

Key environmental factors influencing occupants' perceived indoor air quality and SBS in public buildings

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03 | Results & Discussions

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01

Introduction

01 Introduction

Public Buildings



Office



Educational



Medical



Entertainment



Transportation

Indoor Environment Parameters



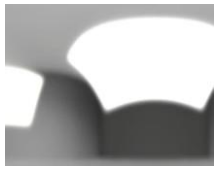
IAQ



Thermal



Acoustic



Lighting

Current Situation

Complex building context

Different occupants' perceptions

Key parameters remain unclear

Integrated evaluation is lacking

Aims of the study

KEY PARAMETER IDENTIFICATION

↓

EVALUATION MODEL

Health Comfort

Evidence basis

02

Methods

02 Methods: Literature Review

1 LITERATURE SEARCH



CNKI



Web of Science

Keywords:

"Building Type"
AND
"Environmental Parameter"
AND
"Human Response"

2 SCREENING

Title & abstract screening

Full text reading

Eligible studies

Objective	Subjective
Environmental Measurement	Survey/test on occupants

EXCLUDE!

- Objective only
- Subjective only
- Review/Patent
- No measured data

3 EVIDENCE EXTRACTION & EVALUATION

Extracted information

- Study Context
- Environmental Data
- Human Response
- Interaction Effects

Evaluation

Relevance	Quality
(partial) Conclusive	High
Suggestive	Moderate
Irrelevant	Low
	Very Low

Statement is based on papers

Conclusive OR Partial conclusive + Reliable methodology

02 Methods: On-site Measurement and Survey

Environmental Parameters

◆ Thermal Environment

- **T(℃)、RH (%)、Airflow velocity (m/s)**

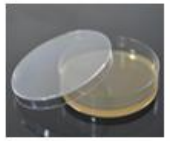

Green Eye


Testo 425

◆ Air Environment

- **VOCs (μg/m³):** active sampling, DNPH (6 carbonyls) + Tenax-TA (30 VOCs)
- CO_2 (ppm)
- **SVOCs**
- **Airborne microorganisms** (CFU/m³)
- **$PM_{2.5}$** (μg/m³)、**O_3**(ppb)


SidePak


Petri plate


Ozone analyzer


DNPH


Tenax-TA


Air Sampling Pump

◆ Acoustic & Light Environment

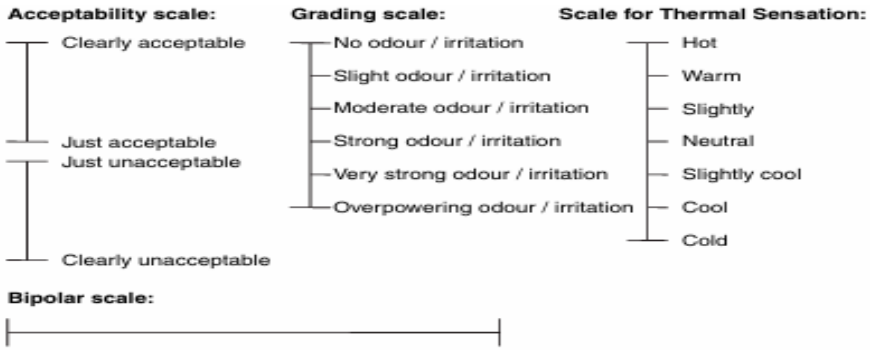
- **Noise (A-weighted, dB)**
- **Illuminance (lux)**


TES1352S


TES 1339R

Passenger Subjective Evaluation

Demographic information: (gender\ age\ height et al.)	**Thermal comfort perception(TSV)**
Air quality perception (VAS)	**Acoustic & light environment survey (VAS)**



