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Ventilation and IAQ in bedrooms

CONTENT

- What is the IAQ in bedrooms?
- Does ventilation work to control IAQ?
- What are the relevant metrics for bedroom ventilation?
- What is still unknown?

IAQ IN BEDROOMS

Statistical description of mean CO_2 and air change rate (ACR) during sleep.

	Mean	Std.	min	Percentile 25th	Percentile 50th	Percentile 75th	max
Mean CO_2 (ppm)	1305.3	942.4	427.5	638.0	981.8	1547.6	4803.7
ACR (h^{-1})	1.1	1.3	0.1	0.3	0.6	1.5	4.9

CO_2: 1000 ppm (Cat. II, Central European Standard)
ACR: 2.0 h^{-1} (Cat. II, Central European Standard)

Statistical description of bedroom pollutants during sleep.

	Mean	Std. Dev.	min	Percentile 25th	Percentile 50th	Percentile 75th	max
NO_2 (ppb)	5.7	5.9	0.2	1.7	3.4	7.1	30.2
VOCs (ppb)	187.7	80.9	84.1	146.7	166.2	204.0	445.9
PM_{10} ($\mu g \cdot m^{-3}$)	24.5	26.0	3.9	7.1	11.0	36.4	99.4
$PM_{2.5}$ ($\mu g \cdot m^{-3}$)	5.0	4.0	2.0	2.3	2.8	7.1	19.5

NO_2: 10 ppb (WHO standard)
VOCs: 600 ppb (Portuguese standard)
PM_{10}: 15 $\mu g \cdot m^{-3}$ (WHO standard)
$PM_{2.5}$: 5 $\mu g \cdot m^{-3}$ (WHO standard)

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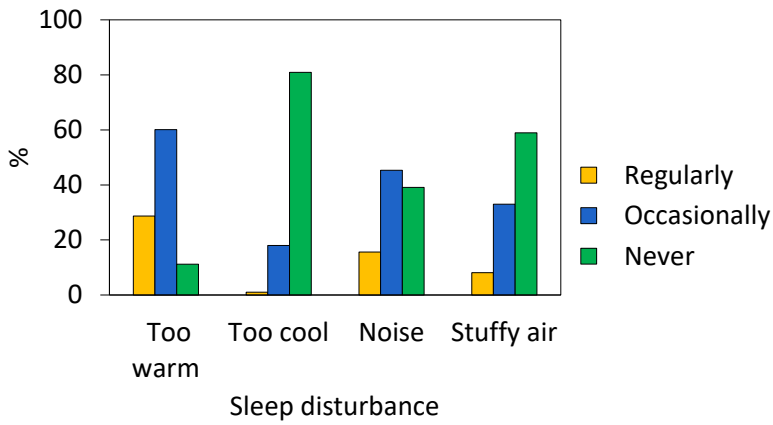
A QUESTIONNAIRE SURVEY



Incidence of sleep disturbance caused by noise, stuffy air, and thermal discomfort experienced in bedrooms.

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Targeted and non-targeted compounds:

19 compounds: 2 TC + 17 NTC
[258 compounds: 43 TC + 215 NTC]

	Time in bed	Time asleep	Sleep efficiency	Sleep latency	Light sleep (min)	Deep sleep (min)	REM sleep (min)	Light sleep (%)	Deep sleep (%)	REM sleep (%)	Time awake DS (min)	Strong odor BS	Strong odor AS	WADO	CO_2 BS
TC23				-0.41		-0.38			-0.38						0.42
TC29						-0.36									0.48
NTC19			-0.43									-0.36			
NTC22											0.35				-0.35
NTC29										0.36		0.38			
NTC49							0.44			0.42				-0.35	
NTC56				0.36									0.39		
NTC63				0.35									0.36		
NTC69						0.39			0.36						-0.45
NTC81			-0.38										0.37		
NTC88					-0.39			-0.34					0.52		
NTC90			-0.37								0.36		0.35		
NTC97					-0.42			-0.35					0.45		
NTC117				0.38										-0.43	
NTC122								-0.37						-0.35	
NTC138				0.36											-0.47
NTC164				0.37			0.41							-0.35	
NTC168				0.42		0.37							0.35		
NTC205					-0.43			-0.36	0.38				0.41		

