Training material for architects

Health aspects of indoor air pollution in schools: Specific actions aimed at reducing the health risks due to indoor pollutants

National Public Health Center

Outline

Indoor Air Quality

Factors influencing IAQ

Primary sources of IAQ contaminants

- Outdoor sources
- Indoor sources

Overview of air pollutants

Health impacts of indoor air pollution

Contribution of indoor air pollution to the disease burden

Sick Building Syndrome

Indoor Environmental Quality (IEQ)

Health impacts of climate change

Why IAQ issues important in schools?

- Children spend 90% of their time indoors (classrooms, homes, vehicles)
- Studies have indicated that indoor air often contain higher levels of contaminants than outdoor air.
- In Hungary there are 3585 primary schools with 735 thousands pupils. This is almost 10% of the population!
- Number of teachers in primary schools: 78 thousand (in 2018).
- Focus on Children’s Health and healthy environmental issues according to the European Environment and Health Process (WHO/Euro, UN ECE) has high priority.

Children's Health and Environment Action Plan for Europe

Children's health and healthy environmental issues according to the European Environment and Health Process (WHO/Euro, UN/ECE) has gained a high priority.

In 2004, the Fourth Ministerial Conference on Environment and Health adopted the Children's Health and Environment Action Plan for Europe, which includes four regional priority goals to reduce the burden of environment-related diseases in children (CEHAPE).

One of the goals (Regional Priority Goal, RPG III) aims to prevent and reduce respiratory diseases due to outdoor and indoor air pollution, thereby contributing to a reduction in the frequency of asthmatic attacks, and to ensure that children can live in an environment with clean air.

Source: http://www.euro.who.int/__data/assets/pdf_file/0006/78639/E83338.pdf

Indoor Air Quality (IAQ)

Indoor space: any closed area surrounded by boundary elements (including the indoor space of vehicles)

Indoor Air Quality refers to the quality of the air inside buildings as represented by concentrations of pollutants and thermal (temperature and relative humidity) conditions that affect the health, comfort, and performance of people staying inside.

Indoor air pollution does not include technology-related air pollution in the workplace!

Why did IAQ come into focus?

- Reduction of outdoor air pollution
- Changing construction practices

  - construction material (concrete) – air permeability

  - widespread use of plastics and adhesives
- Prefabricated buildings – lower ceiling height
- New heating methods
- Energy conservation aspects – thermal insulation
- Different habits in the usage of indoor spaces
- Time spent indoors: 80-90%

What is the significance of IAQ in schools?

- Growing children with developing their physiological capability are very sensitive to hazardous chemicals.
- Exposure to poor IAQ in school can interfere with a pupil's ability to learn.
- Asthma, headaches, nausea, drowsiness, and dizziness can be troubling.
- Toxic chemicals can cause not only acute symptoms like irritation, but long lasting adverse health damage.
- Low level of comfort leads to dissatisfaction.

Factors influencing IAQ

- Outdoor air quality
- Extent of air exchange
- The binding capacity of indoor surfaces
- Indoor pollution sources (people, animals, furniture, building- and covering materials etc.)

$$\text{Indoor Air} = \text{Outdoor Air} + f\,(\text{Building}) + \varphi\,(\text{Activities})$$

Outdoor sources of pollution

- Traffic (proximity of busyroads, petrol vs. diesel, cars vs. trucks)
- Power plants
- Other industrial plants
- Pollution from constructions
- Waste deposit sites
- Agricultural activity (e.g. spraying pesticides)

Architectural factors that influence the pollutants' infiltration from outdoor

- Orientation
- Storey level
- Classrooms facing the street or the yard
- Role of vegetation
- Parking places, smoking area near the windows of the classrooms

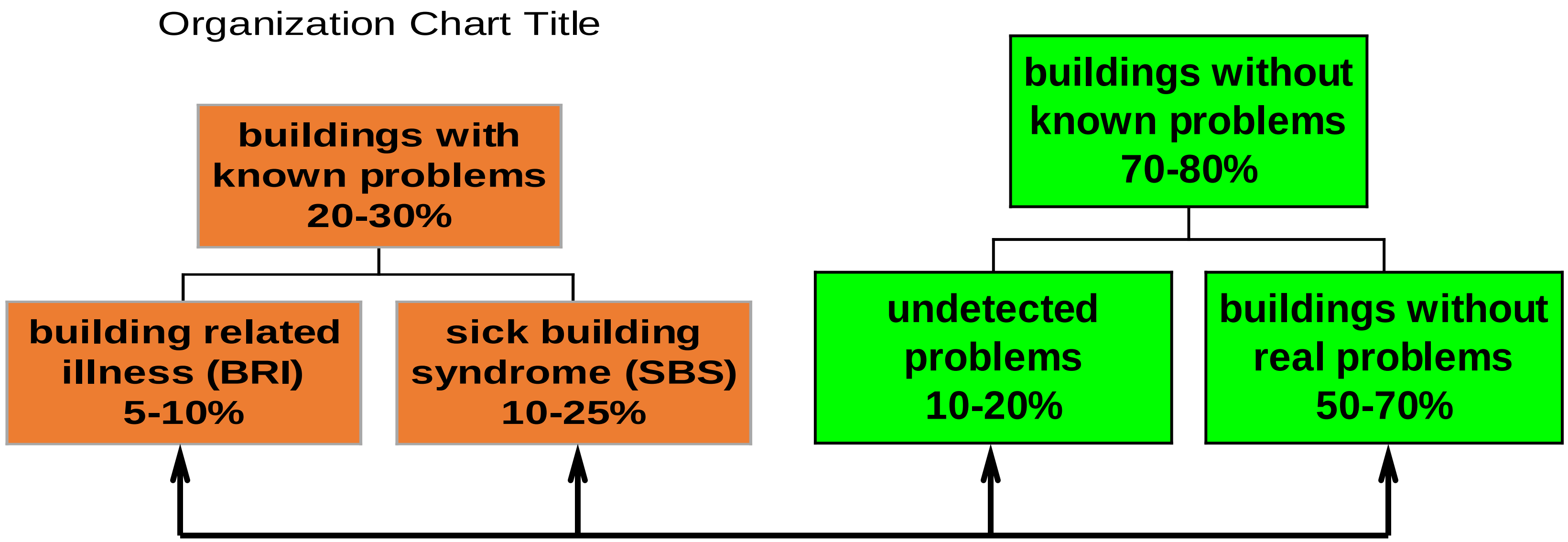
Indoor sources of air pollution in classrooms

- Dust
- Construction and insulating materials
- Surface materials (wall covering, carpets, blinds, curtains)
- Furnishings
- Evaporation of volatile chemicals from new materials
- Paints
- Waxes, repellents
- Glues and resins
- Solvents
- Photocopiers, inks
- Cleaning/disinfecting products
- Biocides
- Personal care products
- People (exhaled air, smoking?)
- Pets, rodents, insects
- Mould (from moisture)

Secondary material emissions:

- e.g., due to moisture
- ozone from laser printers
- outdoors and nitrogen oxides reacting with VOCs
- cleaning materials can react with surfaces

How common are IAQ problems?

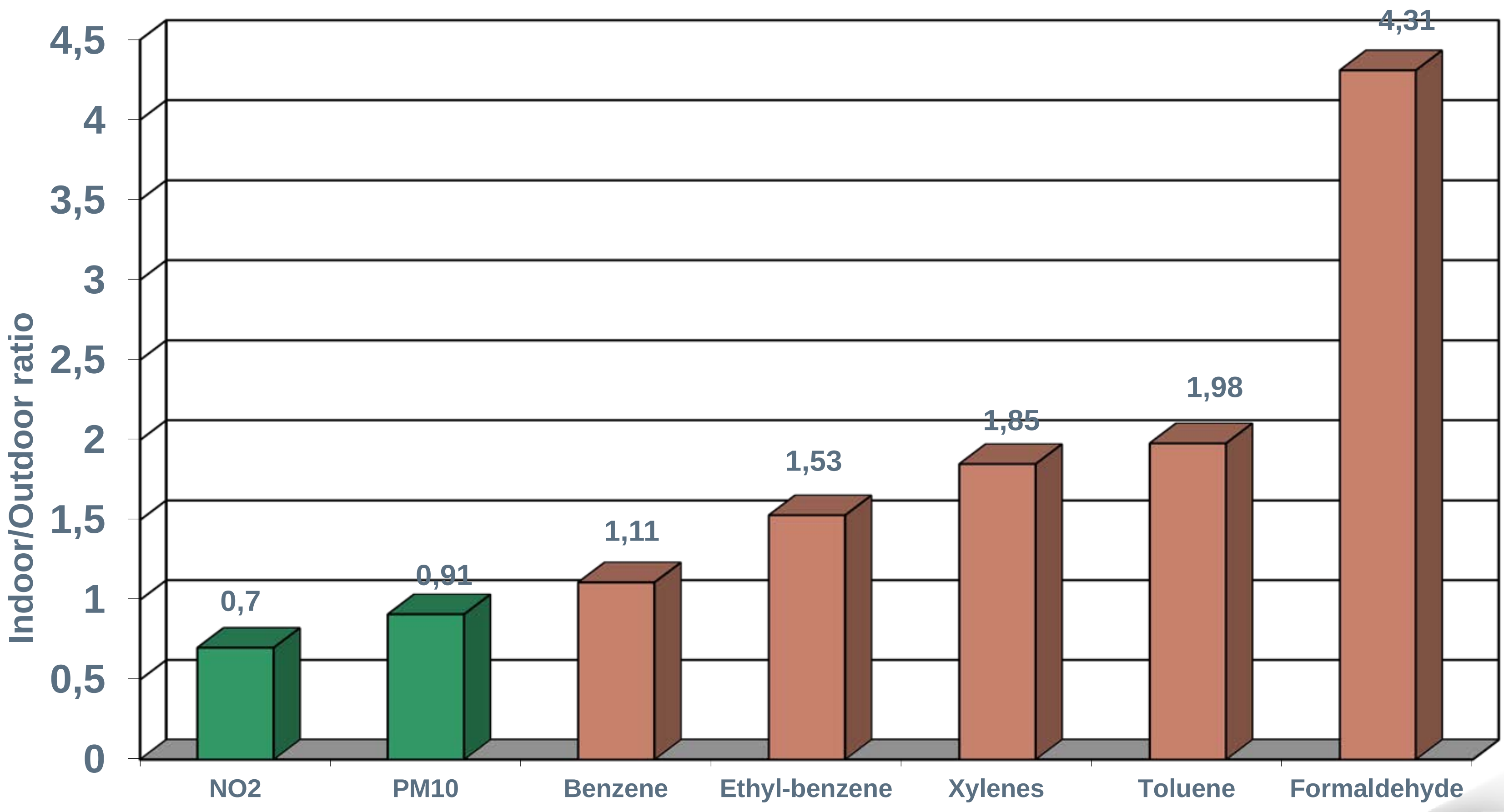


John Oudyk: Doing Something about Indoor Air Quality. Occupational Health Clinics for Ontario Workers Inc., 2014