Location & Procedure

Measurement points: 1.0–1.5 m,

Time period: 9:00 – 19:00, 2-3 days

Areas: Waiting area / Commercial area / Restroom



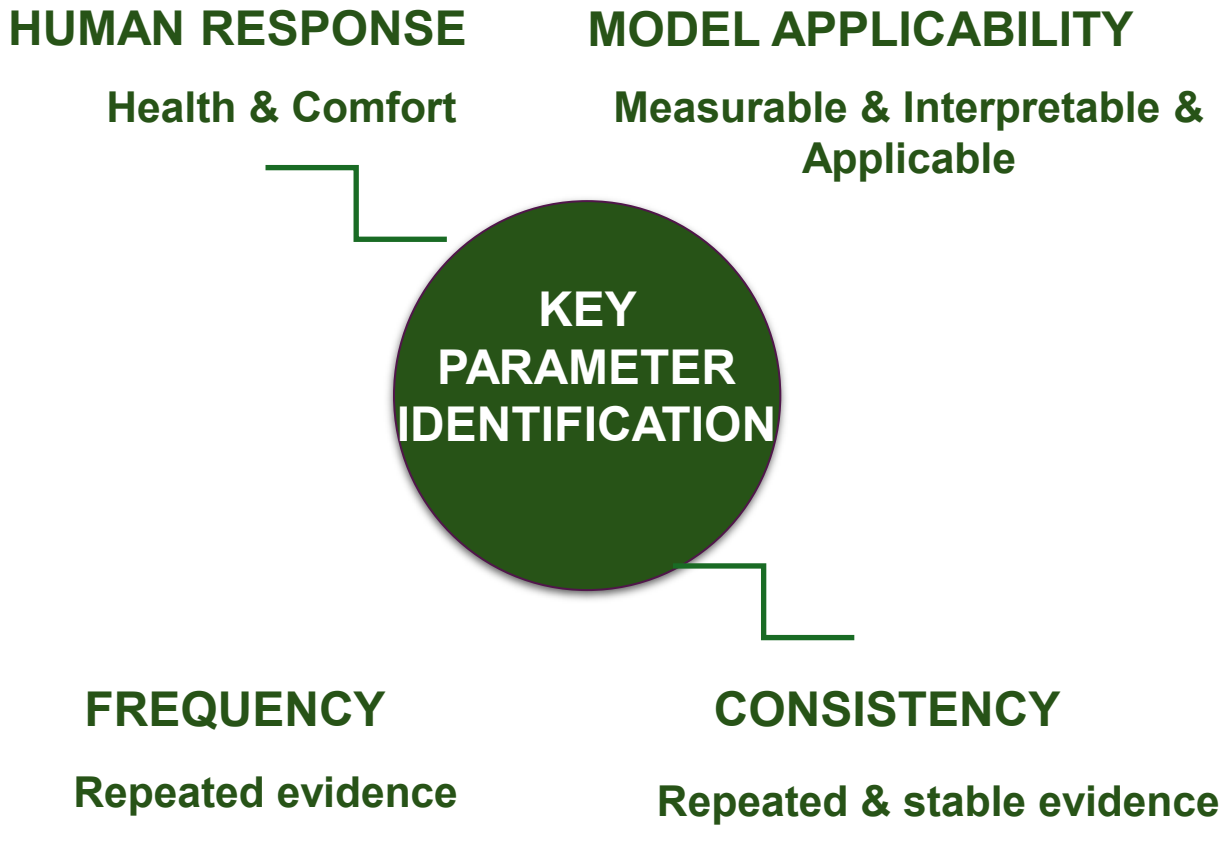
02 Methods: Key Parameter Identification

What makes a parameter as a “KEY” one?

Measured Parameter ≠ Key Parameter

Qualified Evidence Base

- Five Building Types
- Standardized Environmental Parameters
- Objective-Subjective Association Evidence



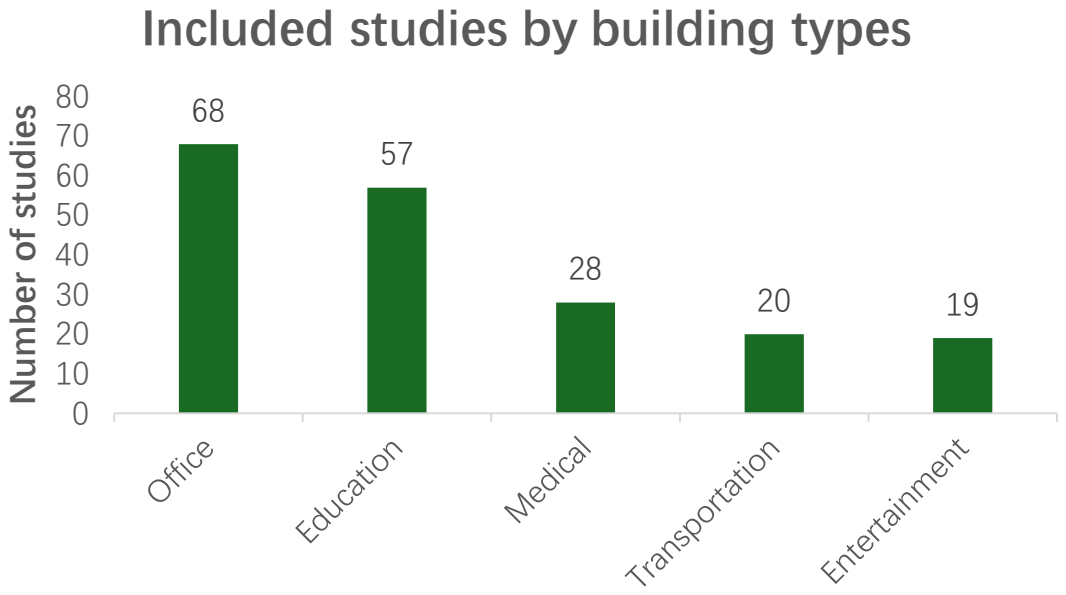
Different Building Types Different Key Parameter Sets

