# WELCOME TO THE

# IAQ matters CONFERENCE by Eurovent

## BREATHING ACHIEVEMENT INTO EVERY CLASSROOM

EUROVENT
EUROPEAN INDUSTRY ASSOCIATION

EUROVENT CERTIFIED PERFORMANCE
www.eurovent-certification.com

BESA
BUILDING ENGINEERING SERVICES ASSOCIATION

CIBSE

IAQmatters CONFERENCE by Eurovent

BREATHING ACHIEVEMENT INTO EVERY CLASSROOM

EUROVENT
EUROPEAN INDUSTRY ASSOCIATION


# SANI DIMITROULOPOULOU, DUNCAN GRASSIE, KAJA MILCZEWSKA

## UKHSA


*'UKHSA literature review: impacts and benefits of indoor environmental quality (IEQ) in educational buildings'*

UK Health Security Agency

UK Health
Security
Agency

# UKHSA work on IEQ in schools


## Prof. Sani Dimitroulopoulou

Principal Environmental Public Health Scientist - Indoor Environments,
Air Quality and Public Health, Environmental Hazards and Emergencies Dept, UK Health Security Agency
Visiting Professor, IEDE, The Bartlett School, University College London
Chair, UK Indoor Environments Group (UKIEG)
Fellow of ISIAQ Academy (International Society of Indoor Air Quality and Climate)


*IAQmatters Conference, London, 22 January 2025*

# UKHSA: Who we are

UK Health Security Agency (UKHSA) prevents, prepares for and responds to infectious diseases and environmental, radiological and chemical hazards, to keep all our communities safe, save lives and protect livelihoods.

We provide scientific and operational leadership, working with local, national and international partners to protect the public's health and build the nation's health security capability.

UKHSA is an executive agency, sponsored by the Department of Health and Social Care.

## Strategic priority 4: Protect health from threats in the environment

Exposure to environmental hazards, including chemicals, radiation, adverse weather and natural disasters results in significant ill-health and loss of life, as well as impacts on the economy and wider society. There were estimated to be almost 3,000 excess deaths during heatwaves in England in 2022[13]. Meanwhile, air pollution contributes to up to 43,000 deaths in the UK each year and causes a range of long-term conditions, with many deprived communities disproportionately affected[14].

We will provide scientific expertise, advice and guidance to policy makers to protect health from these threats. We will increase public and cross-government understanding of evidence-based interventions to protect health from hazards such as heat waves and flooding. We will monitor the impact of climate change on environmental hazards.

- **a more developed evidence base on the health impacts of outdoor and indoor air quality**, with a greater understanding of the health impacts on different groups and communities, and effective health interventions to address these, working closely with the Office for Health Improvement and Disparities (OHID)

team of highly-specialist experts in fields such as toxicology, radiation protection and environmental monitoring, and strengthen knowledge and expertise across UKHSA to support the wider system

- **clear public health leadership across chemical, radiological and nuclear risks** and input to policy development. This includes UKHSA's contribution to the National Security Risk Assessment, and our direct input to cross-government responses where there is a health security element, domestically and internationally
- **delivery of the Adverse Weather and Health Plan** including updating adverse weather guidance, developing a supporting evidence document, implementing a new alert system for adverse weather events and providing specialist support and advice to partners and the public
- **a more developed evidence base on the health impacts of outdoor and indoor air quality**, with a greater understanding of the health impacts on different groups and communities, and effective health interventions to address these, working closely with the Office for Health Improvement and Disparities (OHID)

https://www.gov.uk/government/publications/ukhsa-strategic-plan-2023-to-2026

Health Inequalities

## **Programme Outcomes:** Core ambitions of the programme

| Increasing the evidence base | Improving awareness and understanding | Influencing and supporting stakeholders |
| --- | --- | --- |
| Develop the evidence base on air quality, including on sources of pollution, levels of exposure and how this contributes to health outcomes. | Improve the understanding of the holistic view of the effect of indoor and outdoor air pollutants; Improve how advice and information on indoor and outdoor air pollution can be communicated. | Advise and influence decision-makers; Support the implementation, sharing information and learning at various scales. |

## **Programme Key Elements:** Where we will focus our effort

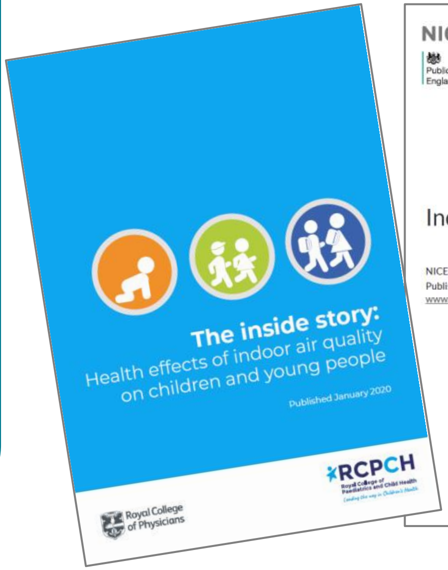
| Increasing the evidence base | Improving awareness and understanding | Influencing and supporting stakeholders |
| --- | --- | --- |
| Identify the evidence gaps and contribute to filling them. | Quantify the impacts of indoor and outdoor air pollutants on health and wellbeing, considering the wider environmental and social determinants of health. | Review the effectiveness of interventions and actions used by the public and decision makers to assess effectiveness. |
| Develop the evidence on the link between sources of indoor and outdoor pollutants, exposure, and health outcomes. | How we can most effectively target our actions towards the most vulnerable population groups, including more deprived communities, people with pre-existing respiratory and cardiovascular conditions and young and older people. | Work with local authorities including directors of public health to equip and enable them to lead and inform local decision-making to improve air quality more effectively. |
| Understanding of future opportunities and threats and their association with air pollution and health e.g. climate change, new technologies, low-emission vehicles etc. | Develop tools, resources, training for the public, local authorities, health, and medical professionals. | Strengthen our response to air quality incidents and emergencies. |
| | | Strengthen our Global Health activities to protect health against air pollution in the UK and globally. |
| | | Support the development of the Air Pollution Control plan to implement the government Clean Air Strategy and support commitments in the |

Communication

# Indoor air – Health effects

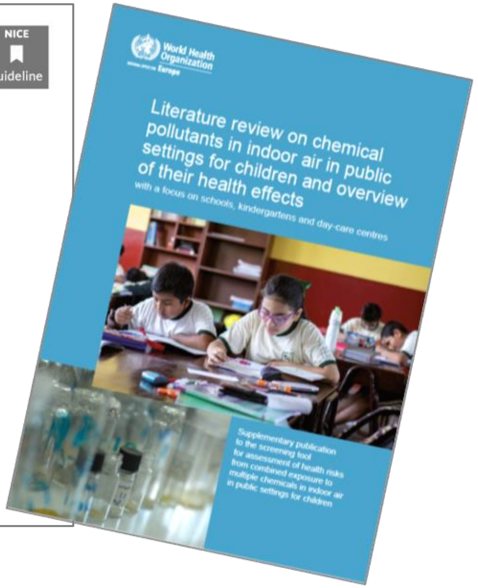
***Exposure to indoor air pollutants, chemicals and biological contamination is associated with***

- respiratory system
- nervous system
- cardiovascular system
- carcinogenicity
- respiratory irritation




RCPCH (2020)


NICE (2020)




WHO (2021)

## Birth and infancy

- Respiratory problems – wheeze, rhinitis, atopic asthma, respiratory infections
- Low birthweight and pre-term birth