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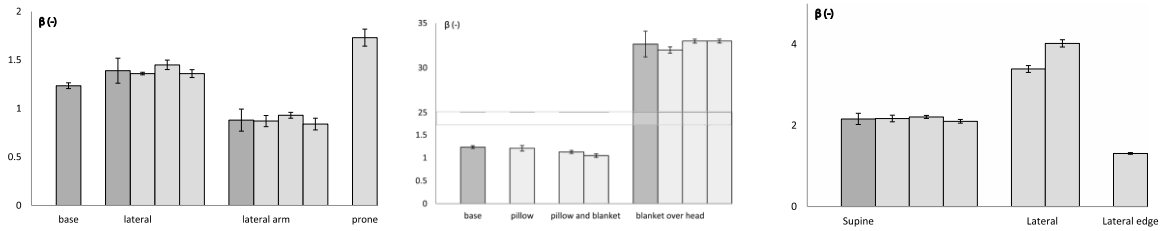
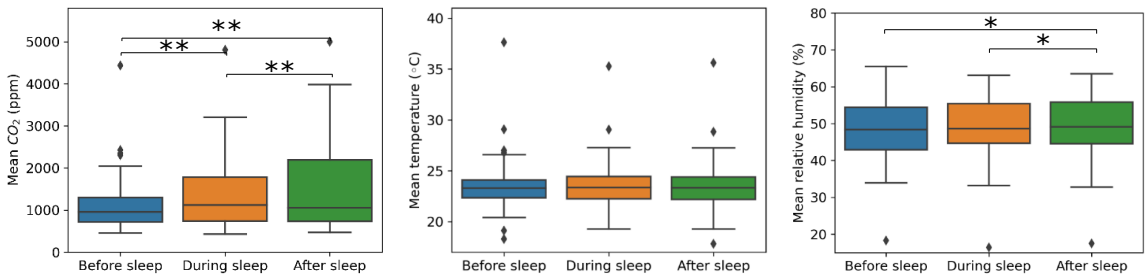
Sleep quality and sleep-related ventilation factors:





Distribution of CO_2 level, mean temperature, and relative humidity before, during, and after sleep. The diamond indicates outliers.
** p-value < 0.05, ** p-value < 0.01.*

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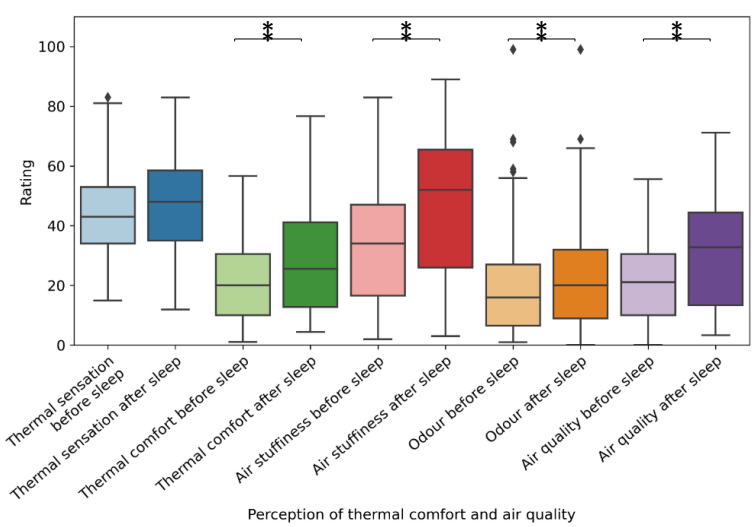

