



AMCA International

#4 Lunch and Speaker

Pawel Wargocki

Assoc. Prof., DTU, Kgs. Lyngby, Denmark

paw@byg.dtu.dk



Air System Engineering & Technology (ASET) Conference-Europe

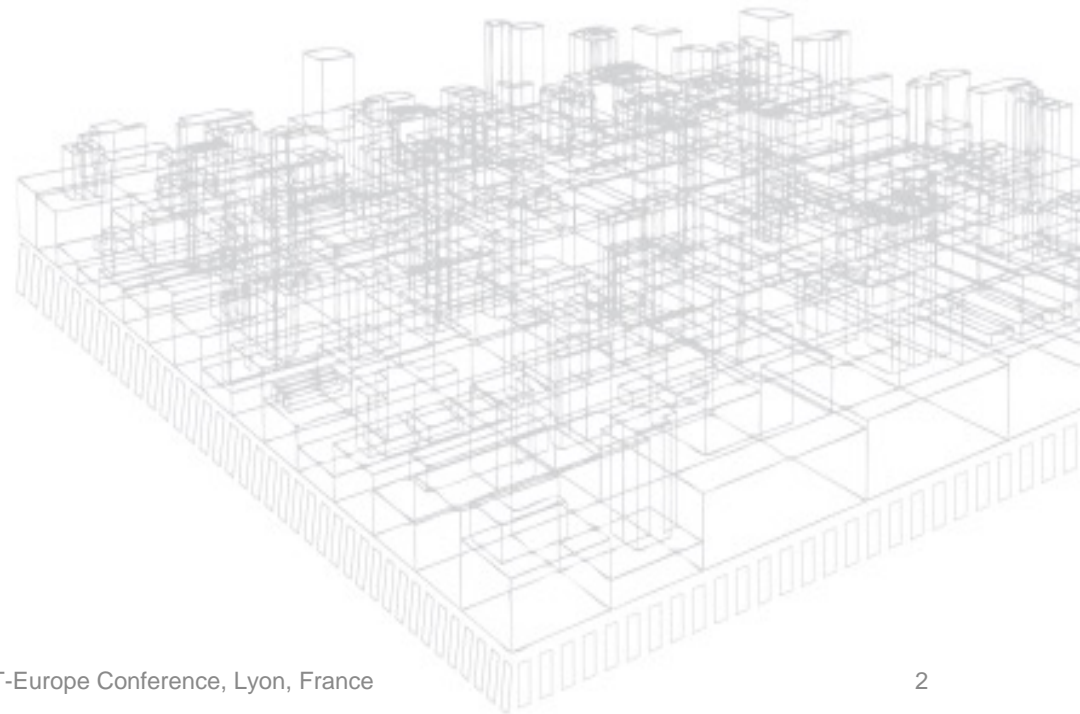
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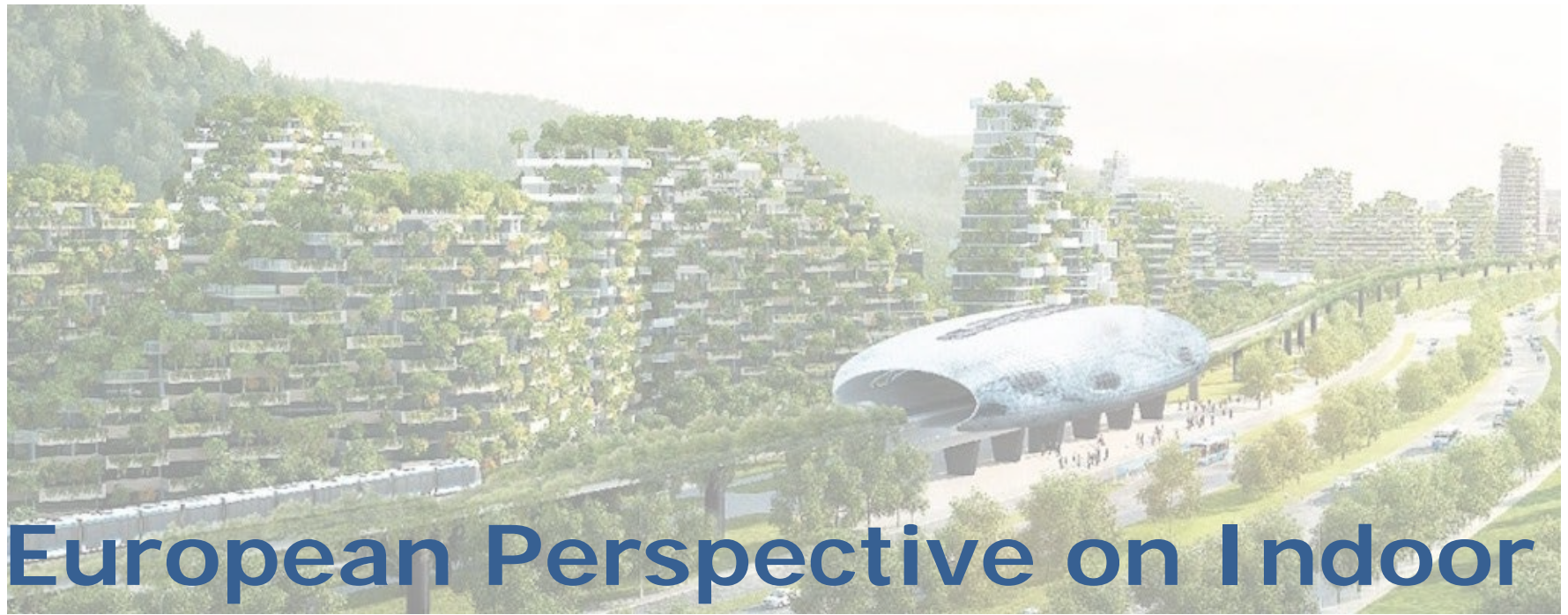
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Learning Objectives

- Learn how IEQ affects health, wellbeing and cognitive performance
- Learn what are the potential challenges that built environment will face in the future with respect to IEQ and changing climate
- Learn whether green buildings improve IEQ
- Learn whether CO₂ in built environment is toxic?
- Learn how ventilation requirements for reducing health risks should be defined
- Learn whether bedroom IEQ affects sleep quality



European Perspective on Indoor Environmental Quality (IEQ)

Pawel Wargocki



International Centre for Indoor Environment and Energy
Department of Civil Engineering
Technical University of Denmark



Synopsis

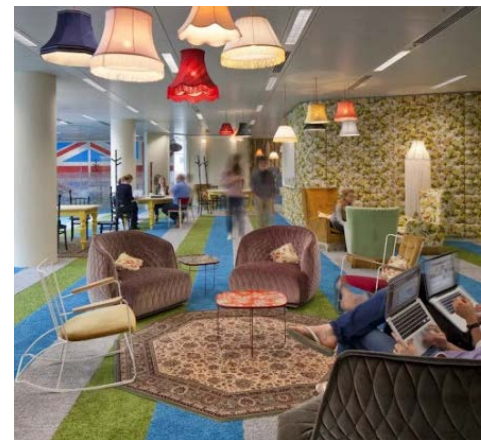
Research shows that exposure to poor air quality has negative effects for health, productive work and efficient learning. These effects reduce quality of life and can result in considerable economic losses.

This talk will summarize projects that studied the quality of air in relation to sleep quality and the next day performance, performance of green buildings, importance of CO₂ and human bioeffluents and means for involving participation of building occupants. A framework for revising current ventilation guidelines will be outlined.

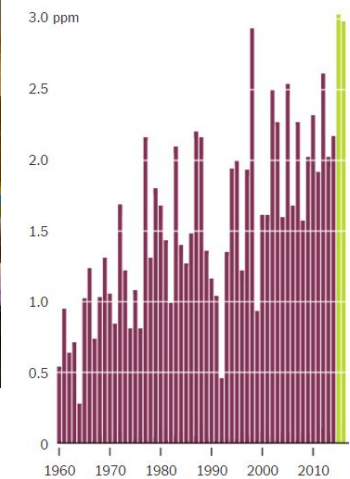
New challenges will be defined and addressed.

What has happened in the last 30 years (or actually a decade)?

- CO₂ outdoors increased by ca. 60 ppm (now nearly @410 ppm)
- Earth temperature increased by nearly 1K
- Ozone about 20 ppb
- No ETS in public spaces
- Energy and green buildings set out the agenda for research
- Building certification schemes are flourishing (>30)
- Energy use nearly doubled
- Offices/indoor spaces are designed differently ("active office" design)
- IT is ubiquitous, on-line access to sensing technology: all-can-measure



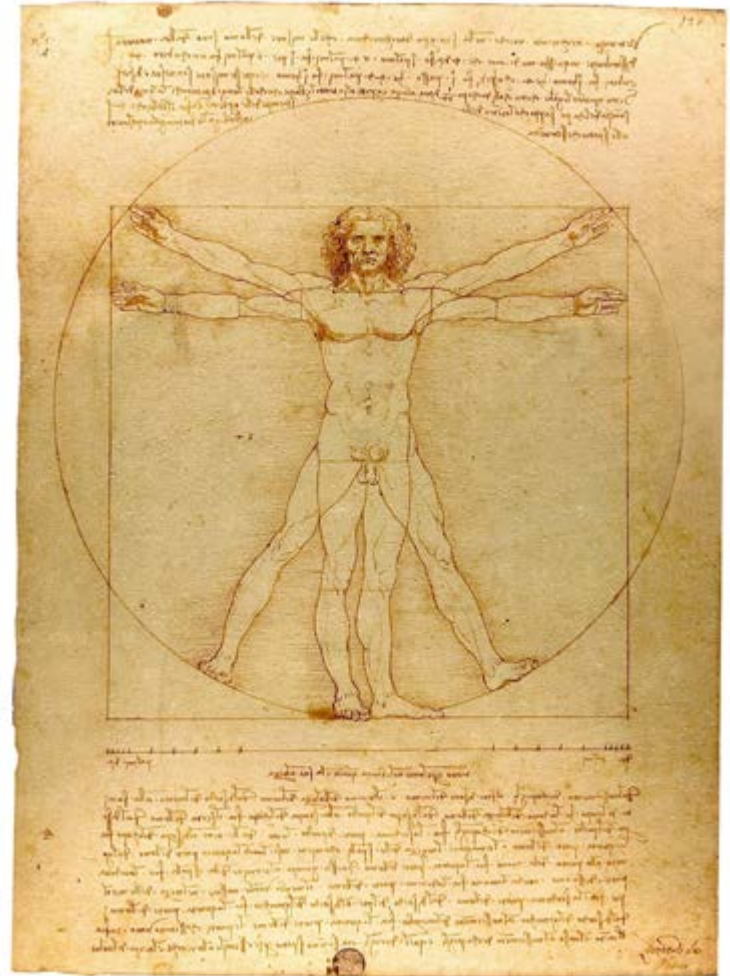
Atmospheric Carbon Dioxide Rose At Record Rate in 2015 and 2016
Annual mean growth rate of CO₂ in Mauna Loa, Hawaii



Source: NOAA

Motivation for this talk

- Building sector is under transformation
- Focus is on energy
- Focus should be on humans in buildings
- People use energy, not buildings and influence IEQ to a much larger extent than anticipated
- There are significant consequences of not considering buildings as promoting IEQ that outweigh considerably the energy savings



WGBC (2014)

A framework for organisations is:
to measure how their building impacts on their most valuable asset, their employees



Health, Wellbeing & Productivity in Offices

The next chapter for green building
Key Findings

September 2014

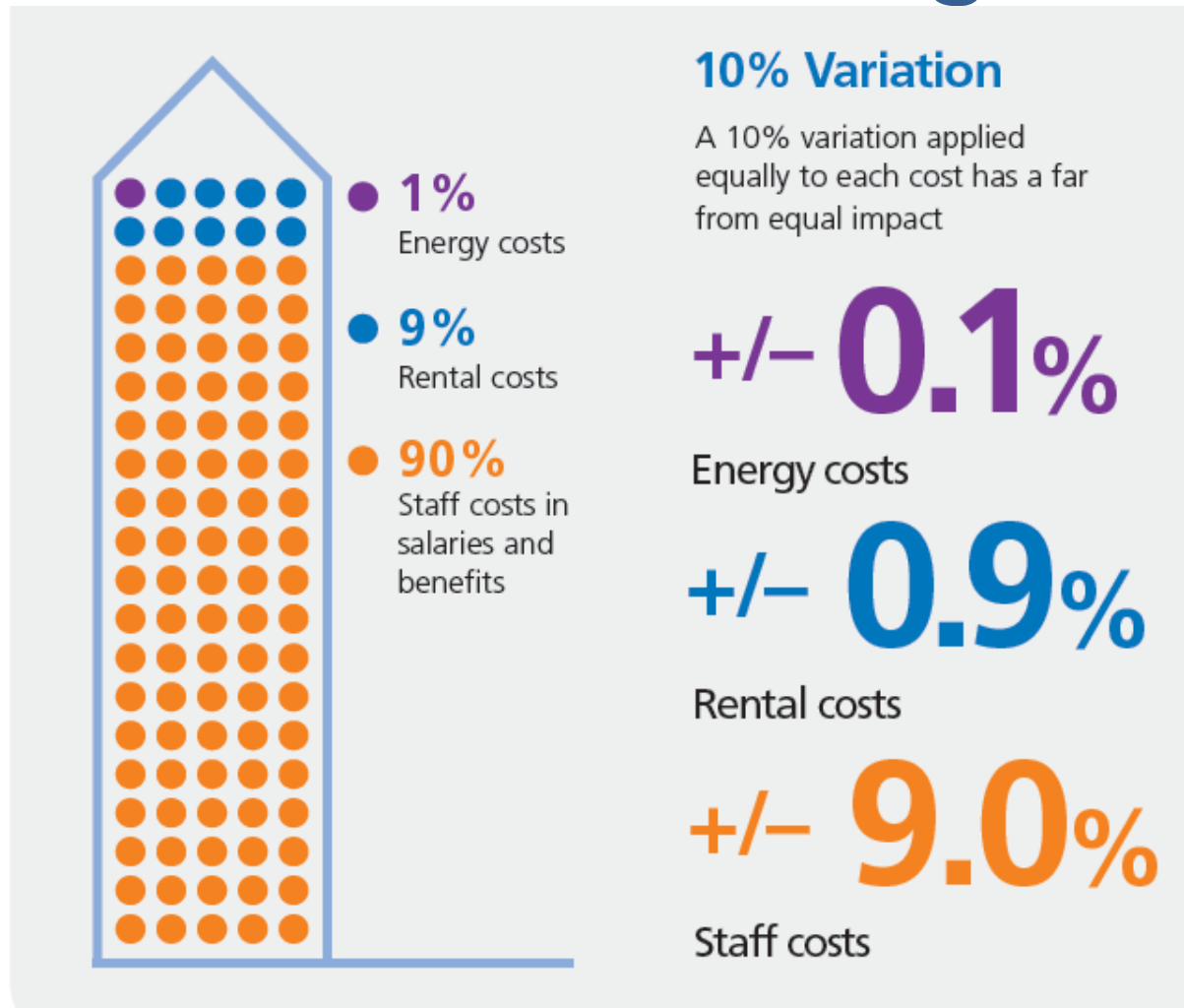
Sponsors



SKANSKA



Modest gains in staff health and wellbeing can deliver significant financial savings