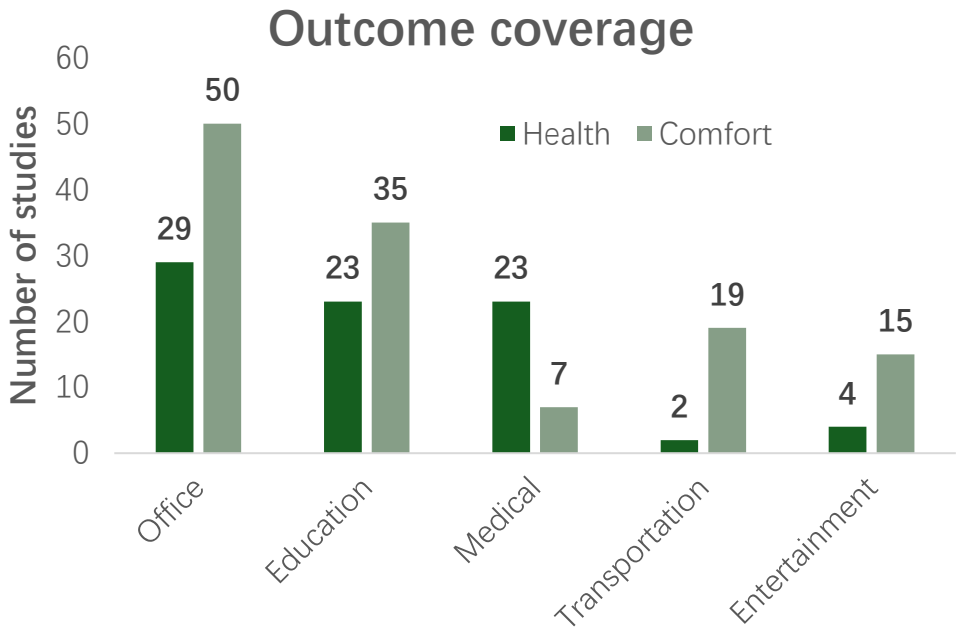
03

Results & Discussions

03 Evidence from Literature Review

Total included studies: N = 192





Note: Health and Comfort categories are not mutually exclusive; one study may address both outcomes.

Key finding: Office and education buildings had substantial evidence. Medical buildings focused mainly on health, whereas transportation and entertainment studies focused mainly on thermal comfort.

03 Key-parameter Selection

OFFICE BUILDINGS

IAQ

CO_2 n = 28

SBS / respiratory symptoms · IAQ / thermal satisfaction

Repeated adverse evidence | Some null / context-dependent findings

$PM_{2.5}$ n = 14

SBS / respiratory outcomes · well-being / IAQ perception

Repeated adverse evidence | Some mixed findings

VOCs n = 13

SBS · ocular / respiratory symptoms · IAQ perception

Predominantly adverse | Compound-specific

THERMAL

Temperature n = 48

SBS / cold-related symptoms · thermal comfort / acceptability

Repeated comfort evidence | Non-linear / range-dependent

Humidity n = 28

Upper respiratory symptoms · thermal / humidity acceptability

Limited direct evidence | Several null findings | Not retained

ACOUSTIC

Noise / sound level n = 14

Acoustic comfort / annoyance · thermal acceptability

Repeated comfort evidence

Mixed / context-dependent

LIGHTING

Illuminance n = 17

Visual comfort / satisfaction · glare / lighting perception

Mixed

Threshold / context-dependent

n = number of result-involved studies for each parameter family.
Evidence profiles summarize evidence volume, human-outcome associations, and association patterns; model applicability was considered in the final key-parameter selection.

03 Key-parameter Selection

EDUCATION BUILDINGS

IAQ

CO_2 n = 25

SBS · respiratory/nasal symptoms · rhinitis / asthma

Predominantly adverse for Health | Some inconsistent / null findings

Bacteria n = 6

Rhinitis · asthma · SBS / mucosal symptoms

Repeated health evidence | Taxa-specific / mixed direction

Fungi n = 7

Asthma · respiratory symptoms · SBS / school-related symptoms

Repeated health evidence | Species / marker-specific

$PM_{2.5}$ n = 8

SBS / respiratory outcomes

Limited direct human-effect evidence | Not retained

THERMAL

Temperature n = 37

Thermal sensation / comfort / acceptability · SBS / respiratory symptoms

Repeated comfort evidence | Non-linear / season-dependent

Humidity n = 37

Nasal/respiratory symptoms · thermal sensation / comfort

Repeated Health + Comfort evidence | Context-dependent

ACOUSTIC

Noise / sound level n = 11

SBS · acoustic perception / comfort · soundscape preference

Repeated comfort evidence | Context-dependent

LIGHTING

Illuminance n = 10

SBS · lighting satisfaction / visual comfort · glare perception

Repeated comfort evidence | Threshold / context-dependent

n = number of result-involved studies for each parameter family.

Evidence profiles summarize evidence volume, human-outcome associations, and association patterns; model applicability was considered in the final key-parameter selection.

03 Key-parameter Selection

MEDICAL BUILDINGS

IAQ

CO_2 n = 10

SBS · respiratory/nasal symptoms · IAQ / thermal perception

Predominantly adverse | Threshold-related

VOCs n = 10

SBS · ocular/nasal symptoms · respiratory outcomes

Predominantly adverse

Bacteria n = 7

Respiratory symptoms · skin symptoms · SBS

Predominantly adverse

Fungi n = 6

Respiratory symptoms · asthma · nasal function

Predominantly adverse | Broader health evidence

$PM_{2.5}$ n = 6

Respiratory outcomes · wheezing · PEF

Mixed / limited | Not retained

THERMAL

Temperature n = 13

SBS · ocular/nasal symptoms · thermal perception

Mixed | Condition-dependent

RH n = 10

Nasal/throat/eye symptoms · thermal perception

Low RH generally unfavorable | Seasonal dependence

ACOUSTIC

Noise n = 5

SBS · headache/sleep/anxiety · acoustic satisfaction

Adverse | Limited evidence

LIGHTING

Illuminance n = 5

SBS · lighting satisfaction

Mixed

n = number of result-involved studies for each parameter family.
Evidence profiles summarize evidence volume, human-outcome associations, and association patterns; model applicability was considered in the final key-parameter selection.