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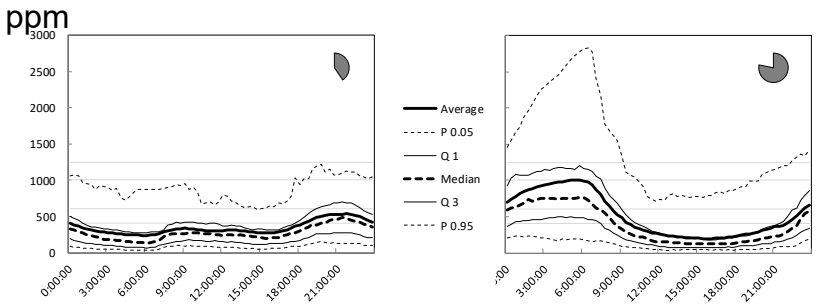
*Distribution of the perception of thermal comfort and air quality before and after sleep. IEQ, indoor environmental quality. The diamond indicates outliers. ** p-value < 0.01.*



Living room exposure to carbon dioxide

Bedroom exposure to carbon dioxide

VENTILATION AS STRATEGY

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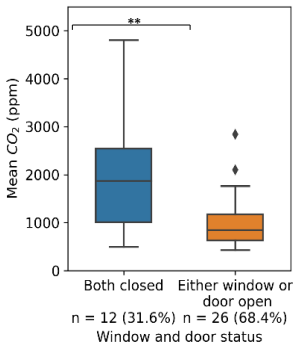
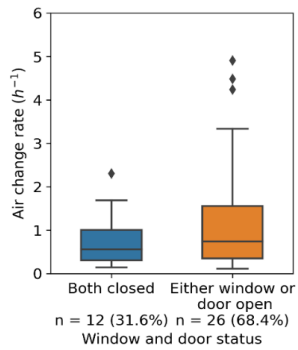


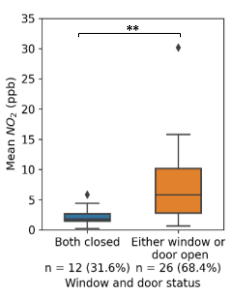
Mean CO_2 levels between two "window and door status" during sleep.
** *p*-value < 0.01.



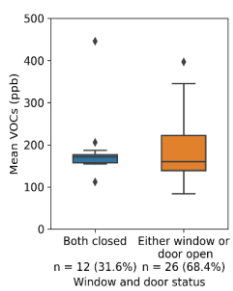
Air change rate between two "window and door status" during sleep.

Results

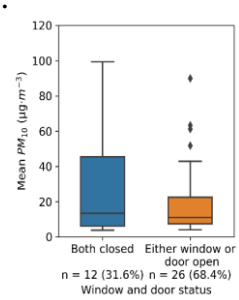
A.



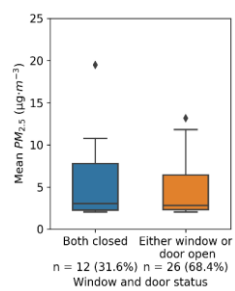
B.



C.

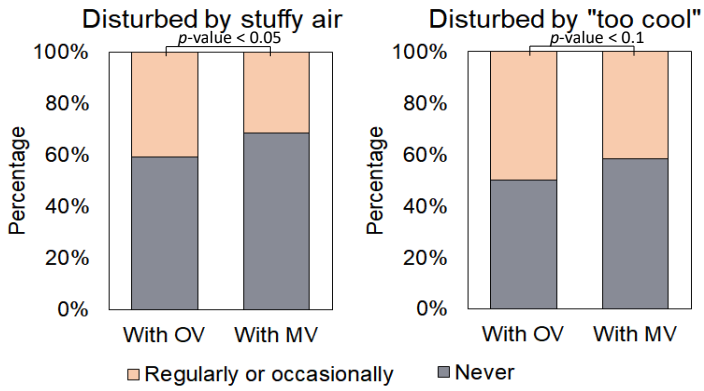


D.



Mean levels of indoor pollutants during sleep between two "window and door status".
A, NO_2; B, VOCs; C, PM_{10}; D, $PM_{2.5}$.
NO_2, nitrogen dioxide; VOCs, volatile organic compounds; PM, particulate matter.
** *p*-value < 0.01.

A QUESTIONNAIRE SURVEY



Mechanical ventilation in bedrooms reduced responses of being disturbed by stuffy air or "too cool" conditions during sleep.
MV, mechanical ventilation; OV, other ventilation including exhaust ventilation and natural ventilation.