Relative importance of indoor air pollutants (Stolwijk)*

Pollutant	Outdoor cc. (μg/m^3)	Daily outdoor exp. (μg) (1.5m^3/day)	Indoor conc. (μg/m^3)	Daily indoor exp. (μg) (13.5m^3/day)	Total daily exp. (μg) (15m^3/day)
HCHO	3 →	4.5	50 →	675	679
NO_2	5 →	7.5	30 →	405	412
Ozone	100 →	150.0	30 →	405	555
Toluol	5 →	7.5	75 →	1012	1020
PM_{10}	30 →	45.0	80 →	1080	1125

The ratio of pollutant concentrations measured outdoors and in the classrooms



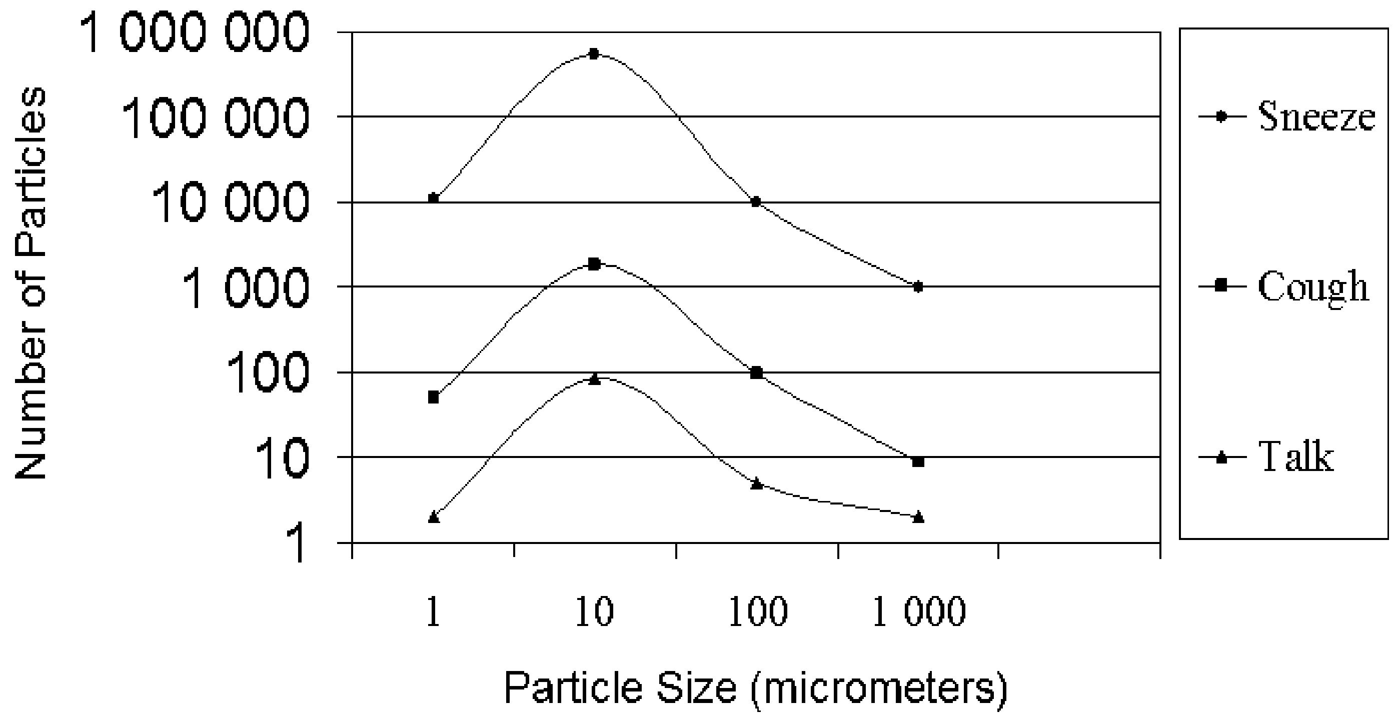
Contaminants generated by people staying inside (biocontaminants)

- Fresh air contains 21.0% (v/v) O_2
- Exhaled air contains 17.0% (v/v) O_2 and 83.0 % (v/v) CO_2
- An adult emits 45 g sweat / hour
- An adult produces 300 British Thermal Unit (BTU) of heat /hour [300 calories].

Particle Emission Based Upon Activity

Activity	Particles
Standing/Sitting (no movement)	100,000
Light movement	500,000
Body & arm movement	1,000,000
Changing Positions	2,500,000
Slow walking	5,000,000
Average walking	7,500,000
Gymnastics	>15 million

Particles Produced by Infected Persons



National Air Filtration Association; 2006
Rev. 2

Microbial Indoor Air Pollution

- mould
- bacteria, viruses
- pet hair, skin flakes, faeces, urine
- insects (cockroach faeces, dust mites, etc.)
- pollen

- Outdoor sources: mould, pollen in outdoor air
- Indoor sources - major concern:
  - humidifiers and stagnant waters
  - moist surfaces and materials
  - vapour from showering
  - air conditioning
  - upholstered furniture and carpets
  - animals (**the allergens can be present months after the removal of the source)**
  - infected people

Causes of dampness/mould in the buildings

Rising dampness

- The capillary-like absorption of groundwater into the structural elements of the building (bad insulation)

Penetrating dampness

- leaking, rain, melted snow (through the roof, walls or joints)

Condensation

- Excessive vapour production or inadequate ventilation
- Inadequate heating
- Cold surfaces

Health consequences of dampness/mould in the buildings

Increased risk of - respiratory symptoms
- respiratory infections
- exacerbation of asthma
- development of asthma
- allergic rhinitis
- allergic alveolitis
- hypersensitivity pnemonitis

N.B.: Atopic and allergic people are particularly susceptible!

WHO Indoor Air Quality Guidelines on Dampness and Mould (2009)

„As the relationships between dampness, microbial exposure and health effects can not be quantified precisely, no quantitative, health-based guidline values or thresholds can be recommended for acceptable levels of microorganism contamination.

Instead, it is recommended that dampness and mould-related problems be **prevented**. When they occur, they should be remediated because they increase the risk of hazardous exposure to microbes and chemicals.”

An overview of the chemical pollutants

Combustion products:

- Carbon monoxide (CO)
- Nitrogen dioxide (NO_2)
- Sulphur dioxide (SO_2)
- Nitrogen oxides (NOx)
- Particulates (PM)
- PAH compounds

Sources:

- Ambient air (traffic, power plants, industry)
- Heating, stoves and fireplaces
- Environmental tobacco smoke (ETS)
- Garages
- Parking lots nearby classroom windows
- Candles, sparklers and incenses
- Mosquito coils

Nitrogen-dioxide (NO_2)

I/O ratio ~ 0.8

Health effects: Asthmatics are especially sensitive (!)

- Increased bronchial reactivity
- Reduced respiratory function
- Increased respiratory morbidity
- Reduced immunological protection
- Middle ear, nose-, ear-, pharynx inflammation
- Increases the allergenic effect of allergens (e.g. Food allergy!)
- Eczema
- Increased blood coagulation in adults

Limit values:

- **WHO**: indoor 1 hour: 200 µg/m^3
  annual: 40 µg/m^3

Carbon monoxide (CO)

I/O ratio ~ 1.0

It is caused by incomplete combustion. Sources:

- Heating and cooking devices
- ETS
- Running car engines in the garage!
- Car traffic
- Other outdoor CO sources (power plant, incinerator, industrial pollution)

CO binds 250 times stronger to haemoglobin than O_2. Foetal Hb also has a stronger affinity to CO. CO causes tissue hypoxia.

Carbon monoxide (CO)

Increasing COHb concentration

Acute symptoms:

- Headache, vertigo, tiredness, heavy breathing
- Nausea, vomiting
- Irritability
- Drowsiness, confusion, desorientation
- Loss of consciousness, coma
- Death

Chronic exposure:

- Ischemic heart disease, myocardiac failure, AMI
- retardation in fetal development, reduced birthweight, congenital malformation
- Increased cardiovascular and total mortality
- Asthma, sinusitis, pneumonia

Carbon monoxide (CO)

Taking sensitive populations into account (!)

WHO Guideline:

- 15 min.: 100mg/m^3
- 1 hour: 35 mg/m^3 (INDEX project: 30 mg/m^3)
- 8 hours: 10 mg/m^3
- 24 hours: 7 mg/m^3

Ozone

At ground level ozone is not emitted directly, but it is created by chemical reactions between NOX and VOCs in the presence of sunlight and heat.

OZONIZERS – as air purifiers

Ozone is harmful to health

- Chest pain, coughing, throat irritation, airway inflammation, lung damage

The air purifying effect of ozone is ineffective in concentrations under the limit values

- WHO AQG for Europe (2nd ed.) 120µg/m^3 (8 hours),

It is used in high concentrations to disinfect, deodor, or for chemical decontamination of spaces not intended for human staying.

Pollutants released indoors

- Formaldehyde
- Other Volatile Organic Compounds
- Phthalates, polybrominated flame retardants, per- and polyfluorinated chemicals
- Vinyl chloride
- Trichloroethylene, tetrachloroethylene, ammonia
- Terpenes (limonene, alpha-pinene)
- Phenol
- Naphthalene
- Asbestos

VOCs

formaldehyde, organic solvents (benzene, xylenes, ethylbenzene, toluene, carbon tetrachloride, styrene), methylene, perchloroethylene, vinylchloride, benzene, toluene, xylene, aniline, terpenes (limonene, alpha-pinene), etc.
Concentrations of many VOCs are consistently higher indoors (up to ten times higher) than outdoors.

Sources:

- paints, paint strippers and other solvents
- wood products (formaldehyde)
- varnishing
- aerosol sprays
- air fresheners, deodors, hair sprays
- cleansers and disinfectants
- pesticide
- building materials and furnishings
- office equipment (copiers and printers
- glues and adhesives, permanent markers, highlighters, correction fluids

Health effects:

- eye, nose and throat irritation
- headaches, fatigue, dizziness, nausea
- damage to liver, kidney and central nervous system
- some organics are suspected or known to cause cancer

Formaldehyde

Sources:
- Furniture
- Wood products
- Insulation (urea formaldehyde insulators - UFFI)
- Disinfectant – preservatives (paints, varnishes, parquets, wallpapers)
- Laminated and extruded plastic products (urea- and phenol-formaldehyde resins)
- Polymers (polyacetates, melamine-resins)
- Traffic (exhaust emissions)
- Cigarette smoke

Emission increases with temperature and humidity!

