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# Occupants' Thermal Sensation and Perception in Naturally Ventilated Public Office Buildings in a Hot–Dry Climate: A UTCI-Based Field Study in Latur, Maharashtra, India

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## Abstract

Naturally ventilated public offices are common in hot-dry climates of Indian cities, where ceiling fans are the primary comfort technology. This field study examines how ceiling-fan operation affects thermal sensation (TSV; −3 to +3) and thermal perception (TPV; 1 to 5) in three public office buildings in Latur, Maharashtra. Across four daily time blocks, n = 295 questionnaires were paired with concurrent microclimate measurements to compute the Universal Thermal Climate Index (UTCI). This study compared fan ON and fan OFF conditions using paired *t*-tests and fitted ordinary least-squares (OLS) regressions between UTCI and TSV/TPV. Relative to fan OFF, fan ON shifted TSV toward neutrality and increased TPV at comparable UTCI values. TSV rose with UTCI and TPV declined as UTCI increased, but both sensitivities were smaller when fans were ON, indicating perceptual relief from elevated air speed. Results are consistent with adaptive comfort theory and current standards and support low-energy, fan-enabled strategies for thermal comfort in naturally ventilated public offices.

**Keywords:** Thermal comfort; Adaptive comfort; UTCI; Ceiling fans; Naturally ventilated buildings; Hot–dry climate; India.

## 1. Introduction

Hot–dry interiors in the Ballaghat Deccan plateau of Maharashtra state routinely experience afternoon heat stress that challenges comfort and productivity in government offices. Adaptive strategies, particularly elevated air movement via ceiling fans, offer low-energy relief while respecting India's long tradition of free-running buildings. The Universal Thermal Climate Index (UTCI), although devised for outdoor bioclimate assessments, has increasingly been used to characterise heat stress relevant to indoor exposures with high solar gains and variable air speeds (Chen et al., 2025; Lee et al., 2024). Parallel advances in adaptive comfort synthesise how occupants in naturally ventilated (NV) buildings accept a wider range of temperatures through behavioural and physiological adjustments; India's IMAC evidence base formalises this for local contexts (Rawal et al., 2022).

Recent peer-reviewed work demonstrates that personal air movement from ceiling or desk fans improves thermal sensation and comfort and enables higher HVAC setpoints when present (André et al., 2024; Kent et al., 2023; Ilmiawan et al., 2024; Zhou et al., 2023). Aligned with these developments and with guidance in EN 16798-1 and ASHRAE Standard 55-2023.

This study addresses two questions in naturally ventilated (NV) public offices under hot–dry conditions:

**Q1.** To what extent does thermal comfort affect occupants' thermal sensation and perception?

**Q2.** To what extent does ceiling-fan influence occupants' thermal sensation and perception in naturally ventilated spaces?

## 2. Background

### 2.1 Universal Thermal Climate Index (UTCI)

UTCI expresses an equivalent temperature that elicits comparable physiological responses under a reference environment, integrating air temperature, humidity, mean radiant temperature, and air speed. Its stress categories permit comparative interpretation across time and space (Chen et al., 2025; Lee et al., 2024). While originally outdoors-focused, several studies apply UTCI to indoor or semi-indoor scenarios with strong radiative loads where operative and radiant effects are salient.

### 2.2 Adaptive comfort and Indian evidence

Adaptive comfort theory indicates that comfort expectations in NV buildings track the prevailing outdoor conditions and occupants' ability to adapt. The India Model for Adaptive Comfort (IMAC) consolidates multi-city field evidence and supports wider acceptable temperature ranges for NV buildings, which is key for low-energy operation (Rawal et al., 2022). Recent syntheses further document the evolution and performance of adaptive models and their design implications (Yao et al., 2022).

### 2.3 Elevated air speed via fans

Elevated air movement augments convective and evaporative heat loss, shifting sensation toward neutrality at warmer operative temperatures. Recent field and experimental studies corroborate comfort gains and the potential to raise temperature setpoints without compromising satisfaction (André et al., 2024; Ilmiawan et al., 2024; Kent et al., 2023; Zhou et al., 2023).

