Interreg CENTRAL EUROPE
European Union European Regional Development Fund
InAirQ

# HEALTH ASPECTS OF INDOOR AIR POLLUTION IN SCHOOLS

Teaching materials for architects

Version 2
2019

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# A. Introduction

## A.1. Why are IAQ issues important in schools?

Nowadays children spend - on average - over 90% of their time indoors. Air pollution is one of the particular challenges for the future generations (**slides 3-7**). Indoor air quality partly depends on that of the outdoor air depending on the rate of penetration. On the other hand indoor environments contain sources of pollutants which – depending on the level of exchange rate - may reach a high concentration, sometimes surpassing the outdoor concentration.

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 (CEHAPE1). 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.

The EC has supported several multicenter studies (ENVIE, SINPHONIE2, Search etc) in order to get more information about the ways of indoor exposure and potential health effects. The InAirQ project is dedicated to assess the indoor air quality (IAQ) in primary school buildings and to plan actions to ensure children's health and well-being at school in Central Europe. In the participating countries children spend 7 to 9 hours in primary school buildings where healthy indoor air is not yet guaranteed by law with the exception of the Czech Republic. There is a need to prepare national action plans aiming at controlling and improving indoor environment of schools. As a

[1] http://www.euro.who.int/__data/assets/pdf_file/0006/78639/E83338.pdf

[2]https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/sinphonie-schools-indoor-pollution-and-health-observatory-network-europe-final-report

part of the action plans education of different target groups like architects is one of the most important aims.

## B. Factors influencing indoor air quality

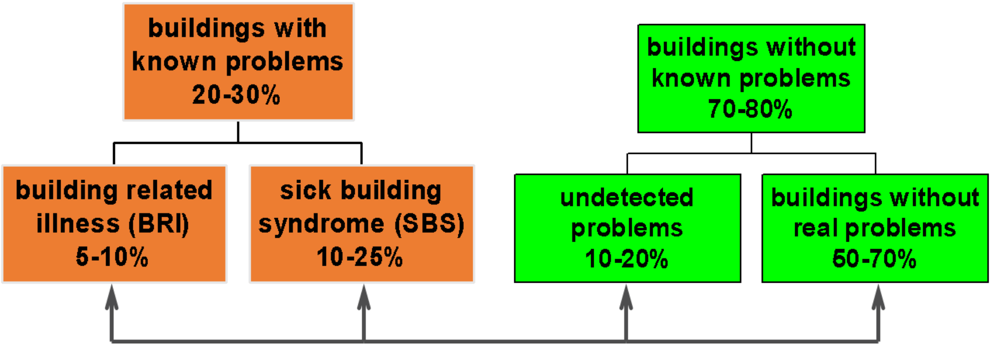
The extent of air pollution in the building of a school depends on the interaction between the building and its external environment. Indoor air quality is defined by the outdoor air quality, extent of air exchange, the binding capacity of indoor surfaces and indoor pollution sources (people, animals, furniture, building- and covering materials etc.) (**slide 8**).

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

The ambient concentration of air pollutants, different sources of emission (traffic, power plants, construction, waste disposal), the protective functions of the building envelope as well as the sources of indoor air pollutants, climatic conditions have an influence on the indoor air quality (**slide 9**). Other important factors are the way the building was built, what kind of building material was used, how it is equipped and how it is used. There are important aspects which define the indoor air quality. Architectural factors also 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) (**slide 10).** This slide summarizes the wide range of emission sources indoors**.** When we are speaking about the ways how to achieve and maintain healthy indoor environment this environmental issue should be tackled in its complexity.

According to figure 1(**slide 11**) indoor air quality problems are quite common. This can be explained by a lot of factors like the changes in constraction practices, constraction material (the more frequent use of concrete) which influences air permeability; the energy conservation aspects (thermal insulation), new heating methods; lower ceiling heights, widespread use of plastics and adhesives, different habits in the usage of indoor spaces.

*Figure 1.* How common are IAQ problems?




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

## B.1. Primary sources of IAQ contaminants

The source of indoor air is ambient air polluted from outdoor sources. The rate of penetration of outdoor pollutants is different, some contaminants like $O_3$ have much higher outdoor concentration, $PM_{10}$ can penetrate in a range of 50-90%. Indoor contaminants can reach a high concentration due to the insufficient air exchange e.g. formaldehyde can have 10-15 times higher indoor concentration than outdoors, this can be said about $NO_2$ or toluene pollution (figure 2), (**slide 12, 13**).

| 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 |

*Figure 2.* Relative importance of indoor air pollutants (Stolwijk)

Indoor air pollution can be a result of indoor air activity (**slides 14-16**).

Airborne allergens as pollen grains and fungal spores penetrate form outdoors (fungal spores can emerge also indoors) these are important biological contaminants causing or aggravating allergic and asthmatic symptoms. Dampness is also an important indoor problem causing respiratory and allergic symptoms (**slides 17-19**).

Heating is a major source of the following air pollutants: carbon monoxide (CO), nitrogen dioxide ($NO_2$), sulphur dioxide (if brown coal or lignite is used for heating) ($SO_2$), and particulates ($PM_{10}$, $PM_{2.5}$) **(slide 21)**.

The maintenance activities in a school building and the activity of pupils could be sources of pollutants like particulates, organic and inorganic chemicals. Dampness, mold and fungi problems could be prevented by regular checking and prompt solving of problems like water leakage. It is well known that insufficient air exchange, problems of bridges of heat conduction may contribute to dampness problems. On the other hand insufficient maintenance of a HVAC-system (heating, ventilation, and air conditioning system) may be source of chemical and biological pollutants, increasing the prevalence of several health problems, among others sick building syndrome. The major sources of pullutants and the considered exposure agents are summarized in table 1.