## Pre-school

- Respiratory problems – wheeze, allergies, asthma, risk of respiratory diseases and pneumonia
- Eczema and atopic dermatitis
- Greater hyperactivity, impulsivity and inattention

## School age

- Respiratory problems – wheeze, rhinitis, asthma, throat irritation, nasal congestion, dry cough
- Eczema, dermatitis, conjunctivitis, skin and eye irritation
- Reduced cognitive performance, difficulty sleeping

RCPCH (2020) https://www.rcpch.ac.uk/sites/default/files/2020-01/the-inside-story-report_january-2020.pdf

# Department for Education - Building Bulletin 101 Guidance on ventilation, thermal comfort and indoor air quality in schools (2018)

## 6.1 Indoor and outdoor air quality guidelines and UK air quality standards

- *For the first time in the UK policy, BB101 recommends:*
  - WHO (2010) guidelines for selected indoor air pollutants
  - WHO (2009) guidelines for dampness and mould.
- Distinguish between indoor and ambient air:
  - UK National Air Quality Objectives (DETR, 2007) for ambient air pollutants.
- Refer to HSE EH40: Pollutant levels in *Science, Design and Technology and Art* should always be kept below the levels given in EH40.



https://www.gov.uk/government/publications/building-bulletin-101-ventilation-for-school-buildings

# Approved Document F, 2021 edition - for use in England

B



**Table B1 Indoor air pollutants guidance values[1][2]**

| Pollutant | Exposure limit | Exposure time |
|---|---|---|
| Carbon monoxide (CO) | 100mg/m³ | 15-minute average |
| | 30mg/m³ | 1-hour average |
| | 10mg/m³ | 8-hour average |
| Nitrogen dioxide ($NO_2$) | 200µg/m³ | 1-hour average |
| | 40µg/m³ | 1-year average |
| Formaldehyde ($CH_2O$) | 100µg/m³ | 30-minute average |
| | 10µg/m³ | 1-year average |
| TVOC[3] | 300µg/m³ | 8-hour average |

**NOTES:**

1. No safe levels can be recommended for benzene or trichloroethylene so they have not been considered in the definition of ventilation rates in dwellings. The best strategy for reducing their concentration indoors may be to control them at source.
2. Even if the designer and builder choose to reduce volatile organic compound (VOC) levels in dwellings by controlling them at source, the ventilation requirements must still be met.
3. The total volatile organic compound (TVOC) metric is representative of all airborne indoor air VOC concentrations and should not be used as a direct indicator of health. The simplified metric is used as an indicator for the purpose of ventilation control strategies. As an alternative to the TVOC limit, individual VOC limits may be used where justified in accordance with the guidance in paragraph B5.

**B5** As an alternative to using TVOC, the individual VOCs may be applied where their use is supported by robust independent evidence. Public Health England's *Indoor Air Quality Guidelines for Selected Volatile Organic Compounds (VOCs) in the UK* should be used. Testing against these metrics is likely to be more complex than testing against TVOC.

**B6** Control of bio-effluents (body odours) for people who have been exposed to the environment for a period of time will be achieved by an air supply rate of 4 litres per second per person (**BS EN 16798-1**).

## Assumptions used in applying performance criteria for dwellings in Section 1

### General

**B7** Where the guidance for less airtight dwellings is followed, dwellings are assumed to have an infiltration rate of 0.15 air changes per hour.

**B8** Where the guidance for highly airtight dwellings is followed, dwellings are assumed to have an infiltration rate of 0 air changes per hour.

**B9** Ventilation effectiveness is assumed to be 1.0 – that is, it is assumed that supply air is fully mixed with room air.

CIBSE's Guide A *Environmental Design* provides further information on ventilation effectiveness.





Volume 1: Dwellings

B



**Table B1 Indoor air pollutants guidance values[1][2]**

| Pollutant | Exposure limit | Exposure time | Guidance |
|---|---|---|---|
| Carbon monoxide (CO) | 100mg/m³ | 15-minute average | WHO, 2010 |
| | 30mg/m³ | 1-hour average | WHO, 2010 |
| | 35mg/m³ (occupational exposure) | 8-hour average | HSE, 2020 |
| Nitrogen dioxide ($NO_2$) | 200µg/m³ | 1-hour average | WHO, 2010 |
| | 40µg/m³ | 1-year average | WHO, 2010 |
| Formaldehyde ($CH_2O$) | 100µg/m³ | 30-minute average | WHO, 2010 |
| | 10µg/m³ | 1-year average | PHE, 2019 |
| TVOC[3] | 300µg/m³ | 8-hour average | ECA, 1992/WHO, 2010 |
| Ozone | 100µg/m³ | | DETR, 1994 |

**NOTES:**

1. No safe levels can be recommended for benzene or trichloroethylene so they have not been considered in the definition of ventilation rates in buildings. The best strategy for reducing their concentration indoors may be to control them at source.
2. Even if the designer and builder choose to reduce volatile organic compound (VOC) levels in buildings by controlling them at source, the ventilation requirements must still be met.
3. The total volatile organic compound (TVOC) metric is representative of all airborne indoor air VOC concentrations and should not be used as a direct indicator of health. The simplified metric is used as an indicator for the purposes of ventilation control strategies. As an alternative to the TVOC limit, individual VOC limits may be used where justified in accordance with the guidance in paragraph B3.

**B3** As an alternative to using TVOC, the individual VOCs may be applied where their use is supported by robust independent evidence. Public Health England's *Indoor Air Quality Guidelines for Selected Volatile Organic Compounds (VOCs) in the UK* should be used. Testing against these metrics is likely to be more complex than testing against TVOC.

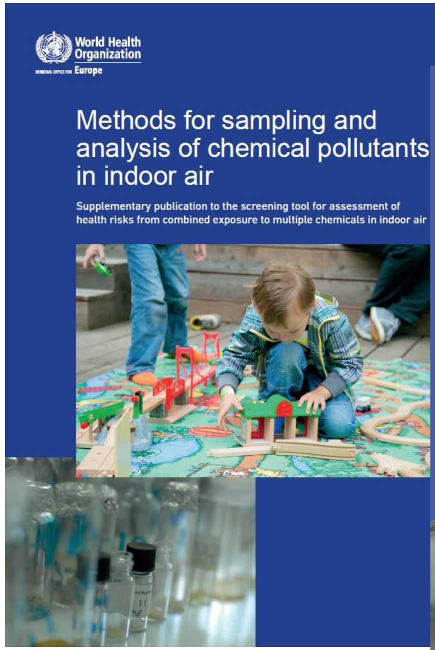
Where the Health and Safety Executive gives guidance for specific situations, that guidance should be followed in preference to the guidance given here.