IEQ is strongly associated with work performance

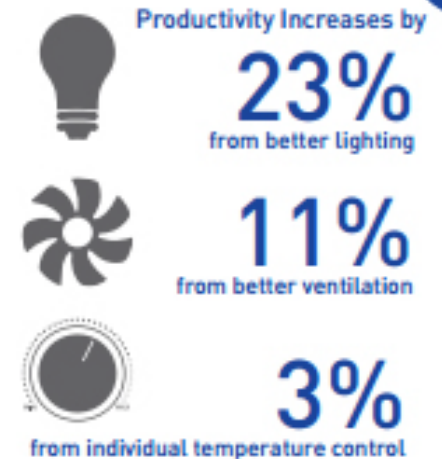
OUTSIDE VIEWS



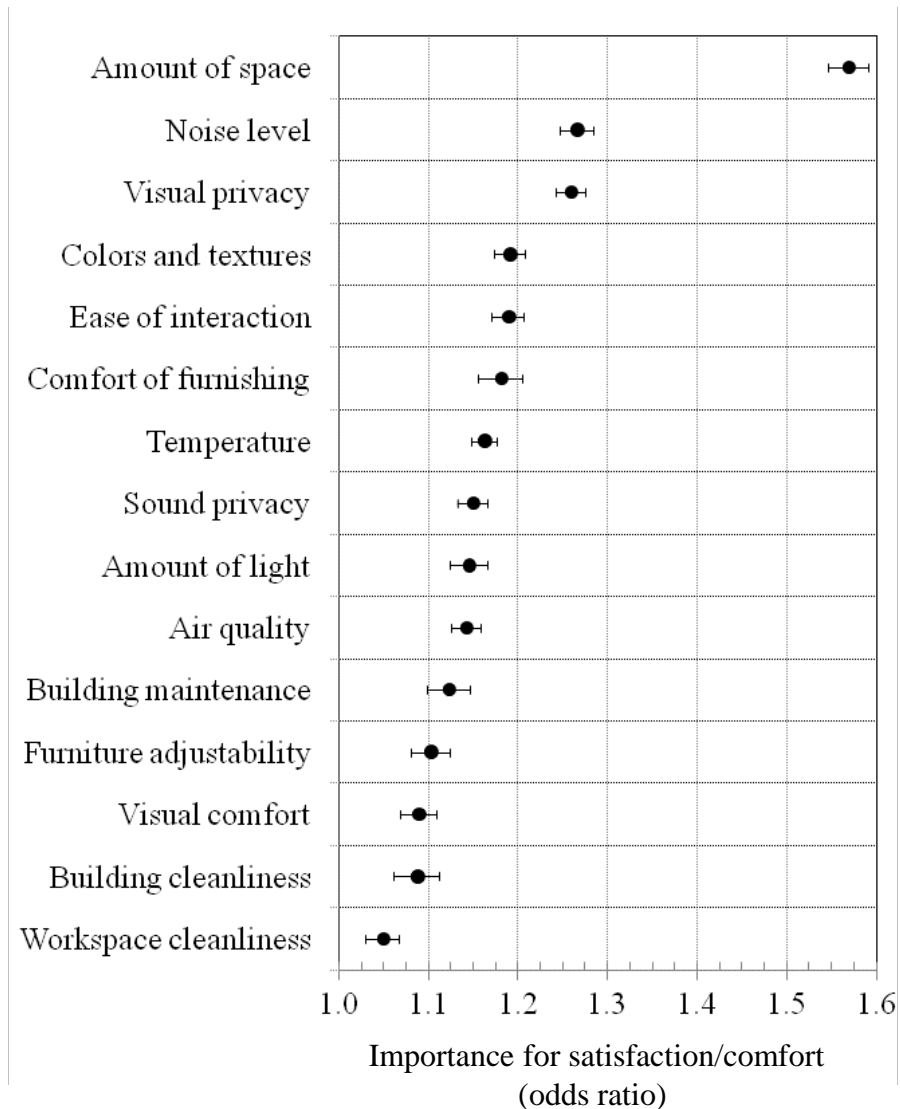
DAYLIGHT



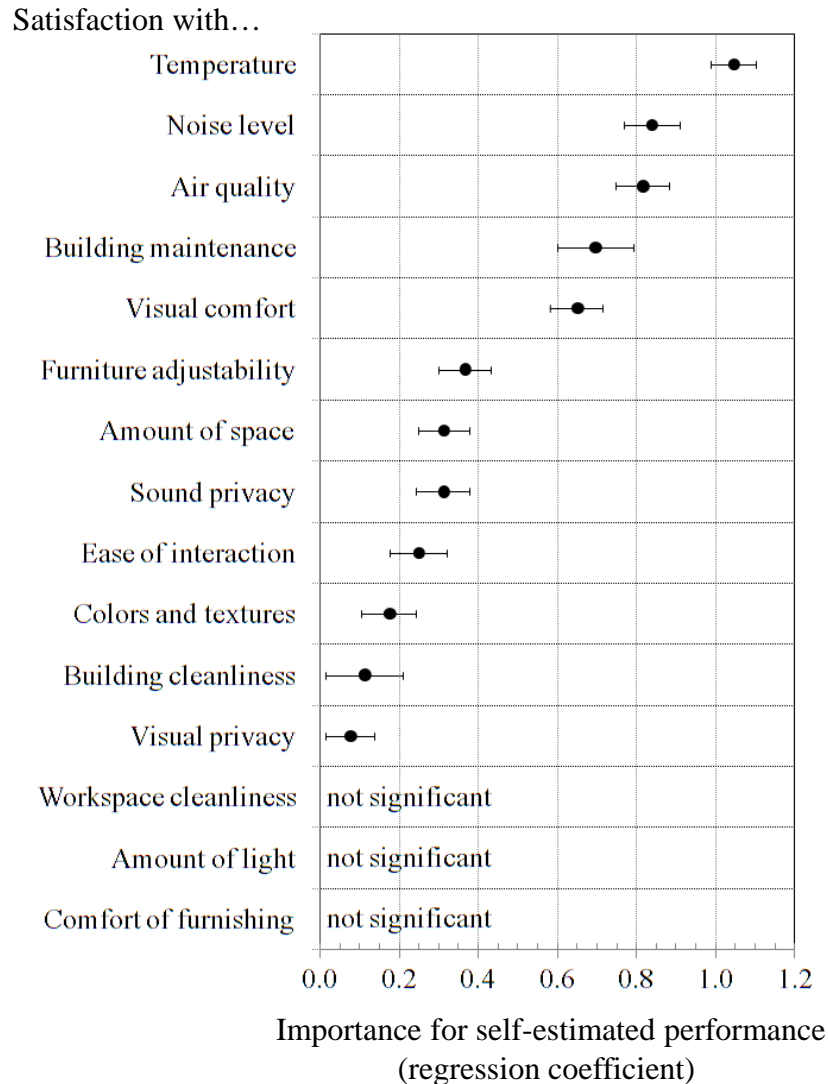
SYSTEMS



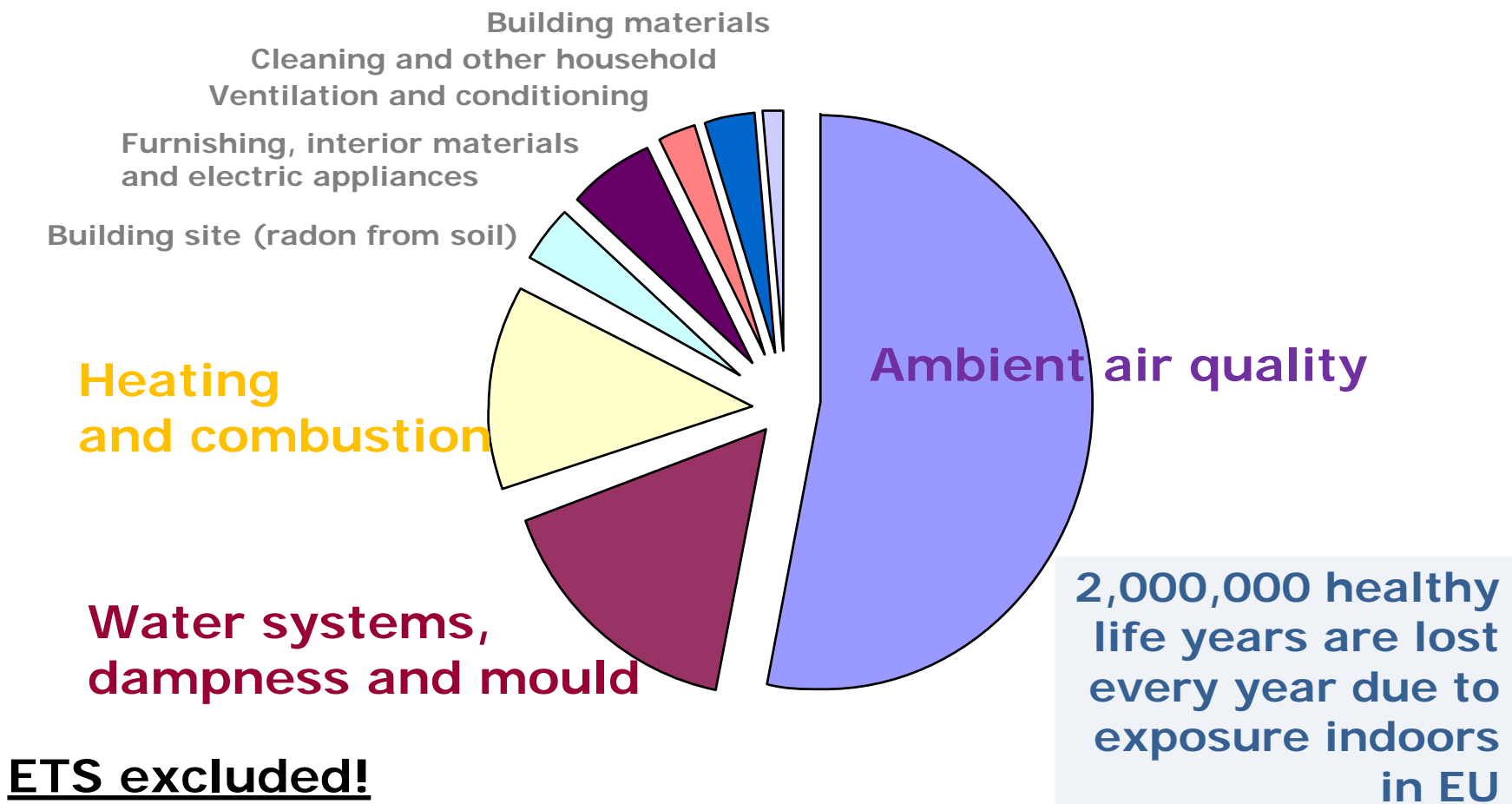
Building features are important for satisfaction