Acute health effects of exposure:
- Mucous membrane irritation (lacrimation, sneezing, throatache, increased expectoration)
- Inhibits ciliary activity
- Skin irritation (rash, itching)
- Allergenic, sensitizing effect
- Sinusitis, headache, nausea, insomnia
- Weak mutagenic effect, but synergism (UV, rtg)

Chronic health effects of exposure:
- Chronic rhinitis, bronchitis
- Bronchial asthma
- Allergy
- Carcinogen (IARC Group 1)

Formaldehyde

Odour threshold:

10% = 30 µg/m^3; 50% = 180 µg/m^3; 90% = 600 µg/m^3

WHO guideline: 100 µg/m^3 – 30 minutes

Exposure reduction:

- Reduced formaldehyde-emitting products
- Temperature and humidity control
- Proper ventilation

Benzene

Sources:

- Varnishes, paints, adhesives
- Cigarette smoke (430-590μg/cigarette),
- Combustion, oil heating
- Traffic (gasoline),
- Garages
- Oil industry
- Chemical- and pharmaceutical industries

Health effect (less toxic with toluene) :

- Acute poisoning: euphoria, nausea, vertigo, cramps, loss of consciousness, respiratory arrest
- Chronic poisoning: haematological disorders (bone marrow anaplasia, leukaemia - IARC 1A carcinogen), chromosome aberrations, immunological disturbances, asthmatic symptoms

Benzene

Guideline values: **No safe concentration (!)**

- US/EPA lifetime cancer risk:

  1 µg/m^3 = 2.2-7.8 / 1.000.000

- WHO excess lifetime risk (leukaemia):

  1 µg/m^3 = 6 /1.000.000

  0.17 µg/m^3 = 1/1.000.000

  1.7 µg/m^3 = 1/ 100.000

  17 µg/m^3 = 1/ 10.000

- WHO guideline value: 5 µg/m^3 – yearly average

Toluene

Source: Chemical industry (to replace benzene!)

Health effects: liver and kidney damage, central nervous system damage (glue sniffers!), reproductive damage, disruption of foetal development (spontaneous abortion, developmental disorder, IUGR). Not genotoxic, not carcinogen

Guideline values:

- **WHO Guideline value:**

  260 µg/m^3 (weekly avg. concentration)

  (also good protective effect in terms of reproduction)

  based on odour threshold: 1 mg/m^3 (30 min avg)

- **Values measured in Hungary:**

  SEARCH: 4.7 ± 4.0 (1.0-21.4) µg/m^3

Xylenes

Less toxic than benzene.

Acute effect: skin irritation

Chronic effect: liver and kidney damage

Values measured in Hungary:

SEARCH: 7.4 ± 12.4 μg/m^3 (range: 0.4 – 69.3)

Naphthalene

Sources: coal tar, industry (phthalate production), car exhaust, moth repellents, disinfectants, deodorants

Health effect:

- Respiratory damage (inflammation, cancer- in animals)
- Carcinogen (IARC 2B) – possibly

Guidelines:

- WHO IAQ Guideline: 10 µg/m^3
- values measured in Hungarian schools: 3.2 ± 2.1 (range: 0.3 -9.0)

Limonene

Source: Cleaning products

Values measured in Hungarian schools:

37.3 ± 41.8 µg/m^3 (range: 4.9-149.5)

Trichloroethylene (TCE)

Sources:

- ambient air (18 µg/day on average)
- indoor air (woodstains, varnishes, coatings, lubricants and adhesives, paint removers, cleaning products)
- drinking water (6 µg/day on average)

Health effects:

- **Toxic effect**: - central nervous system (headache, tiredness, irritability, alcohol intolerance, it was used as a general anesthetic)
  - liver
  - kidneys
- **Adverse pregnancy outcomes** (spontaneous abortion (+/-), heart malformation)
- **Carcinogenic effect:** IARC 2A category (probably human carcinogen), liver and biliary cancer (risk increase of 90%), non-Hodgkin lymphoma (risk increase of 50%), leukaemia, myeloma multiplex, cervical cancer, renal cancer (risk incease of 70 %)

TCE

According to WHO Air Quality Guideline for Europe , 2000:

NO SAFE CONCENTRATION (!)

Excess lifetime risk values: in case of 2.3 μg/m³: 1/1million,
in case of 23.0 μg/m³: 1/100thousand,
in case of 230.0 μg/m³ :1/10thousand.

Based on this, the Hungarian limit value for ambient air is: 23 μg/m³.

Indoor spaces are not regulated. The expert opinion of NIEH/HU designated 11 μg/m³ as the level where intervention is necessary.

Concentrations measured in Hungarian schools (SINPHONIE):
9.7 ± 24 μg/m³ (range: 0.0 – 86.2 μg/m³)

Tetrachlorethylene

Source: clothes cleaning (service and detergent residue)

Exposure: inhalation

Health effects:

- carcinogenic (IARC 2A, ie. Probably carcinogenic to humans)
- nephrotoxic effect (derived guideline value: 250 $\mu g/m^3$

NIEH/HU recommendation: 260 $\mu g/m^3$

Concentrations measured in Hungarian schools:

SINPHONIE: 0.06 ± 0.26 $\mu g/m^3$ (range: 0.0 – 1.0 $\mu g/m^3$)

Vinyl chloride

Source:

Vinyl chloride is produced in water under anaerob circumstances from trichlorethylene and tetrachlorethylene. It gets into the air where its half-life is around 20 hours. After it is inhaled it transforms into very reactive and mutagenic metabolites.

Health effects:

- Its acute toxicity is low, but even in low concentrations (whether short or long exposure) it is toxic to the liver.
- It is mutagenic, carcinogenic (IARC 1A, liver haemangiosarcoma and other tumors: liver tumour, brain tumour, lung cancer, and malignancy of the lymphatic and haematopoietic system. The liver is the most sensitive to VC exposure.

The different regulations contain the following limit values and guideline values for VC:

COUNTRY	μg/m³
Hungary: 4/2004. (IV.7.) KvVM-ESZCSM-FVM Joint Decree occupational limit value: 10 mg/m³	5 (annual)
The Netherlands, 1984, carcinogenic life-time unit risk: for **10^{-6}**	0.35
EPA/IRIS carcinogenic life-time unit risk: **1 □g/m³ □4.4 x 10^{-6}** **from childhood: 8.8 x 10^{-6}**	0.23 (for 10^{-6}) 2.3 (for 10^{-5}) 0.11 (for 10^{-6}) 1.1 (for 10^{-5})
WHO (1987) carcinogenic life-time unit risk: **1 0□g/m³ □1.0 x 10^{-6}**	10 (for 10^{-5})
WHO, Geneva, 2000 as above	

Endocrine disrupting chemicals

- **Phtalates** (plasticizers in soft plastic and gum objects)
- **Polybrominated flame retardants, BFRs (PCBs, PBBs, PBDEs)** (plastic, electrical and electronic equipment, upholstered furniture, curtains, blinds)
- **Per/polyfluorinated water- and stain repellents, PFCs (PFOSs, PFOAs, PFCAs)** (carpets, upholstery stain-protectants, carpet-care liquids, treated home textiles, floor waxes)
- **Pesticides** (see next slide)
- **Polycyclic aromatic hydrocarbons (PAHs)** (in ambient air by incomplete combustion of organic matter, smoke, diesel exhaust)

Higher concentrations of phthalates, BFRs, PFCs in newly constructed or renovated buildings.

Most of them are very stable, persistent and bioaccumulating chemicals.
Molecules from consumer products spread into indoor air, dust and indoor surfaces.

Endocrine disrupting chemicals

Health effects (through disturbing the normal hormonal functions):

- reduced semen quality with consequent decreased fertility, genital malformations, testicular and prostate cancer
- early puberty, cysts in the ovaries, endometriosis, decreased fertility, pregnancy complications with early abortions, breast cancer
- diabetes and obesity
- disorders in brain development (ADHD, ASD), and degenerative diseases in the brain (Parkinson's disease)
- Hyper- and hypo- thyroidism and thyroid tumours.

Pesticides (insecticides, herbicides, rodenticides, etc.)

Problems arising from the indoor use of pesticides:
- Greater concentration near the floor
- They stay longer on certain surfaces (e.g. carpets)
- Sometimes too frequent, too extensive and in some cases unnecessary application

Insecticide types commonly used indoors:
- Pyrethroids: allergens, damage central nervous system (in large concentrations)
- Cholinesterase inhibitors: neurotoxins, inhibit the neuro-development
- Hydramethylnone (relatively new)
- Insect repellants
- Mosquito coils

Health effect:
- Acute poisoning – usually accidental
- Allergic and general symptoms are frequent due to inhalation
- Long term pesticide exposure has been linked to the development of asthma? central neural system disorders (attention deficit and hyperactivity disorder, ADHD) and degenerative diseases (Parkinson's disease); cancer (leukaemia, non-Hodgkin lymphoma)

Asbestos

Types : chrysotile (white asbestos) (90-95%)

crocidolite (blue asbestos)

(amosite – brown asbestos) tremolite, actinolite, anthophyllite

Dangerous: > 5 μm long and <3 μm wide fiber

length / width > 3

Exposure:

Mining, construction, oil refineries, automotive industry, paper production, rubber industry

During the production of asbestos textiles (PPE, sealants), friction pad production, seals, (automotive industry), thermal insulation, flame retardants (buildings, vehicles, heaters), spraying technology, during the installation of filters (food industry, air purifying), through the usage of additives (paper production, rubber industry), contamination (talcum).

Corrugated and flat roofing sheets, pipes transporting air, gas, water, wastewater

In Hungary approx. 200,000 people got exposed to asbestos

Asbestos

Prevention:

- Legislation: ban
- Limit value: NO SAFE CONCENTRATION

acceptable risk (10^{-5} – 10^{-6}): WHO: 1000 F/m^3 lifetime exp.

The built-in asbestos, until it is in a good condition, is better left alone

Removal has to be done by experts and with appropriate protection!