03 Key-parameter Selection

TRANSPORTATION

THERMAL

Temperature — n = 11
Thermal sensation · thermal comfort · preference/satisfaction
Repeated comfort evidence
Condition-dependent

Air velocity — n = 6
Thermal sensation · airflow sensation/preference · draught discomfort
Beneficial in hot conditions
One null study

Humidity — n = 5
Thermal / humidity / dryness perception
Limited / weaker evidence
Not retained

IAQ

CO_2 / air quality — n = 1
Overall satisfaction · air-quality satisfaction
Adverse at higher CO_2
Single-study evidence

ACOUSTIC

SPL / SNR — n = 1
Loudness · acoustic comfort · speech intelligibility
Direct evidence
Single-study basis

LIGHTING

Lighting parameters — n = 1
Safety · comfort · pleasure
Insufficient direct evidence

ENTERTAINMENT

IAQ

CO_2 — n = 6
Negative mood/fatigue · IAQ satisfaction/acceptability
Adverse signals
One direct null result

THERMAL

PMV — n = 6
Thermal sensation · thermal comfort/preference
Repeated comfort evidence
Model–perception mismatch

Temperature — n = 9
Negative mood · thermal sensation/comfort
High study frequency
Limited direct evidence

Humidity — n = 6
Thermal preference/comfort
Limited direct evidence
Not retained

ACOUSTIC

Noise / sound level — n = 4
Depression · loudness · acoustic comfort
Adverse
Repeated direct evidence

03 Evidence from on-site measurement and survey

Ten stations in five climate zones for cold, warm & transitional seasons



03 Distribution of environmental parameters

VOCs

- **31 VOCs:** detection >50%
- Formaldehyde (98.8 ug/m^3)
- Acetaldehyde (21.9 ug/m^3)

SVOCs

- **22 SVOCs** with detection rate >50%
- **PFAs:** HFPO-DA highest (263 ng/g), much higher than PFOA & PFOS
- **BPs:** BPA dominant (2.04 μg/g), >70% of total BPs
- **OPEs:** TCEP highest (0.99 μg/g), followed by TPHP (0.61 μg/g)