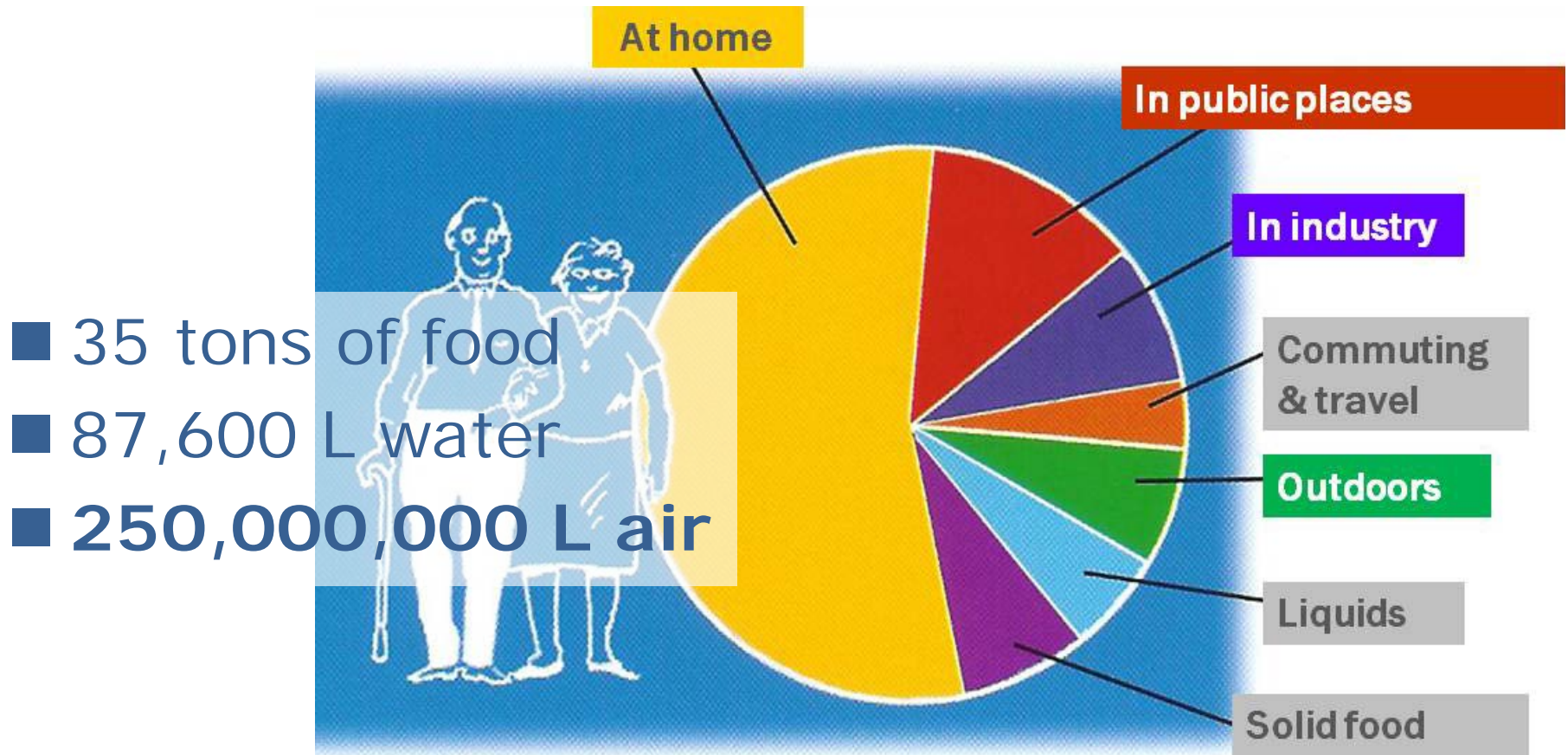
Satisfaction w/IEQ important for work performance (rated by occupants)



Exposure INDOORS is a significant determinant of population health

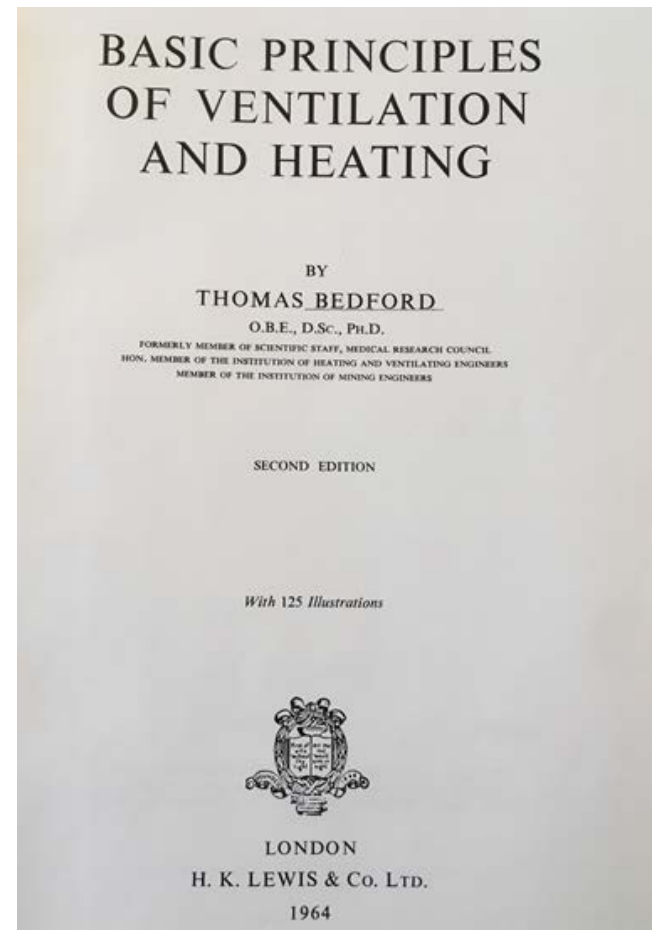


Indoor air is significant contributor to life-time exposures



“great care is devoted to ensuring that we have a pure water supply and no one would suggest that in the interest of economy we should be doomed to drink polluted water;

on aesthetics ground alone it should be one’s right to be allowed to live and work in a clean atmosphere which is free from objectionable odours”

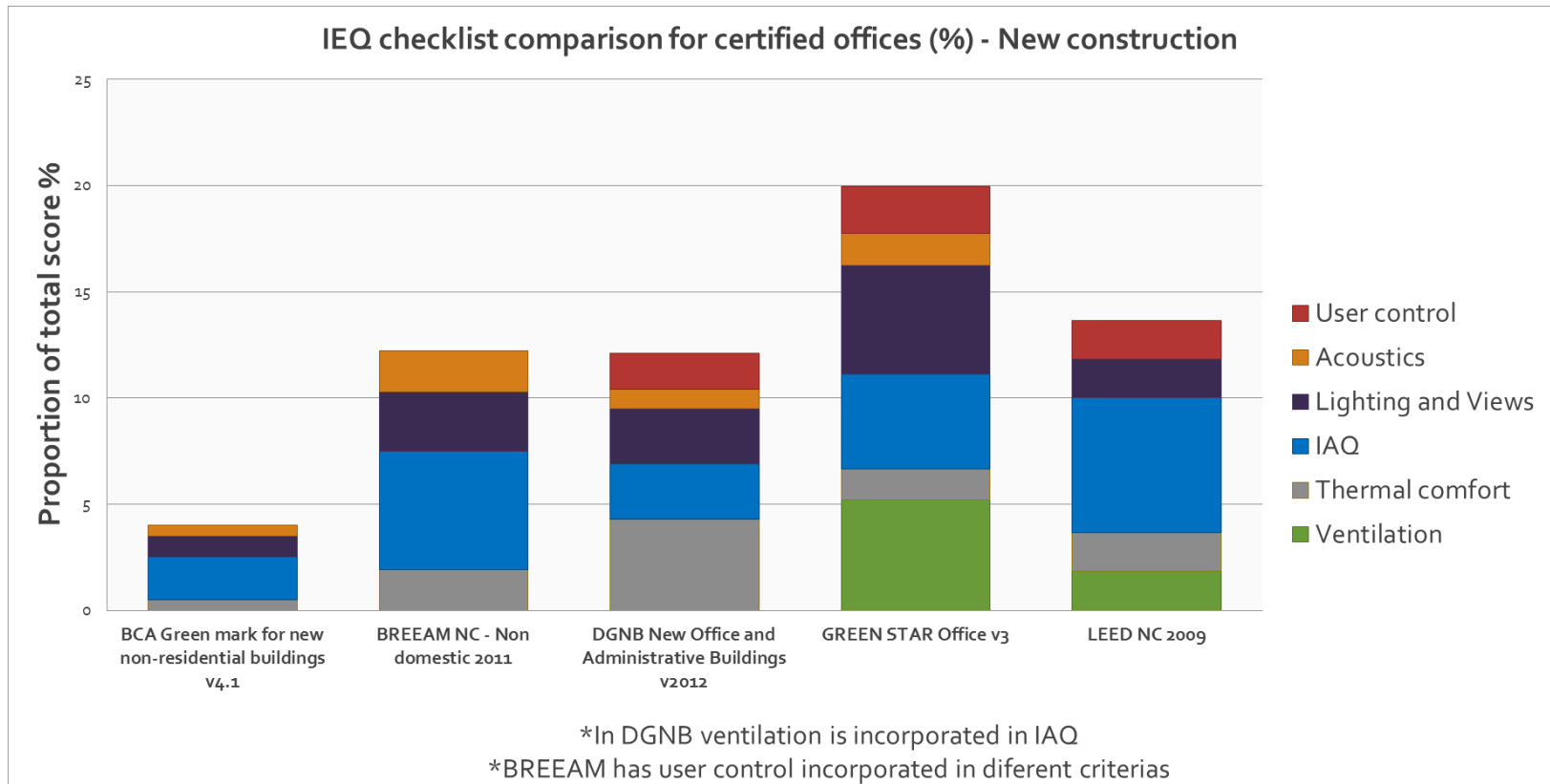


Some relevant questions that need answers here and now

- How do green buildings perform with respect to IEQ?
- What about human emissions, CO₂ and other human bioeffluents? Are they toxic?
- Is bedroom IEQ (temperature/air quality) important for our sleep quality?
- How should ventilation requirements for reducing health risks should be defined?

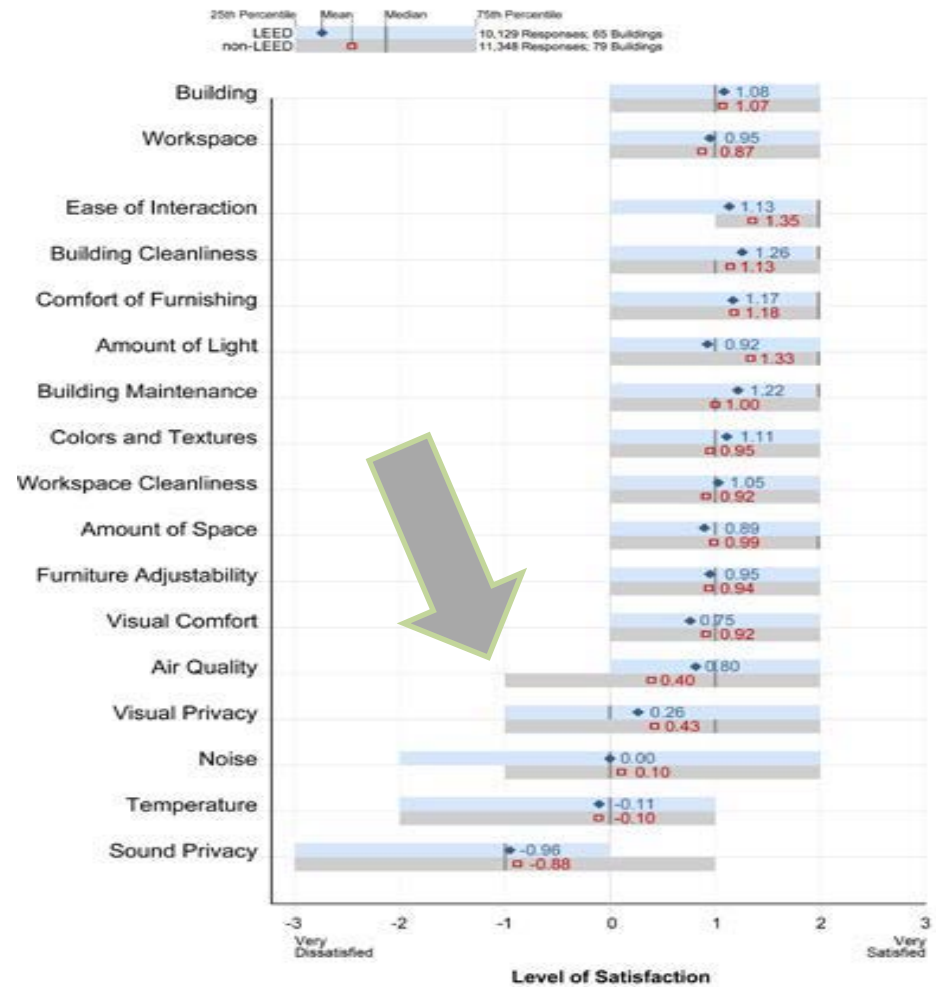
Certification schemes

IEQ credits



IAQ criteria reviewed in [31 certification schemes](#), the average contribution of IAQ to green building schemes worldwide is 7.5% (Source: Wei et al., 2015)

- 144 buildings (65 LEED certified)
- No significant influence of LEED certification on occupant-rated satisfaction with IEQ
- Occupants of LEED buildings tend to be slightly more satisfied with IAQ and more dissatisfied with amount of light



Performance of certified buildings with respect to IEQ

- 37 peer-reviewed papers
- 12 white papers or corporate/governmental reports/studies
- 15 only from green buildings and 24 by comparing green and non-green buildings
- Mostly post-occupancy evaluations of IEQ or subjective responses by occupants with limited data on physical measurements
- Subjective ratings: satisfaction(comfort) with IEQ, also acute health symptoms (and absence rates) and self-estimated performance

Objective data, physical data, stakeholders valuation



Objective Data n=8	Productivity Absenteeism	Mostly cohort studies (Pre/Post-Occupancy). θ Values are the same or better, in most of the case studies. Sick leave reduction estimated to be between 5%- 39% (n=1 increase of absenteeism). No information whether effects remain after years of working or are temporary.
Phyc. Data n=10	Measured IEQ	$\oplus\theta$ Overall measured IEQ parameters in green building are in the range recommended by building codes/standards, less departures than in conventional buildings. Sporadic cases of temperature departures.
Stakeholders valuation	Appraisal	Online surveys, interviews, and annual barometers show that green buildings are perceived by tenants to help improving productivity, recruitment and retention of employees. Practitioners draw attention to the uncertainty about the size of productivity and health benefits. Stakeholders perceive the lack of documentation on IEQ payback values and long-term benefits are still a barrier.