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RELEVANT METRICS

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HEALTH

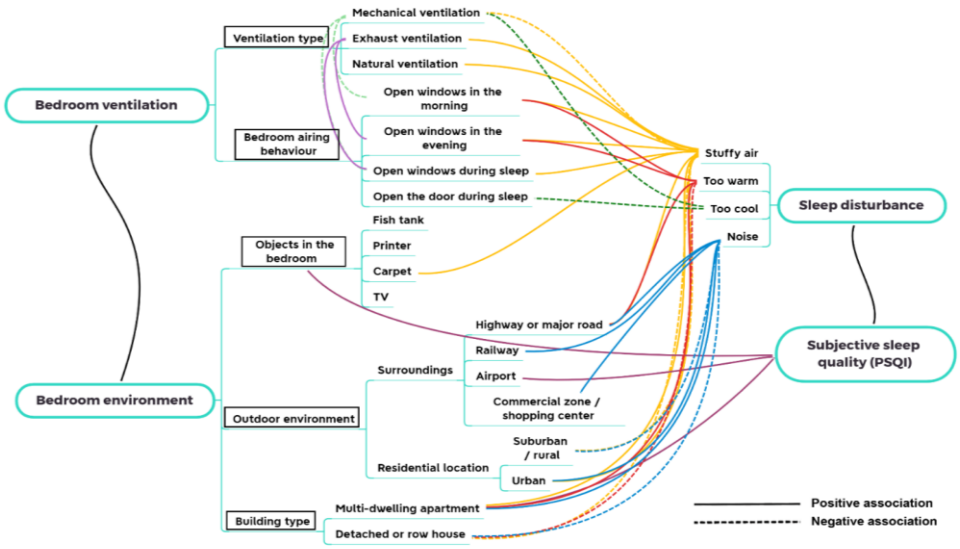
- Take into account the increased exposure compared to well mixed assumption

HEALTH & WELLBEING

=> Impact on sleep

- Impact of perceived air quality?

A QUESTIONNAIRE SURVEY



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HEALTH & WELLBEING

=> Impact on sleep

- Impact of perceived air quality?
- Avoiding disturbances

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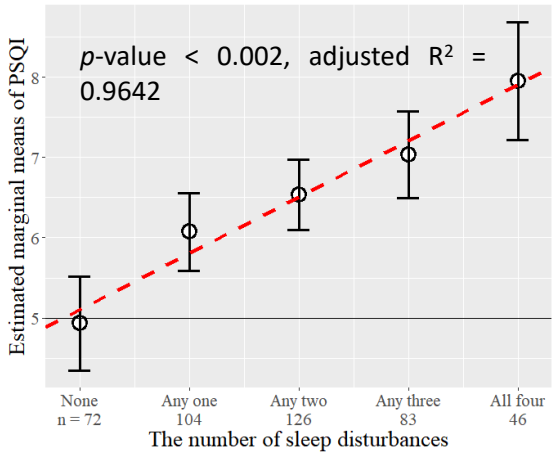
A QUESTIONNAIRE SURVEY



PSQI increased with an increased number of sleep disturbances. Sleep disturbances include stuffy air, noise, too warm, and too cool (max four min zero). The results were adjusted by chronic disease, exercise, age of the youngest child living at home, sleep habits and BMI. Error bars represent 95% confidence intervals of the estimated marginal means of the PSQI scores.