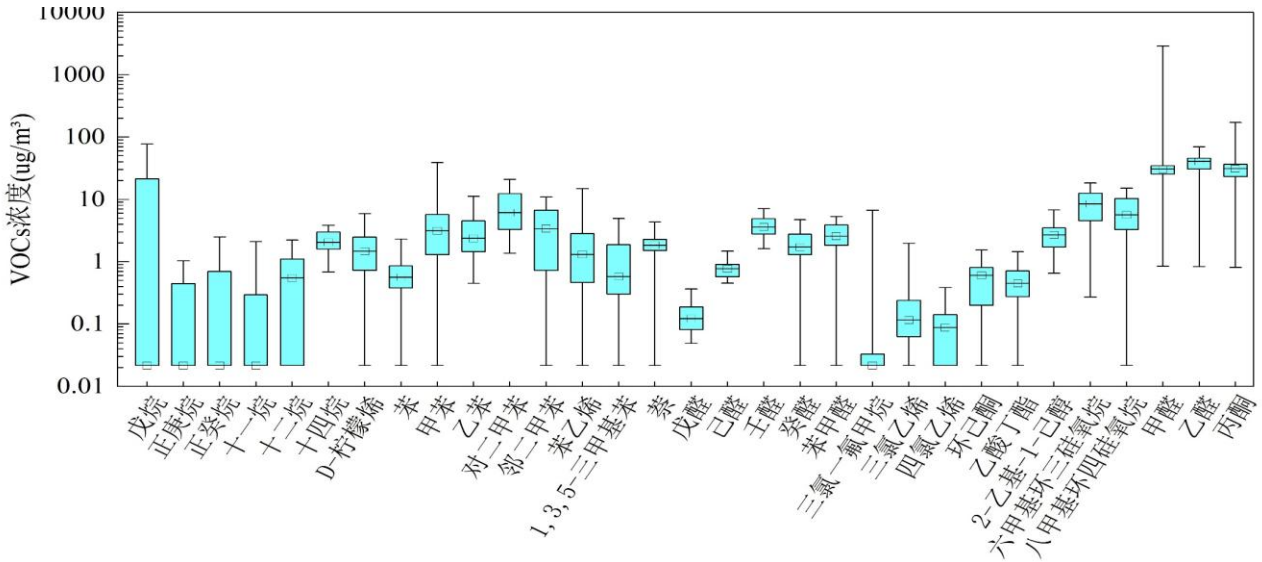


表 3-4 SVOCs 检出率及总体浓度分布

类别	变量	检出率	平均值	最小值	最大值	25%分位数	50%分位数	75%分位数
PFAs (ng/g)	PFHxA	78.50%	6.987	0.104	30.538	1.439	3.178	8.358
	PFHpA	43.10%	2.836	0.000	18.071	0.000	0.058	2.612
	PFOA	92.30%	15.031	0.210	45.171	3.332	14.218	18.213
	PFNA	76.90%	4.388	0.152	16.446	1.111	2.848	5.584
	PFDA	75.40%	3.025	0.000	8.722	0.287	2.076	5.268
	PFUdA	52.30%	1.095	0.000	5.131	0.000	0.292	1.246
	PFDoA	63.10%	2.126	0.000	9.162	0.093	1.327	2.514
	PFTrDA	36.90%	1.248	0.121	6.304	0.150	0.158	1.807
	PFTeDA	52.30%	2.272	0.083	10.712	0.103	0.749	3.099
	PFBS	49.20%	3.894	0.743	13.499	0.961	2.672	4.559
	PFHxS	18.50%	1.682	0.789	6.204	0.941	1.020	1.468
	PFOS	92.30%	13.848	0.470	85.634	5.329	8.548	12.276
	HFPO-DA	78.50%	269.010	3.483	610.286	148.650	263.097	384.350
	ADONA	9.20%	0.023	0.000	0.254	0.000	0.000	0.006
	9Cl-PF3ONS	49.20%	2.023	0.281	18.914	0.365	0.687	2.128
	N-MEFOSAA	27.70%	0.117	0.000	1.027	0.000	0.000	0.108
	N-ETFOSAA	4.60%	0.009	0.000	0.082	0.000	0.000	0.000
	11Cl-PF3OUDS	55.40%	1.148	0.182	3.151	0.235	0.576	2.029
BPs (ug/g)	BPA	100.00%	4.649	0.436	35.633	1.352	2.040	2.469
	TCS	80.00%	0.073	0.002	0.862	0.008	0.023	0.044
	BPS	96.90%	0.050	0.004	0.230	0.023	0.038	0.063
	BPF	100.00%	1.070	0.114	6.391	0.393	0.583	1.058
	4tBPDPP	100.00%	0.084	0.007	0.188	0.073	0.086	0.106
	TOCP	100.00%	0.679	0.031	3.578	0.137	0.330	0.781
OPEs (ug/g)	TCEP	100.00%	1.861	0.076	7.829	0.515	0.993	1.809
	TDCIPP	75.40%	0.397	0.061	1.303	0.124	0.353	0.494
	TNBP	84.60%	0.051	0.004	0.457	0.010	0.015	0.031
	TPHP	100.00%	0.718	0.107	1.871	0.525	0.610	0.832
	TEP	100.00%	0.176	0.012	0.624	0.051	0.117	0.253
	TMP	95.40%	0.143	0.002	0.725	0.014	0.046	0.072

High detection rates of VOCs/SVOCs in indoor air; high concentrations of certain substances → potential health risks.

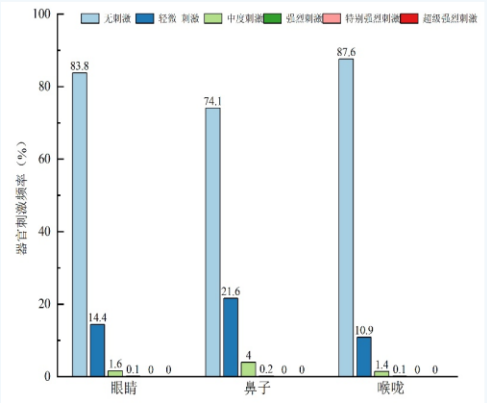
03 Subjective evaluation on indoor environment

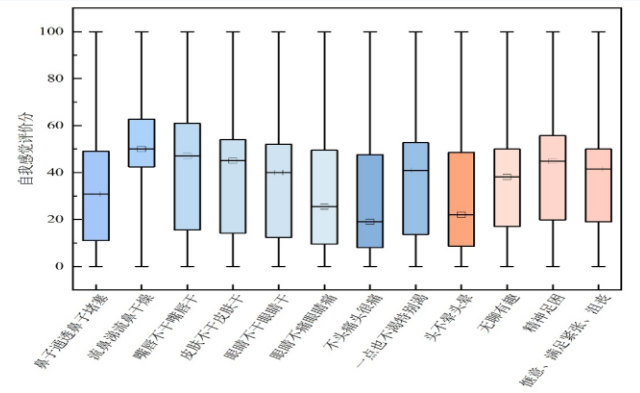
Demographic information

- **4,111** valid questionnaires, gender (49.2% / 50.8%)
- Mean age **26.8** years, predominantly young adults (18–29: 69.6%)

Air perceptions

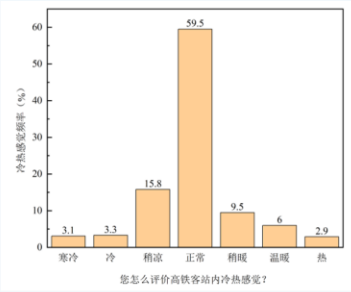
- **Organ irritation:** mild irritation predominant (27.2%)
- **Air freshness:** median 50, large dispersion
- **SBS symptoms (median): nasal dryness most prominent** (50), dry lips (47), general: drowsiness (45) next; headache (19), dizziness (22)