*Table 1.* Major pollutant sources in school buildings

| Sources/controls for indoor air pollution | | Considerd exposure agents | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Combustion/PM | CO&NO2 | HCHO | Benzene | Napthalene | Radon | Microbes, allergens |
| Outdoor air | | | | | | | | |
| | Air cleaning and indoor pollution dulution | x | x | | x | | | x |
| Buildings/ventilation | | | | | | | | |
| | Building materials | | | x | x | x | x | |
| | Heating system | x | x | | | | | |
| | Water system | | | | | | | x |
| | Dampness and mold | | | x | | | | x |
| | Ventilation/air conditioning system | x | x | x | | | x | x |
| Consumer products used in schools | | | | | | | | |
| | Furnishing | | | x | x | x | | |
| | Cleaning products | | | x | | x | | |
| | Chemicals used for teaching, practicing | | | x | x | | | |
| Occupant behaviour | | | | | | | | |
| | Maintenance | x | x | x | | | | x |
| | Cleaning products | | | x | | x | | |
| | Ventilation | x | x | x | x | x | x | x |
| | Cooking | x | x | | | | | |

Source: EnNVIE final report 2008

## B.2. Health effects:

Indoor air pollutants can evoke general symptoms (see *table* 2) like headache, dizziness etc. can irritate the eyes, upper and lower airways (sick building syndrome), can aggravate the allergic and asthmatic symptoms, airborne respiratory infections, chronic obstructive pulmonary disease (COPD); some pollutants can cause malignant diseases like oral cavity and lung cancer and leukaemia.

Allergic diseases are supposed to be caused by a complex interaction between genetic and environmental exposures. Asthmatic patients are sensitive to allergens present in indoor environments and are often hyperreactive to a number of gases and particles microbes, fungi spores or pollen. It should be mentioned that some pollutants are carcinogenic like asbestos, radon, formaldehyde or benzene.

*Table 2.* Major symptoms and health effects related to major types of air pollutants

| | Particles | | | Bioaerosols | | | | Gases | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Symptoms/diseases | dust, soil, ash | smoke | pollen | mold, fungi | bacteria, viruses | animal dander | housedust mite | CO | formaldehyde | VOCs | radon |
| Headache | | X | X | | | | | X | X | X | |
| Dizziness | X | | | X | | X | X | | | | |
| Fatigue | | | X | | | | | X | | X | |
| Nausea | | | | | | | | X | X | | |
| Vomiting | | | | | | | | | X | | |
| Skin rushes | | | | | X | | | | | X | |
| Eye irritation | X | X | X | X | X | X | | | X | X | |
| Nose irritation | X | X | X | X | X | X | X | | X | X | |
| Throat irritation | X | X | | | | | | | X | | |
| Airways irritation | | X | | X | X | | X | | X | X | |
| Coughing | X | X | X | X | X | X | X | | X | | |
| Chest pains | | | | X | X | X | X | | X | | |
| Airways infection | X | X | | X | X | | | | | X | |
| Asthma exacerbation | X | X | X | X | X | X | X | | X | | |
| Allergic symptoms | X | | X | X | X | X | X | | | | |
| Cancer of the oral cavitiy | | | | | | | | | X | | |
| Lung cancer | x | X | | | | | | | | | X |
| Mesothelioma | X | | | | | | | | | | |
| Leukaemia | | | | | | | | | X | X | |

Source: Thrasher JD és Crawley S. Toxicol Ind Health. 2009 Oct-Nov;25(9-10):583-615. doi: 10.1177/0748233709348386. Epub 2009 Sep 30

It is worth going into details concerning the different pollutant sources and the potential health effects with special regard to school environment (table 3).

*Table 3.* Sources and Potential Health Effects of Indoor Air Pollutants

| Pollutant | Major Indoor Sources | Potential Health Effects |
|---|---|---|
| Asbestos | Damaged or deteriorating insulation, fireproofing, and acoustical materials | Asbestosis, lung cancer, mesothelioma, and other cancers |
| Biological Agents (House Dust Mites, Animal Dander, Mold, Bacteria, Viruses) | House dust; pets; poorly maintained air conditioners, humidifiers and dehumidifiers; wet or moist structures (e.g., due to plumbing leaks) | Allergic reactions; asthma symptoms; eye, nose, and throat irritation; humidifier fever, influenza, and other infectious diseases |
| Carbon Monoxide (CO) | Gas stoves, malfunctioning heating devices, car or truck exhaust from outside attached garages | Headache; nausea; angina; difficulty concentrating; death at high concentrations |
| Formaldehyde | Pressed wood products such as plywood and particleboard, furnishings; wallpaper; durable press fabrics; personal care products | Eye, nose, and throat irritation; headache; allergic reactions; cancer |
| Lead | Lead containing water pipes; sanding or open-flame burning of lead paint; house dust | Nerve and brain damage, particularly in children; anemia; kidney damage; cardiovascular effects; growth retardation |
| Nitrogen Oxides ($NO_x$) | Outdoor air; gas stoves, malfunctioning gas appliances | Eye, nose, and throat irritation; lung irritation and damage; increased respiratory infections in children |
| Organic Chemicals | Solvents, glues, cleaning agents, pesticides, paints, insect repellents, air fresheners, and treated water | Eye, nose, and throat irritation; headaches; loss of coordination; damage to liver, kidney and brain; various types of cancer |
| Ozone ($O_3$) | Ozone-generating indoor air cleaners, printers, copy machines | Respiratory tract (lung) irritation and inflammation, serious breathing difficulty including asthma, permanent lung damage |
| Particulate Matter (PM) | Activities, movements of pupils; wood stoves, cooking, vacuuming, cleaning; burning candles and incense, products of reactions of ozone with fragrances | Eye, nose and throat irritation; worsening of asthma; increased respiratory disease; lung cancer; cardiovascular disease; premature death |
| Phthalates | Used to soften plastics and add flexibility [i.e., polyvinyl chloride (PVC)]; plastic floor covers, building/construction products; and food and beverage packaging | Associated with asthma and respiratory symptoms, allergies, and rhinitis in some studies; reproductive and developmental problems |
| Polybrominated Diphenyl Ethers (PBDE) | Flame retardants in foams in furniture, electronic printed circuit boards, electronics casings, carpet backing, upholstery | Disrupt thyroid hormones, may cause developmental deficits, may act as a reproductive toxin, and may cause cancer |
| Radon | Soil under buildings, some earth-derived construction materials, and groundwater | Lung cancer |

