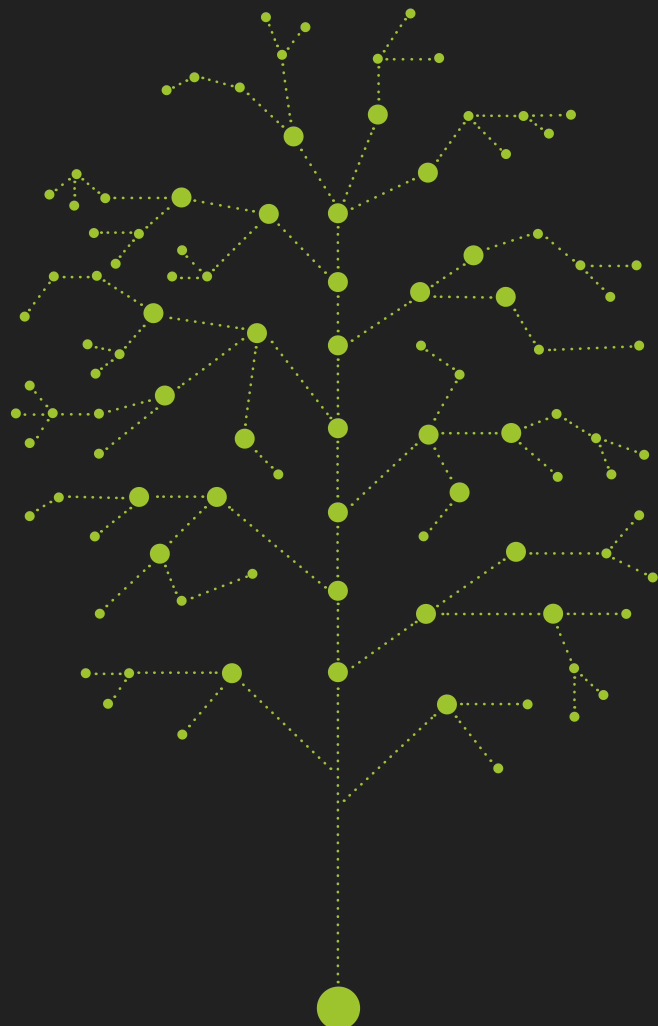

Cracow University of Technology

environmental engineering

Indoor Air Quality

Jarosław Müller
Dorota Skrzyniowska
Renata Sikorska-Bączek

Kraków 2020

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Table of Contents

Part 1

General

JAROSŁAW MÜLLER

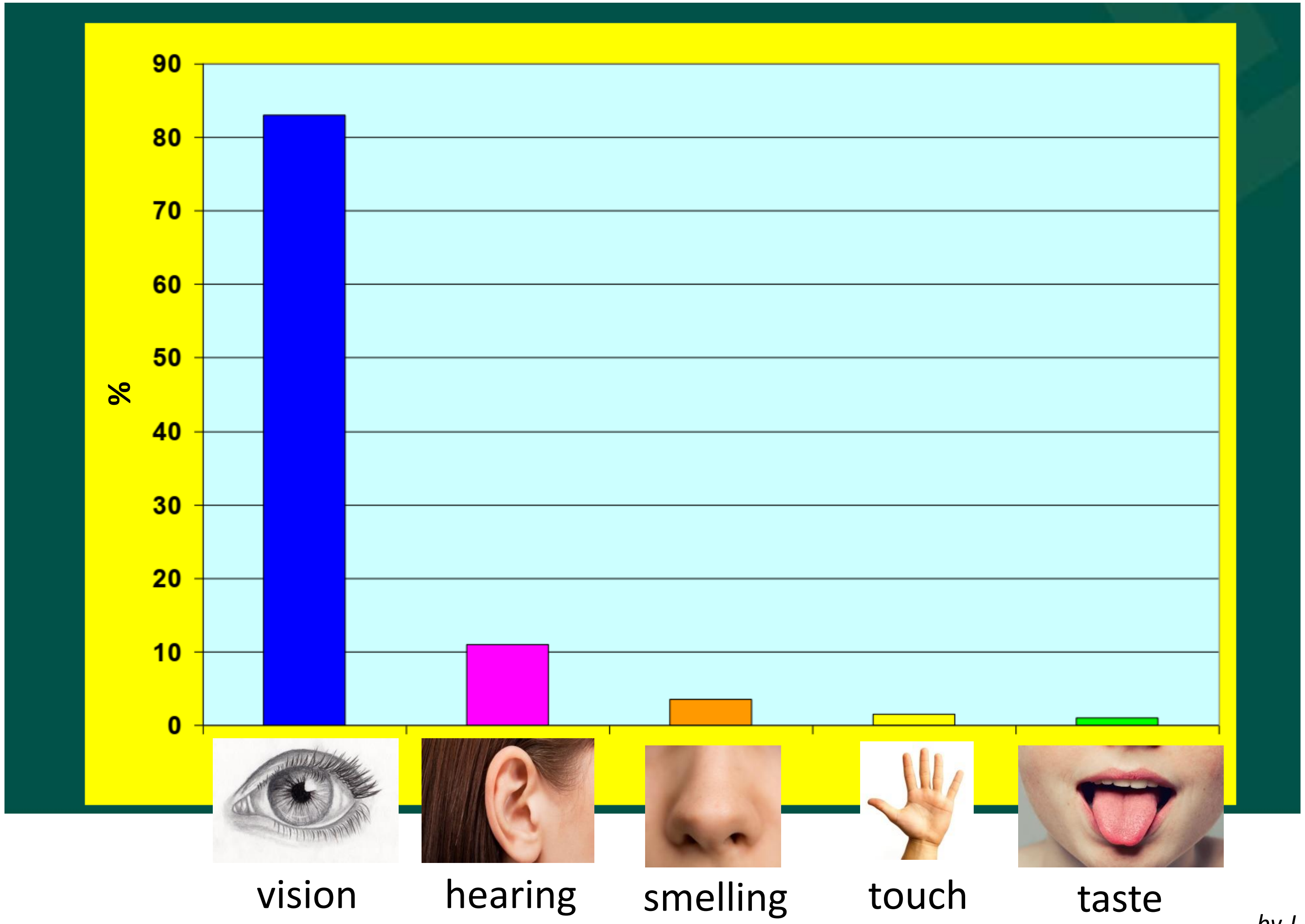
Is the measurement of indoor air quality often encountered?