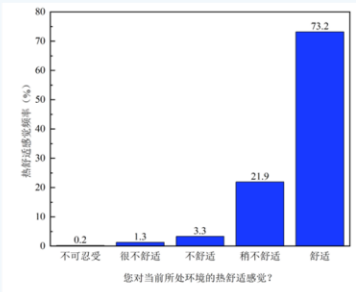




Thermal comfort

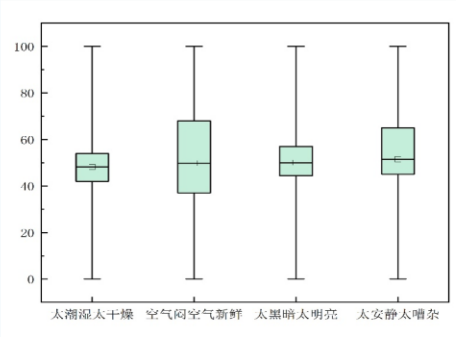
- 84.8% of passengers reported acceptable thermal sensation (–1 to +1)
- 59.5% voted "Neutral", 15.8% "Slightly cool", 9.5% "Slightly warm"

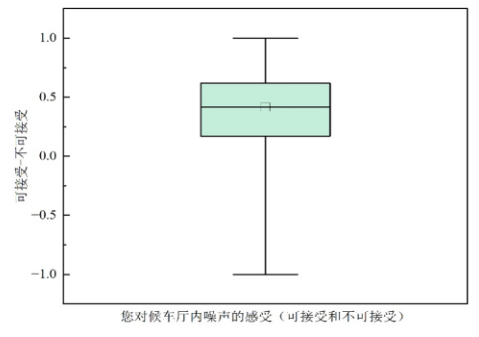




Acoustic and light environment

- **Noise score:** median 51 (somewhat noisy)
- **Illuminance score:** median 50 (moderate)





03 Subjective vs objective evaluations

Variables	AOR (95% CI)	*p*	Interpretation
T	0.92 (0.89–0.95)	**0.000**	T ↑→ Reduced discomfort
RH	1.41 (1.17–1.70)	**0.000**	RH ↑ → 41% increased risk of discomfort

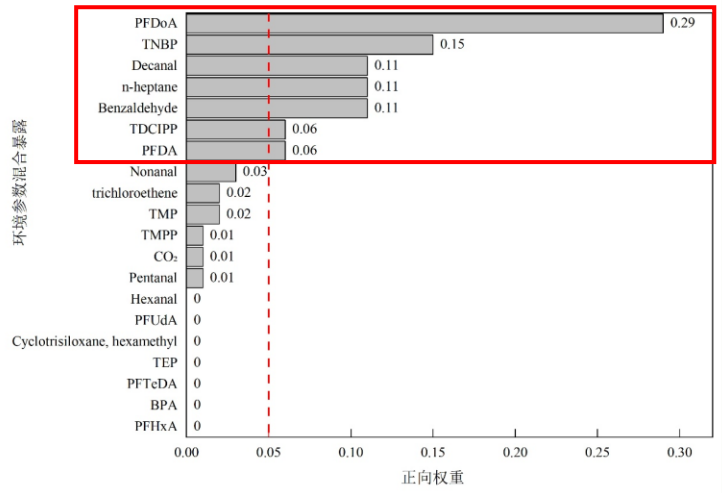
Temperature: protective factor; RH: risk factor

Variables	Dependent variable	AOR (95% CI)	*p*	Interpretation
Noise	Noise perception	1.40 (1.25–1.57)	**0.000**	Noise↑→ Noise discomfort risk↑40%
Illuminance	Light perception	1.10 (1.03–1.17)	**0.004**	Illuminance↑→ Brightness perception risk↑10%

Sound pressure level & illuminance → significant positive effects on subjective perception