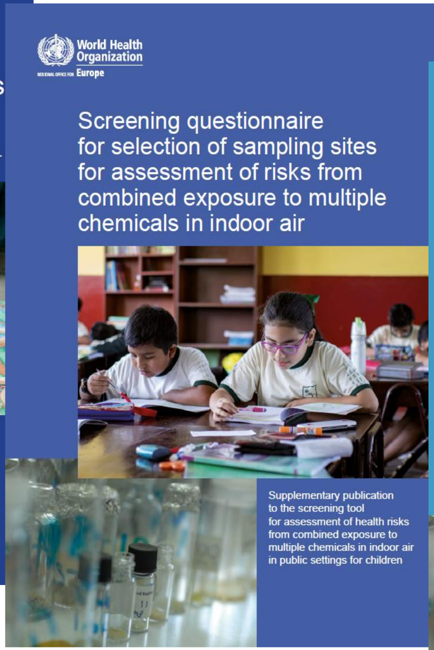


Volume 2: Buildings other than dwellings

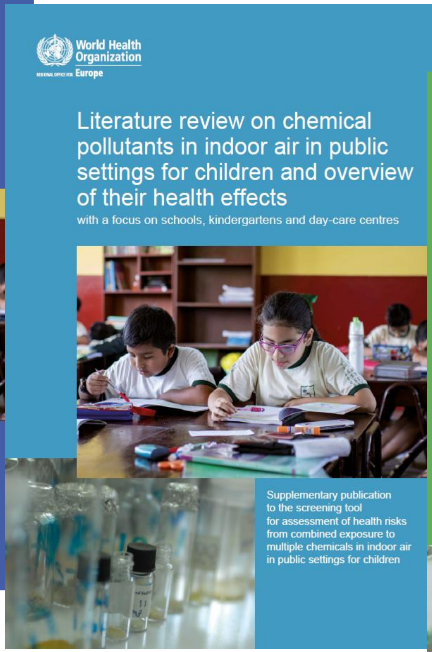
# WHO – assessment of combined exposure of children in schools



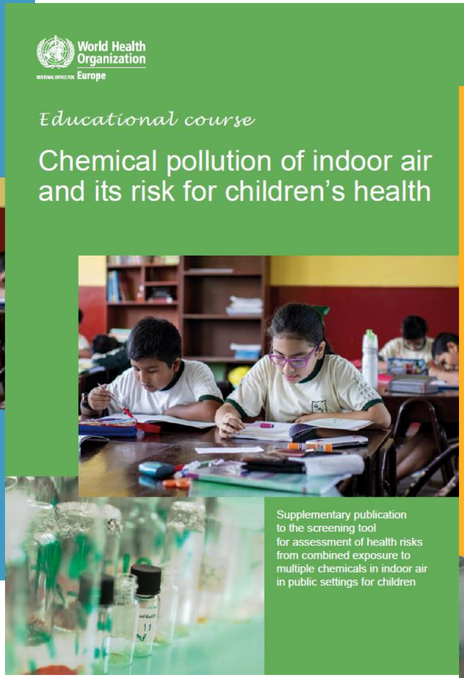

WHO (2020)
https://apps.who.int/iris/bitstream/handle/10665/334389/9789289055239-eng.pdf



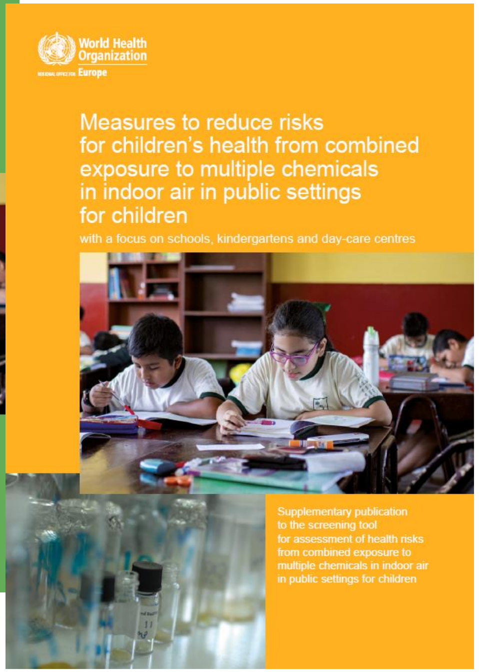

WHO (2021)
https://apps.who.int/iris/handle/10665/341466




WHO (2021)
https://iris.who.int/handle/10665/341467



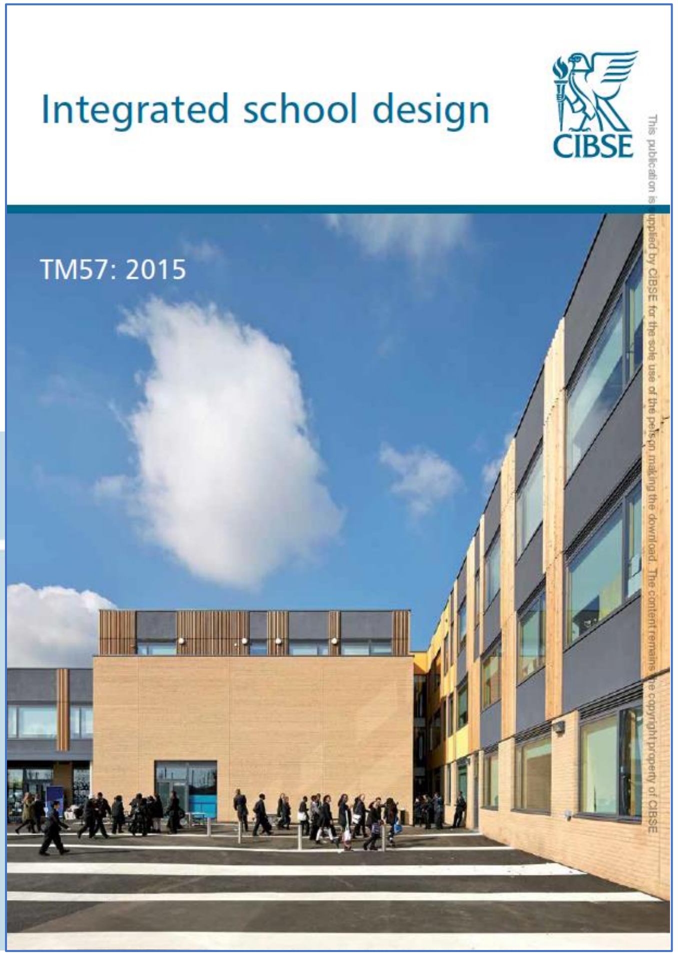

WHO (2021)
https://iris.who.int/bitstream/handle/10665/341984/9789289055628-eng.pdf




WHO (2022)
https://www.who.int/europe/publications/i/item/9789289057974

# Contribution to CIBSE's work

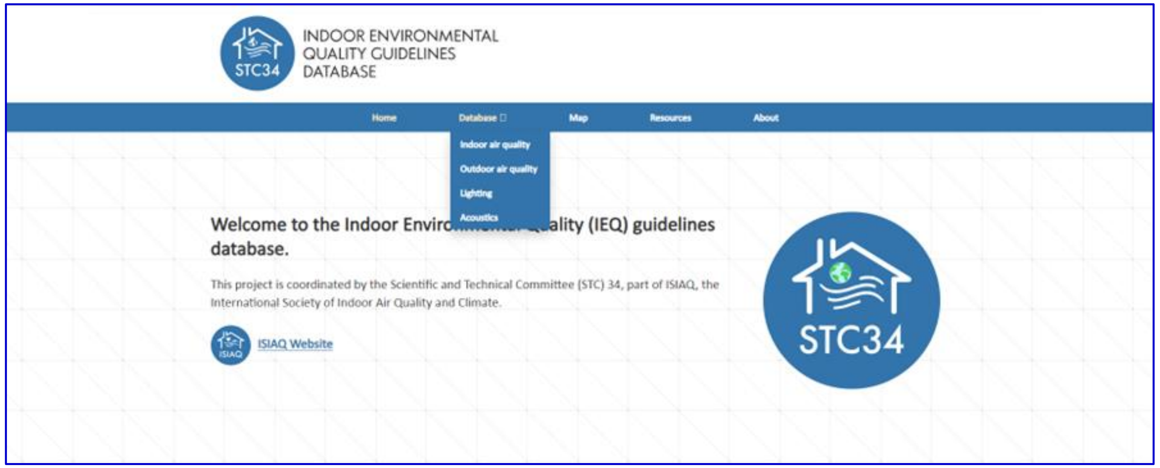





CIBSE Knowledge Generation Panel

Revision of TM57, including:
- revised chapter on overheating
- new chapter on IAQ

# ISIAQ – International Society of IAQ and Climate - Indoor Environmental Quality open database




https://ieqguidelines.org/

An ISIAQ Scientific and Technical Committee (STC34) was officially launched in September 2020.