YES, very often

We say:

- But it's stifling!
- But it's cold here!
- But here it is hot!
- …

Perception of the environment



by J. Sowa

Is the measurement of indoor air quality often encountered?

In buildings with mechanical ventilation, we often measure:

- Temperature
- CO_2
- Smoke (fire detectors)

Is the measurement of indoor air quality often encountered?

In buildings with gravity ventilation, we often measure:

- Temperature
- CO_2
- Relative humidity
- Smoke (fire detectors)

But nothing comes of it!

Scents

About five million smell neurons located in the upper part of the nasal cavity determine whether the air is perceived as having a fragrance. The fragrance receptors are connected by means of nerve fibers to the fragrance center in the brain. The center transmits information to various brain structures, including the so-called centre of emotions. One whiff of a fragrance can restore emotional memories, eg. a childhood scene. Organic compounds with a molecular weight above 300 do not have an odour. Some compounds with a molecular weight below 300 are detectable by the sense of smell at concentrations so low that it is impossible to measure the concentration of these substances using direct devices. An example of such a compound is trimethyamine, which a human can sense at a concentration of 10^{-4} ppm.

Atmospheric air

Gas name	Formula	Volume rate [%]
Nitrogen	N_2	78.084 ± 0.004
Oxygen	O_2	20.946 ± 0.002
Argon	Ar	0.934 ± 0.001
Carbon dioxide	CO_2	0.033 ± 0.001
Neon	Ne	$(18.18 \pm 0.04)*10^{-4}$
Helium	He	$(5.24 \pm 0.004)*10^{-4}$
Methane	CH_4	$\approx 2.2*10^{-4}$
Krypton	Kr	$(1.14 \pm 0.01)*10^{-4}$
Nitrogen oxides	NO, N_2O, etc.	$(0.5 \pm 0.1)*10^{-4}$
Hydrogen	H_2	$\approx 0.5*10^{-4}$
Xenon	Xe	$(0.87 \pm 0.001)*10^{-4}$
Ozone	O_3	$(0 \pm 0.07)*10^{-4}$
Radon	Rn	$6*10^{-18}$

VOC Volatile Organic Compounds

- There is usually a large variety of organic substances in the air in which people reside. Identified are aliphatic and aromatic hydrocarbons, chlorinated hydrocarbons, ketones, esters and others.
- According to the WHO classification, volatile organic compounds include organic substances with a melting point below room temperature and boiling in the range of 50÷290°C.
- Volatile organic compounds are formed during combustion processes (e.g. heating of flats), cooking, emanate from building materials, furniture, varnishes and finally they are metabolic products.

VOC Volatile Organic Compounds

- Their concentration in the air in buildings is generally in the range of 0.03÷2.8 mg/m^3. The most common are average values of 0.2÷1.0 mg/m^3.
- About 50% of the concentration are aromatic hydrocarbons, headed by toluene and xylene. Due to toxicity, styrene, chlorobenzenes, phenols, alkylbenzenes and naphthalene should also be mentioned. Aromatic hydrocarbons can cause acute and chronic poisoning. In acute intoxications, the effect is narcotic, while in chronic poisoning the influence on the hematopoietic system is prevalent.

TVOC – Total Volatile Organic Compounds MØLHAVE (1990)

The influence of mixtures of volatile organic compounds on humans

Because usually from several dozen to one hundred and several dozen chemical compounds are identified in the premises, extensive research is currently being conducted on the combined effect of mixtures of many chemical compounds on humans. Classical toxicology dealing with single impurities is not able to explain many ailments experienced by users.