Source: http://www.arb.ca.gov/research/indoor/healtheffects1table1.htm

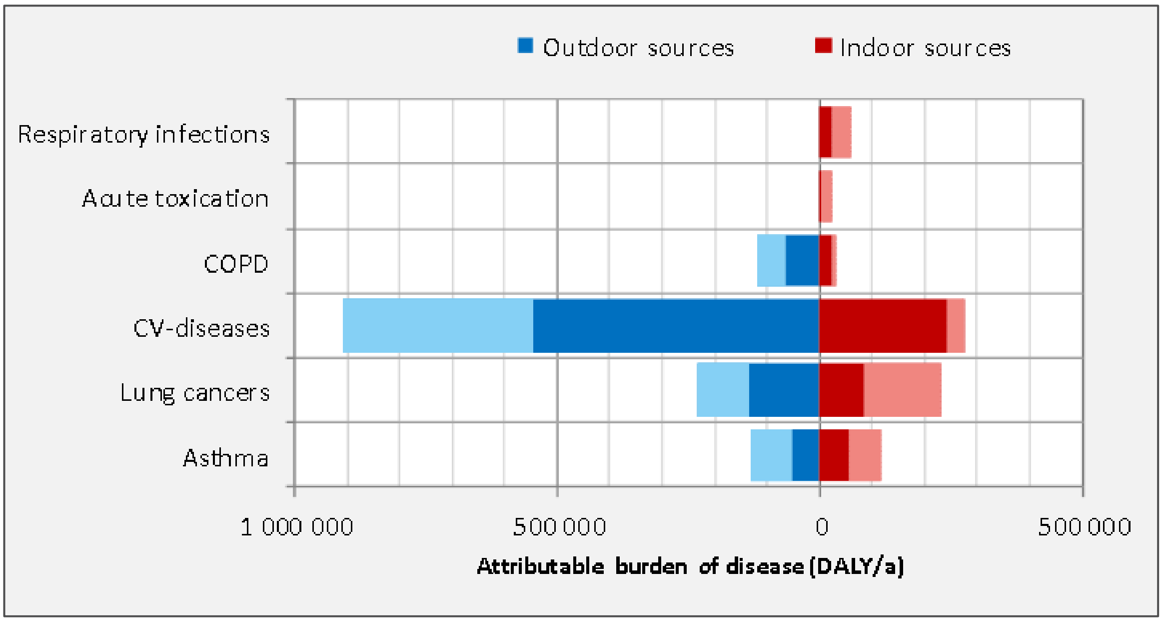
An overview of chemical pollutants and their health effects are described in **slides 22-45.**

# C. Contribution of indoor air pollution to the disease burden

The annual burden of disease caused by 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) (**slide 46**). Based on measurements of the European Environment Agency (EEA), approximately 90 % of EU citizens live in areas where the World Health Organization (WHO) guidelines for air quality of particulate matter sized < 2.5 mm ($PM_{2.5}$) are not met.

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) (**slide 47**). More than half of this burden (1.28 million DALYs) is caused by exposures to outdoor air pollution indoors. The remaining 0.74 million DALYs are associated with pollutants from various indoor sources.

*Figure 3.* Attributable burden of diseases due to indoor exposures in 2010 in EU26. The lighter shade represents the maximum reducible fraction