Subjective assessments



Overall IEQ	<p>⊕ High satisfaction with greenery, design, views and openness of the space. Daylight improved (n = 10)</p> <p>⊖ On average green superior to conventional buildings. After a move or retrofit, overall IEQ rated higher in green buildings (n=20).</p>
IAQ	<p>⊖ In most cases IAQ rated high in green buildings compared with the conventional buildings (n=20).</p>
Comfort	<p>⊖ On average green buildings rated better in questions related to the overall comfort scores (n=21).</p>
Health	<p>⊕⊖ Generally improved self-reported acute health symptoms (n=15). No studies where green buildings scored low on health.</p>
Self-estimated productivity	<p>⊕⊖ Generally improved in green buildings (n=14) (n=3 reverse effect). Self-estimated productivity strongly correlated with subjectively assessed health and comfort. Effects estimate between 2% and 16%.</p>
Tolerance	<p>⊖ Collected data suggest that occupants are more tolerant, engaged and forgiving to inadequate IEQ (e.g. temp.) in green buildings compared to conventional buildings (n=8), at least after moving to such building. Whether this “affection” remains longer or is temporary is unclear.</p>
Satisfaction	<p>⊕⊖ Green buildings achieve better satisfaction scores when occupants are committed with sustainability, and proud of their workplace. Premium location and outside views may also influence perceptions.</p>

Subjective assessments



Personal Control	⊕ Lack of controls is one of the main causes for discomfort. There is no tendency in the results when compared with conventional buildings.
Thermal	⊕ Overheating, overcooling and draft are reported (n=8) but in (n=15) of studies, occupants have been satisfied. Results suggest that complaints are mostly the result of preferences and the facility management.
Lighting	⊕ ⊖ Acoustic and lighting environment are frequently characterized as comparable as or worse than conventional buildings, especially in case of the open-plan offices where excessive noise and lack of privacy affecting concentration. Dissatisfaction with glare, bad layout design, and low light controls is also reported in green buildings (n=17). Users are commonly more dissatisfied with these parameters above compared with conventional buildings.
Glare	
Acoustics	

Satisfaction with IEQ, Singapore case

6 NonGreen Mark Office Buildings

Buildings

Construction: 1969-2011

GM credit (hypothetical): 16-26 of 67

Gross floor area >2,000 m²

1 floor with min 30 employees

Usually CAV, MERV4, no CO₂ control

6 Green Mark Office Buildings

Gold-Platinum

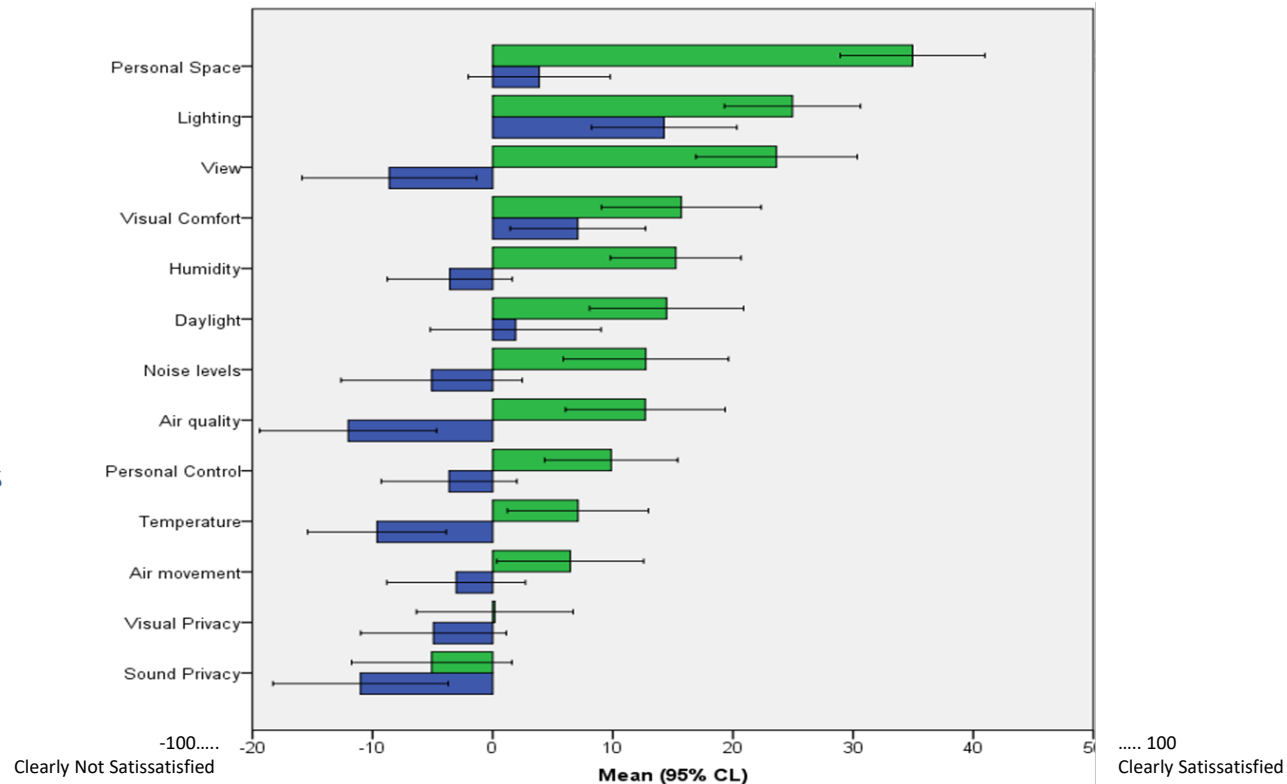
Construction: 1995-2011

GM credit (IEQ): 43-55 of 67

Gross floor area >2,000 m²

1 floor with min 30 employees

Usually VAV, MERV13, CO₂ control



Do ‘green’ buildings have better indoor environments? New evidence

Guy R. Newsham¹, Benjamin J. Birt², Chantal Arsenault¹, Alexandra J. L. Thompson¹, Jennifer A. Veitch¹, Sandra Mancini¹, Anca D. Galasiu¹, Bradford N. Gover¹, Iain A. Macdonald¹ and Gregory J. Bums¹

¹National Research Council Canada, 1200 Montreal Road, Building M24, Ottawa, ON K1A 0R6, Canada
E-mails: guy.newsham@nrc-cnrc.gc.ca, chantal.arsenault@nrc-cnrc.gc.ca, alexandra.thompson@nrc-cnrc.gc.ca, jennifer.veitch@nrc-cnrc.gc.ca, sandra.mancini@nrc-cnrc.gc.ca, anca.galasiu@nrc-cnrc.gc.ca, bradford.gover@nrc-cnrc.gc.ca, iain.macdonald@nrc-cnrc.gc.ca and greg.bums@nrc-cnrc.gc.ca

A post-occupancy evaluation (POE) of 12 green and 12 conventional office buildings across Canada and the northern United States was conducted. Occupants ($N = 2545$) completed an online questionnaire related to environmental satisfaction, job satisfaction and organizational commitment, health and well-being, environmental attitudes, and commuting. In each building on-site physical measurements at a sample of workstations ($N = 974$) were taken, including: thermal conditions, air quality, acoustics, lighting, workstation size, ceiling height, window access and shading, and surface finishes. Green buildings exhibited superior performance compared with similar conventional buildings. Better outcomes included: environmental satisfaction, satisfaction with thermal conditions, satisfaction with the view to the outside, aesthetic appearance, less disturbance from heating, ventilation and air-conditioning (HVAC) noise, workplace image, night-time sleep quality, mood, physical symptoms, and reduced number of airborne particulates. A variety of physical features led to improved occupant outcomes across all buildings, including: conditions associated with speech privacy, lower background noise levels, higher light levels, greater access to windows, conditions associated with thermal comfort, and fewer airborne particulates. Green building rating systems might benefit from further attention in several areas, including: credits related to acoustic performance, a greater focus on reducing airborne particulates, enhanced support for the interdisciplinary design process and development of POE protocols.

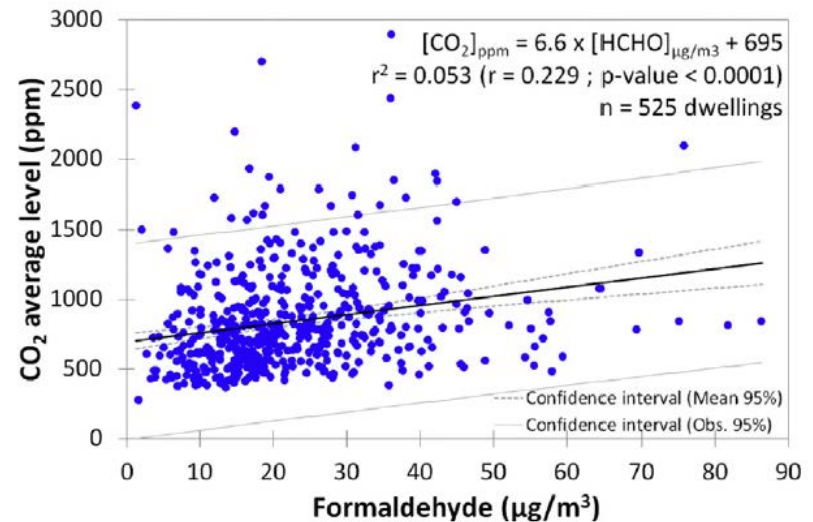
How does it compare with the use of energy?

- USA TODAY: LEED schools on average 2-3% more expensive (first cost) than conventional, up to 10%, and many schools use more energy
- Newsham et al. (2009): 100 LEED certified buildings; on average 18-39% less energy per floor area than the conventional counterparts but 28-35% LEED buildings used more energy and LEED certification buildings did not correlate with number of credits (level)

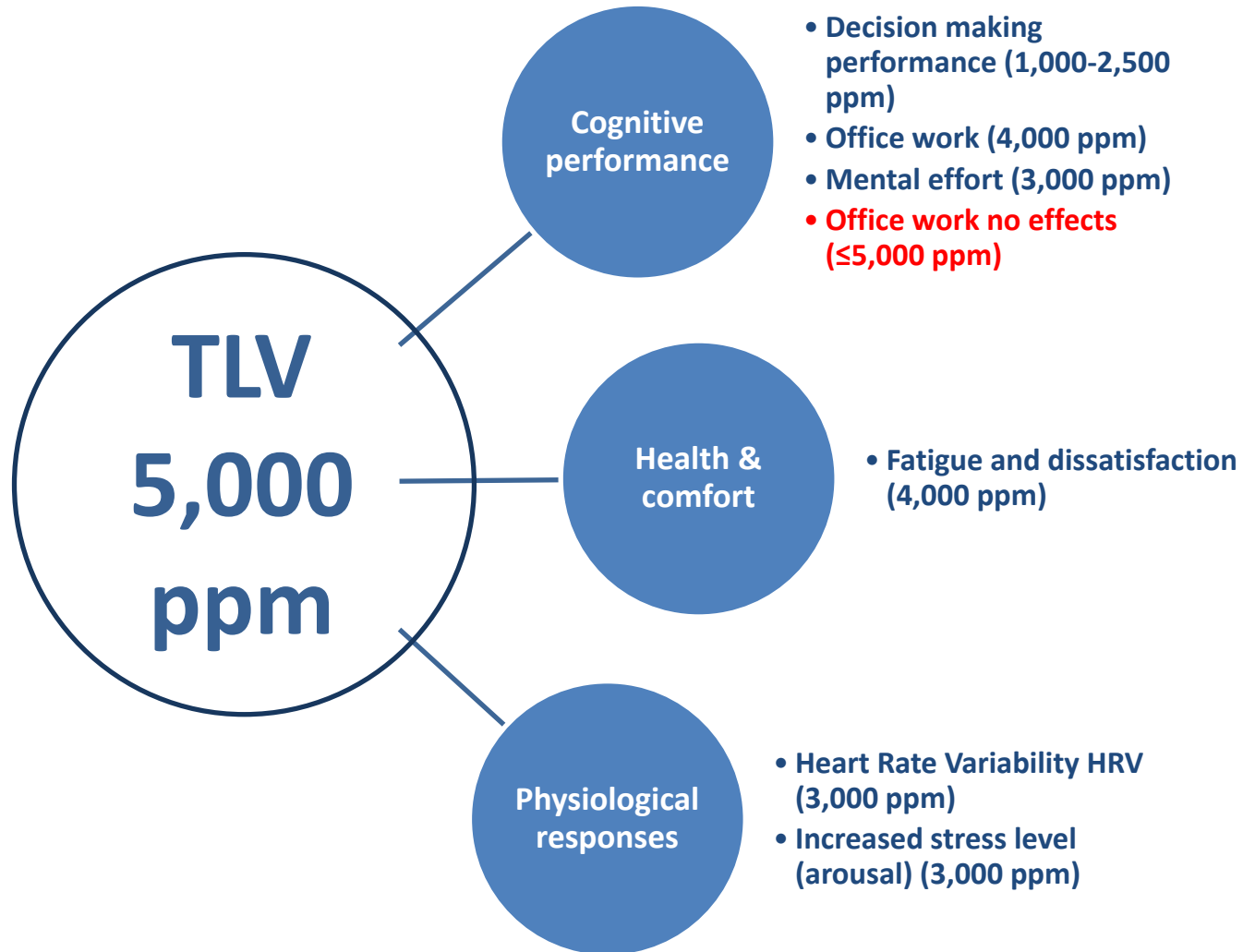


CO₂ - a marker of IAQ

- A marker of ventilation thus contains all pros and cons of ventilation
- Time effects, highly variable, often steady state assumed (nearly never reached)
- Requires assumptions regarding generation rates of CO₂ (metabolic rates), which are quite crude and affected by many factors mainly activity but, as recently shown, also thermal discomfort
- Correlation of CO₂ with indoor pollutants other than human bioeffluents is positive but weak