In 1990, Lars Molhave proposed using as a measure of indoor air quality the total amount of Volatile Organic Compounds (TVOC).

TVOC – Total Volatile Organic Compounds MØLHAVE (1990)

TVOC – total amount of volatile organic compounds measured using a gas chromatograph with flame ionization detector calibrated against toluene

Concentration of TVOC [μg/m^3]	Effects
< 200	Comfort
200÷3,000	Possible discomfort when combined with other components
3,000÷25,000	Discomfort
> 25,000	Toxic

Recommended TVOC concentrations by Seifert

Organic volatile	Recommended concentration [μg/m^3]
Alkenes	100
Aromatic hydrocarbons	50
Terpenes	30
Halon hydrocarbons	30
Esters	20
Aldehydes and ketones (without formaldehyde)	20
Other	50
Total (TVOC)	300

Currently, TVOC is understood as the sum of the concentrations of identified organic compounds that are contained in the chromatographic print between the h-hexane and n-hexadecan peaks, assuming that only surfaces of undefined peaks are converted into toluene.

Ozone

Ozone is a colorless gas with a characteristic odour already at a concentration of 0.2 mg/m^3. At room temperature, it decomposes slowly, at high temperature, it takes place quickly.

The harmful effects of ozone and other oxidants are mainly directed to the respiratory system. Due to its low solubility in water, it penetrates into the bronchioles and alveoli. High ozone concentration, on the order of a dozen or so mg/m^3 causes toxic pulmonary edema, haemorrhage and death.

In microbiology, ozone is used as the strongest disinfectant that easily destroys bacterial cells.

Ozone

Ozone is a very active compound that reacts strongly with other elements. As a strong oxidant, it can oxidize other compounds very quickly by changing their structure and properties. Many pollutants that are in the air after mixing with each other and reacting become much more irritating than before the process. An example of this is the oxidation of turpentine by ozone, resulting in the formation of aldehydes, ketones and organic acids, which are more dangerous than turpentine alone.

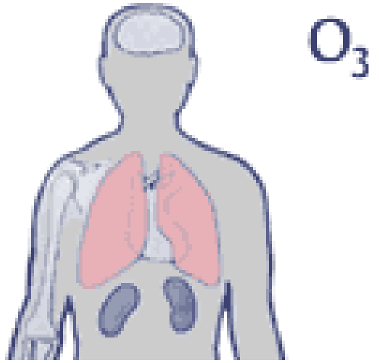
Ozone

The way of ventilation has a significant impact on the formation of new compounds. The smaller the exchange of air in the room, the longer the components have to react with each other. In experiments with various turpentine, it was found that the amount of reaction with ozone increased about 40÷70 times.

The average concentration of indoor ozone generally does not exceed 0.1 mg/m^3 (50 ppm), which is 10÷80% of the level in the outdoor air. Therefore, the main source of ozone is infiltration from outside air. The situation changes with the activity of electrostatic equipment, which creates high local concentrations.

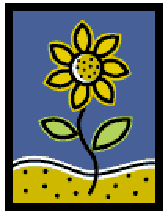
Health effects of exposure to ozone

Concentration of ozone [mg/m³]	Health effects
0.2	After prolonged exposure, it irritates, causes coughing, fatigue, drowsiness, headaches, drop in blood pressure
2.0	The same symptoms after 2 hours of exposure
6.0	The same symptoms after 1 hour of exposure
9÷20	Acceleration of heart rate, drowsiness and headaches



Ground level ozone

What problems does ozone pose for plant and animal life?



The effects of ozone on animals are similar to its effect on humans: decreased lung capacity and lung elasticity. As for plants, ozone damages leaf tissue. This can greatly affect the ability of plants to grow and thrive. Visible damage to leaf tissue includes discolouration, black and white spots, paper thin areas on the leaf, as well as leaf loss. Ozone damage can lead to 10 to 40% growth loss, premature aging, and a decrease in pollen lifespan. Damage can affect crop yields by as much as 20% in some cases.

What effect can ozone have on structures and materials?

- Destroys most forms of synthetic materials.
- Can cause cracks in rubber and synthetic rubber products – with continued exposure – total disintegration.
- Damages the integrity of cotton, acetate, nylon, polyester, and other textiles.
- Bleaches materials, dyes, paints, and coatings.

The effect of temperature and humidity on the assessment of air quality

In recent years, the hypothesis has also been reiterated that elevated temperature is a very serious factor affecting the negative assessment of air quality. The first one to formulate such a hypothesis in the nineteenth century was J. Hermans. Later, the hypothesis was confirmed by Billings, Flugge and his students, as well as Haldane and Hill.