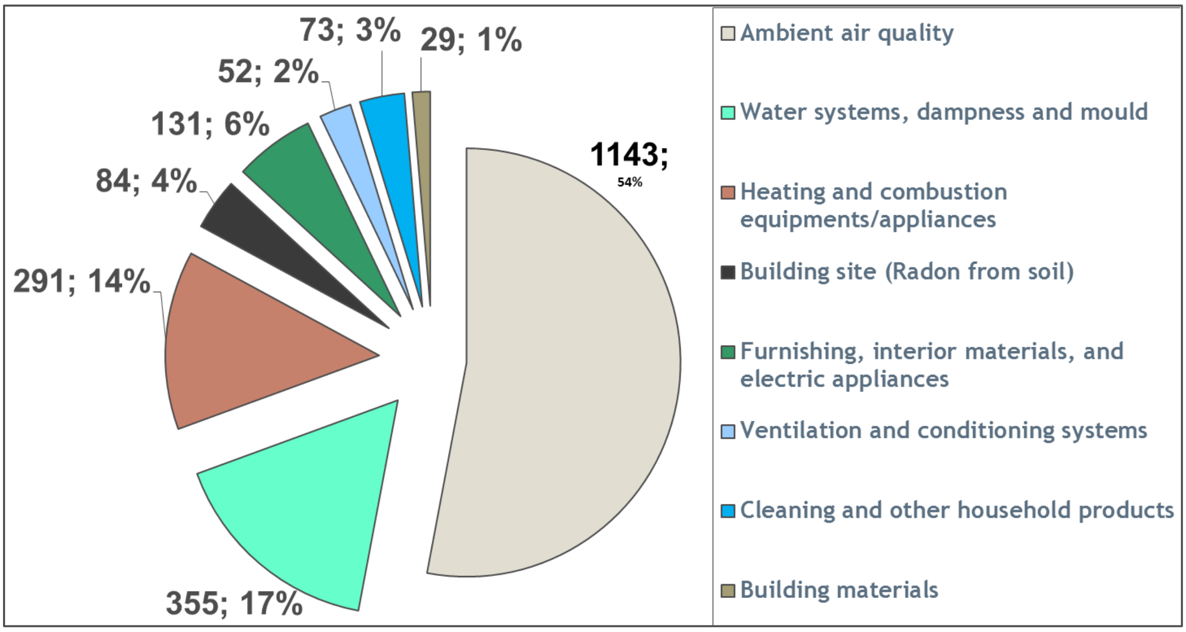

Source: Hanninen et al. 2013.

The burden of disease caused by indoor exposures is dominated by cardiovascular (CV) diseases; followed by asthma (total of 12%) and lung cancer (23%). The remaining 8% is divided between various respiratory symptoms and conditions (*figure 3*) (**slide 48).**

Within the frames of HEALTHVENT (Asikainen et al. 2016) project the effectiveness of three main measures to reduce health risk was compared: (i) optimizing ventilation rates only; (ii) filtration of outdoor air; and (iii) indoor source control. The results showed that all three approaches were able to reduce health risks, varying from approximately 20 % to 44 %, corresponding to 400 000 and 900 000 saved healthy life years in EU-26. $PM_{2.5}$ caused majority of the health effects in all included countries, and the importance of the other pollutants varied by country. The combination of controlling the indoor air sources and selecting appropriate ventilation rate was the most effective measure to reduce health risks.

The contribution of different exposure sources to the burden of disease is shown in *figure 4* (**slide 49**). It shows that although the most important source is ambient air pollution (54%), the different types of the building site, heating and combustion equipment, furnishing, ventilation and air conditioning systems have also a significant impact on the burden of diseases. **Slide 50** - Contribution of inadequate IAQ to the European symptom- and disease burden (x 1000 DALY/year, %), not including environmental tobacco smoke - shows the contribution of indoor air exposur to the European symptom and disease burden. It can be stated that the major pollutants are combustion products (39%) followed by volatile organic compounds (36%). Inadequate air quality contributes to the disease burden first of all to asthma (30%), cardiovascular diseases (31%) and sick building syndrome (23%) (**slide 51**).

*Figure 4.* The contribution of indoor air pollution to the European symptom- and burden of disease (x 1000 DALY/year) not including environmental tobacco smoke *Source: Hanninen et al. 2013*




## D. Sick Building Syndrome

The sick building syndrome (SBS) comprises of various nonspecific symptoms that occur in the occupants of a building. This feeling of ill health increases sickness absenteeism and causes a decrease in productivity of the pupils and teachers (**slide 52**). The sick building syndrome (SBS) is used to describe a situation in which the occupants of a building experience acute health- or comfort-related effects that seem to be linked directly to the time spent in the building. No specific illness or cause can be identified. The pupils/teachers may have complaints only in a particular room or zone or may have them throughout the building. People staying inside experience acute health and comfort effects that are apparently linked to the time learning/teaching/working indoors. Sick building syndrome should be differentiated from building-related illnesses **(slide 53**). This group of illnesses can be characterized by 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 (*table 4*).

*Table 4.* Comparison of the characteristics of sick building syndrome and building related illnesses

| Sick Building Syndrome<br>building related non-specific symptoms | Building-Related Illness<br>recognized building related diagnoses |
|---|---|
| • Headaches<br>• Fatigue<br>• Irritated eyes, nose, throat and/or skin<br>• Dry mucous membranes dry or itchy skin<br>• Hoarseness of voice and wheezing<br>• Difficult to trace to a specific source | • infection<br>- Legionnaires' Disease<br>- Aspergillosis (immune- compromised patients)<br>- cold, flu<br>• allergic reaction<br>- asthma,<br>- rhinitis<br>• The cause is clearly related to the building |
| **Symptoms clear when away from building** | **Symptoms may not clear upon leaving the building** |

## D.1. Causes of SBS

Causes of SBS may originate during planning and construction or during operation, maintenance and usage of the building. It is difficult to find the cause in individual cases. The problems can be sorted into 4 categories (WHO): (i) local factors; (ii) construction materials, equipment, problems connected to the function of the building (chemical release of construction materials and furniture, lighting, heating); (iii) problems independent of the structure of the building (dust-, mould-, or pollen allergy); (iv) psychological problems (societal, physical attributes and other factors) (**slide 54**).