## 3. Methods

### 3.1 Setting and sample

The study covers three NV public office buildings: Zilla Parishad (Z.P.), Collector Office (C.O.), and Panchayat Samiti (P.S.) in Latur (Maharashtra, India). Surveys were administered in four time blocks (11:30, 13:30, 15:30, 17:30). In total, n = 295 matched questionnaires with concurrent microclimate measurements were retained after quality control.

**Table 1. Buildings and sample summary**

| Building | Floors | Key features (similarities) | Valid N |
|---|---|---|---|
| Zilla Parishad (Z.P.) | 3 | Comparable construction; ceiling fans | 97 |
| Collector Office (C.O.) | 3 | Comparable construction; ceiling fans | 97 |
| Panchayat Samiti (P.S.) | 3 | Comparable construction; ceiling fans | 101 |

Single-day questionnaire sampling during four time blocks (11:00–12:30, 12:30–14:00, 15:00–16:30, 16:30–18:00). At each block, one Fan OFF set and one Fan ON set were collected.

**Table 2. Time-block sampling schema and fan treatment.**

| Time label | Clock window | Office status | Fan OFF/ON set | Sample size (n) |
|---|---|---|---|---|
| 11:30 | 11:00–12:30 | Routine work | Yes | Yes |
| 13:30 | 12:30–14:00 | Routine work | Yes | Yes |
| 15:30 | 15:00–16:30 | Routine work | Yes | Yes |
| 17:30 | 16:30–18:00 | Routine work | Yes | Yes |

### 3.2 Measurements

Air temperature, relative humidity, globe temperature (for mean radiant temperature), and local air speed were measured at the occupant level. Fan state (ON/OFF) was logged. UTCI was computed from measured inputs using standard procedures. Indoor Ta, RH, MRT, and Va were measured ~1.10 m above floor level using the TESTO 480 instrument, and questionnaires were concurrent with measurements.

Thermal sensation votes followed the ASHRAE 7-point scale (−3 cold … 0 neutral … +3 hot). Thermal perception/acceptability was recorded on a 5-point scale (1 unacceptable … 5 comfortable).TSV: ASHRAE 7-point; TPV: 5-point acceptability/preference.

Ordinary least squares (OLS) regressions related UTCI to TSV and TPV separately for fan ON and fan OFF subsets. Paired t-tests compared mean TSV and TPV between fan states within matched room-time observations. Statistical assumptions (linearity, residual normality, and homoscedasticity) were verified. Reporting follows ASHRAE, 2023; CEN, 2019 adaptive comfort guidance.

## 4. Results

### 4.1 UTCI vs. TSV and TSP regression

Descriptive trends indicated monotonic TSV increases with UTCI and reduced comfort (TPV) at higher UTCI. Relative to fan OFF, fan ON shifted TSV toward neutrality and increased TPV at comparable UTCI levels. Paired t-tests showed statistically significant improvements for both TSV and TPV during fan ON (two-tailed $p < .01$). OLS slopes for TSV~UTCI were positive in all buildings, but shallower under fan ON; for TPV~UTCI, the negative slope at high UTCI was attenuated when fans were ON. Building-wise intercept and slope differences aligned with envelope factors such as shading ratio, exposed roof area, and depth/volume noted during site audits.

**Table 3. UTCI–vote regressions by building and fan state.**

| Building | Fan State | TSV model | TPV model |
|---|---|---|---|
| Z.P. | OFF | $TSV = -40.09 + 1.17 \cdot UTCI$ | $TPV = 31.73 - 0.84 \cdot UTCI$ |
| Z.P. | ON | $TSV = -35.02 + 0.99 \cdot UTCI$ | $TPV = 27.69 - 0.70 \cdot UTCI$ |
| C.O. | OFF | $TSV = 0.7696 \cdot UTCI - 34.9185$ | $TPV = -0.9680 \cdot UTCI + 37.8146$ |
| C.O. | ON | $TSV = 0.87 \cdot UTCI - 31.22$ | $TPV = -0.57 \cdot UTCI + 23.22$ |
| P.S. | OFF | $TSV = -14.992 + 0.443 \cdot UTCI$ | $TPV = 19.509 - 0.491 \cdot UTCI$ |
| P.S. | ON | $TSV = -14.055 + 0.399 \cdot UTCI$ | $TPV = 16.472 - 0.391 \cdot UTCI$ |