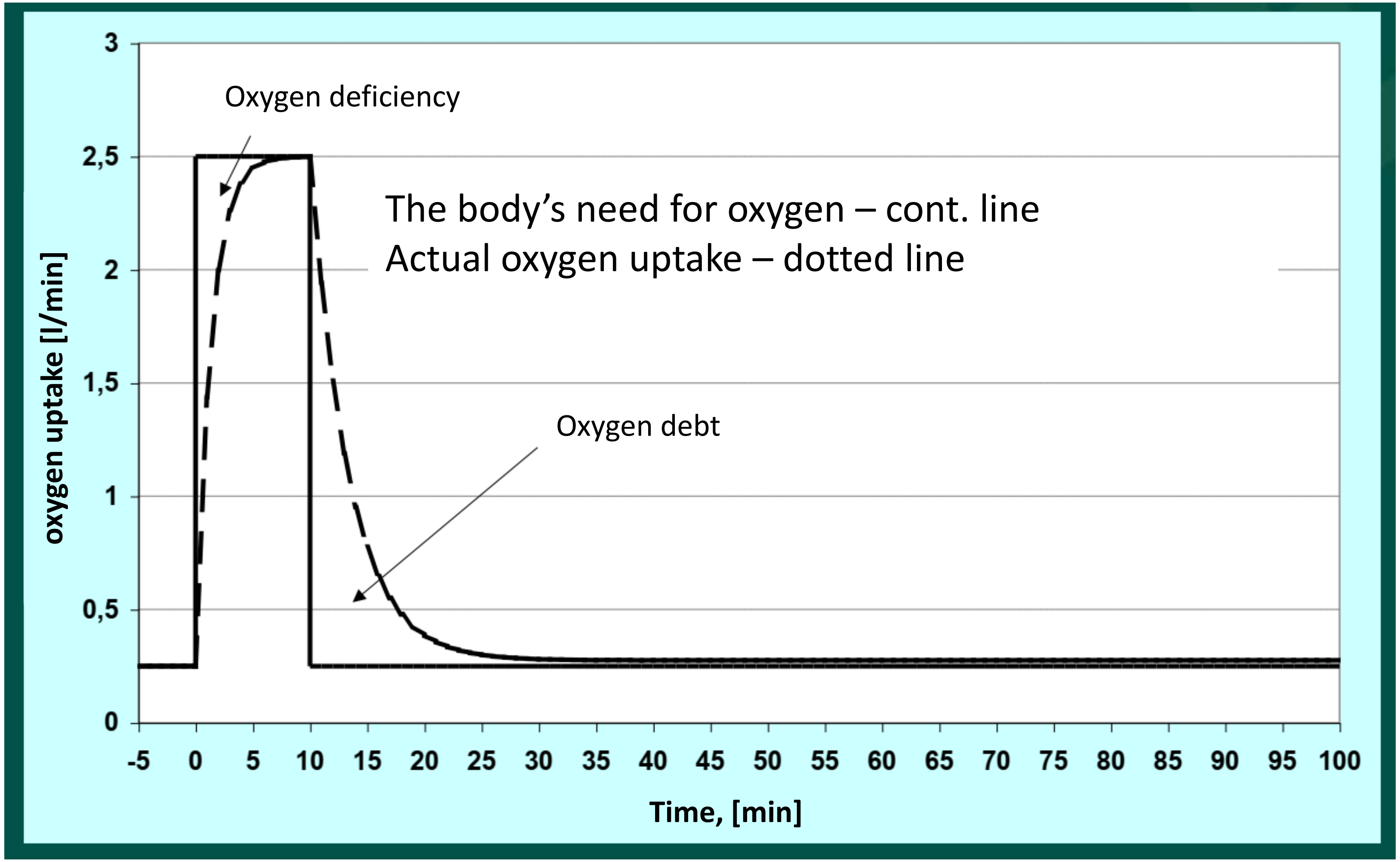
Co-operative work carried out in Denmark by Lei Feng under the direction of P.O. Fanger also indicate elevated humidity as a factor negatively affecting the perceived air quality.

Oxygen

Lack of oxygen in the air brings about hypoxia and asphyxia. The rate of increase of these symptoms depends on the oxygen concentration in the air. At a concentration of 16% oxygen in the air, the oxygen saturation of hemoglobin is still full and amounts to approximately 95% HbO_2. In lower concentrations, symptoms of oxygen starvation **develop quickly**.

If gas mixtures with enriched oxygen or pure oxygen are used, **the toxic effects of this gas are revealed**. The organs most exposed to the negative effects of elevated oxygen concentrations are the lungs and eyes.