Since then, the committee has created an open IEQ guideline database, held regular online meetings, and organized workshops at ISIAQ conferences.

Toyinbo O, et al., on behalf of the STC 34 / ISIAQ, 2022. Open database for international and national indoor environmental quality guidelines. Editorial; Indoor Air. 2022;32:e13028. https://doi.org/10.1111/ina.13028

Dimitroulopoulou S, et al., 2023. Indoor Air Quality Guidelines from across the world: An appraisal considering energy saving, health, productivity and comfort. Environment International, 178, 108127 https://doi.org/10.1016/j.envint.2023.108127

# UKHSA research on air quality around schools

Environmental Research 196 (2021) 110817

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

ELSEVIER

Review article

Air quality around schools: Part I - A comprehensive literature review across high-income countries

Stephanie Osborne, Onyekachi Uche, Christina Mitsakou, Karen Exley, Sani Dimitroulopoulou *

*Air Quality & Public Health Group, Environmental Hazards and Emergencies Department, Centre for Radiation, Chemical and Environmental Hazards, Public Health England, Harwell Science and Innovation Campus, Chilton, Oxon, OX11 0RQ, UK*

Environmental Research 197 (2021) 111038

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

ELSEVIER

Air quality around schools: Part II - Mapping $PM_{2.5}$ concentrations and inequality analysis

Stephanie Osborne, Onyekachi Uche, Christina Mitsakou, Karen Exley, Sani Dimitroulopoulou *

*Air Quality & Public Health Group, Environmental Hazards and Emergencies Department, Centre for Radiation, Chemical and Environmental Hazards, Public Health England, Harwell Science and Innovation Campus, Chilton, Oxon, OX11 0RQ, UK*

Interventions to mitigate exposure:

- Clean air zones around schools
- Green infrastructure
- School site selection
- Active travel to and from school
- Playtime outside of rush hours
- Follow a holistic approach, tacking emissions and mitigating exposures

The analysis highlighted that:

- large number of children (in approximately one third of schools - 7,801) in England are experiencing poor air quality outside their school;
- this happens disproportionately for children from low-income families and ethnic minority backgrounds.

# New funded research

Funding opportunity

## Realising the health co-benefits of the transition to net zero

| | |
|---|---|
| **Opportunity status:** | Closed |
| **Funders:** | UK Research and Innovation, Arts and Humanities Research Council (AHRC), Biotechnology and Biological Sciences Research Council (BBSRC), Economic and Social Research Council (ESRC), Engineering and Physical Sciences Research Council (EPSRC), Medical Research Council (MRC), Natural Environment Research Council (NERC), Science and Technology Facilities Council (STFC) |
| **Co-funders:** | National Institute for Health and Care Research (NIHR) |
| **Funding type:** | Grant |
| **Total fund:** | £30,000,000 |
| **Maximum award:** | £6,000,000 |
| **Publication date:** | 12 September 2023 |
| **Opening date:** | 12 September 2023 9:00am UK time |
| **Closing date:** | 14 November 2023 4:00pm UK time |

Last updated: 13 October 2023 - see all updates

Apply for funding to lead a transdisciplinary research hub towards realising the health co-benefits of the UK transition to net zero

### Timeline

- **12 September 2023 9:00am** – Opening date
- **5 October 2023 3:00pm** – Webinar
- **14 November 2023 4:00pm** – Mandatory expression of interest deadline closing date
- **12 and 13 December 2023** – Workshop event
- **To be confirmed** – Full application deadline
- **April or May 2024** – Panel meeting
- **June 2024** – Decisions communicated

https://www.ukri.org/opportunity/realising-the-health-co-benefits-of-the-transition-to-net-zero/

## 5 Challenge areas:

.....

Indoor environments in a net zero world

UCL GREAT ORMOND STREET INSTITUTE OF CHILD HEALTH


Home | Study | Research | Partnerships | Alumni | News | Short Courses & Events | People | About us

UCL Home » UCL Great Ormond Street Institute of Child Health » The CHILI Hub

## The CHILI Hub

The aim of the CHILI Hub is to ensure that we support and improve children's education as school and nursery buildings are being made environmentally sustainable.

**Who are we?**

We are a group of researchers from a range of backgrounds, including engineering, public health, clinical medicine, mental health research and education.

Organisations working on the CHILI Hub include University College London, Imperial College London, London School of Hygiene & Tropical Medicine, Swansea University, UK Health Security Agency, University of Leeds and University of York.

**Contact CHILI Hub**

Email the team at: chilihub@ucl.ac.uk

**The Child And Adolescent Health Impacts Of Learning Indoor Environments Under Net Zero : The Chili Hub**

# Government + Industry + Academia:
# We produce our best
# when we ALL work together

Thank you

Sani.Dimitroulopoulou@ukhsa.gov.uk

# Impact of indoor environmental quality in educational buildings on health, wellbeing, and performance

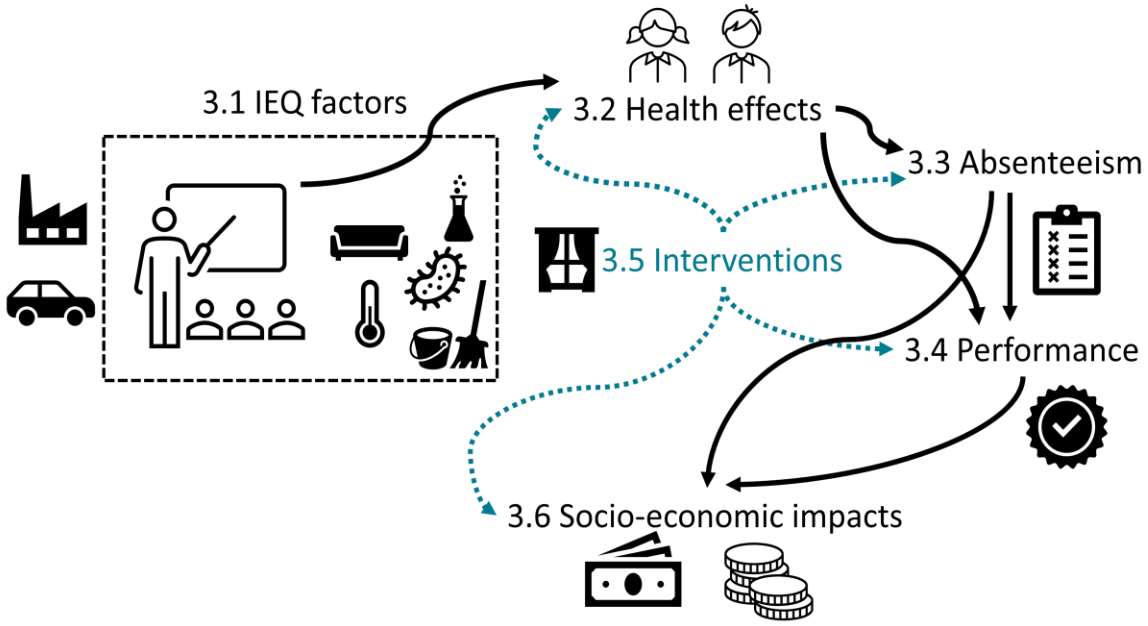
Duncan Grassie, Kaja Milczewska, Sani Dimitroulopoulou

Air Quality and Public Health,
Radiation, Chemicals, Climate and Environmental Hazards Directorate
UK Health Security Agency

*IAQmatters Conference, London, 22 January 2025*

# Background

- 30% of a child's waking hours spent in educational buildings – a key setting for environmental exposures.
- Exposure to air quality, thermal, audio and visual aspects of indoor environmental quality (IEQ) can impact young people's health and wellbeing
- Links also to absenteeism and academic performance
- Interventions required to improve IEQ and energy efficiency to reach net-zero carbon and GHG emission targets.