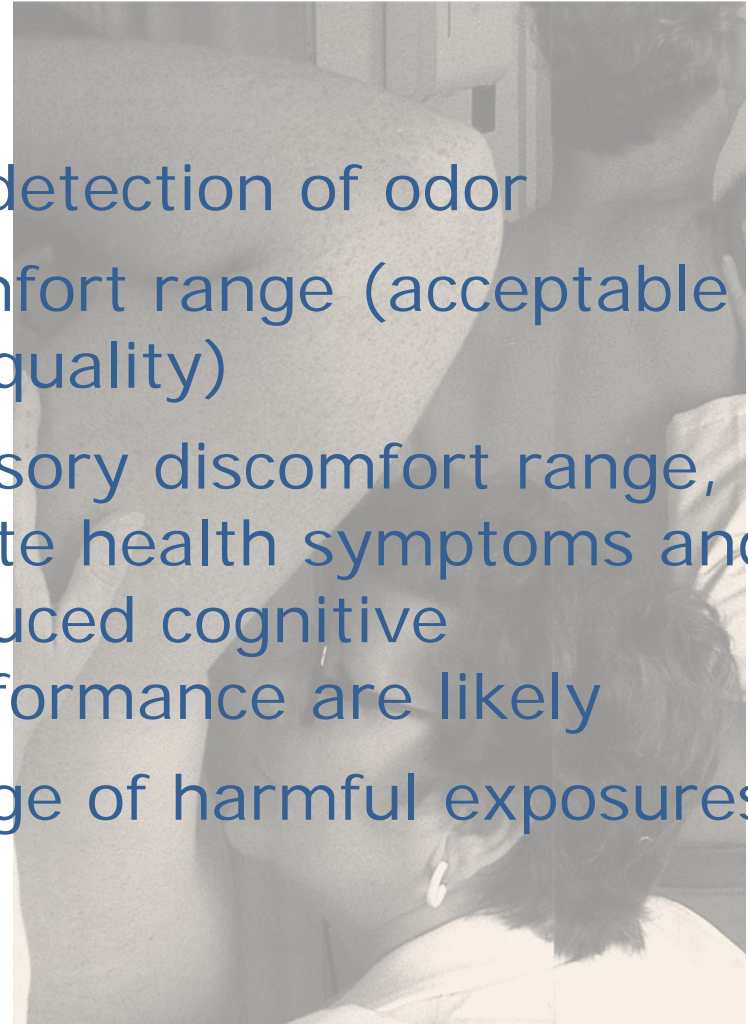


CO₂ - a pollutant



CO₂ – a marker of human bioeffluents

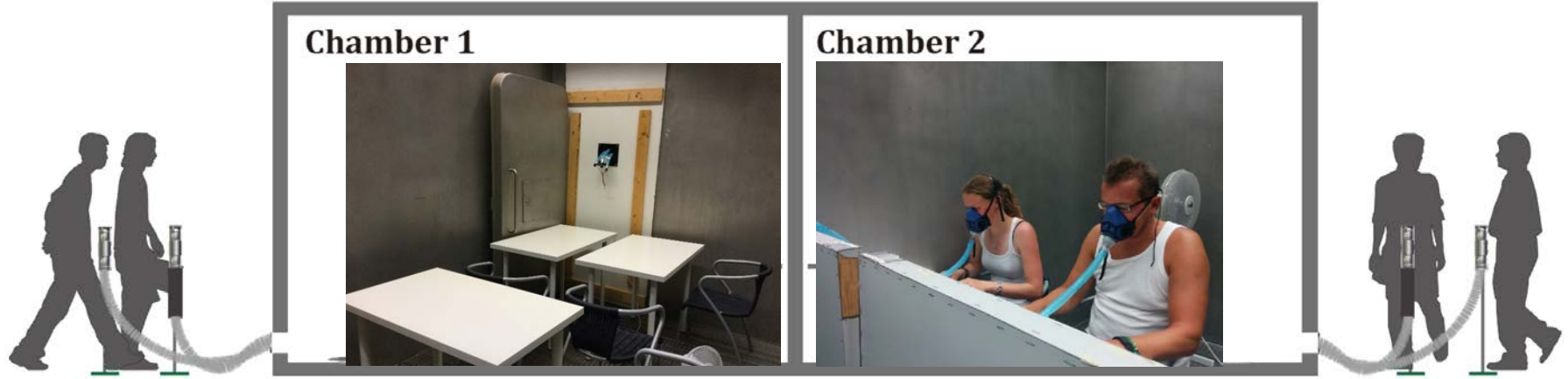
<500-600 ppm CO ₂ :	no detection of odor
<1,000 ppm CO ₂ (?):	comfort range (acceptable air quality)
1,600-3,000 ppm CO ₂ :	sensory discomfort range, acute health symptoms and reduced cognitive performance are likely
>3000 ppm CO ₂ :	range of harmful exposures



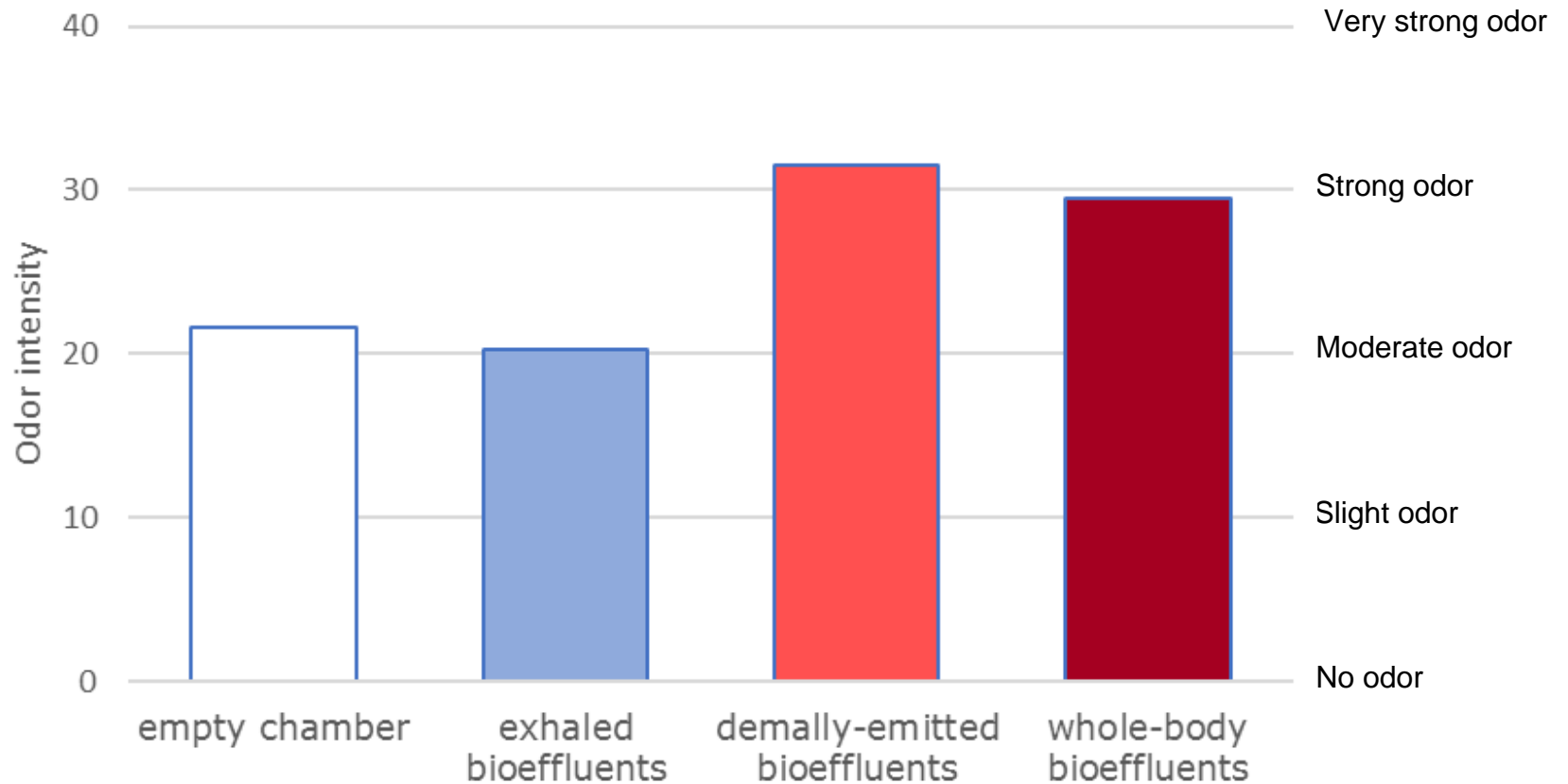
Disclaimer:
Excluding transmission of pathogens

Source: Zhang et al. (in the press)

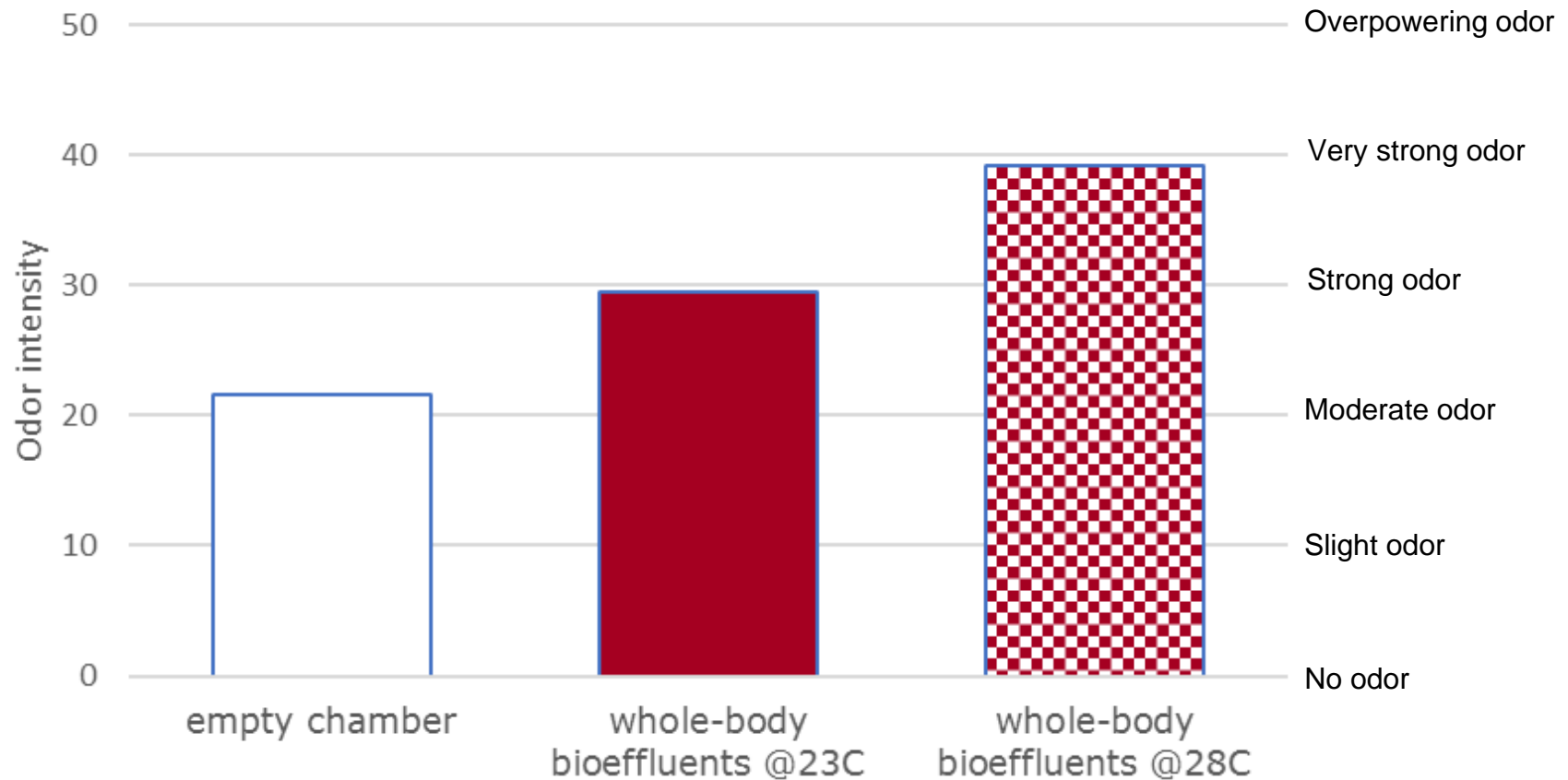
Human bioeffluents and sensory discomfort



Dermally emitted bioeffluents produce sensory nuisance

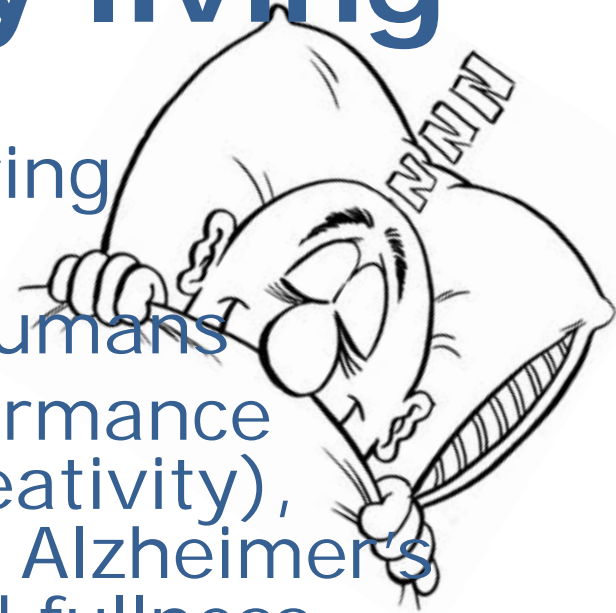


High temperature increase bioeffluents



Sleep and healthy living

- People sleep over 20 years during their life time
- High quality sleep is vital for humans
- Sleep improves cognitive performance (memory and learning, and creativity), reduce health risks (dementia, Alzheimer's disease), regulates hunger and fullness (obesity), reduce risks for car accidents, improves concentration and next-day performance
- People are getting more and more deprived of sleep, length (<7,5 hrs) and quality
- Is IEQ important?