Oxygen deficiency and oxygen debt



by J. Sowa

Oxygen stages of oxygen deficiency in the blood

Oxygen concentration, [%]	The observed effects
16÷12	Increased breathing due to stimulation of the respiratory center. the consequence is a loss of CO_2 from the blood and an increase in blood pH. Pulse accelerated. A slight disorder of coordination of movements. A prolonged loss of CO_2 may result in reduced excitability of the respiratory center and, as a result, impaired lung ventilation.
12÷10	A quick breath, going into intermittent or breathing of the CheyneStockes type. In the presence of consciousness, there are disturbances in the functioning of higher nerve centers. Fatigue occurs quickly due to impaired muscle work.
10÷6	Nausea and vomiting; inability to move and perform larger muscle movements. No possibility to help yourself. There is a loss of consciousness and apathy – leading to death.
< 6	Convulsions, interrupted breath, often limited only to the opening of the mouth. After prolonged periods of apnea, the heart activity stops.

Oxygen – elevated concentrations

Breathing with pure oxygen at 1 atm for 6 hours leads to perceived disturbances in the airways. Extending the exposure for 24–48 hours damages the pulmonary vesicles and causes them to swell. The prolonged exposure leads to the death of the epithelium lining the pulmonary vesicles. The effect is intensified and pulmonary fibrosis occurs.

In the fifties of the twentieth century, it was diagnosed that the cause of blindness of the children's eye disease of left-sided fibrosis was **excessive oxygen administration to premature babies in incubators**. A 10-day exposure to a gas mixture containing 35–40% oxygen was sufficient for the onset of the disease. The result of breathing the atmosphere with such an enriched participation of oxygen is the narrowing of the blood vessels of the eye, the death of the blood vessels that supply blood to the retina and the formation of new blood vessels that grow into the vitreous body of the eye and result in retinal detachment.

Oxygen – elevated concentrations

Breathing with oxygen at a pressure of 2÷3 atm causes almost immediate disturbances of the central nervous system. Initial cramping of individual muscle groups degenerates into general convulsions that are associated with irritation of the cerebral cortex.

Cases of internal ear bleeding and deafness due to hyperbaric oxygen therapy have been described.

Currently, it is believed that the main cause of oxygen toxicity is the formation of reactive oxygen species in cells.

CO carbon monoxide

- It is absorbed in the lungs and in small amounts through the skin.
- It is dangerous for the human body because it has the ability to bind to hemoglobin from the blood and block its oxygen transfer function. This ability of CO to combine with hemoglobin in red blood cells is about 200÷250 times greater than oxygen. The effect of this phenomenon may be a significant reduction in the ability of hemoglobin to transport oxygen and, as a result, tissue ischemia of the body.
- The most sensitive to the action of CO will be organs with a high oxygen demand, like the brain or heart – carbon monoxide is especially dangerous for tchem.

CO carbon monoxide

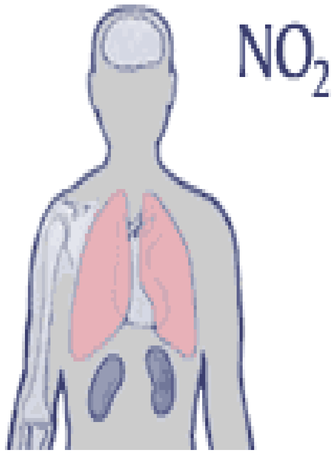
Level COHb, [%]	The observed effects
0.4	Normal physiological value for non-smokers.
5÷10	Changes in the metabolism of the myocardium and even the possibility of its damage; statistically significant deterioration of visual perception, manual efficiency and learning ability.
10÷20	Light vasodilation, headache, effort dyspnoea, frontal pressure.
20÷30	Headache and throbbing at the temples, tiredness, dizziness, vomiting.
30÷40	Significant weakness, severe headaches, orientation disorders, nausea, vomiting.
40÷50	Acceleration of heart rate, arrhythmia, significant acceleration of breath, cyanosis, feeling of anxiety, muscle weakness, disturbed consciousness.
50÷60	Significant acceleration of cardiac function, increased breathing disorders, cyanosis, coma.
60÷70	Coma, fits, slow heart and breath, death.

Nitrogen oxides NO_x

Nitrogen oxides have a yellow-red-brown colour and give off a strong odour. NO is detectable by the human body already at a concentration of 0.12 ppm, i.e. much earlier than there are health effects. The sensitivity to the smell of nitrogen dioxide increases as the humidity rises from 60 to 80%. Nitric Oxide undergoes oxidation to nitrogen dioxide in the atmosphere and the mixture of both gases is treated as NO_x.

The total amount of NO_x formed during combustion processes and the ratio of NO to NO_2 depends on the type of fuel and the ratio of fuel to air and combustion temperature. It is known that the factor conducive to the coupling of oxygen and nitrogen atoms to nitrogen oxides is high temperature. In Nature, nitrogen oxides are found primarily during fires and thunderbolts. On the other hand, anthropogenic sources of NO_x generation generally include municipal and industrial combustion of fuels for heating and energy purposes as well as motorization. When it comes to closed rooms, smoking and the use of domestic gas appliances still pump out NO_x.