# Scope of the study

Poor IEQ → Health Impacts → Absenteeism → Academic performance → Tangible, quantifiable impacts?

- To identify impact of IEQ on health, wellbeing, absenteeism and performance in educational settings
- Focus on IAQ, ventilation, thermal comfort, noise (related to ventilation)
  - Indoor sources of pollutants
  - Infiltration of traffic-related air pollution (TRAP)
  - Hygrothermal conditions
- To identify interventions for controlling IEQ
- To quantify monetary gains (or losses) associated with interventions

| Key literature reviews | Topic |
|---|---|
| Toyinbo et al. 2023 | Ventilation and health |
| Sadrizadeh et al. 2022 | Academic outcomes |
| Gartland et al. 2022 | TRAP |
| Osborne et al. 2021 | Outdoor pollution exposure |
| Vakalis et al. 2019 | Green schools |
| Fisk et al. 2017 | Ventilation and student performance |
| Salthammer et al. 2016 | Indoor and outdoor, climate change |
| Wargocki et al. 2013 | Temperature & IAQ vs performance |
| Annesi-Maesano et al. 2013 | Health effects |
| Mendell and Heath, 2005 | Student performance |

# Methodology of scoping literature review

| | Included | Excluded |
|---|---|---|
| **Type of building** | Educational building, Classroom, Exam hall, School, Nursery, University | Residential settings<br>Recreational facilities |
| **Type of occupants** | Students, Pupils, Toddlers, Children | Occupational exposure studies, staff. |
| **Environmental conditions** | Indoor environmental quality (IEQ), Indoor air quality (IAQ) / pollution, Thermal comfort, Ventilation, Heating, Cooling, Carbon dioxide ($CO_2$), Particulate matter (PM), Nitrogen dioxide ($NO_2$), Temperature, Relative humidity, Allergens, Volatile organic compounds (VOCs), Radon, Noise from ventilation system, External noise | |
| **Health impacts** | Respiratory disease (Asthma, Allergies, Transmission of airborne disease, COVID-19, Influenza), Irritation, Neurological/ dizziness/ fatigue | |
| **Attainment** | Absences, Exams, Standardised scoring tests | |
| **Impact of climate change policy** | Retrofit/retrofitting, Energy efficiency, Net zero | |

- Scoping review initiated through UKHSA's Knowledge and Library Service
  - OVID Medline, Embase & Scopus databases
- Eurovent expert panel provided papers and grey literature
- Considered high-income countries only

# Summary of literature review

**Stage 1:** Initial search by KLS

Ovid Medline, Embase, Scopus

7,600 records identified

**Stage 2:** Exclusion criteria applied:

1,035 records remained

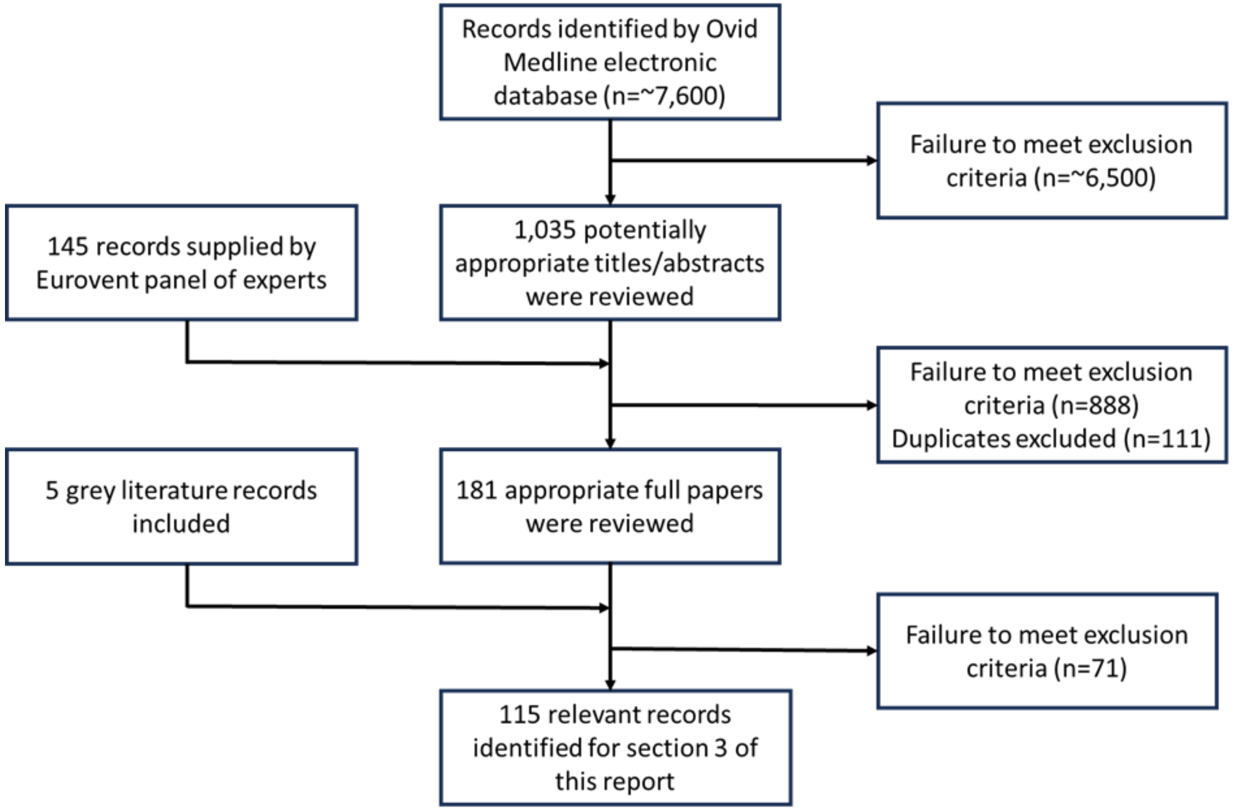
145 records added by Eurovent

**Stage 3:** Review on title & abstract:

181 records remained

**Stage 4:** Review on full text

115 relevant records identified



# IEQ factors, sources and exposures

Challenge: Isolating school effects from other environments (outdoor, domestic)

- Spatial
  - Proximity to industrial sites, roads
  - Orientation, design of buildings
- Non-spatial
  - Easier to mitigate, possibly not by staff/pupils
  - Use of building, cleaning, furnishing materials
  - Heating/cooling systems
- Air pollution exposures can be dependent on, e.g.,
  - Indoor and traffic-related air pollutants
  - Damp and mould, poorly ventilated conditions

