting, and time × area setting were implemented

and monitored across two office floors during the summer of 2025. Preliminary observations suggest that patterns integrating both temporal and spatial differentiation tend to provide more stable comfort conditions and potentially lower cooling energy consumption.

While full data analysis is in progress, the findings to date indicate that adaptive zoning based on occupant and environmental conditions offers a feasible and scalable pathway toward improving both comfort and energy efficiency in conventional SME office buildings. The continued analysis of PMV, energy consumption, and occupant responses will provide quantitative evidence to refine these strategies. Subsequent phases of the research will extend the investigation to winter operation, integrate CO₂ based demand control, and evaluate the applicability of the zoning framework within district-level energy management systems in the Nihonbashi area.

ACKNOWLEDGEMENT

This work was supported by Council for Science, Technology and Innovation (CSTI), Cross-ministerial Strategic Innovation Promotion Program (SIP), the 3rd period of SIP “Smart energy management system” Grant Number JPJ012207 (Funding agency:JST).

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