Has to be treated as hazardous waste after removal

Contribution of indoor air pollution to the disease burden

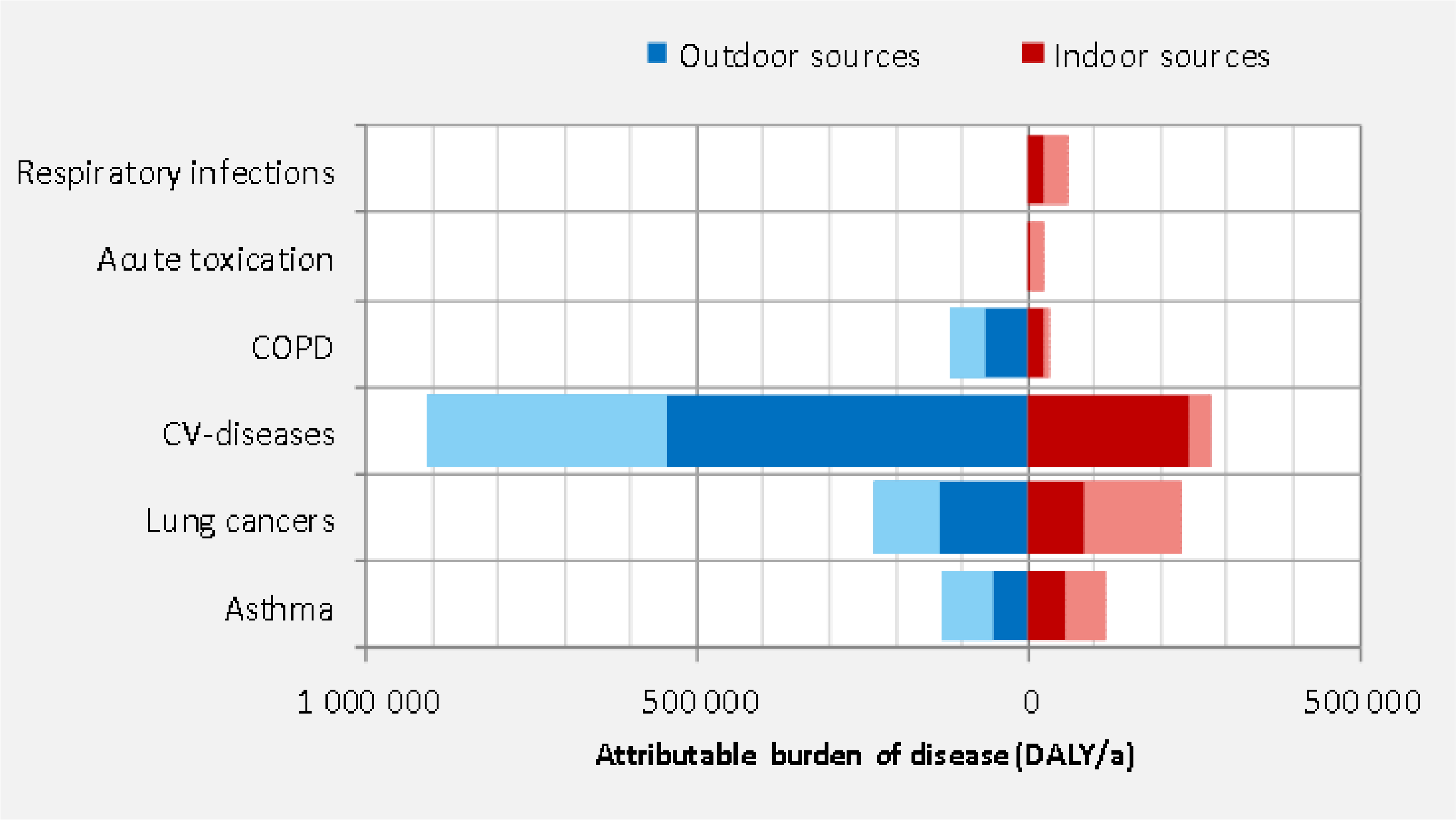
The annual burden of disease caused indoor air pollution, including polluted outdoor air used to ventilate indoor spaces, is estimated to correspond to a loss of over 2 million healthy life years in the European Union (EU).

These estimates are calculated as disability adjusted life-years (DALY) and account for loss of life years due to premature mortality and due to years lived with disabilities (i.e. morbidity).

DALY (Disability-Adjusted Life Years)

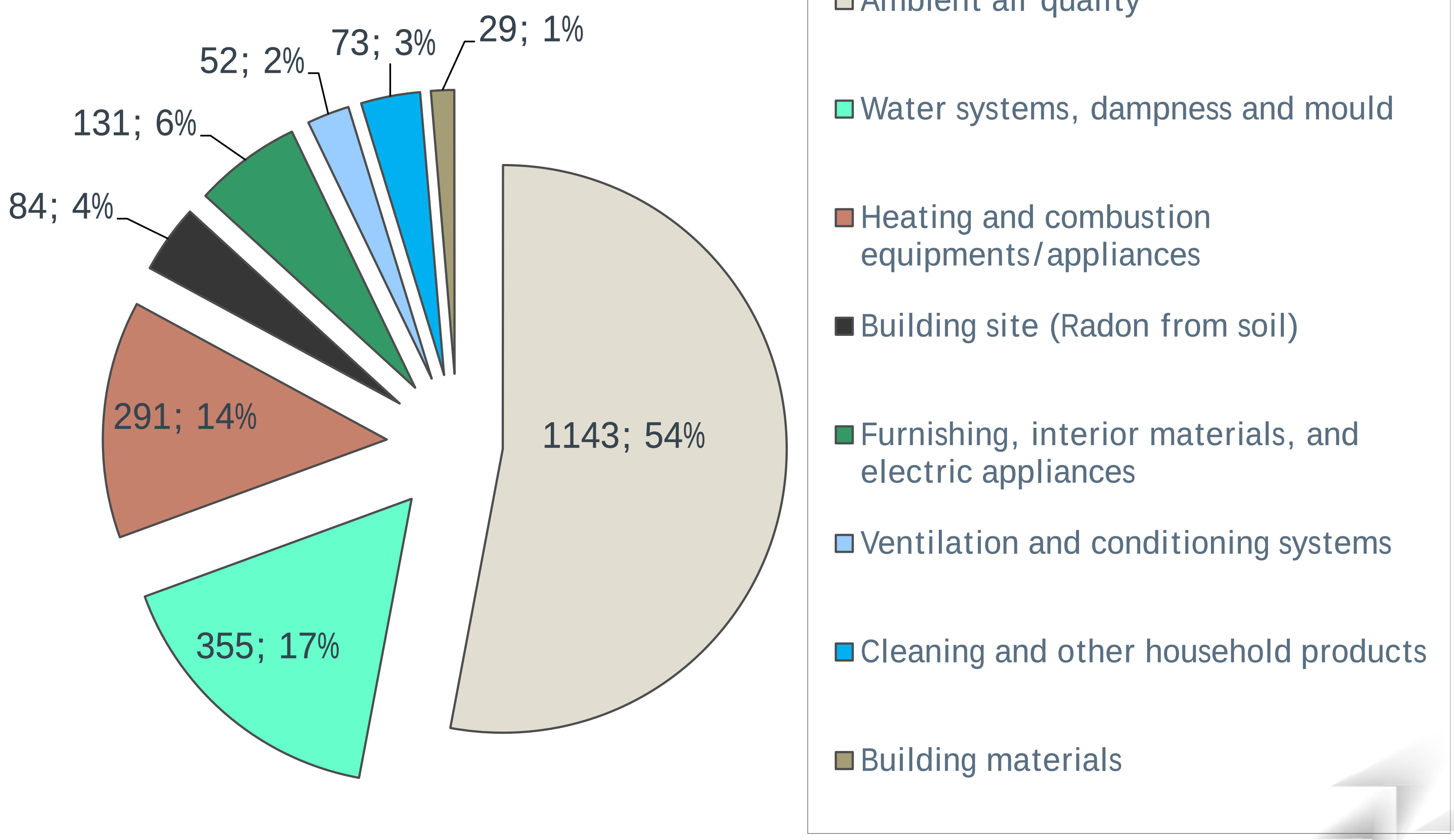
- DALY is the sum of Years of Life Lost (YLL) due to premature mortality
- and the Years Lost due to Disability (YLD) for people living with the health condition or its consequences. (WHO)

Attributable burden of diseases due to indoor exposures in 2010 in EU26.



The lighter shade represents the maximum reducible fraction

The contribution of indoor air pollution to the European symptom- and burden of disease (x 1000 DALY/year) not including environmental tobacco smoke



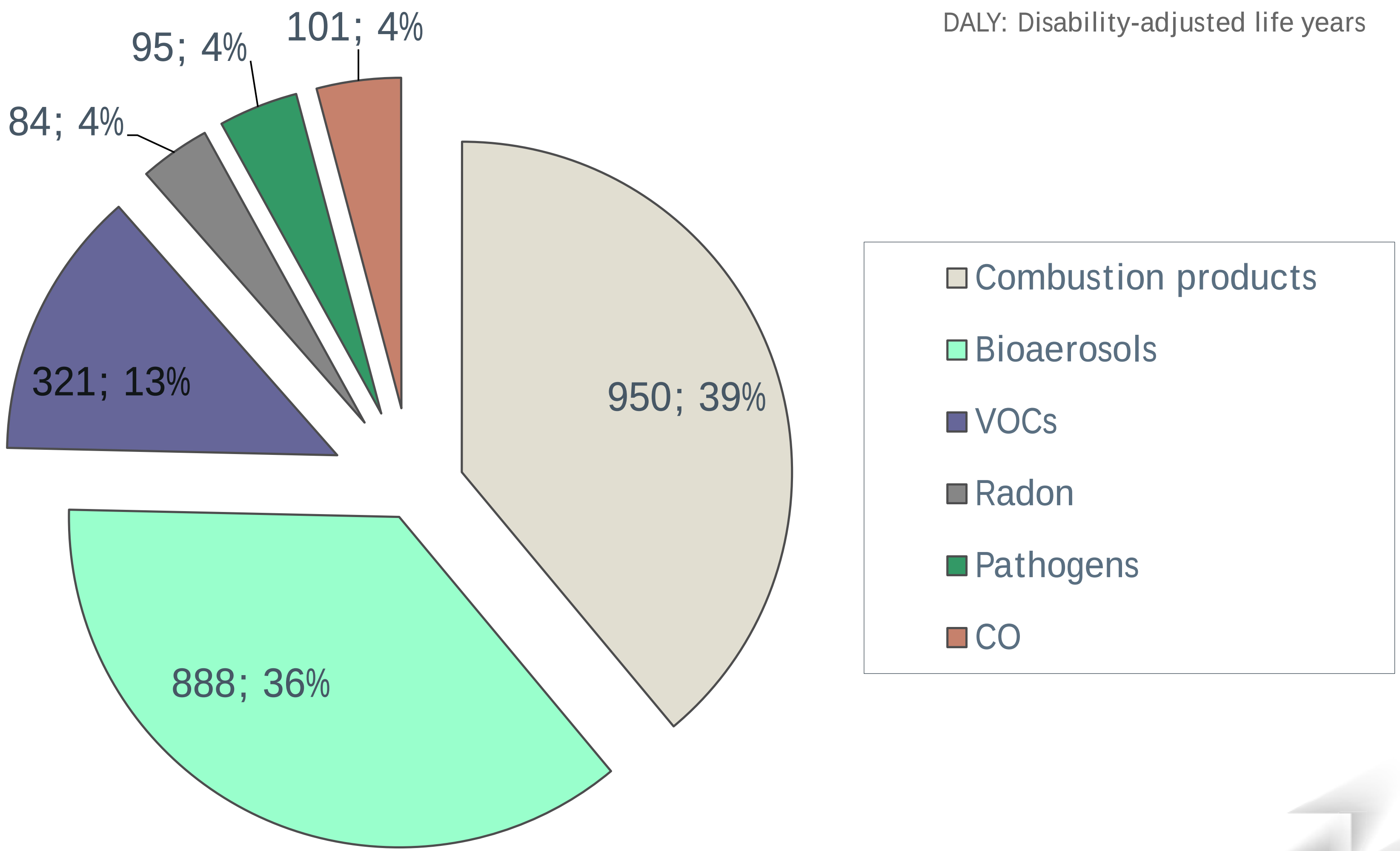
Source: ENVIE Final Report, 2008

DALY: Disability-adjusted life years

Contribution of indoor air exposure to the European symptom- and disease burden (x 1000 DALY/year),