# IEQ factors: Ventilation

**Types:**

- Natural: Dominant in US, S. Europe, pre-1980s
- Mechanical: Similar % to natural ventilation in Nordics, dominant in modern buildings

**Guidelines:**

- Scientific Technical Committee 34 (STC34) developed a worldwide database
- Building Bulletin 101 (Department for Education, 2018) limits daily average $CO_2$ concentration while occupied to 1500 ppm (natural), 1000 ppm (mech).
- During Covid, UK HSE (Health and Safety Executive) doubled minimum fresh air supply guidelines

STC 34

Department for Education

# Health effects and pollutants

| Pollutant | Symptoms |
|---|---|
| $NO_2$ | Irritative cough, wheezing, decreased lung function |
| $O_3$ | Irritative cough, decreased lung function |
| $PM_{2.5}$ | Irritative cough, airway inflammation, slower cognitive development, increased risk of asthma symptoms |
| $PM_{10}$ | Lifetime allergic rhinitis |
| VOCs | Irritative cough, wheezing, nasal symptoms, increased risk of asthma symptoms, allergic rhinitis, neuro-physical development (PAHs), carcinogenic (e.g., Benzene, formaldehyde), |
| Mould | Eye/throat irritation, headache, concentration problems, dizziness |

Key publications: (a) The Inside Story (RCPCH, 2020), (b) Literature review on chemical pollutants in indoor air in public settings for children and overview of their health effects (WHO, 2020)

Individual studies on:

a) Mechanisms, e.g., narrowing of retinal blood vessels due to fine particles, causing inflammation.
b) Mitigations, e.g., dermatitis decreased by ventilation/baking out new school buildings.
c) Limits: e.g. Increased symptoms from extra $NO_2$, $O_3$ exposure, even when below threshold.

# Absenteeism: building-related factors

- Behind effect of acoustics on cognitive performance, absenteeism is most analysed impact.
- Associations recorded with:
  - Temperature: 1.28-fold increase when 27-30 $^{o}$C
  - Ventilation rate: 1.6% to 5.8% decrease of absences for 1 l/s/person increase
  - $CO_2$: Often used to demonstrate ventilation effectiveness.
- Mould/allergen impact often driven by confounding factors:
  - Age of building, absences caused by home rather than school environment, vermin issues

# Absenteeism: Relationships with pollutants

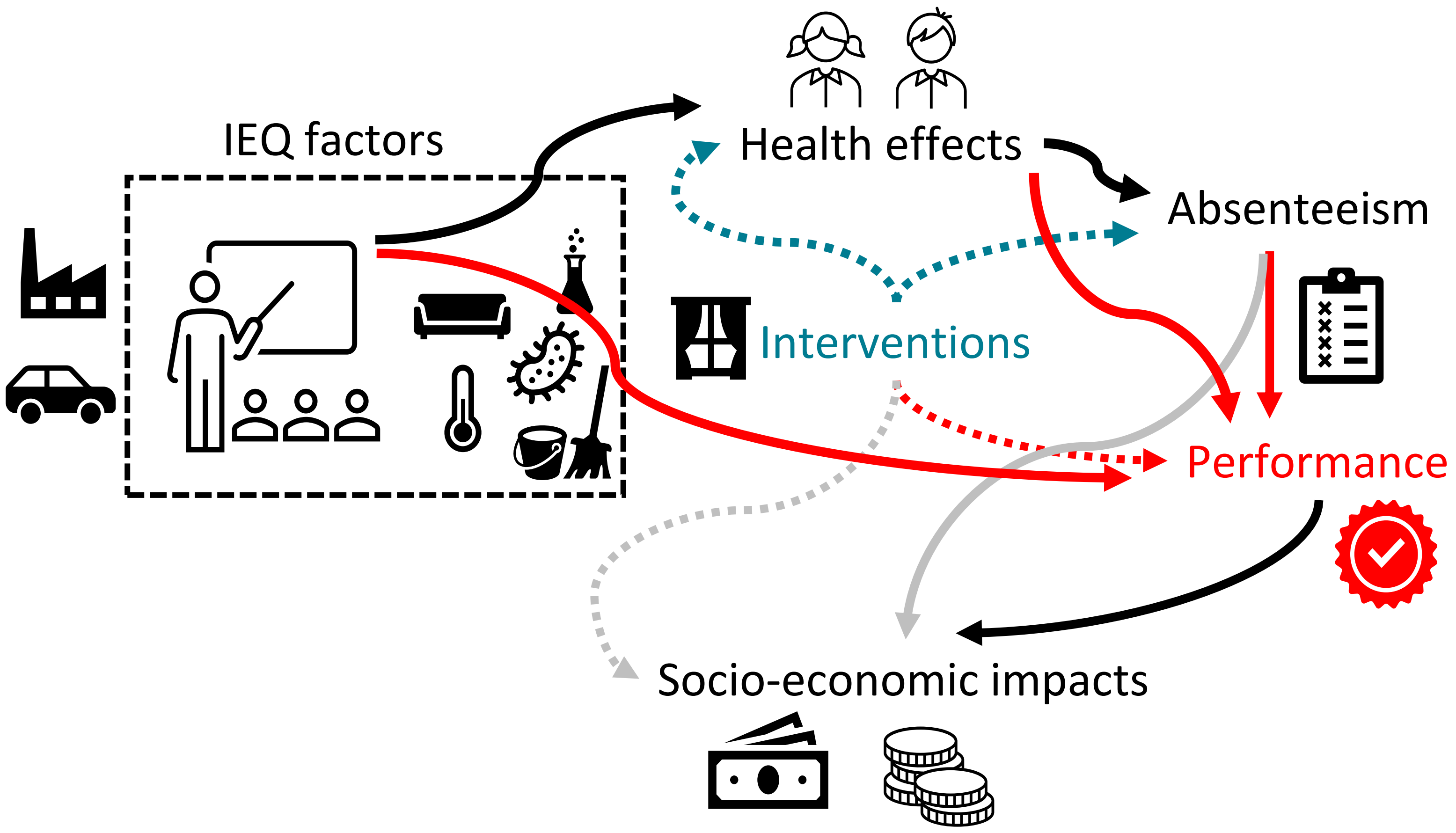
| Pollutant | Study | Details | Relationship with absenteeism |
|---|---|---|---|
| $PM_{10}$ | Marcon et al. (2014) | Absenteeism at school near cement factory in Italy | 10 µg/m$^3$ increase over 5 days associated with 2.4% (CI = 1.2-3.5%) rise in absenteeism 2 days later. Driven by longer exposures rather than peak. |
| $PM_{2.5}$ | Deng et al. (2021) | 85 elementary classrooms, Midwest USA | 3% increase in illness-related absenteeism with 1,000,000 counts/l $PM_{2.5}$ increase (heating season) |
| | Deng et al. (2023) | 144 classrooms, 31 schools, Midwest USA | Mean indoor $PM_{2.5}$ is 3.6µg/m$^3$, every additional 1 µg/m$^3$ increase associated with 7.36 increase in days with absences / year |
| $SO_2$ | Ponka (1990) | Day care, nurseries, offices, Helsinki, Finland | Correlation with day care absences only, despite significant correlation between $SO_2$ and reported URIs ($p<0.0001$) and tonsilitis ($p=0.0098$).<br><br>2-day lag correlation highest (exposure to onset) |
| $NO_2$ | Ponka (1990) | Day care, nurseries, offices, Helsinki, Finland | No correlation with absences, significant correlation between $NO_2$ and URIs from health centres ($p=0.0225$). |
| | Pilotto et al. (1997) | 41 classrooms: 4 electric, 4 gas-heated<br><br>Focus on short term hourly peak levels of $NO_2$ | Short, hourly $NO_2$ peaks of ~80 ppb, (20 ppb ambient), caused respiratory absences, significant dose-response relationships as $NO_2$ increased.<br><br>During heating period, cold symptoms last >7 days (average) when highly exposed rather than 4 days. |
| Mould | Simons et al. (2009) | Condition & absentee data for 2751 New York schools | Where visible mould was reported, OR = 2.22 (CI = 1.34-3.68) |

- Relationships relate to indoor concentrations of pollutants, rather than outdoor
- No significant studies relating to VOCs causing absenteeism
- Longer exposures to PM, drive absences 2 days later
- Short peaks of $NO_2$ may cause respiratory absences.