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 **(slide 55):**

- 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

The problems related to SBS can be prevented by careful planning (**slide 56**):

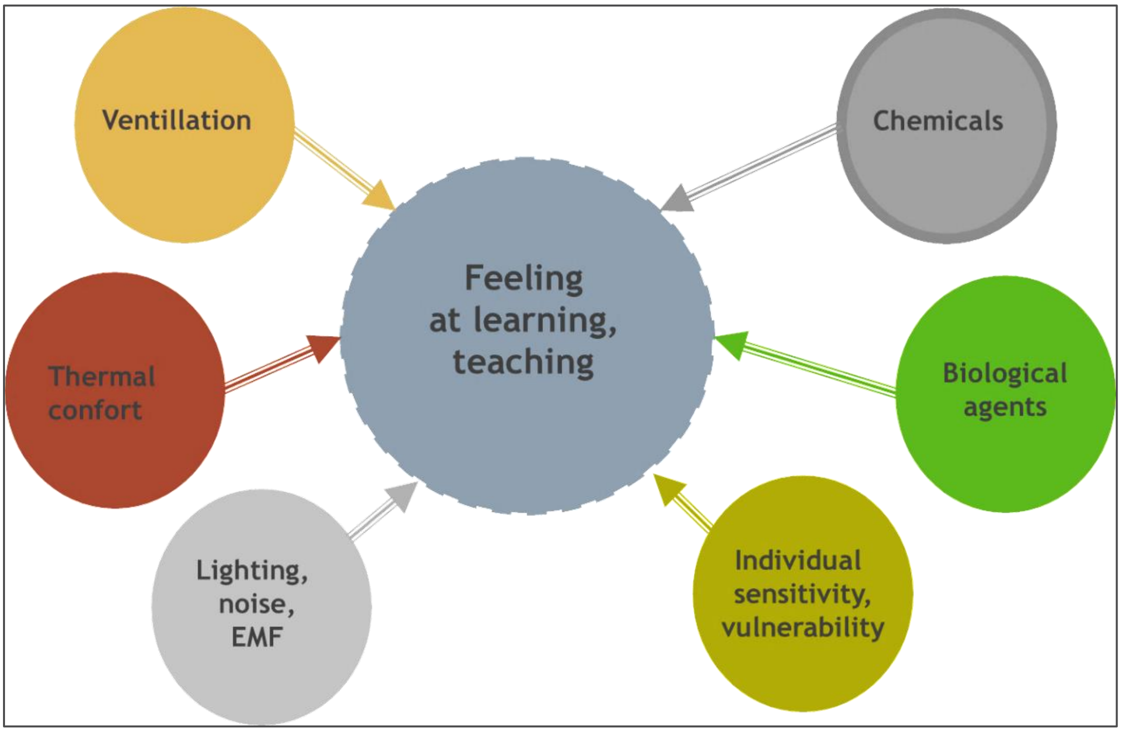
- are there hidden problems at the building site? (e.g. High ground water, radon, other contamination)
- every potential risk factor should be taken into consideration (proper ground plan, cleaning properties, appropriate heating factors)
- what is the quality of the local ambient air? If it is bad,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

The operation of the building can also prevent the majority of problems like proper ventilation, cleaning of surfaces, ventilation equipments, filters etc. If appropriate comfort level is ascertained, the risk of SBS is also low (low level of noice, temperature, humidity according to the recommendations and natural lighting.

# E. Indoor Environmental Quality (IEQ)

IEQ means good quality performance in indoor air quality + thermal comfort + daylight, lighting and views (visual conditions) + acoustic conditions + electromagnetic frequency levels (*Figure 5*) **(slides 57-58).**

*Figure 5.* Factors influencing indoor air quality




The fundamental difference between indoor and outdoor air is in the mixing volume. The mixing volume of the buildings is much smaller than that of the outdoor air. In this way, a pollutant that does not cause harmful effects outdoors, at most in the immediate vicinity of the emission, in the case of similar emission can reach dangerous concentrations indoors.

**Slide 59** shows the concentration of pollutants in a building depending on many factors and can be described by the following simplified equation:

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

where V is the total volume of indoor air ($m^3$), $C_i$ is the indoor concentration of the pollutant ($\mu g/m^3$), P is the hourly pollutant production or release rate (µg/h), E is the hourly elimination rate of the pollutant by chemical reaction or surface attachment (µg/h), Q is the hourly air exchange rate between the outdoor and indoor air ($m^3/h$) and $C_o$ is the outdoor concentration of the pollutant ($\mu g/m^3$).
The air exchange rate can be replaced by the number of total air changes per hour, that is, the number of times the volume of air in the indoor space is changed every hour. This can happen by natural ventilation (through windows) or mechanical ventilation (ventilation) or leakage through the walls of buildings or other structural elements. In highly insulated houses, the rate of air exchange can be reduced to 0.2. When equilibrium is reached, the equation is simplified:

$$C_i = C_o + (P-E) / Q$$

If the pollutant is formed mainly indoors, then $C_o$ can be considered practically zero and the internal concentration will be inversely proportional to the air exchange rate. A similar mathematical description can be used for outdoor spaces.

Ventiation can be measured in differnt ways. Ventilation is very important to ascertain good indoor air quality, it has to provide fresh air, to remove accumulated pollutants. Ventilation is needed to remove carbon dioxide and humidity emitted by the occupants (**slide 60**). Further, for pollutants with higher indoor than outdoor concentrations ventilation can be used to dilute the indoor levels and thus lower the exposures. However, for pollutants with higher outdoor levels, such as typically e.g. pollen and particulate matter, ventilation actually leads to their infiltration. Lastly ventilation is way to reduce temperature. In naturally ventilated buildings inflitration is measured as air exchange (ACH) per hour. ACH is 0.1 to 0.2 in „leaky buildings" whereas 2.0 to 3.0 in normally ventilated ones. Tracer gas technique is applied to measure infiltration. Nonreactive gases are used with the assumption that the loss of tracking gases is only due to ventilation/exfiltration (**slide 61**).