### 4.2 Paired comparisons of fan state (Fan ON vs. Fan OFF)

In each building, paired observations taken in the same time blocks with ceiling fans OFF and ON were compared using paired-samples t-tests (two-tailed, $\alpha = .05$). Differences were defined as OFF − ON. Thus, a positive t for TSV (thermal sensation) indicates warmer sensations when fans were OFF (cooling benefit when ON). In contrast, a negative t for TPV (thermal perception/acceptability) indicates lower acceptability when OFF (higher acceptability when ON). This study report within-subject effect sizes as Cohen's $d_h = t/\sqrt{n}$ (APA-aligned reporting). (APA, 2024; Lakens, 2013).

The direction of effects is fully consistent: turning fans ON yields cooler sensations (TSV↓) and higher perceived acceptability (TPV↑) with large within-subject effects ($|d_h| \approx 1.1$–$2.1$). This matches adaptive comfort practice when elevated air speed is provided via ceiling fans; current guidance and design tools (e.g., CBE Thermal Comfort Tool) extend the warm-side comfort zone at higher air speeds (ASHRAE, 2023; CBE, 2023).

## 5. Discussion

### 5.1 Interpreting UTCI indoors

Despite its outdoor origin, UTCI's thermo-physiological basis and use of equivalent temperature provide a coherent way to compare heat-stress conditions across rooms and times with strong radiative loads; our monotonic TSV/TPV responses mirror reported behaviour (Chen et al., 2025; Lee et al., 2024).

In every building and time block, Fan ON significantly reduces TSV and increases TPV. This is consistent with controlled studies showing that elevated indoor air speed provides a cooling effect (lower TSV at the same heat stress) and improves acceptability in warm conditions. In ASHRAE-55:2023, these effects are formalised through the Elevated Air Speed Comfort Zone Method, which increases allowable operative temperature as air speed rises (ASHRAE, 2023; Zhou et al., 2023).

### 5.2 Fans as low-energy comfort

The significant paired differences and slope attenuation under fan ON are consistent with recent peer-reviewed findings that elevated air movement improves comfort and permits higher setpoints, with associated energy benefits (André et al., 2024; Kent et al., 2023; Ilmiawan et al., 2024; Zhou et al., 2023).

Observations cohere with the IMAC database and broader adaptive comfort literature, reinforcing the role of personal control and NV operation in India's public buildings (Rawal et al., 2022; Yao et al., 2022).

EN 16798-1 categories and ASHRAE 55-2023's elevated air speed provisions offer practical compliance pathways for NV offices in warm climates (ASHRAE, 2023; CEN, 2019).

## 6. Conclusions

Ceiling-fan operation materially improves perceived comfort in NV public offices under hot–dry conditions. At comparable UTCI values, fan ON states shift TSV toward neutrality and raise TPV; regression slopes indicate attenuated heat-stress sensitivity with elevated air speed. The findings endorse occupant-centric, low-energy strategies, well-placed fans, robust shading, and reflective roofs, within adaptive comfort frameworks and current standards.

Ceiling-fan operation exerts a strong, beneficial influence on both outcomes: it reduces thermal sensation (cooler TSV). It improves comfort perception (higher TPV) with large within-subject effects in Z.P., C.O., and P.S. Practically, these results justify fan-enabled extensions of the comfort envelope in naturally ventilated public offices, consistent with ASHRAE-55:2023's elevated air-speed provisions and recent research on the comfort benefits of higher indoor air speeds.

Limitations include the absence of a full multivariable envelope model and seasonal replication. Future work should combine detailed envelope metrics, measured air-speed distributions, and personal-control variables with UTCI-based outcomes across seasons.

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