Bedroom IEQ in buildings today

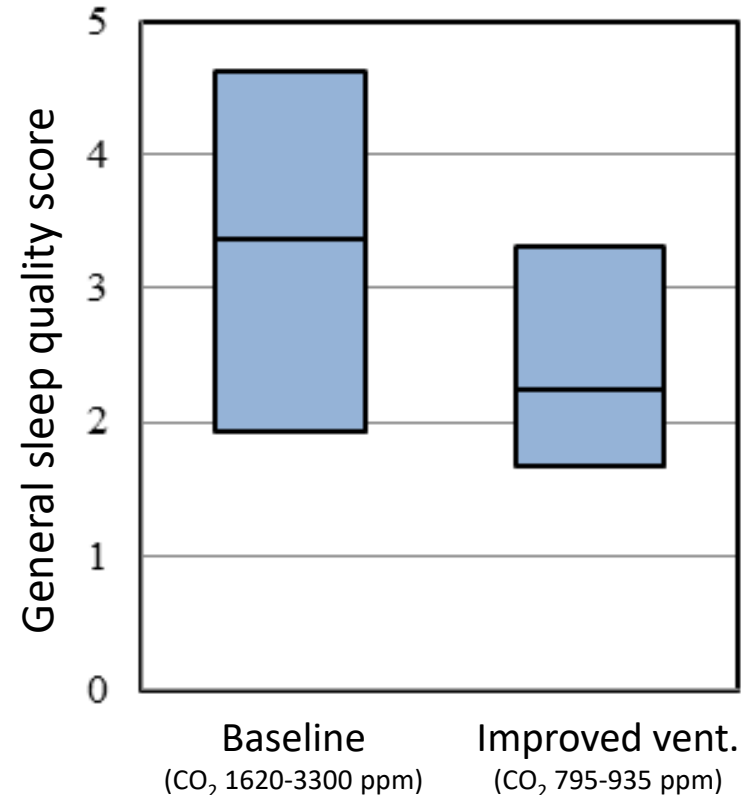
- Split AC in the Tropics reduce temperature and RH but reduce air quality due to need to conserve energy
- Housing insulation conserve energy but increase bedroom temperatures during summer
- CO₂ levels in bedroom reach 5,000 ppm indicating very poor ventilation

Temperature and sleep

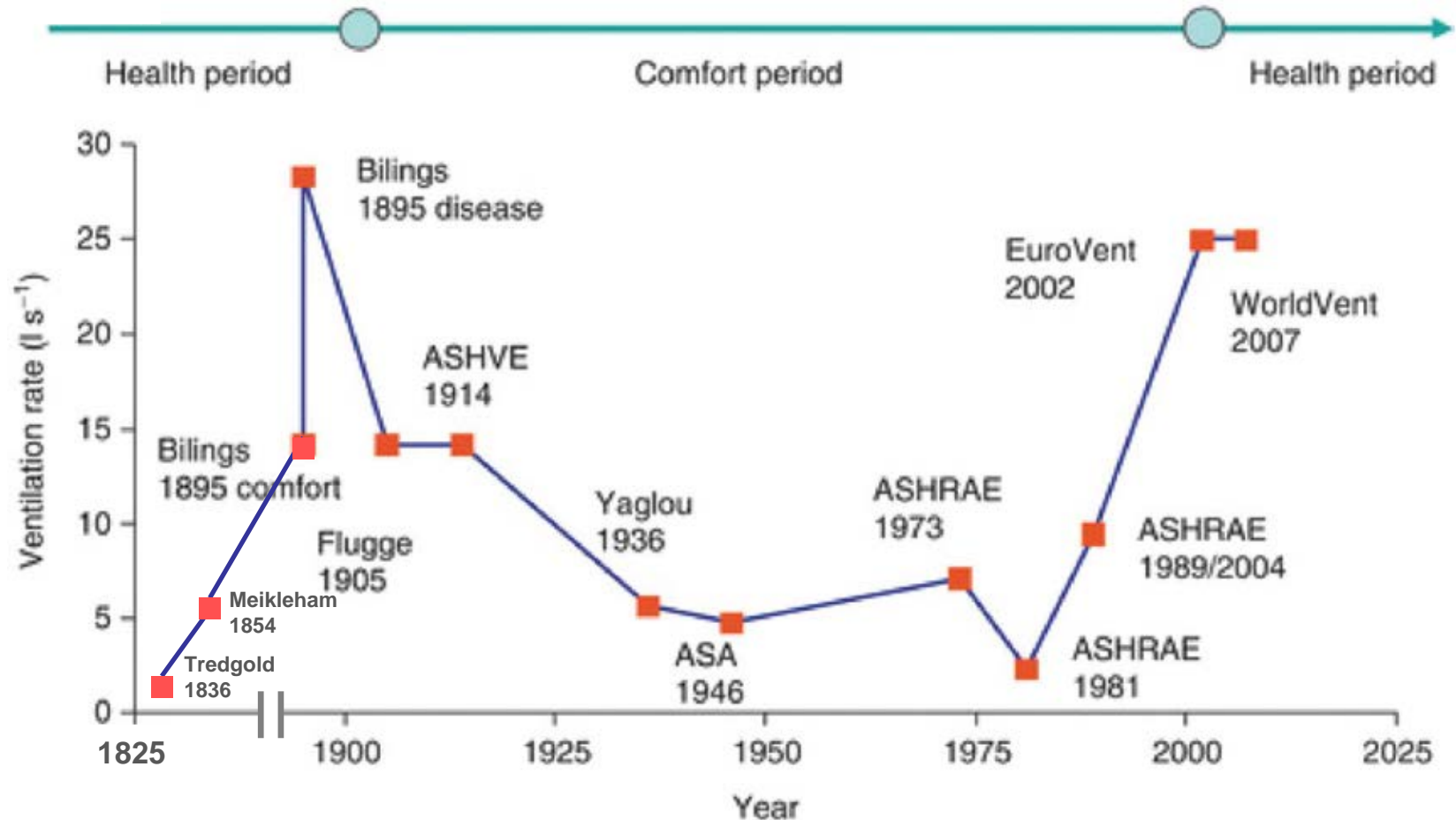
- It is difficult to fall asleep and to stay asleep when the bedroom is too cold or too hot
- There is no single temperature that is ideal at all stages of the night
- Sleep quality seems to be enhanced when bedroom temperatures are warm when falling asleep and when waking but cool in between

IAQ and sleep

- Both sleep quality and next-day performance can be negatively affected when the outdoor air supply rate to the bedroom is reduced
- A small current of fresh air to the breathing zone seems to improve sleep quality



How to define ventilation requirements?



Two-step exposure-control approach if health is an endpoint

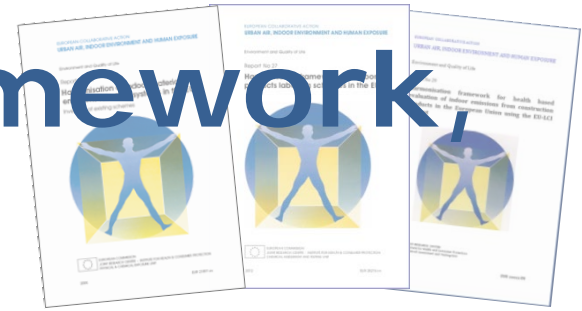
- First priority - source control
- Appropriate ventilation rate while all source control measures have been exercised

Source control is an absolute prerequisite for defining solid and reliable ventilation

- Sources dominate
- Great diversity of sources
- Great diversity of products purchased and used by people
- Minimum standardization is needed otherwise no progress will be achieved

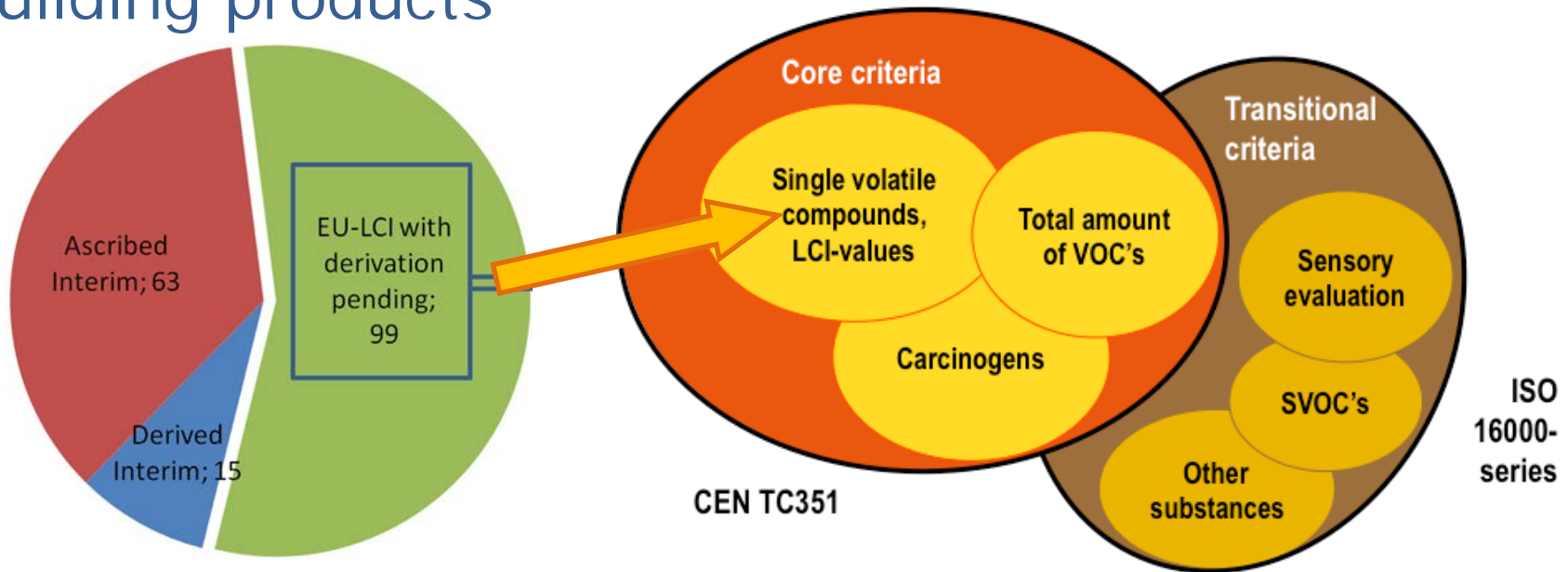


Harmonization Framework Labeling

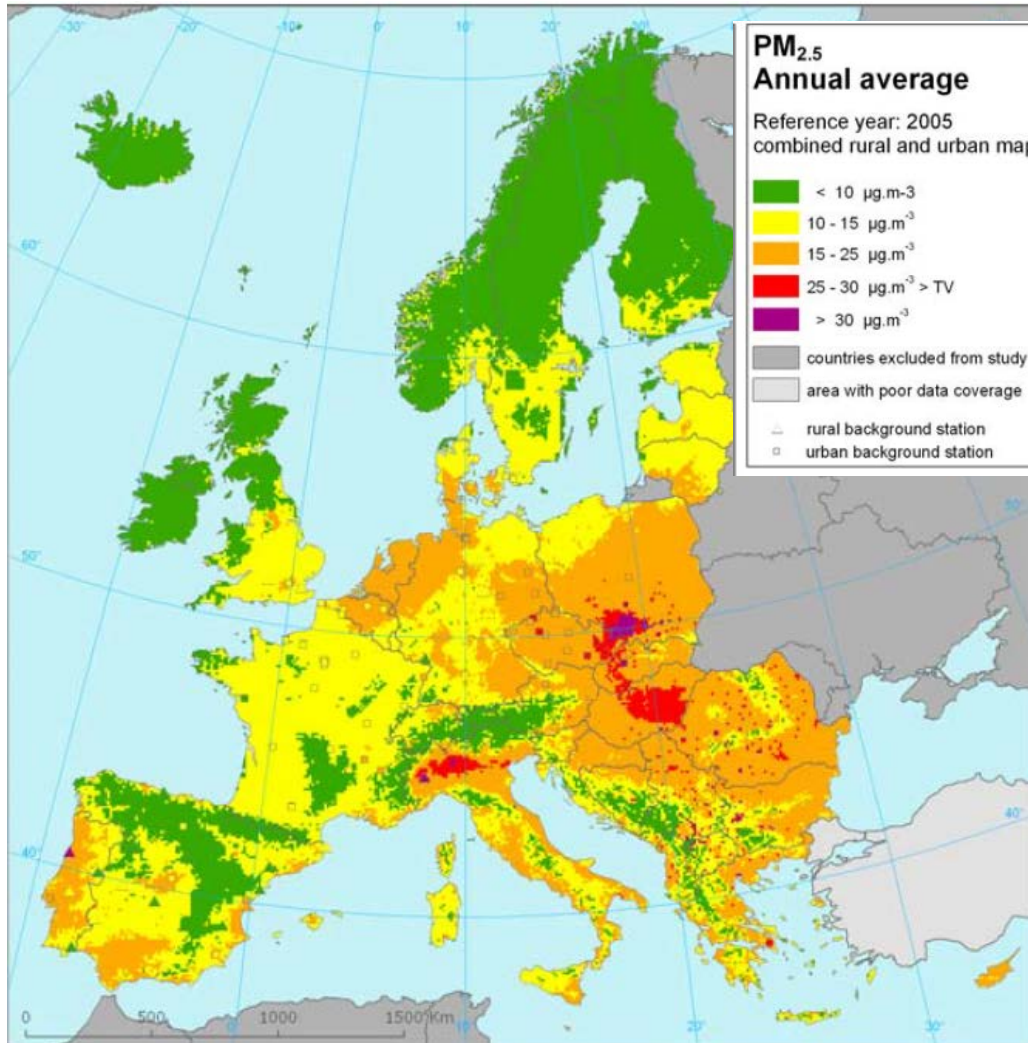


- EU-LCI: Harmonization of the health based evaluation of **chemical emissions** from building products