Standards on fresh air demand of building rooms according to fresh air need of persons: fresh air demand = minimum 30 $m^3$/person. Average classroom condition: 2$m^2$/person $\rightarrow$ 6$m^3$/person. The total air should be exchanged minimum 5 times

/hour. 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 (**slides 62-64**).

Insufficient natural ventilation causes increased moisture/mold, enhanced concentration of bacteria/viruses/fungi and chemical pollutants, as well unpleasent odors. Natural ventilation in general inefficient as it is not uniformly distributed. Air circulate evenly and stale air remains in some spaces. It transfers pollen and other contaminants from ambient air. In a longer run polluted air can have an effect on different organs like the immune, nervous, cardiovascular, respiratory system, can have cancerogenic effect and can disturb the endocrine system as described above in details **(slide 64-65).**

Mechanical ventilation involves the use of fans and/or air conditioning equipments. main points are pulling fresh air from outside to indoor; transfer stale air to outside; adjust temperature and humidity inside. These goals define the function of HVAC system (heating, ventilation, air conditioning system **(slide 66).**

## E.1. 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 (**side 67**). *Figure 6* summarizes the health impacts of different $CO_2$ levels (**slide 68**).

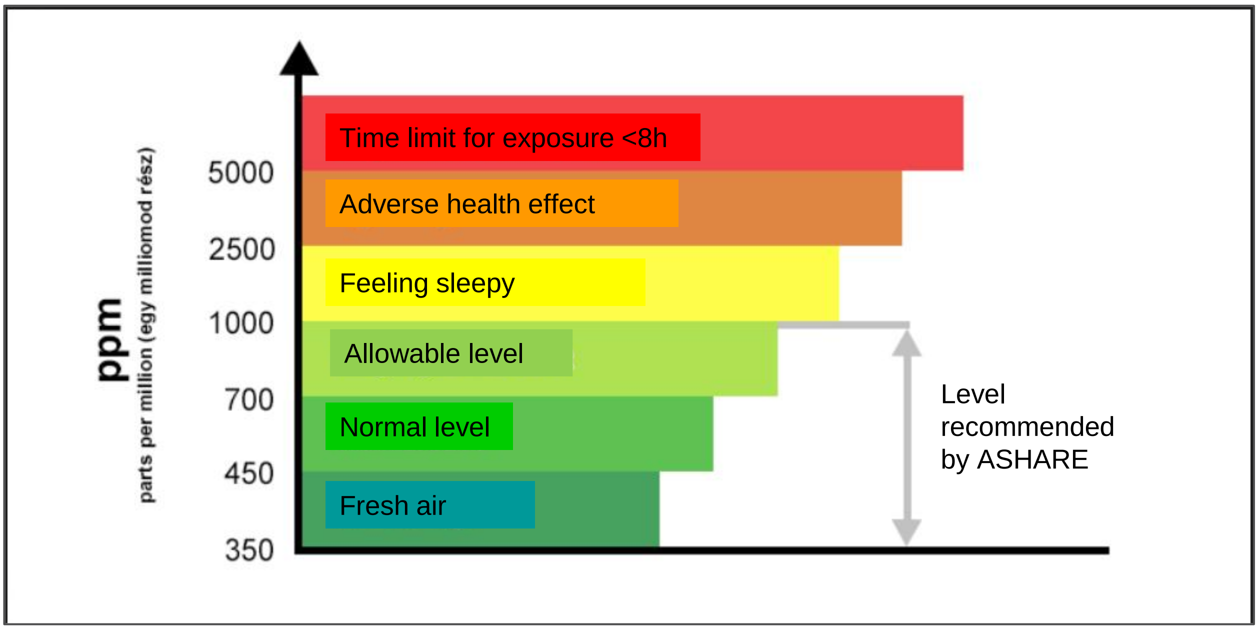



*Figure 6*. Relationship between indoor $CO_2$ concentrartion and health risks

In case of tight building envelops the best method to provide good indoor air quality is to install HVAC (Heating, ventilation, and air conditioning) system.

Poor indoor air quality can cause different symptoms and diseases. **Slide 69** summarizes the effects by pollutants, **slides 70-72** describes the different health symptoms by organs, **slide 73** displys the results of studies focusing on the effect of increaing ventillation rates in classrooms on task performance of pupils.

## E.2. Optimal ventilation – future perspectives

“Build tight and ventilate right” policies have been developed to ensure that air exchange and distribution within the building is sufficient and controlled to meet the needs for fresh air, contaminant filtration and dilution, and environmental thermal control. In addition, in particular when building on radon rich or contaminated soils, it is also necessary to construct and maintain an airtight floor against the ground and/or well ventilated and underpressurised space under the building (**slide 74**).

Building codes and engineering guidelines exist for the design of building envelopes, for the estimation of outdoor air exchange needs and/or outdoor and recirculation air filtration needs to reach indoor air quality targets with given indoor source rates and ambient air contaminant levels. 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.

Ventilation does not only extract or dilute indoor air pollutants and replace it with fresh air, it also brings outdoor air pollutants indoors. The requirements for air cleaning in the ventilation system should therefore be a prerequisite for obtaining a building permit in polluted urban and industrial areas or along major traffic roads. Location of the air intake ducts at an elevated level and as far as possible from traffic also helps bring clean fresh air to the building.