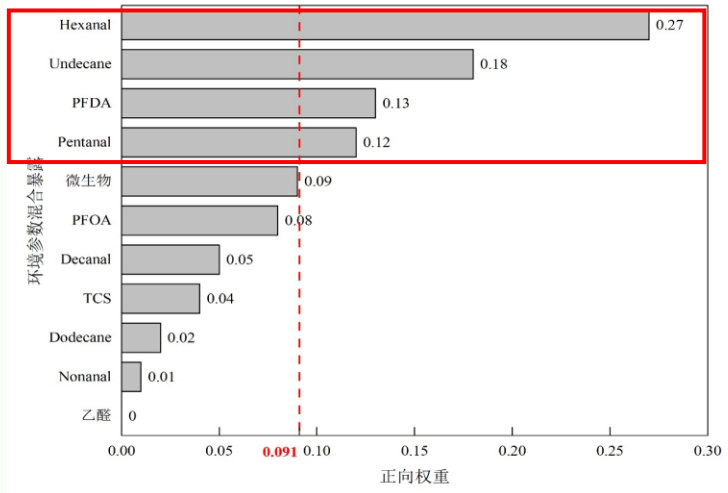
03 Subjective–objective correlation

Mucous Membrane Irritation



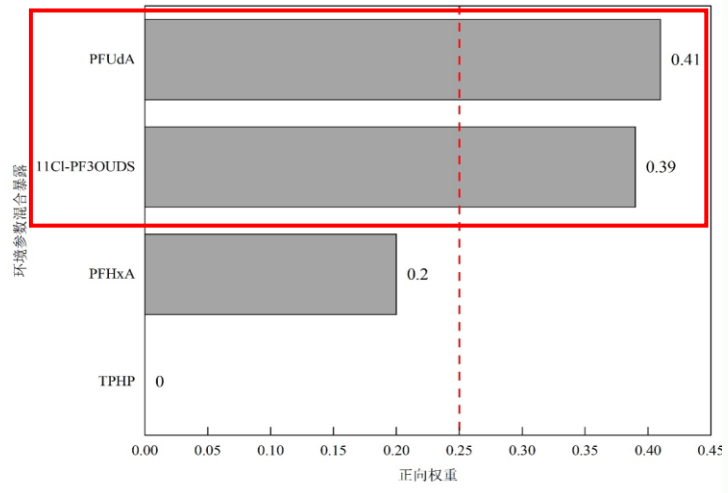
- **PFAs/OPEs** – chronic irritation
- **Aldehydes** – acute irritation
- **Alkanes** – enhance discomfort via odor background

Air Freshness



- **Aldehydes** – stale sensation
- **Alkanes** – stuffy sensation
- **PFDA** – stagnant sensation (indicator of insufficient ventilation)

Headache Symptom



Chronic accumulation → oxidative inflammation → barrier disruption → reduced neural tolerance

12（VOCs/SVOCs）：PFDoA、TNBP、Decanal、Heptane、Benzaldehyde、TDCIPP、PFDA、Hexanal、Undecane、Pentanal、PFUdA and 11Cl-PF3OUDS

03 Env. factors × subjective perception: interaction effects

Stratification factors	Level	T AOR (95% CI)	RH AOR (95% CI)
Indoor pollutants	Low(≤P75)	0.99 (0.96–1.02)	**0.70 (0.61–0.80)** ***
	High(>P75)	**1.11 (1.04–1.19)** **	**0.64 (0.57–0.72)** ***
Noise	Low(≤P75)	0.99 (0.96–1.01)	**0.75 (0.66–0.85)** ***
	High(>P75)	1.01 (0.96–1.05)	**0.54 (0.46–0.64)** ***
Illuminance	Low(≤P75)	0.98 (0.95–1.00)	**0.63 (0.57–0.70)** ***
	High(>P75)	1.11 (0.99–1.24)	**0.57 (0.47–0.70)** ***

- **Temperature effect modulated by indoor pollution**
- **Higher pollution → elevated temperatures → increased thermal discomfort**

03 Env. factors × subjective perception: interaction effects

Organ irritation (eyes, nose, throat)			Air freshness perception	Headache symptoms
Strata	**Level**	**Significant pollutants**	**Significant pollutants**	**Significant pollutants**
T	Low	TNBP, Heptane, Benzaldehyde	PFDA	PFUdA, 11Cl-PF3OUDS
	High	Decanal, Benzaldehyde,TDCIPP	Undecane, PFDA	11Cl-PF3OUDS
RH	Low	TNBP, Benzaldehyde	Hexanal	PFUdA, 11Cl-PF3OUDS
	High	—	Undecane, PFDA	—
Noise	Low	PFDoA, TNBP, Heptane, Benzaldehyde, TDCIPP	—	PFUdA, 11Cl-PF3OUDS
	High	PFDoA, TNBP	Undecane, PFDA	11Cl-PF3OUDS
Light	Low	PFDoA, TNBP, Heptane	—	PFUdA, 11Cl-PF3OUDS
	High	—	PFDA	—

- **Health effects of pollutants co-moderated by multiple factors**
- **Env. conditions alter perceptual sensitivity & symptom intensity**
- **Indoor health assessment → consider multi-factor co-exposure**

03 Env. factors × subjective perception: interaction effects

Interaction effects of environmental factors on light perception

Stratification factors	Level	AOR (95% CI)	*p*
Indoor pollutants	Low(≤P75)	1.13 (1.01–1.25)	**0.032**
	High(>P75)	1.10 (1.00–1.22)	0.056
Temperature	Low(≤P75)	**1.20 (1.04–1.37)**	**0.012**
	High(>P75)	1.22 (0.96–1.55)	0.096
RH	Low(≤P75)	1.08 (1.01–1.15)	**0.027**
	High(>P75)	1.15 (1.02–1.29)	**0.020**
Noise	Low(≤P75)	**1.12 (1.05–1.21)**	**0.001**
	High(>P75)	1.02 (0.91–1.15)	0.691

Interaction effects of environmental factors on acoustic perception

Stratification factors	Level	AOR (95% CI)	*p*
Indoor pollutants	Low(≤P75)	**1.37 (1.21–1.55)**	**0.000**
	High(>P75)	**1.54 (1.15–2.07)**	**0.004**
Temperature	Low(≤P75)	**1.40 (1.21–1.62)**	**0.000**
	High(>P75)	1.23 (1.00–1.51)	0.051
RH	Low(≤P75)	**1.52 (1.28–1.80)**	**0.000**
	High(>P75)	**1.25 (1.06–1.48)**	**0.008**
Illuminance	Low(≤P75)	**1.43 (1.21–1.68)**	**0.000**
	High(>P75)	**1.45 (1.22–1.71)**	**0.000**