- Harmonization framework for indoor **products labeling schemes** in EU



Source control for outdoor air



- Indoor air quality issues need to be integrated in the review of Ambient Air Directive accounting for the associated environmental, health, social and economic impacts

WHO Guideline Values

POLLUTANT	AIR QUALITY GUIDELINES		SPECIFIC INDOOR AIR QUALITY GUIDELINES	
	AQ WHO (2000)	AQ WHO (2005)	EU-INDEX (2005)	IAQ WHO (2010)
CO	100 (15 min)		100 (15 min)	100 (15 min)
	60 (30 min)		60 (30 min)	60 (30 min)
	30 (1 h)		30 (1 h)	30 (1 h)
	10 (8 h)		10 (8 h)	10 (8 h)
NO ₂	200 (1 h)	200 (1 h)	200 (1 h)	200 (1 h)
	40 (1 y)	40 (1 y)	40 (1 w)	40 (1 y)
SO ₂	500 (10 min)	500 (10 min)		
	125 (24 h)	20 (24 h)		
PM ₁₀		50 (24 h)		
		20 (1 y)		
PM _{2.5}		25 (24 h)		
		10 (1 y)		
OZONE		100 (8 h)		
RADON				No safe level Refer. level: 100
Benzene	UR 6×10^{-6}		No safe level - Not more than outdoor level	No safe level
Tetrachloroethylene	250 (1 y)			250 (1 y)
	8000 (30 m)			
Toluene	260 (1 w)		300	
	1000 (30 m)			
Styrene	260 (1 w)		250	
	70 (30 m)			
Xylenes			200	
Formaldehyde	100 (30 min)		30 (30 min)	100 (30 min)
Naphthalene				10 (1 y)



Lyon Centre AQI: Lyon Centre Real-time Air Quality Index (AQI).

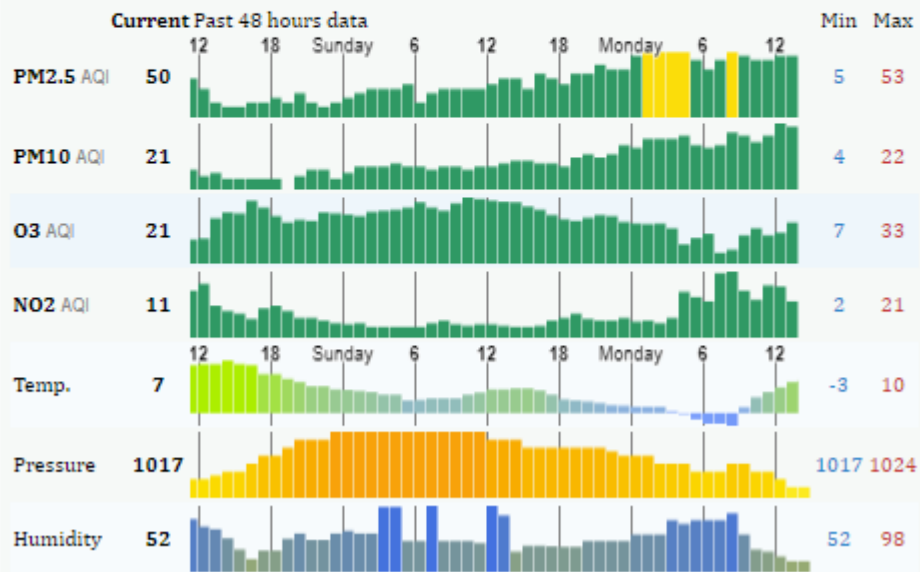


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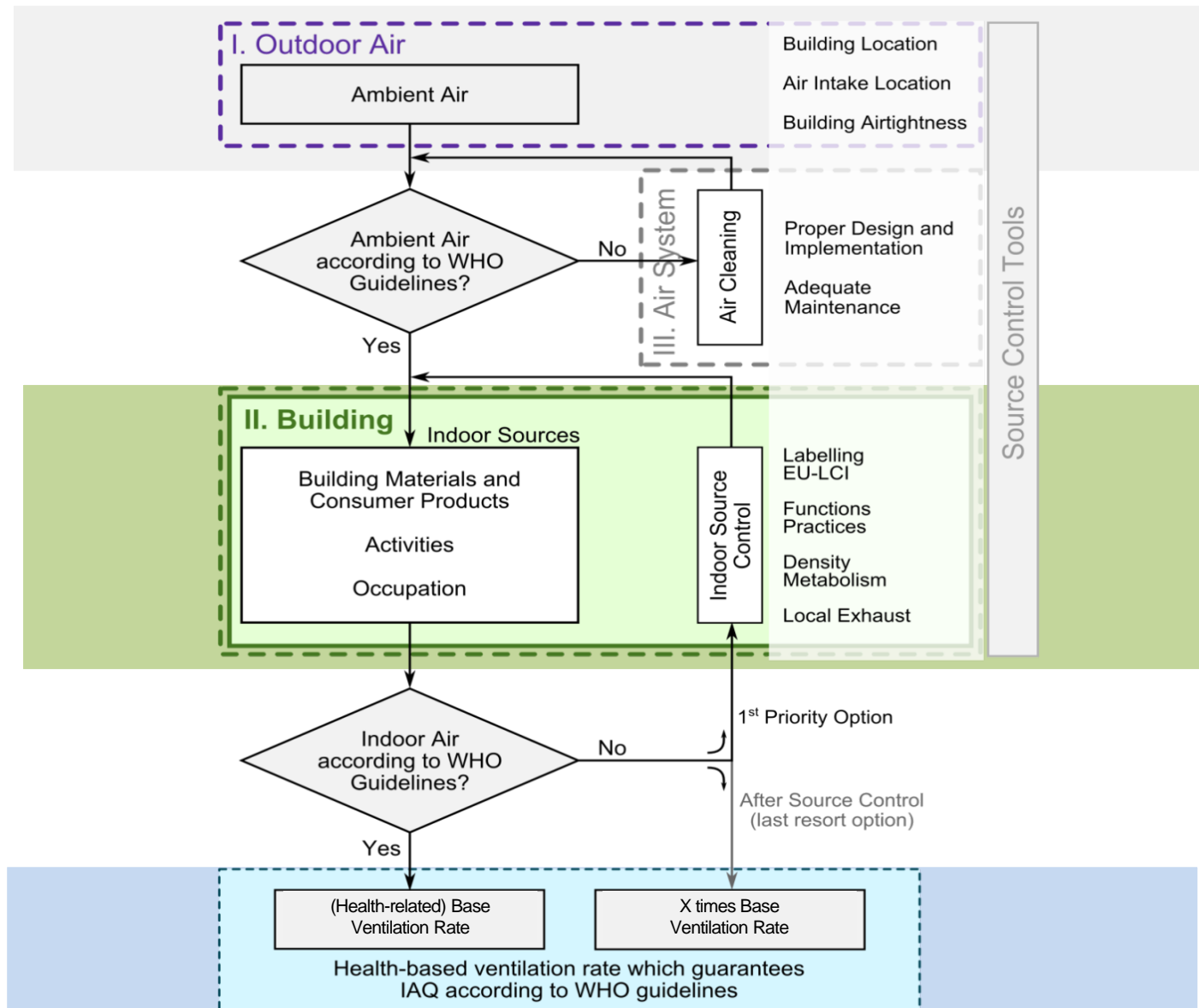
Moderate

Updated on Monday 14:00

Temp.: 7°C



Framework for setting health-based ventilation rates



Source:
 ECA 30
 (2017)

What is the base ventilation rate requirement?

- It is a basic requirement that must always be satisfied when people are present indoors.
- The base ventilation rate is the rate intended to dilute and exhaust occupant bioeffluents.
- Proposed to be 4 L/s per person* acknowledging limited data but the rate may be different.

*CO₂ equivalent ca. 1,600 ppm

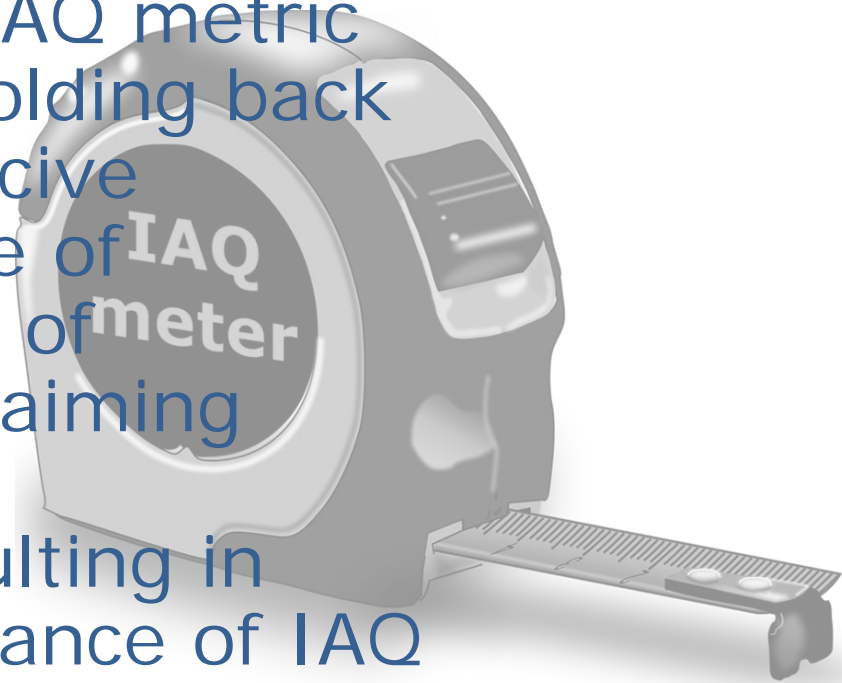
What are the future challenges that may affect IEQ?