Nitrogen oxides NO_x



Nitrogen oxides have a harmful effect primarily on the human respiratory tract – causing mainly irritation of the lungs, bronchitis, pneumonia and a general increase of susceptibility of the body to viral infections. Nitrogen oxides dissolving in water contained in the secretion covering the mucous membranes form nitrous and nitric acid. After some time, there is a reaction from the absorption and damage to the mucous membrane of the airways, alveoli and lung capillaries that leads to the development of pulmonary edema. By penetrating into cells and causing oxidation of surface-active lipids, they are also the cause of enzymatic disorders. Moreover, there are immunological and hematological changes, as well as a decrease in the level of vitamin C. In addition, the paralysis of the snap movement of the ciliary cells leads to a decrease in the self-cleaning ability of the airways.

Nitrogen oxides NO_x

Level of NO_2		The observed effects
[mg/m^3]	[ppm]	
0.0005÷0.001	0.00025÷0.005	The level of natural background in the atmospheric air.
0.02÷0.09	0.0098÷0.044	Average annual concentration in densely populated areas.
0.23	0.12	The level of reaction of the human sense of smell.
0.14÷0.50 0.	0.07÷0.24	The level of appearance of a reversible change in the adaptation of sight to the dark.
1÷10	49÷4.9	Concentrations observed in rooms where domestic gas appliances are used.
103÷300	50÷150	Chronic respiratory diseases.
> 300	> 150	A level that can cause death.

Mould fungi

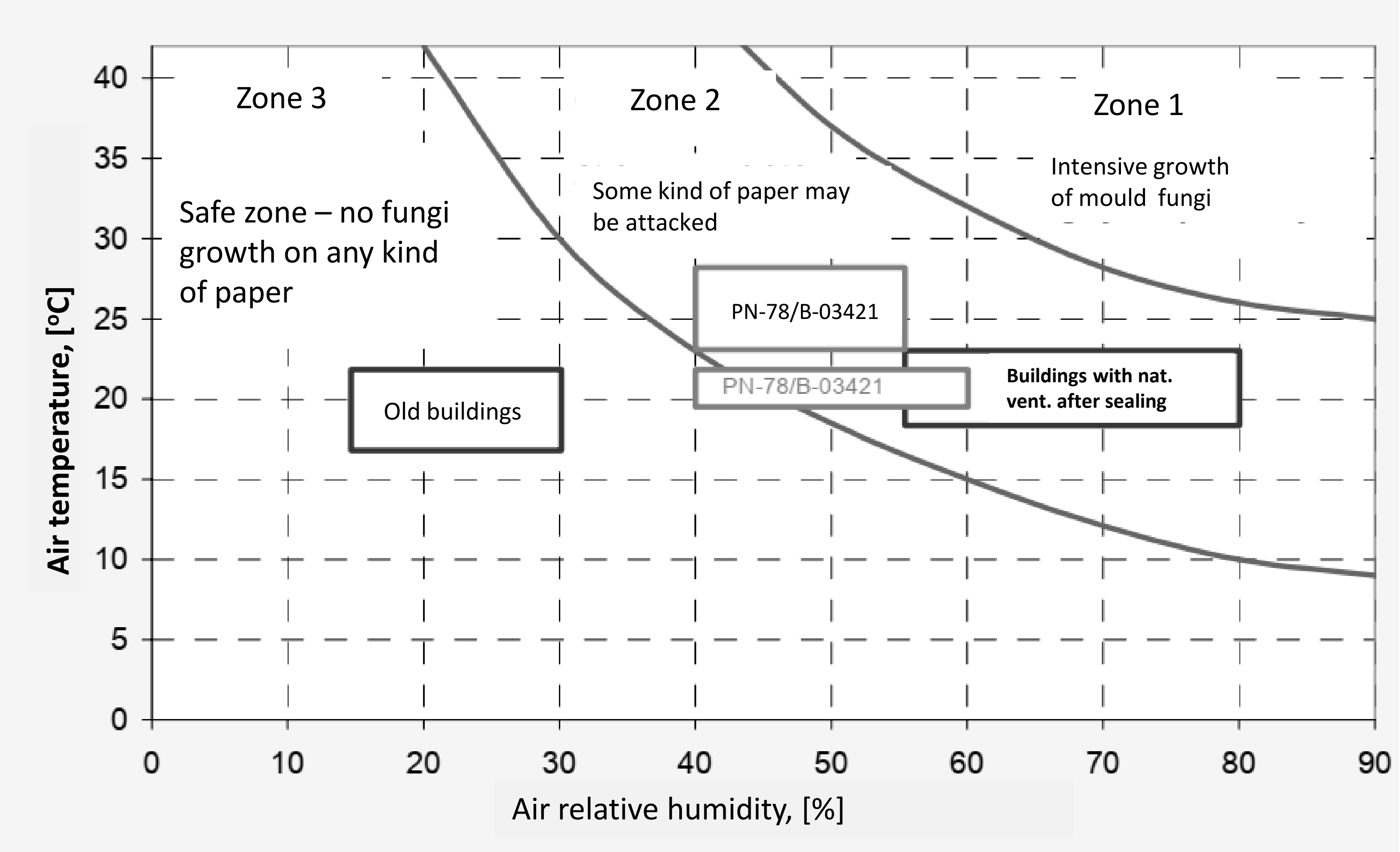
Development conditions:

- oxygen
- medium – organic coal
- temperature 5÷25°C
- humidity 70÷99%

Mycotoxins

- aflatoxin – liver cancer
- ochratoxin – nephropathy
- trichothecenes – immunosuppression, hemorrhage
- sterigmatocystin – carcinoma of the liver'
- petulin

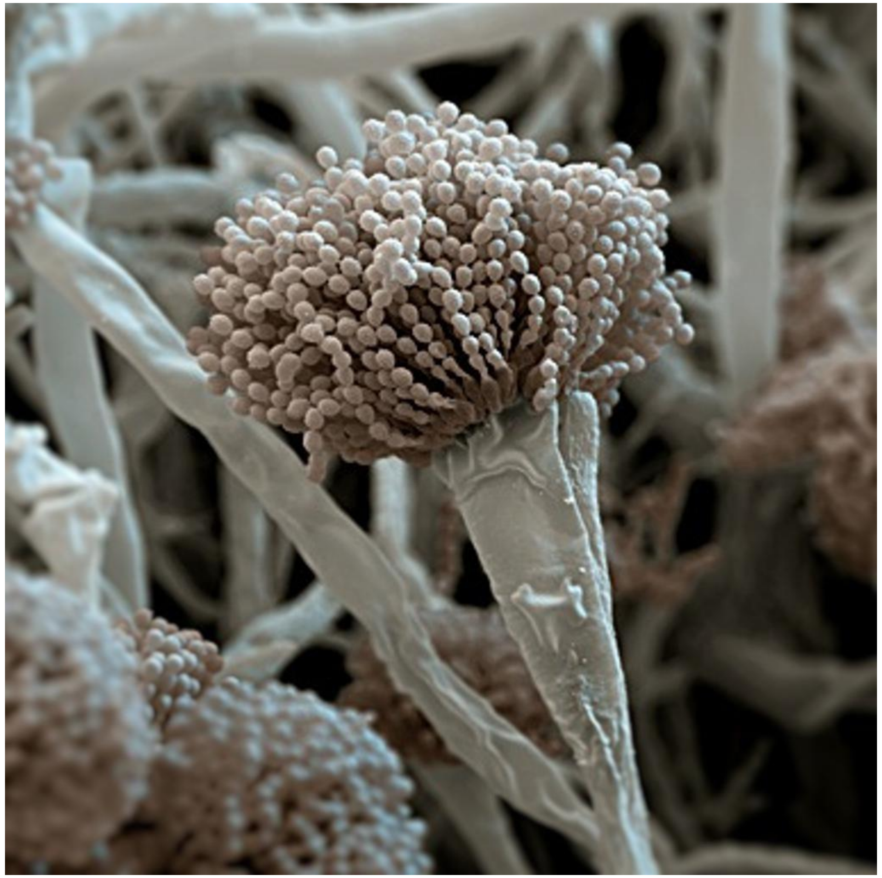
Microclimatic conditions conducive to the development of mould fungi



By J. Sowa

Mould fungi

Mould spores



biobalance.pl

Mould fungi

Author: WAIGEL s.c.

Part 2

Radon

JAROSŁAW MÜLLER

Basic information about the Radon – environment

Soil, raw materials, building materials

^{40}K, ^{226}Ra, ^{232}Th

Soil air

^{220}Rn, ^{222}Rn

Atmospheric air

^{137}Cs, ^{134}Cs, ^{7}Be, ^{40}K, ^{226}Ra, ^{232}Th, ^{220}Rn, ^{222}Rn

Water

^{222}Rn

Basic information about Radon

- Radioactive gas, mainly from the decay of uranium
- Element from the ^{222}Rn helium group
- Colourless, odourless, non-flammable, tasteless
- Content in the earth's crust 6x10÷16%
- The heaviest gas element (9.73 g/dm^3)
- Dissolves in water and organic solvents
- Half-life of the most frequent ^{222}Rn isotope is 3.823 days
- Boiling point: –62°C
- It has 35 isotopes, 4 of which are naturally occurring