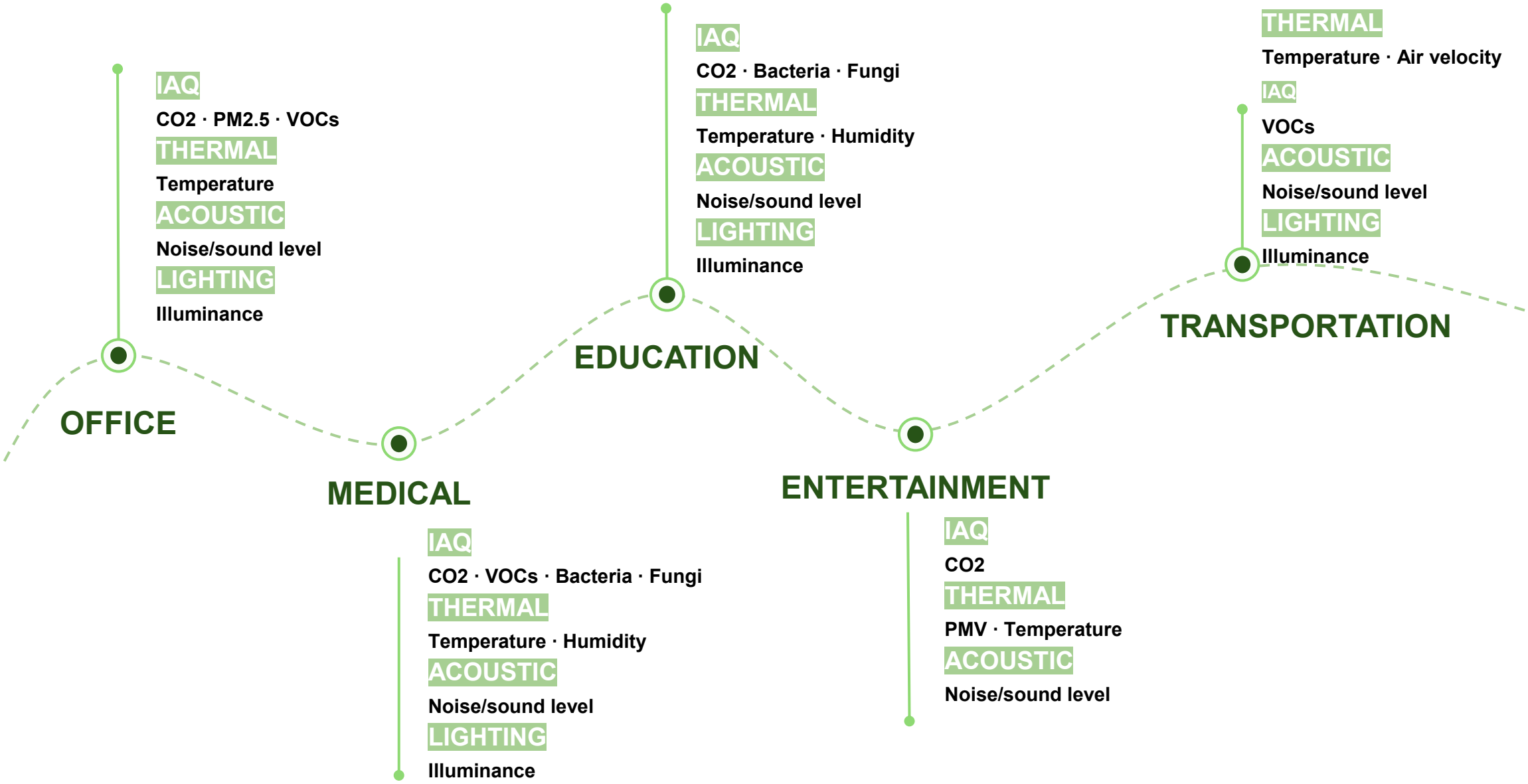
- **Light vs. perception: robust positive correlation**
- **AOR > 1, consistent across strata (pollution, T/RH, sound)**

- **Noise vs. acoustic perception: robust positive association (AOR > 1)**
- **Consistent & significant across strata (pollution, T/RH, light)**

04

Conclusions

04 Key Parameter



04 Preliminary Evaluation Model

KEY PARAMETERS → REFERENCE VALUES → SUB-INDEX → COMPOSITE INDEX

Single-parameter Sub-index

$$R_i = \frac{C_i}{S_i}$$

C_i **Measured value**
S_i **Reference value**
R_i **Dimensionless sub-index**

Reference values mainly derived from international standards and guidelines.

Composite Index

$$I = \sqrt{(max\, R_1, R_2, \dots \dots R_n)\left(\frac{1}{n}\sum_{i=1}^{n} R_i\right)}$$

MAXIMUM COMPONENT

Most unfavorable parameter

AVERAGE COMPONENT

Overall environmental level

Special parameters: Parameter – specific function → R_i → Composite index



THANK YOU!

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please contract yuexiasun@tju.edu.cn for further information