- Climate change: severe weather events, new pollutants arising naturally (new allergens), increased likelihood of pandemic outbreaks
- Building stock change: new and retrofitted buildings to reduce energy consumption and carbon footprint (green buildings), adaptation of existing buildings, use of resources limited, re-use of existing ones
- New man-made pollutants: endocrine disruptors, flame-retardants, etc. often with no toxicological evaluation, overuse of scented products
- Presence & re-appearance of persistent organic pollutants in existing building stock
- Rapidly growing hypersensitivity (intolerance) to pollutants in general population, especially in young population
- Aging population and longer life expectancy
- Reliance on minimum standards and codes that do not promote innovation and neglect somewhat the individual preferences



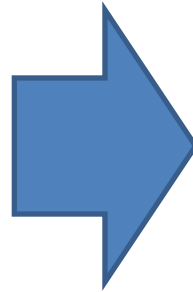
Risks: Lack of IAQ metric

- Lack of IAQ metric or disagreement what should constitute IAQ metric is a significant barrier holding back innovation of IAQ conducive technologies, emergence of undocumented methods of measurements of IAQ claiming their high efficiency and authenticity, this all resulting in undervaluing the importance of IAQ in different credit schemes and compliance metrics related to built environment



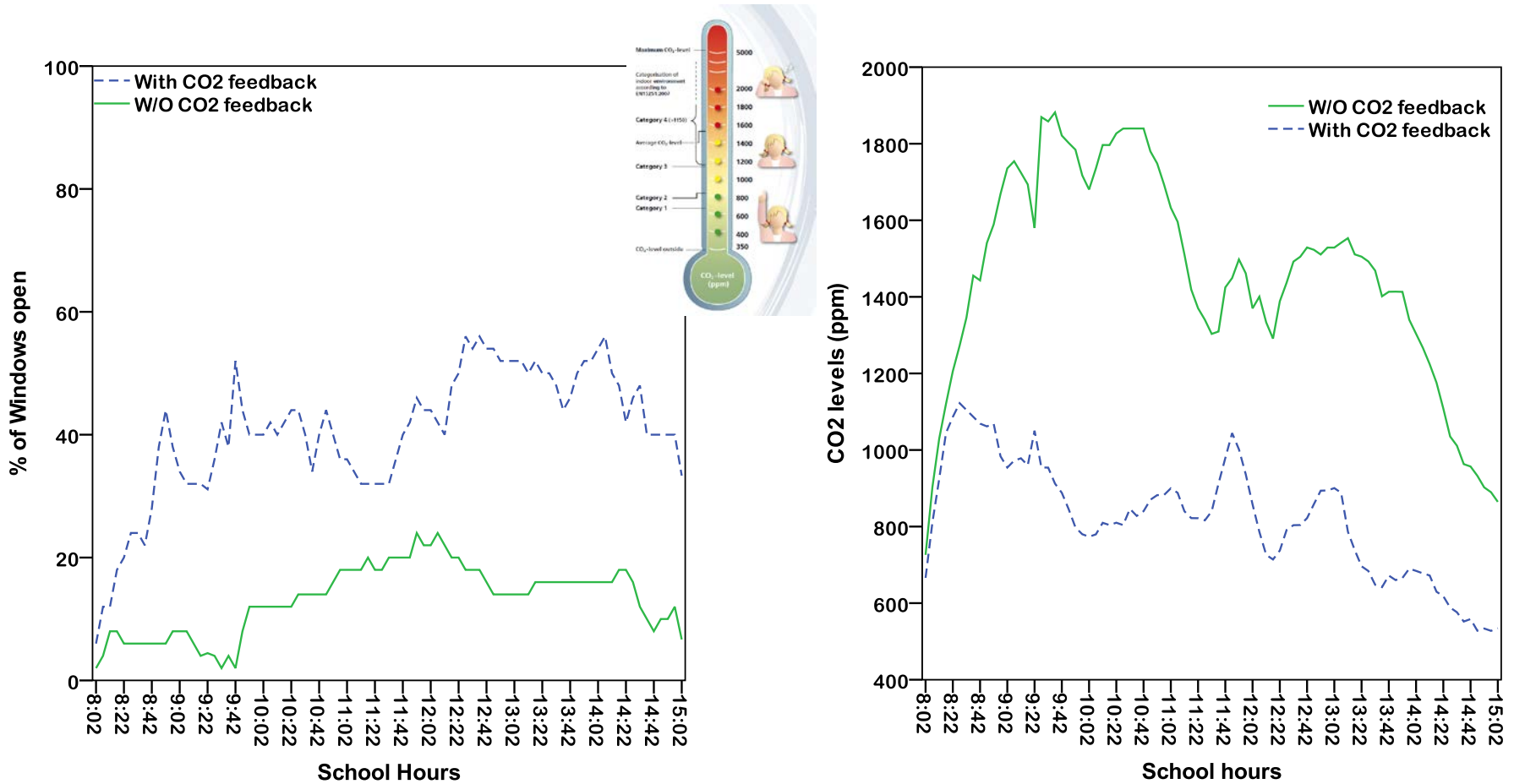
Opportunities: shift in the occupant role in buildings

- “Passive recipients” (occupants) of pre-determined comfort conditions
 - ❑ outcomes predetermined by the building design parameters or performance metrics



- “Inhabitants” (real users) playing an active role in the maintenance and performance of a building
 - ❑ an evolving practice considering dynamic (accept greater seasonal variety, new clothing, institutional flexibility – variable working hours, no dress code) and participatory (social and behavioral) aspects
 - ❑ Use of modern technologies

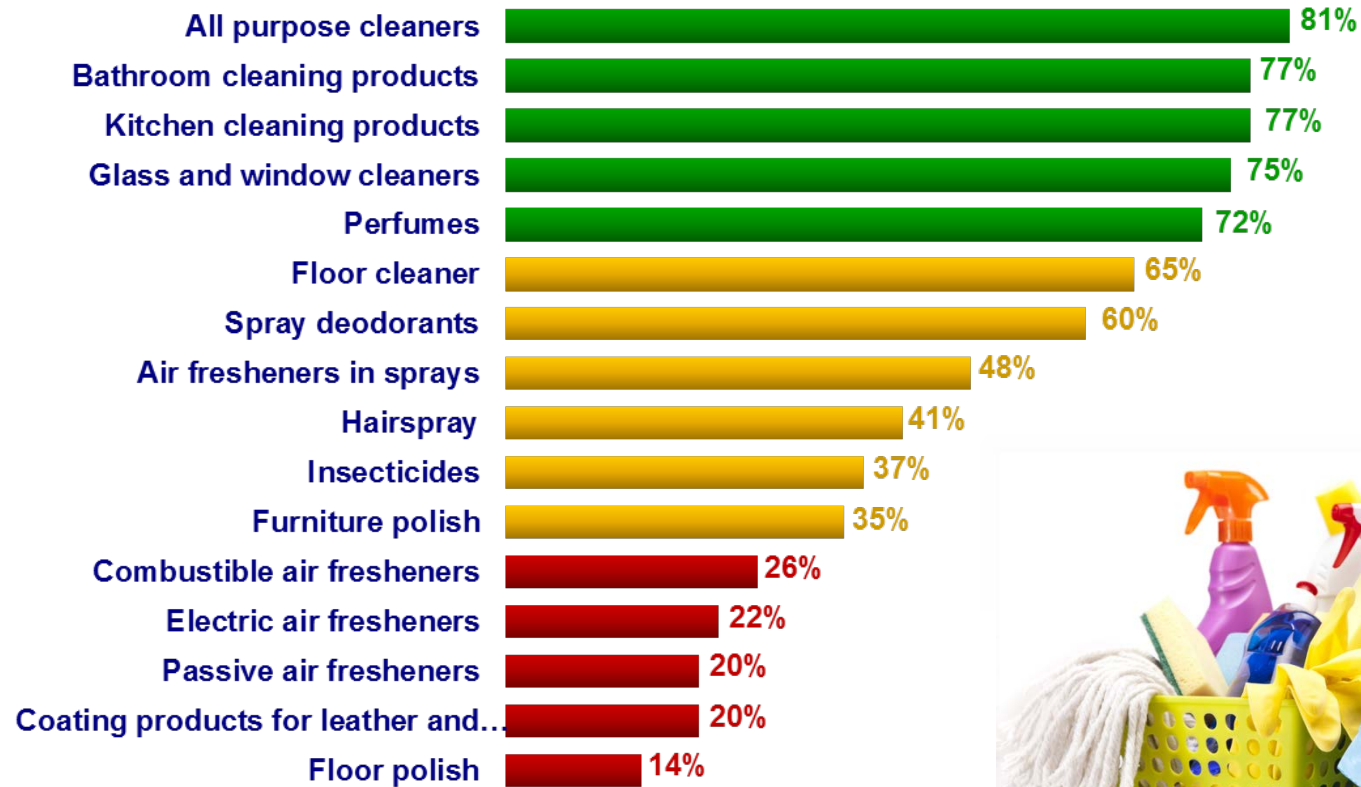
ALERT (schoolchildren)



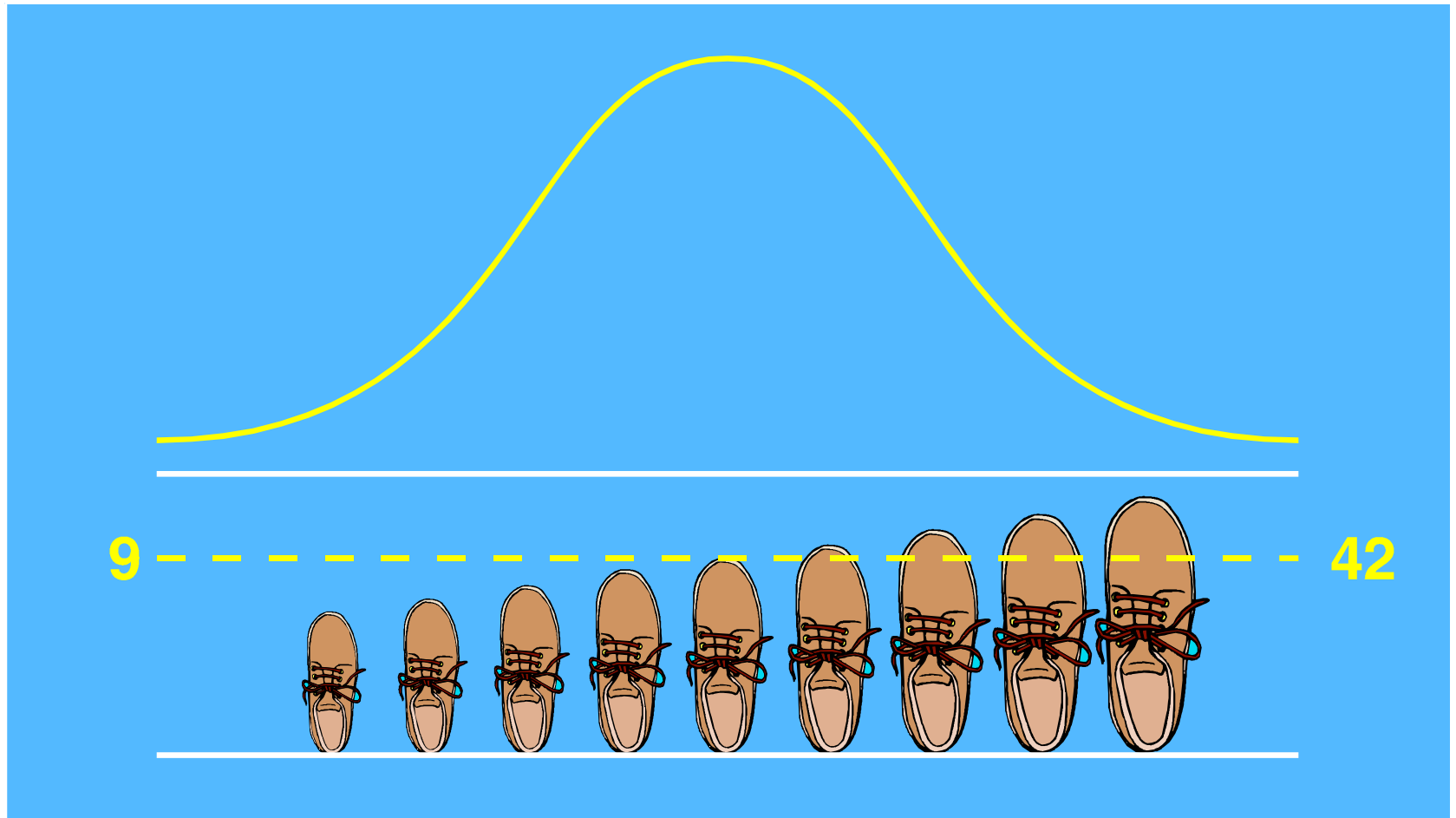
Heating season

INFORM (consumers)

Which of the following products have you personally used in your household in the past 6 months?

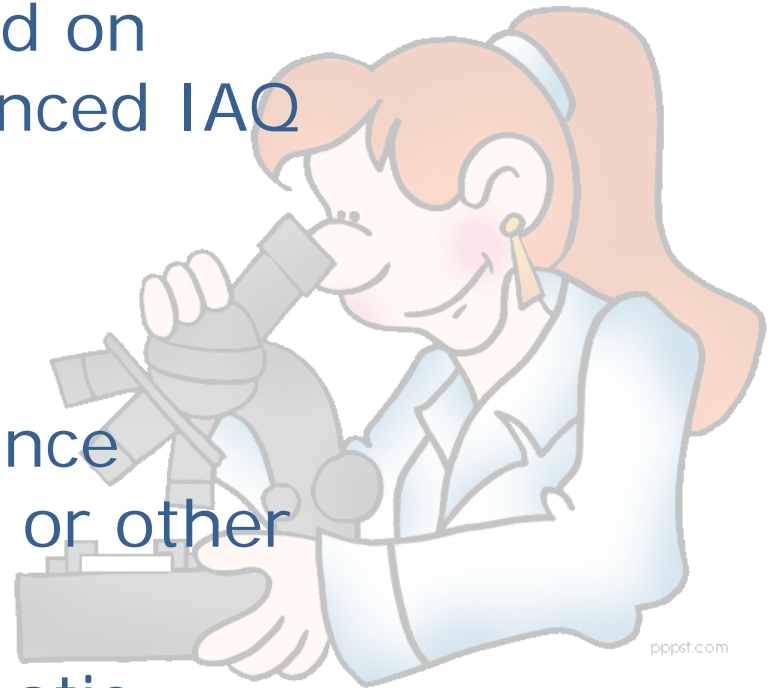


Acknowledge: we are different



Future tasks

- Mapping pollutants and responses:
Developing IAQ metric based on pollutant data and the advanced IAQ sensor technology
Mapping/monitoring human physiological parameters:
- Developing Health Performance Indicators using biomarkers or other physiological responses
- Examine efficiency of pragmatic solutions including individually controlled environments



Takeaways

- IEQ can be monetized
- High IEQ is a prerequisite for sustainable buildings
- Green buildings bring benefits
- CO₂ is a good marker of human emissions
- Source control is crucial
- IEQ is important for sleep quality
- Standards should promote innovation and individual preferences
- Buildings today should address future challenges
- Developing IAQ metric is an imperative

Questions.....

economy sustainability
energy absenteeism council health green
credits offices performance
environmental certification
building indoor
quality



Pawel Wargocki
Assoc. Prof.

Technical University of Denmark
(paw@byg.dtu.dk)