not including environmental tobacco smoke

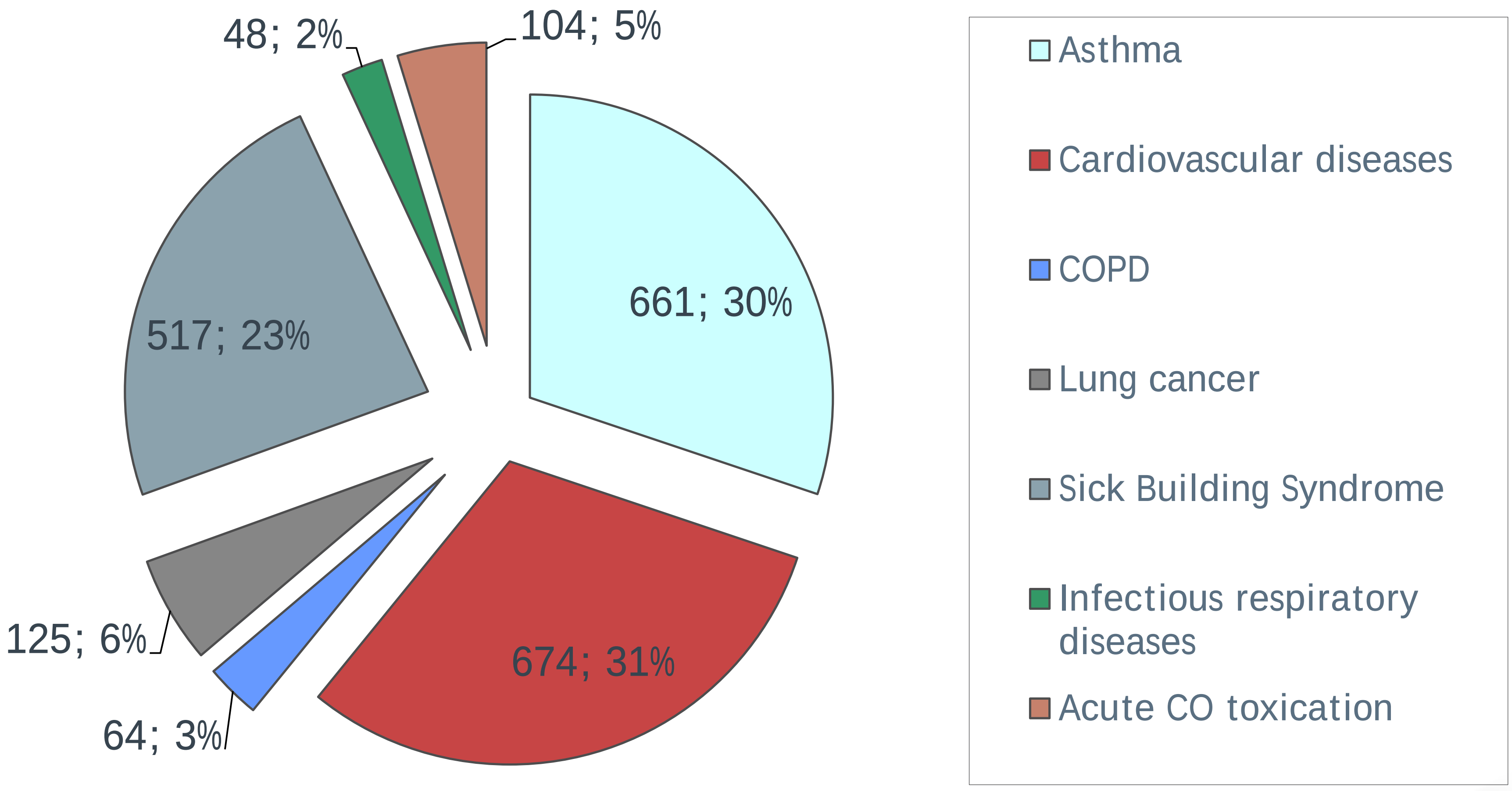
DALY: Disability-adjusted life years



Source: ENVIE Final Report, 2008

Contribution of inadequate IAQ to the European symptom- and disease burden (x 1000 DALY/year, %),

not including environmental tobacco smoke



Source: ENVIE Final Report, 2008

DALY: Disability-adjusted life years

Sick Building Syndrome

People staying inside experience acute health and comfort effects that are apparently linked to the time learning/teaching/working indoors

Building-Related Illnesses

A relatively small number of people staying inside experience health problems accompanied by physical signs that are identified by a physician and/or laboratory findings, and can be attributed to environmental agents in the air

Sick Building Syndrome vs. Building-Related Illness

Sick Building Syndrome building related non-specific symptoms

- Headaches
- Fatigue
- Irritated eyes, nose, throat and/ or skin
- Dry mucous membranes dry or itchy skin
- Hoarseness of voice and wheezing

Difficult to trace to a specific source.

Symptoms clear when away from building .

Building-Related Illness recognized building related diagnoses

- infection
  - Legionnaires' Disease
  - Aspergillosis (immune- compromised)
  - cold, flu
- allergic reaction
  - asthma,
  - rhinitis

The cause is clearly related to the building.

Symptoms may not clear upon leaving the building.

Causes of SBS

- Causes may originate during planning and construction or during operation, maintenance and usage.
- It is difficult to find the cause in individual cases.
- The problems can be sorted into 4 categories (WHO):

- local factors
- construction materials, equipment, problems connected to the function of the building (chemical release of construction materials and furniture, lighting, heating)
- problems independent of the structure of the building (dust-, mould-, or pollen allergy)
- psychological problems (societal, physical attributes and other factors)

Frequent (not exclusive) attributes in sick buildings (WHO)

(Not every sick building has all of them and not every building is sick where the following occur.)

- Building was constructed after 1960
- Air-conditioned building, windows can't be opened
- Very bright and/or flickering lights
- Ventilation, heating, lighting can be insufficiently controlled
- Carpets or upholsteries with a large surface
- Many open shelves or storage compartments
- New furniture, carpet or painted surface
- Neglected maintenance, insufficient cleaning
- High temperatures or large temperature fluctuations
- Very low or very high humidity
- Chemical pollutants (cigarette smoke, ozone) or VOC from building materials, equipment
- Particulate matter and fibers in the air
- Computer monitors

Prevention

PLANNING

- are there hidden problems at the building site? (e.g. High ground water, radon, other contamination)
- every potential risk factors should be taken into consideration (proper ground plan, cleaning properties, appropriate heating factors)
- what is the quality of the local ambient air? If it is bad, was this taken into consideration in the planning of the ventilation and insulation?

OPERATION

- **Ventilation:** bad ventilation (inadequate ventilation or draught) is a frequent cause of SBS
- **Cleaning:** the contamination of surfaces is a frequent cause; hidden nooks; damp places; ventilation equipment, filters, grating etc., cleaning properties
- **Comfort factors:**
    - noise (from the equipment, ventilation system etc.)
    - high temperature (>21°C), fumes, microorganisms, RH
    - lack of natural lighting

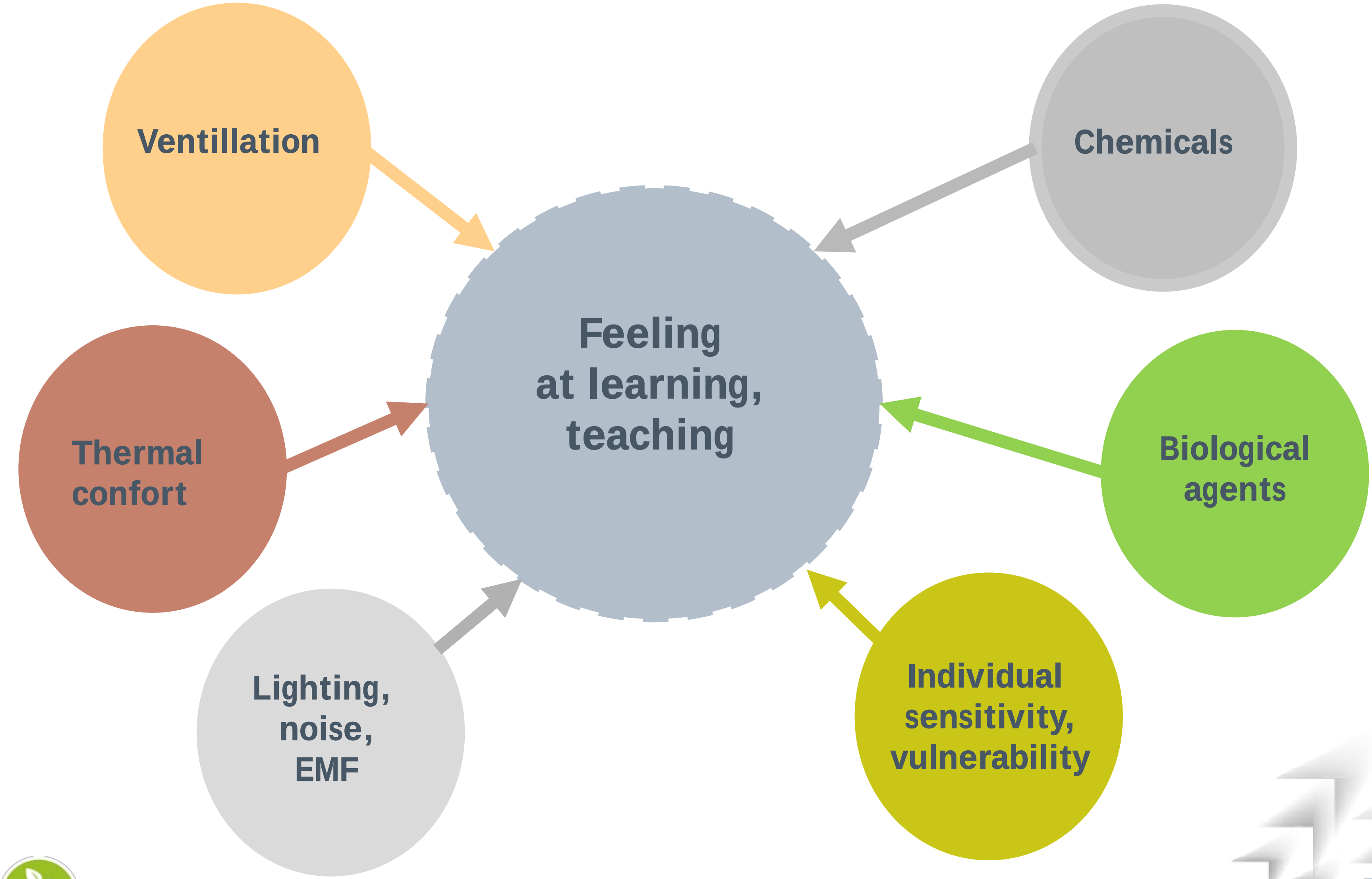
Indoor Environmental Quality (IEQ)

IEQ - Indoor environmental quality is a general indicator of the quality of conditions inside a building.