# Absenteeism: Incorporating within analysis


- Definition of “Absenteeism” is a key consideration:
  - Illness-related?
  - Non-illness related found to have a stronger link to performance
  - High absenteeism may be a symptom of deprivation rather than of poor IEQ
- Quantifying relationships from studies, either:
  - Consider an individual aspect of poor IEQ (e.g. particulate matter), or
  - IEQ is quantified from a number of factors using a numerical index

# Academic performance



# Academic performance: Methods of measuring

- Long-term attainment (e.g., exam results, standardised test scores, GPA)
  - School- or district-wide
  - Standard school subjects
  - Measuring long term impact of interventions

- Controlled tests of executive function
  - Short-term impact of interventions
  - Numerical or language-based tests
    - Concentration, cognitive flexibility, working memory, attention, episodic memory, visual processing speed, reaction time, non-verbal reasoning, and coordination

# Academic performance

## IAQ:

- **PM:** working memory, attention, and other cognitive outcomes
- **Reduction of PM and $NO_2$** associated with improved speed on some tasks (not error rate).
- Lower cognitive development in children attending schools in **highly polluted areas ($NO_2$, EC and UFP)**

## Temperature:

- **High temperatures** negatively affect alertness & working memory;
- **Low temperatures** negatively affect executive ability, mental workload, alertness, mental fatigue
- Performance of psychological tests expected to increase by 20% with classroom temperatures lowered from 30°C to 20°C
- Optimal T ≤ 22° **

## Ventilation:

- 2x outdoor air supply rate could improve task completion speed by 8 to 14%
- Significant association between VR and maths scores.
- **Higher national test scores** for pupils in schools with **mechanical ventilation** than those with only natural ventilation.
- Increasing from 2 to 7.5 l/s per person could improve performance in national tests by 5%, and attendance by 1.5%
- Increased ventilation improves short-term IAQ – effects on neurologic symptoms and decision-making.

**Secondary effects**:

- Absenteeism: decreased number of teaching hours does not always lead to lower attainment.
  - Illness- vs non-illness-related

# Interventions

- source control: minimising both indoor and outdoor sources
- providing adequate, controlled, and well-maintained ventilation
- using air purifiers;
- employing energy efficient systems for HVAC

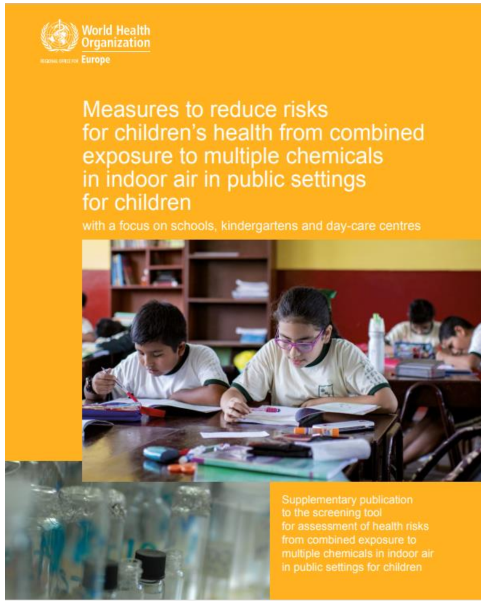
Daily Mail / Georgie Gillard


Peter Dazeley / Getty Images / The Guardian


Wikipedia

# Interventions – source control

- Minimisation of indoor pollutant emissions sources
  - Aldehydes
  - VOCs (e.g., aromatic or chlorinated hydrocarbons, esters, terpenes, PAH)
  - SVOCs (e.g., PAHs)
  - inorganic compounds
- **Continuous sources:**
  - Furniture, floor/wall/ceiling coverings, curtains, varnishes and paint, plastics, formaldehyde resins and glues
- **Intermittent sources:**
  - Class activities (e.g., labs, art class), printers, computers, blackboards, cleaning products, pesticides
- Using smaller quantities of emission sources
- Replacing with certified “green” substitutes or low-emission and solvent-free products
- Temperature and RH (40 – 55%) control
  - Renovation: elimination of microbes and fungi in damp buildings
- Density of occupants – $CO_2$ and bioeffluents

# Source control in schools
(based on WHO (2020; 2022))

| Table 2. Source control of pollutant emissions from indoor sources (based on WHO, 2022) | | |
|---|---|---|
| **Potential indoor sources** | **Pollutants** | **Source control / mitigation measures** |
| Furniture and wooden products (for example, pressed board, plywood, particle board, fibreboard furniture, flooring, panelling, doors) | formaldehyde, acetaldehyde, benzene,<br>α-pinene | Choose certified, eco-labelled materials with low VOC emissions for floor/wall/ceiling coverings and furniture |
| Flooring materials (e.g., PVC flooring with adhesive, carpet backings) | formaldehyde, acetaldehyde, benzene, ethylbenzene, xylenes, styrene, toluene | - Implement renovations and refurbishments in the first month of the summer holiday<br>- Use woven or knotted textile carpets instead of synthetic ones |
| Wall paints, solvent-based (water-resistant) | benzene, xylenes, styrene, toluene | Implement renovations and refurbishments in the first month of the summer holiday<br>- Use water-based paints |
| DIY products (for example, solvents, paints, wallpapers, glues, adhesives, varnishes, lacquers) | formaldehyde, acetaldehyde, benzene, ethylbenzene, trimethylbenzene, xylenes, styrene, toluene, tetrachloroethylene<br>trichloroethylene, n-butyl-acetate, naphthalene,<br>benzo(a)pyrene | - Implement renovations and refurbishments in the first month of the summer holiday<br>- Use smaller quantities of or green alternatives to paints, solvents, adhesives and science laboratory chemicals<br>- Increase ventilation, e.g., open windows when working with chemicals |
| Painted or varnished coatings | benzene, ethylbenzene, xylenes, toluene, dichlorobenzene, n-butyl-acetate | Choose certified, eco-labelled materials<br>Limit the use of chemical products |
| Paint and varnish removers<br>stain removers, wood cleaners | α-pinene,<br>tetrachloroethylene, trichloroethylene | Choose certified, eco-labelled materials<br>Limit the use of chemical products |
| Electronic equipment (e.g., photocopy machines) | formaldehyde, acetaldehyde | Place photocopiers and printers in separately ventilated rooms |
| Plastics | trimethylbenzene, styrene | |
| New books, magazines, newspapers | formaldehyde, toluene | Locate in dedicated rooms /library, well ventilated |
| Cleaning products<br>and<br>disinfectants | formaldehyde, trimethylbenzene, toluene, limonene, α-pinene, trichloroethylene<br>naphthalene | Use fragrance-free cleaning materials |
| Dry-cleaned textiles, curtains, carpets | tetrachloroethylene | Use washable textiles for classrooms instead of textiles that require dry-cleaning |
| Air fresheners | dichlorobenzene, limonene | Do not use air fresheners in classrooms, |
| Human activities (cooking) | formaldehyde, acetaldehyde, benzo(a)<br>pyrene | Install extractor fans in kitchens to be on during cooking activity |
| Secondary formation | formaldehyde, acetaldehyde | Reduce ozone emissions indoors |