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Sleep quality cost

Assumptions

- Many factors influence sleep quality
- Litterature may have divergent opinions
- Sleep quality is hard to quantify from environmental parameters only

→ Improving sleep quality only from ventilation related parameters is complex

→ Detection of bad environment for sleep quality is possible

all bad conditions gathered → probability of sleep disturbance is 1

$$Sleep\ quality = \sum_1^n \frac{k_i w_i}{n}$$

Sq ≤ 0 →good

0 < Sq ≤ 1 → probably bad

Sq ≥ 1 → bad for sure

Good/ Probably good | Neutral/ Uncertain | Bad/ Probably bad | Bad for sure

-1 | 0 | 1 | 2n-1

	Coefficient	Good (-1)	Neutral (0)	Probably bad (1)	Bad (2n-1=3)
T (°C)	0,0447		17-28	<17 or >28	
H° (%)	0,0447		40-60	<40 or >60	
CO2 (ppm)	0,0351		750-1150	1150-2600	2600
Noise (dB)	0,0319			35	

From assessment to health cost

- Translation, from sleep disturbance issue to DALY
  - Equivalent of DALY lost per issue
  - Probability of issue with & without sleep disturbance
  - Cost induced/issue

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HEALTH & WELLBEING

=> Impact on sleep

- Impact of perceived air quality?
- Avoiding disturbances
- Improving sleep quality in healthy subjects

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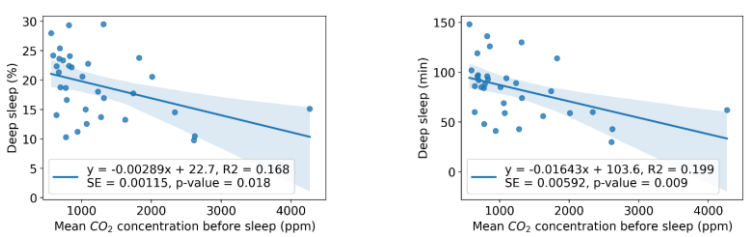

The regression line between mean $CO_{2\text{-bs}}$ concentration and deep sleep (%, min).

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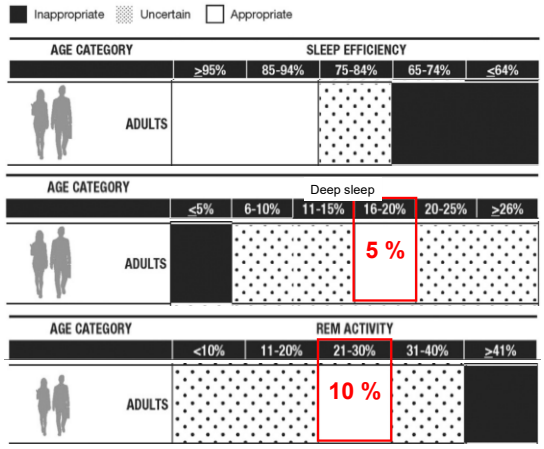
Deep sleep (min, %) in association with $CO_{2\text{-bs}}$ concentration.

Item	Beta (95% credible interval)[a]	R^2 (Q2.5 - Q97.5)
Deep sleep (%)		
$CO_{2\text{-bs}}$ concentration (/1000 ppm)	-2.9 (-5.3 – -0.5)	0.176 (0.006 – 0.376)
Deep sleep (min)		
$CO_{2\text{-bs}}$ concentration (/1000 ppm)	-16.3 (-32.3 – 0.3)	0.201 (0.003 – 0.438)

[a] analyzed by the Bayesian linear regression with the prior distribution of N(0,10).

Sleep quality

American National Foundation (2017)



Statistical description of sleep parameters

Item	mean ± std.	min	25%	50%	75%	max
Sleep efficiency	88.2 ± 2.3	84.3	86.6	88.5	89.5	93.1
Deep sleep (%)	16.9 ± 4.8	6.0	13.7	17.2	20.9	24.8
REM sleep (%)	21.9 ± 5.3	12.6	17.5	23.1	25.3	32.5

Fraction of appropriate ranges

Item	below|appropriate|above
Sleep efficiency	6 (16%) | 32 (84%) | 0
Deep sleep (%)	16 (42%) | 10 (26%) | 12 (32%)
REM sleep (%)	14 (37%) | 21 (55%) | 3 (8%)

UNKNOWNS

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WHAT WE DON'T HAVE (YET)

- Good, conclusive data that supports robust assumptions on correlations between environmental factors and sleep (both disturbances and quality)
- Good conclusive data on the longterm effect of moderately reduced/improved sleep quality for healthy people
- Mechanistic understanding of observed correlations

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