IEQ = good quality performance in indoor air quality + thermal comfort + daylight, lighting and views (visual conditions) + acoustic conditions + electromagnetic frequency levels

Home, work, school, car…all are indoor environments

Indoor Environmental Quality (IEQ)



Factors influencing IAQ

$$V(dC_i/dt)=P-E-Q(C_i-C_o)$$

where

V = the total volume of indoor air space (m^3),

C_i is the indoor concentration of the pollutant ($\mu g/m^3$),

P is the emission rate of the pollutant ($\mu g/h$),

E is the hourly elimination rate of the pollutant through chemical reaction, surface binding, filtering, or deposition ($\mu g/h$),

Q is the air exchange rate between the outdoor and indoor space (m^3/h) and

C_o is the outdoor concentration of the pollutant ($\mu g/m^3$).

The role of air exchange in IAQ (ventilation)

- Providing fresh air
- Removing accumulated pollutants, diluting their concentration
- Reducing temperature

Hygienic aspects of ventilation:

- Air movement aids evaporation, and thus usually has a cooling effect on the body. A **lack of air movement** leads to damp problems and has a negative effect on metabolism and the thermal state of the body: can cause feelings of discomfort and exhaustion.
- The feeling of draught limits ventilation: **air velocity beyond 0.3-0.5 m/sec** is perceived as draught and could result in cooling of the body or parts of the body.
- The IAQ guidance values should not be reached primarily through ventilation, but by **reducing emission**

Ventilation Measurement

In naturally ventilated buildings

By Infiltration measurement. Infiltration is measured as air change per hour (ACH) – the average rate at which indoor air is replaced by fresh outdoor air. ACH is a rough index for different building conditions.
ACH is 0.1 to 0.2, in "leaky building", ACH is 2.0 to 3.0 in normally ventilated buildings

Tracer gas technique is applied to measure infiltration. Non reactive gases are used with the assumption that the loss of tracking gas is only due to ventilation / exfiltration.

In mechanically ventilated buildings

ACH is measured by CO_2 concentration.

Fresh air demand / 1

- In the inhaled air: 21% oxygen, **0.03% carbon dioxide**
  (78% nitrogen, 0.97% inert gases)
- In the exhaled air: 16% oxygen, **3-5% carbon dioxide** + water vapour
- Indicative importance of CO_2 concentration:
  - 0.1% CO_2 perception of stuffy air
  - 1% CO_2 discomfort/malaise,
  - 10% CO_2 life threatening

CO_2 concentration is generally used as an indication of the efficiency of ventilation

According to the CEN Report CR 1752 (1998 Dec):

CO_2 outdoor typically 350 ppm=700 µg/m^3

category A: outdoor CO_2 + 460 ppm (15% dissatisfied)

category B: outdoor CO_2 + 660 ppm (20% dissatisfied)

category C: outdoor CO_2 + 1190 ppm (30% dissatisfied)

Fresh air demand / 2

Fresh air demand is influenced by

occupancy, activity (10-12x in case of physical work)

age, state of health, size and function of the premises

N.B.! There are other than just CO_2 producing/emitting pollution sources!

According to the CEN Report CR 1752 (1998 Dec):

Required ventilation in classrooms for comfort:

Category A: 6.0 litre/sec (l/s) per m^2 **floor area**

Category B: 4.3 l/s per m^2 **floor area**

Category C: 2.4 l/s per m^2 **floor area**

Fresh air demand / 3

Person-related ventilation rate:

Standards on fresh air demand of building rooms according to fresh air need of persons:

fresh air demand ≈ 15-36 m^3**/person/hour**

Average classroom condition: $2m^2$/person → $6m^3$/person

The total air should be exchanged min. 3-6 times /hour

Insufficient natural ventilation causes increased moisture/mold, enhanced concentration of bacteria/viruses/fungi and chemical pollutants, as well unpleasent odors.

Ventilation methods:

- Natural ventilation (windows or vent-holes)
- Mechanical ventilation (with fans)

Natural ventilation

Infiltration: random/ intentional flow of outdoor air through windows, cracks and different openings in the buildings.

Exfiltration: movement of air from indoor to outdoor.

Natural Ventilation

Air Flow- occurs mainly due to two gradients:

- Pressure – difference between outdoor and indoor pressure
- Temperature - when the inside air temperature differs from outside one

Natural ventilation in general inefficient as it is not uniformly distributed. Air doesn't circulate evenly and stale air remains in some spaces.

It transfers pollen and other contaminants from ambient air.

Mechanical ventilation

Involves use of fans and or air-conditioning equipments.

Main points of mechanical ventilation:

- pulling fresh air from outside to indoor
- transfer stale air to outside
- adjusting temperature and humidity inside.

Heating, Ventilation, Air Conditioning (HVAC) systems:

Functions:

- Heating - cooling
- Ventilation
- Filtration
- Humidification - dehumidification
- Air-flow

Parameters:

- Infiltration air
- Exfiltration air
- Air-recirculation

Hygienic aspects of ventilation

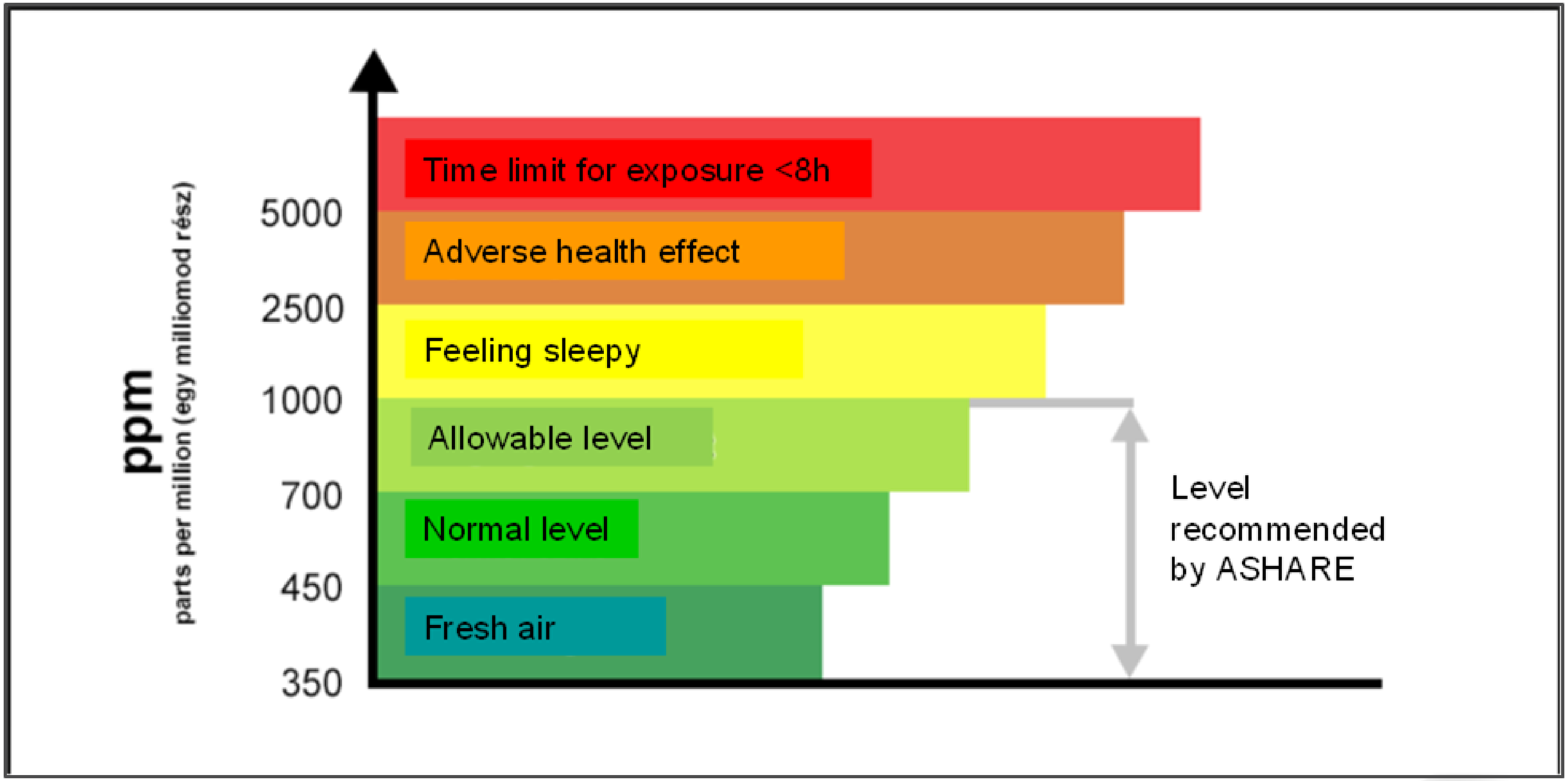
- Air movement helps evaporation, has a cooling effect on the body. A lack of air movement leads to damp problems and has a negative effect on metabolism and the thermal state of the body: can cause feelings of discomfort and exhaustion.

- The feeling of draught limits ventilation: air velocity beyond 0.3-0.5 m/sec is perceived as draught and could result in cooling of the body or parts of the body.

- The IAQ guidance values should not be reached primarily through ventilation, but by reducing emission.

- CO_2 concentration is generally used as an indication of the efficiency of ventilation. Outdoor CO_2 concentration: ~ 400 ppm. Several guidelines recommend/accept 800 ppm indoors

Relationship between indoor CO_2 concentrartion and health risks



Overall effects of poor indoor air quality in underventilated/overcrowded classrooms

- **CO_2↑** ► concentration↓, decreased attention, test performance↓, fatique, headache, increased risk of accidents

- **Bacteria, viruses↑** ► infectious diseases, absenteeism

- **Humidity, temperature↑, odor** ► discomfort, headache

- **Moderately increased concentration of indoor released chemicals**
  - ► mild short-term symptoms (asthmatic symptoms, headache, fatigue, dizziness, nausea)
  - ► long-term negative impact on central nervous system, respiratory system, cardiovascular system, hormonal system and contribution to later development of cancers)

Health effects of exposure to indoor air pollutants in children /1.

Impacts on respiratory system

***Acute effects*:**

- Mucous membrane irritation (eyes, upper respiratory tracts)
- Coughing (bronchitis symptoms)
- Wheezing, attacks of dyspnoe (heavy breathing) (asthmatic symptoms)
- Increased responsiveness of the respiratory tracts to allergens
- Increased acute respiratory morbidity (upper- and lower respiratory airway infections)

***Chronic effects*:**

- Decreased lung function
- Contribution to later pulmonary diseases (COPD, malignant tumours)

Impacts on cardiovascular system

- Elevations in arterial blood pressure and heart rate
- Increased levels of stress hormones

Health effectsa of exposure to indoor air pollutants in children /2.