To further optimise the use of energy and IAQ, however, operation of the ventilation system should be better controlled according to the outdoor air temperature, humidity and pollution level. The building envelope and air cleaning can provide significant protection against outdoor air pollutants. Particulate matter can be effectively removed from the air with state-of-the-art fibre or electrostatic filters in balanced mechanical ventilation systems. It must be emphasized that regular cleaning and maintenance of HVAC systems is of utmost importance in order to reduce the health risks due to improper care.

## E.3. Lighting and acoustic condition, electromagnetic field

**Slide 75: Lighting** is essential for visual tasks and helps maintain attention levels. By using luminaires that combine direct light on the work surfaces with an indirect light aimed towards the ceiling, a varying and appropriate concentration of light is distributed throughout the room. 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.

How much light is needed: 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 from the luminaires gives 500 lx on the table. For reading, uniformity of light is important whereas practical tasks require high levels of light. To ensure what is written or displayed on the whiteboard is easy to read, the standard requires a minimum illuminance of 500 lux. The lighting shall be adjustable.

**Slide 76: Acoustic comfort** has a beneficial impact on the productivity indoors. Acoustic problems come from airborne sounds, outdoor noise, noise from adjacent spaces, noise from office equipment and sound of nearby facilities. The level, the spectrum, and the variation with time of the noise may influence the level of disturbance. Acoustic problems therefore need to be addressed at the design stages of the building. It is recommended that all noise sources (e.g. ventilation systems, office equipment and street noise) do not exceed 40 dBA.

**Slide 77: Electro-magnetic fields** are fields of natural or induced magnetism. Typical exposures are usually below 1 milliGuass (mG) or 0.1 microTeslas (μT).

Electromagnetic fields of all frequencies represent one of the most common and fastest growing environmental influences, with growing concerns. All populations are now exposed to varying degrees of EMF, and the levels will continue to increase as technology advances. Lots of research activities have been carried out concerning the carcinogenic effect of EMF, the current evidences are insufficient to prove that EMF would cause cancer in humans. Laboratory studies confirm *in vivo* biological effects, namely chronic exposure has been associated with increased oxidative stress and DNA damage and cancer risk.

## E.4. 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 (**slide 78**).

## E.5. Thermal comfort

Human thermal comfort can be determined as a function of both temperature and relative humidity. Factors influencing thermal comfort can be grouped as environmental: air temperature, humidity, air movement/velocity (m/s), radiation; and personal: as activity and clothing. The comfort zones are shown in *figure 7* (**slide 79).**

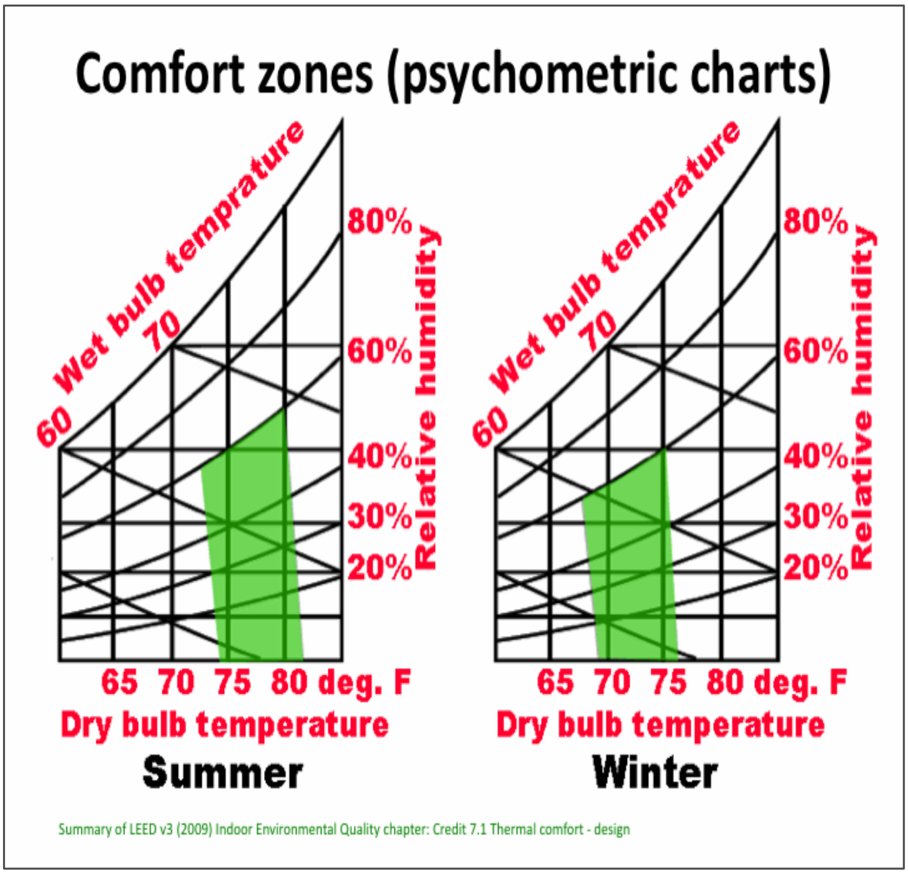



*Figure 7.* Thermal comfort zones in summer and winter

**Factors defining indoor comfort**

- Temperature: ideal in the range of 18,5 – 25,1°C
- Relative humidity: ideal 43%< RH <67 %
- $CO_2$: ideal <1200 ppm

Within the InAirQ project we suggest a ranking of thermal comfort parameters according to the health risk (*Figure 8*) **(slide 80**):

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

*Figure 8.* Ranking the health impact of comfort factors indoors

Humidity is also very important. Out of the ideal range, low and high relative humidity can enhace the growth of different bacteria, viruses, fungi, mites, consequently can increase the risk of infectious and allergic diseases (**slide 81**).