# Interventions

- Source control as a first step.
- Mechanical ventilation can:
  - help achieve a desired air flow rate
  - decrease concentrations of indoor pollutants (e.g., $PM_{10}$, formaldehyde, TVOC) by up to 45% (Choo et al., 2014)
  - reduce $PM_{2.5}$ and UFP concentrations by up to 43%, if system is operated 1 hour before start of rush-hour traffic (Fernandes et al., 2023)
  - contribute significantly to the building's energy budget (Toyinbo, 2023; Salthammer, 2016)
- Air cleaning technologies
  - High MERV (e.g., HEPA) filters in tandem with HVAC air recirculation can be very effective
  - Standalone air purifiers can decrease PM concentrations in classrooms and daycare centres by 35 – 86% (Fernandes et al., 2023, Shree et al., 2024)
  - Reduction of fungal spore counts with HEPA filter

# Interventions – associations with outcomes

- Limited and inconsistent evidence for whether the reduction of pollutants through air filtration is associated with impacts on academic performance and/or absenteeism (Vakalis et al., 2021)
- Doubling outdoor air supply rate improved school task completion speed; using electrostatic air filters had no significant effect – is this due to PM or $NO_2$? (Wargocki & Wyon., 2017)
- Significant positive effect on cognitive performance after 1 hour of NAI intervention in college students (reasoning skills, short-term memory) – suggested due to reduction in PM (Guo et al., 2023)
- Evidence of associations between VR and illness-related absenteeism (Mendell et al., 2013)
- Estimated reduction in relative risk of infection and less coughing with air purifiers present (Banholzer et al., 2024)
- Ventilation interventions reducing pet-related allergens associated with reduced asthma symptoms (Salo, 2009)
- HEPA filters in classrooms improved FEV1% test results by ~ 4% (Vesper et al., 2023)

# Intervention studies: limitations

- Some inconsistent findings, dependent on study design, quality and strength
- Confounders e.g., socio-economic status
- Attribution of improved performance from air cleaning without fully understanding effectiveness
- Intervention studies may not give enough time for potential outcomes to become evident.

# Quantifying economic benefit

- Cost benefit analysis should incorporate:
  - Inputs: initial student health, social conditions, school site
  - Outputs: tangible, difficult to quantify attendance and performance outcomes
- Analysis of benefits:
  - Increased attendance-linked funding from ventilation improvements
    - 4 to 7.1 l/s/person -> 3.4% decrease in absenteeism -> $33mil/yr. (Mendell et al., 2013)
  - Reduced healthcare by following WHO PM guidelines in 25 EU countries
    - Improved lung function -> €31bil in healthcare saving (Salthammer et al., 2016)
  - Country-level benefits: ventilation improvements (average -> building code)
    - Danish GDP increase of €173mil/yr., public finances €37mil/yr. for 20 years (Wargocki et al., 2014)
    - Reduced teacher absences, completion of studies, performance improvement

# Quantifying economic costs

- Analysis of individual costs:
  - % of school budget required for improvements
  - Energy/capital costs of improving HVAC/filtration <0.1% of US educational spend (Fisk, 2017)

- Additional costs of increasing ventilation/air cleaning:
  - Operation: Heat (cool climates), dehumidify (warm) and drive air
    - Doubling ventilation from 2.8 -> 5.6 l/s/person increases energy by 37%, total by 26% (Ito et al., 2010)
  - Design and construct systems
    - Basic (MERV5) to most efficient (MERV 14) filters has marginal cost of $20-32/year/asthmatic student (Martienes et al., 2018), well below benefit of avoided asthma exacerbation of $49-79

# Current limitations to knowledge

- Relationships can be analysed but causal pathways are more challenging
  - Improved ventilation can improve health, however link to academic performance reliant on large number of contrasting factors (socio-economic, attendance)
  - Hard to isolate effect of individual pollutants (e.g., VOCs) on performance
    - Potential differences in attainment / performance due to pollutants from different sources (e.g., indoor-generated PM vs ingress of traffic-related PM from outdoors)
  - Few studies link consequences of poor IEQ through to economic costs/benefits

- Key challenges
  - Low availability of long-term measurements
  - Failure to report key details of study design in individual schools
  - Predominance of self-reported data over quantifiable health measurements

# Key recommendations

- Implementation of current national regulations for ventilation.
- Eliminating or controlling sources of outdoor and indoor pollutants.
- Ensuring provision of adequate classroom ventilation, through hybrid or mechanical systems to conform, with existing ventilation guidance.
- Use of air cleaners in naturally ventilated buildings.
- Regular cleaning of classrooms and maintenance of air filters.
- Provisions for cooling indoor spaces during hot weather.
- Implementation of existing research findings into practice, in terms of both national regulation and local guidance, e.g., working with relevant stakeholders such as local authorities, headteachers and parent groups to encourage change.

# Acknowledgements


- UKHSA Knowledge and Library Services, particularly Michael Cook
- Eurovent (Stijn Renneboog and Francesco Scuderi) for commissioning and funding the work.

# Thank you for your attention

Duncan.Grassie@ukhsa.gov.uk
Kaja.Milczewska@ukhsa.gov.uk
Sani.Dimitroulopoulou@ukhsa.gov.uk

# Examples of select studies of IEQ vs performance

| Study | Key question | Key findings |
|---|---|---|
| **Gignac et al., 2021**<br>High schools, Barcelona | Does purifying the air of classrooms produce short-term changes in attention? | **No substantial difference found in median hit reaction time standard error** (HRT-SE) and other secondary attention outcomes, despite short-term $PM_{2.5}$ and BC concentrations reduced by up to 87% ** |
| **Sunyer et al., 2015**<br>Primary schools, Barcelona | Chronic TRAP exposure effects on development of working memory. | **Lower improvement in cognitive development** (7.4%) in children attending highly-polluted than less polluted schools (11.5%).<br>**Working memory** significantly affected by UFP. |
| **Toftum et al., 2015**<br>Elementary schools (Denmark) | Associations between ventilation mode and learning. | **Higher national test scores** for pupils in schools with **mechanical ventilation** than those with only natural ventilation.<br>**Lowest achievement indicator** (Danish and maths), and highest $CO_2$ concentrations found in naturally ventilated schools. |
| **Wargocki et al., 2020**<br>Elementary schools | Estimating the magnitude of effects of learning and sick-leave due to changes in classroom IAQ | School task performance **speed improved by 12% and accuracy by 2%** when $CO_2$ reduced from 2100 ppm to 900 ppm.<br>**Improved performance in national tests by 5% and attendance by 1.5%** upon increasing VR from 2 to 7.5 l/s per person. |

# THANK YOU!

IAQ matters

# CONFERENCE by Eurovent

## BREATHING ACHIEVEMENT INTO EVERY CLASSROOM

EUROVENT
EUROPEAN INDUSTRY ASSOCIATION

EUROVENT CERTIFIED PERFORMANCE
www.eurovent-certification.com

BESA
BUILDING ENGINEERING SERVICES ASSOCIATION

CIBSE