Impacts on immune system

- Increased risk of infections (pneumonia, otitis media)
- Absenteeism from school due to sore throat, cough, and cold
- Increased levels of biomarkers of oxidative stress and inflammation

Impacts on central nervous system

Acute effects:

- Headache, fatigue, dizziness, nausea
- Impaired task performance

Chronic effects:

- Impairments in different neuropsychological development outcomes (cognitive and psychomotor development delays, global IQ, learning disabilities, reading comprehension, memory functions, reading and maths scores, reaction speed, attention, coordination)
- Changes in brain white matter, gray matter and basal ganglia assessed by neuroimaging methods were associated with air pollution
- Prenatal and early childhood exposure can result in neurodevelopmental diseases (attention deficit/hyperactivity, autism spectrum disorders, etc.)

Health effects of exposure to indoor air pollutants in children /3.

Cancer inducing effect

- childhood leukaemia, and some central neural system tumors in children are associated with certain air pollutants
- childhood exposures may contribute to the development of other cancers in the later life as well

Endocrine disrupting effects of some chemicals

- Impairments on reproductive system
- Disorders in brain development
- Contribution to later diabetes and obesity
- Contribution to later hyper- or hypo- thyroidism

Effects of increasing ventilation rates in classrooms on task performance of pupils

Ventilation rate increase (l/s per person)	Effect on performance	Reference
1.5 → 13.0	Increased speed by 5% on cognitive performance tests	Coley and Greeves, 2004
3.0 → 8.5 5.2 → 9.6	Test speed significantly improved in 50% of tests	Wargocki and Wyon, 2007
0.5 → 13.0-16.0	Increased pupils' speed by ~7% in maths	Bakó-Bíró et al., 2012
3.0 → 9.5	Improved speed by 8% on numerical and language based tests	Wargocki and Wyon, 2013
Prospective studies on long- term academic performance of pupils:		
0.9 → 7.1	Standardized tests increased by 2.9% for math and 2.7% for reading	Haverinen-Shaughnessy et al., 2010
each 10% increase in prior 30-day VRs	Increases of 0.6 points on English and Math tests	Mendell et al., 2016

Optimal ventilation - future perspectives

- "Build tight and ventilate right" principle: ensure that air exchange and distribution within the building is sufficient
- Plan the building envelopes:
  - Tight building envelopes are essential for meeting the increasing demand of energy efficiency.
  - This increases the risk of too low ventilation rates and consequently increased contaminant concentrations and moisture damage.
- Clean the air and the ventilation system
- Control the ventilation system according to the outdoor air temperature

Lighting

- Architectural design has a direct impact on office lighting; geometry of windows, photometry of surfaces, amount of glazing etc., all have an impact on the illumination levels in a work area in schools as well
- Illumination level : the standard requires a minimum illuminance of 150 lx in rooms with demands of good visual communication.
- Vertical light on the wall, 300 lx, provides good ambient light. Indirect light on the ceiling, 300 lx, also provides good ambient light by which students are more alert and perform better
- Direct light: minimum illuminance of 500 lux

Acoustic conditions

- For noise recommendations are: ensure that all noise sources (e.g., ventilation systems, office equipment and street noise) do not exceed 40 dBA.
- Tones are an annoying aspect of sound
- Low frequencies below what are considered normal audio ranges have an impact on healthy hearing

Electromagnetic field

Electro-magnetic fields are fields of natural or induced magnetism.

Frequency: typical alternating current electricity is provided at 50 Hz.

Electronic equipment may change the frequency (e.g. computer screens).

Typical exposures are usually below 1 milliGuass (mG) or 0.1 microTeslas (µT).

EMF exposure levels

computer screen (30 cm away)	< 0.01 µT
hair dryer (at source)	6 – 2000 µT
TV (~ 1 meter away)	0.01 – 0.15 µT
Electric shaver (at source)	15 – 1500 µT

Source: https://www.who.int/peh-emf/about/WhatisEMF/en/index3.html

Temperature

- The increase of outdoor and consequently indoor air temperature in school buildings decreases the vigiliance of children.
  - The complaints for headache, fatigue, and feeling very hot correlate with the increase of indoor temperature.

- Energy efficiency and increase of weather resilience (sealing and insulating), air conditioning moderates temperature changes, contributes to save energy.
  - On the other hand sealing and tightening the building can make existing problems worse, create new problems which can cause discomfort

Thermal comfort

Human Thermal Comfort: function of both temperature and relative humidity

Factors influencing on thermal comfort

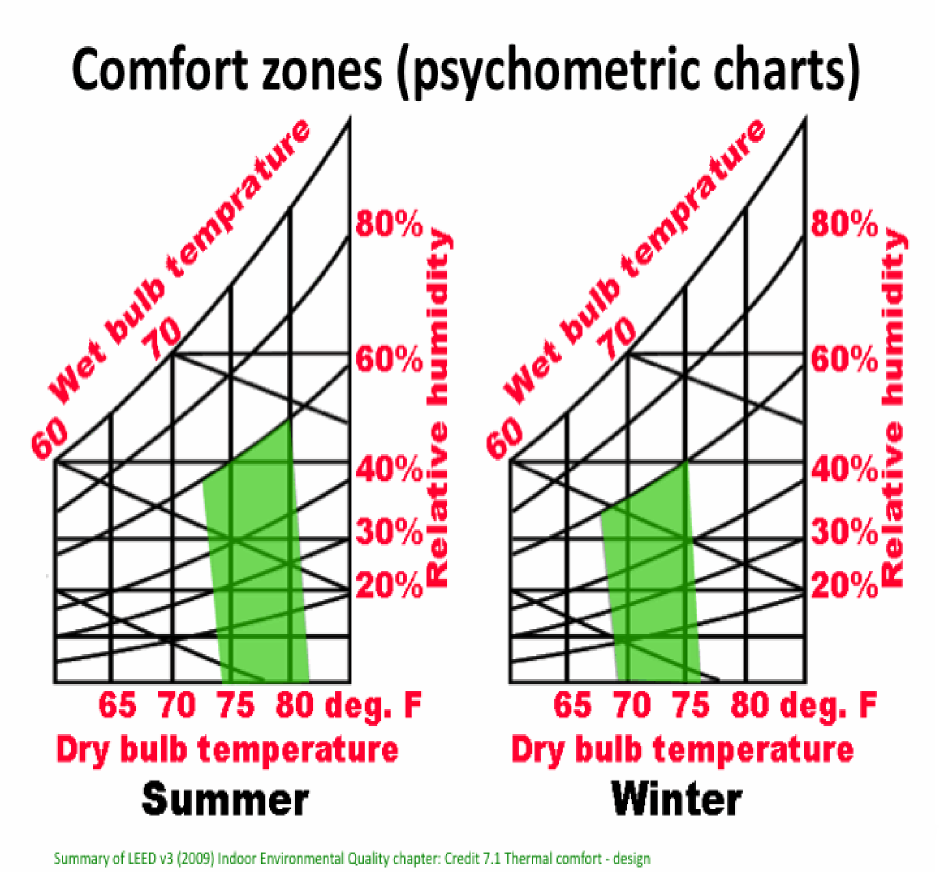
Environmental

1. Air temperature
2. Humidity *
3. Air movement/velocity (m/s)
4. Radiation (Mean radiant temperature)

Personal

5. Activity
6. Clothing

*RH: Ratio of the amount of moisture present in the air to the maximum amount which it can hold at saturation at a given temperature



http://www.suryakund.com

Factors defining indoor comfort

Factors

1. Temperature: ideal in the range of 18,5 – 25,1 °C

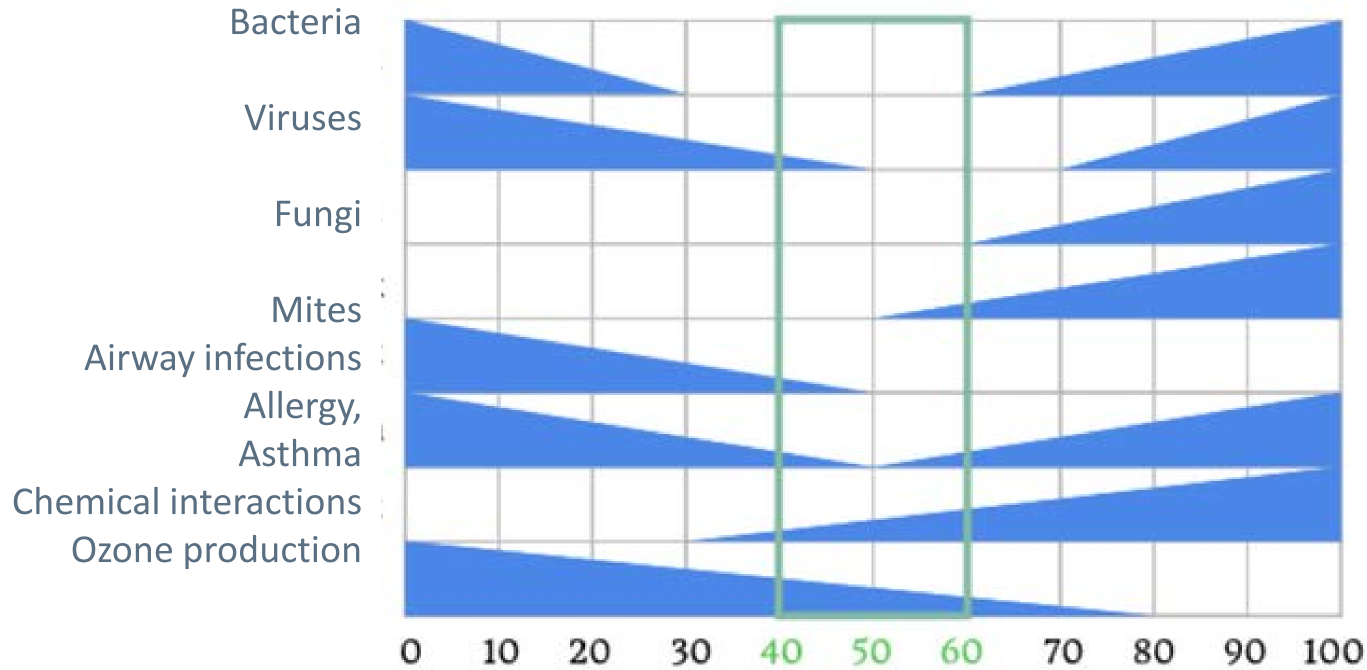
- Relative humidity: ideal 43%< RH <67 %
- CO_2: ideal < 1200 ppm

Ranking the health impact of comfort factors

category	RH[%]	T [°C]	CO_2 [ppm]
healthy	43 < RH < 67	18.5 < T < 25.5	<1200
moderate	37 < RH < 43 67 < RH < 73	17.5 < T < 18.5	1200-1800
unhealthy	RH<37 RH>73	T<17.5 T >25.5	>1800