# F. Health impacts of climates change in school environments

**Slide 82** shows the predicted mean temperature and temperature differences of Europe in the reference, near and far future periods by A1S and A2 emission scenarios. It is of high probability that climate change will impact settlements, especially cities due to urban heat island effects. 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. Internal temperatures in classrooms will increase with rise I future exterior temperature.

According to the findings of the SINPHONIE study, the monthly mean temperature will substantially increase also in spring and early autumn. The highest increase (more than 100%) is predicted for the cities in Northern Europe at the end of the 21$^{st}$ century. The mean temperature increase will be about 50-70% in the central part of Europe. The lowest rate of increase is predicted for the cities in the South and in the West, close to the sea and ocean.

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 (**slide 83**).

As an example we show the predictions for Budapest for the near and far future (*figure 9*) (**slide 84**).It can be seen that to a lower extent, monthly mean temperature will increase in April and May, as well as in September during the teaching periods in the near future, and the effect will be much higher by the end of the century. This predicted increase in late Spring and early Autumn makes necessary to increase the thermal insulation and cooling of school buildings.

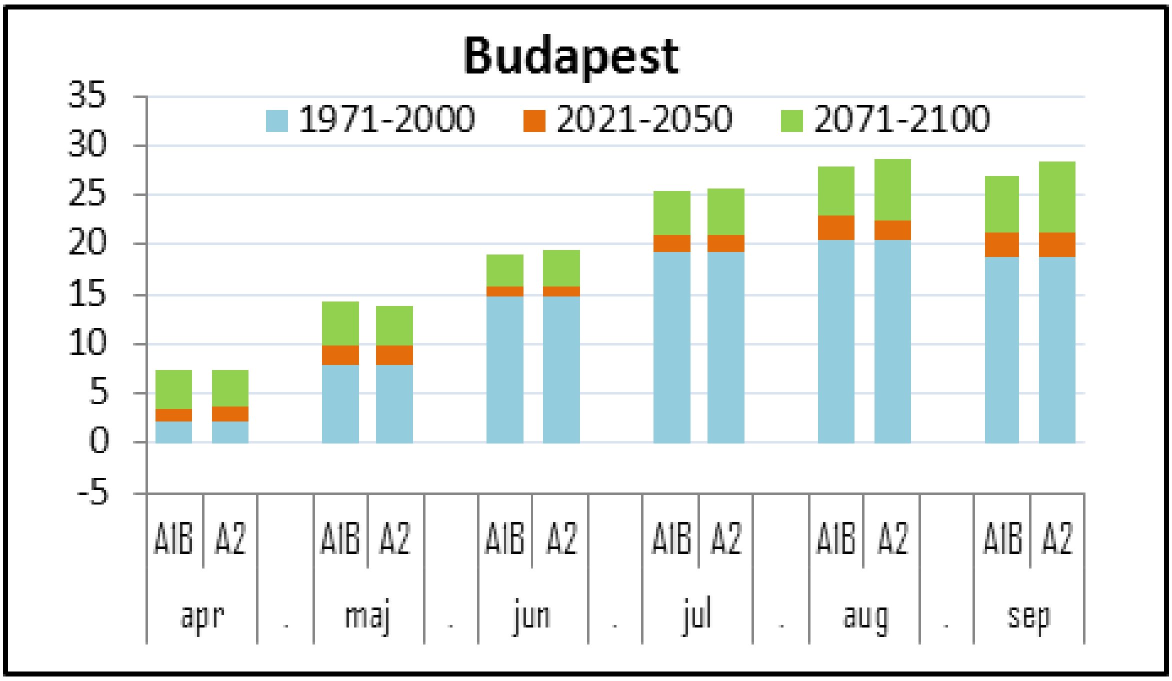



*Figure 9.* Predicted monthly mean temperature increase by A1B and A2 emission scenarios in Budapest for the periods of 2021-2050 and 2071-2100

Climate change will impact 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 (**slide 85**).

Some health risks related to climate change should be mentioned: at the beginning of summer the number of accidents related to outdoor activity like injuries, fratures increase. A direct association between trauma attendance and weather was found with higher attendances on dry and sunny days. Accident 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 (**slide 86**).

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 (**slide 87).**

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 daytime 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 equipments during summer (**slide 88**). 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 (**slide 89**).

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 help improve thermal resistance of building envelope to prevent external heat gains and maintain existing thermal mass to use nighttime cooling **(slide 90).**

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 (**slide 91**).

## G. 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.

- Good IAQ is the guarantee of comfort, health and safety
- Growing children are very sensitive to hazardous chemicals (**slide 92**)

**Potential ways of reducing indoor air pollutions**

- **Reducing emissions** (qualified construction- and covering materials, using cleaner energy and better equipments)
- **Better planning** (modern heating systems, appropriate construction- and covering materials, etc.)
- **Improving ventilation** (chimney, exhausters, windows, ventilation holes, ventilation systems). Note that natural ventilation does not guarantee the minimum air exchange especially in cities.
- The future solution is mechanical ventilation – HVAC- a way to sustaianble indoor air quality

**BUT**

- **Improper maintenance, design, and functioning of HVAC systems contributes to an increased prevalence of SBS symptom (slide 93).**

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 equipments.

# H. Literature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