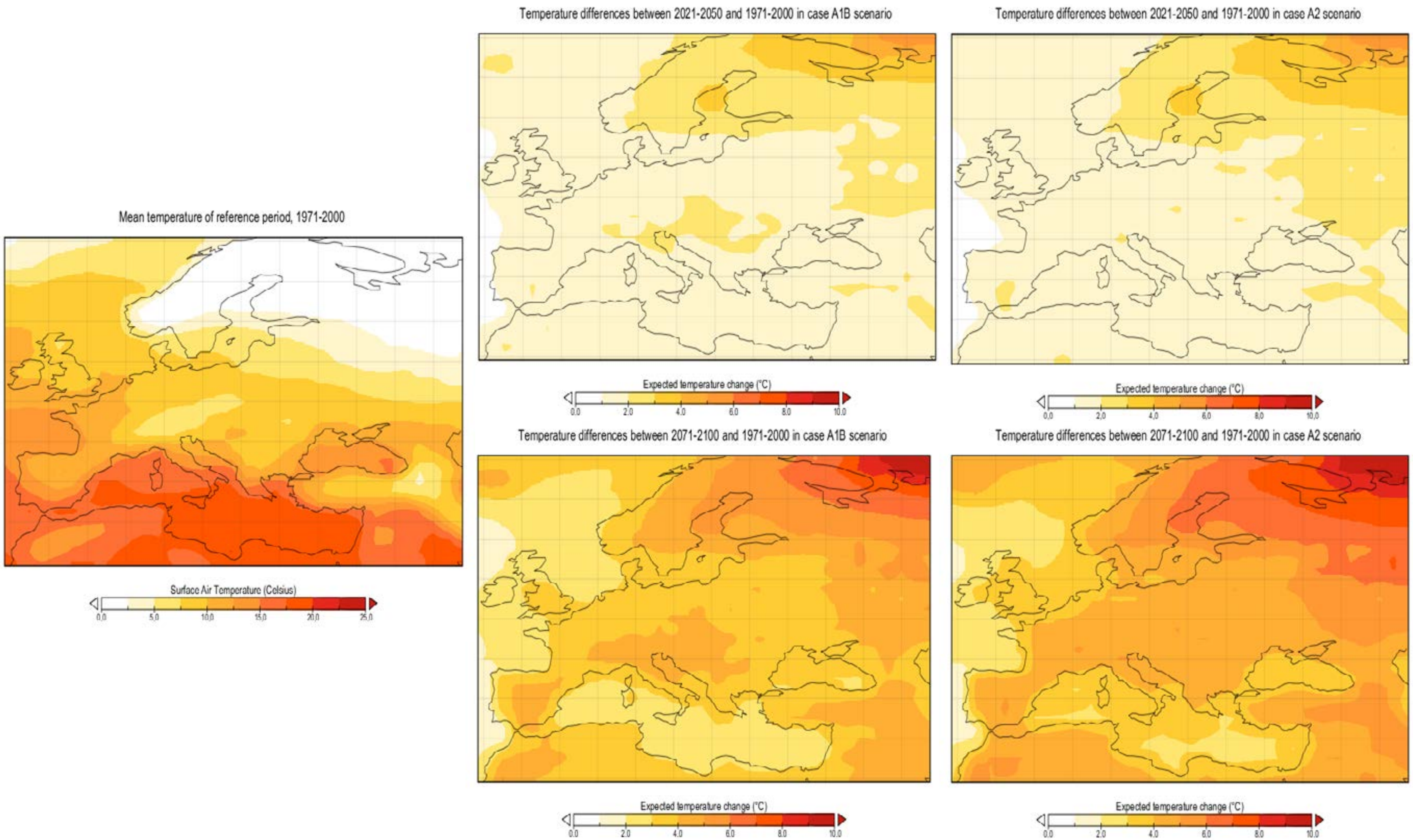
Optimal relative humidity in relation to selected pollutants and health risks

Optimal relative humidity %



Optimal range for humans

Mean temperature and temperature differences of Europe in the reference , near and far future periods by A1S and A2 emission scenarios



Climate change

Resiliance

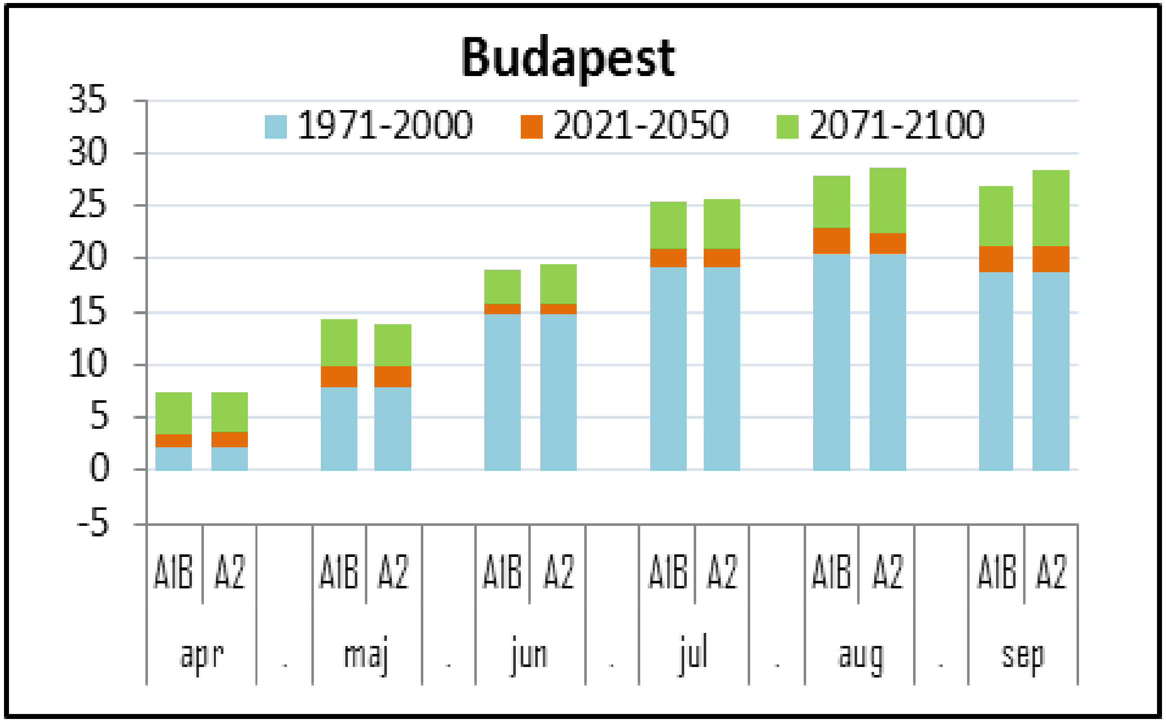
Temperatures in Europe will keep rising with time in future. The peak rise in summer can be up to 5 C from the present peak temperature.

The internal temperatures in class rooms will increase with rise in future exterior temperature.

The percentage of occupied hours under thermally comfortable condition (below 24 °C) during (pre)summer season will decrease and risk of overheating (above 28 °C) will increase with time in future in the classrooms.

The internal temperature will be generally higher than the external temperature due to high internal heat gains from occupants, lights and other electrical equipments used inside.

Predicted monthly mean temperature increase by A1B and A2 emission scenarios in Budapest



Air quality

Weather, climate change determines the development, transport, dispersion and deposition of air pollutants.

Exposure to elevated concentrations of ozone is associated with increased hospital admissions for pneumonia, chronic obstructive pulmonary disease, asthma, allergic rhinitis and respiratory diseases, and with premature mortality.

The concentration of fine particulate matter (PM) depends, in part, on temperature and humidity. The health impacts of PM is stronger than that for ozone. PM is known to affect morbidity and mortality, so increasing concentrations would have significant negative health impacts.

Risk of accidents

The first days of summer, there is an increase in the number of summer-related accidents and injuries.

A direct association between trauma attendance and weather was found with higher attendances on dry and sunny days.

Admissions of children with fractures admitted to hospital strongly correlated with mean monthly sunshine hours.

Accidents risks of children, are connected to different activities at home, at school and in afternoon leisure time, calling the attention that the projected increase of temperature may pose a significant risk for schoolchildren

Problems of contemporary buildings* 1.

Contemporary design schools have higher risk of overheating in both present and future conditions.

This can be explained by not only less internal thermal mass but also higher window to wall ratio in building envelope.

Higher window to wall ratio can lead to higher solar gains in internal spaces in absence of solar shading devices.

Dasgupta A, et al. HVAC&R RESEARCH 2012;(18)1,2.
DOI: doi.org/10.1080/10789669.2011.614318

Problems of contemporary buildings 2.

Energy efficient schools, which also have shaded windows with highly insulated building envelope also lack in providing better thermal conditions inside as they lack in adequate internal thermal mass which can be used for passive night cooling that helps in improving day time thermal conditions.

Also, the insulation of the envelope in such schools not only prevents heat loss during winter but also retains internal heat generated by pupils and electrical equipment during summer.

Problems of contemporary buildings 3.

It is observed that **naturally ventilated passive design schools** are and will be most thermally comfortable followed by energy efficient schools. This can be explained by the better ventilation strategies and high internal thermal mass adopted in their design.

The energy efficient schools, even after having insulated building envelope, well shaded windows and ample ventilation, lack in providing adequate thermal comfort because of less internal thermal mass.

Interventions and measures suggested 1.

The risk of overheating in schools can be reduced if more exposed internal thermal mass is used with night cooling/purge ventilation which helps in absorbing the heat generated inside classrooms even when the external temperature is higher than thermal comfort limit.

By insulating building fabric from outside will also help improve thermal resistance of building envelope to prevent external heat gains and maintain existing thermal mass to use night time cooling.

Interventions and measures suggested 2.

School buildings with high window to wall ratio can be upgraded by using insulated glazing panels and external shading devices to prevent solar and conductive heat gains through windows. Low-E coatings on glazing can significantly reduce direct and indirect infrared radiations, especially where external shading is difficult to provide.

Reducing internal heat gains can also be a useful strategy to provide thermal comfort for pupils. This can be achieved by using energy efficient luminaries, lighting strategies and electrical equipment.

Take home messages for architects

Indoor Air Quality refers to the quality of the air inside buildings as represented by concentrations of pollutants and thermal (temperature and relative humidity) conditions that affect the health, comfort, and performance of people staying inside.

The internal temperatures in class rooms will increase with rise in future exterior temperature. Therefore thermal resistance of building envelope should be improved together with reducing internal heat gains. This can be achieved by using energy efficient luminaries, lighting strategies and electrical equipment.

Good IAQ is the guarantee of comfort, health and safety

Growing children are very sensitive to hazardous chemicals

Potential ways of reducing indoor air pollution

Reducing emissions (qualified construction- and covering materials, using cleaner energy and better equipment)

Better planning (modern heating systems, appropriate construction- and covering materials, etc.)

Improving ventilation (chimney, exhausters, windows, ventilation holes, ventilation systems). Note that natural ventilation don't guarantee the minimum air exchange especially in cities.

- The future solution is mechanical ventilation – HVAC- a way to sustaianble InAIRQ

BUT

Improper maintenance, design, and functioning of HVAC systems contributes to an increased prevalence of SBS symptoms.