by J. Kozak IFJ PAN

Basic information about Radon

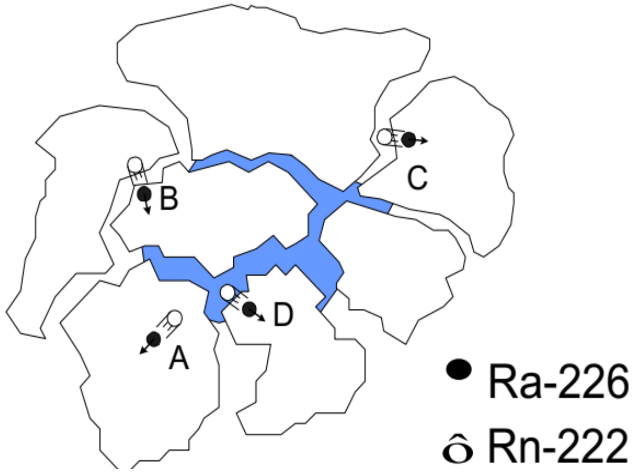
Radon in nature arises as a result of the disintegration of radium (Ra-226), a natural radioactive element that is the constituent of the uranium radioactive series. Radon is a noble gas, heavier than air, invisible, odourless and tasteless. As a radioactive isotope it breaks down by emission of alpha to other radioactive isotopes, short-lived derivatives of radon: polonium, bismuth and lead.

Basic information about Radon

The source of radon in the atmosphere is radon emerging from the soil, where its concentration can get as high as thousands Becquerels per cubic meter.

1 Bekerel (Bq) is 1 atomic decay of an atom in 1 second. The concentration of radon on the outside is about 10 Bq/m^3, and in buildings it can reach concentrations of hundreds or even several thousand Bq/m^3.

^{222}Rn in the soil air

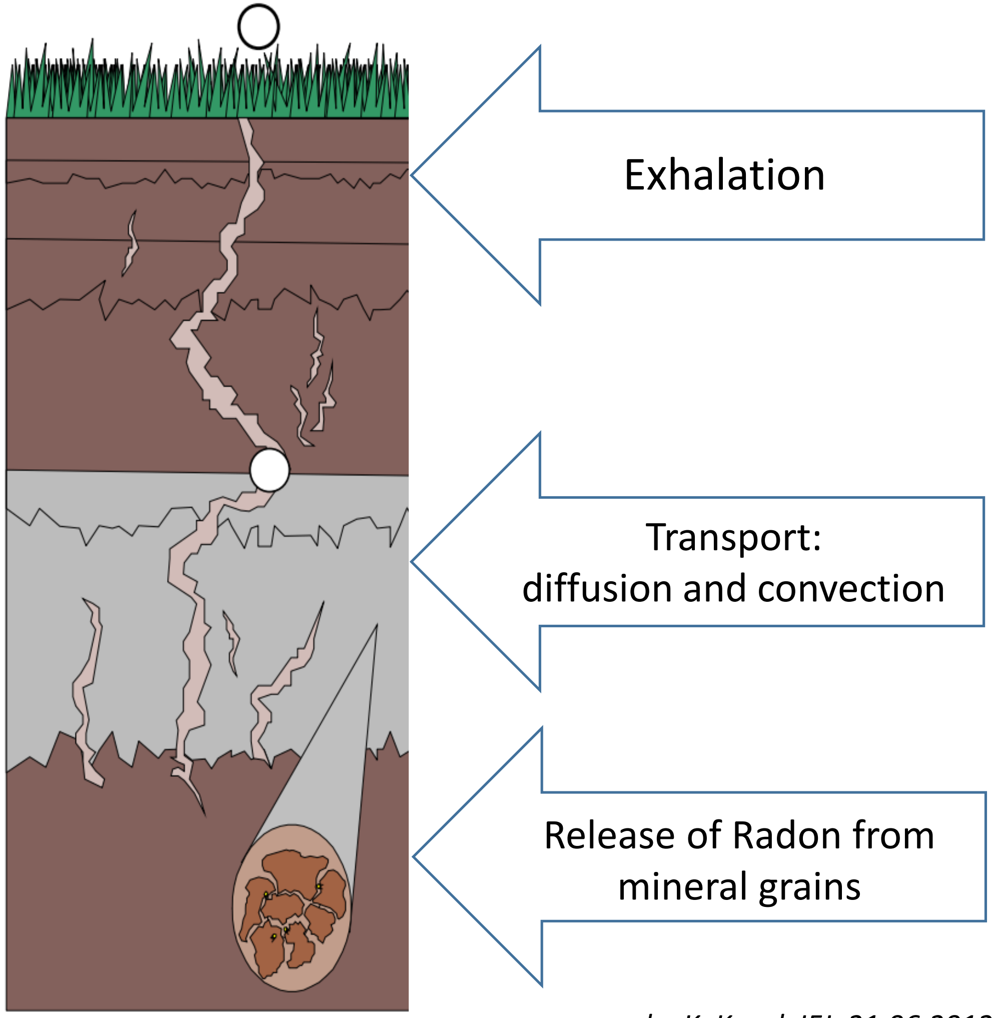


A – Ra-226 Decay inside grain
B – Ra-226 Decay close to grain surface
C, D – r-222 release to intergrain space

α recoil

Recoil Energy = 100 keV and it is:
(10^4÷10^5) > chemical bond energy

Mineral: 20÷70 nm
Water: 100 nm
Air: 60 000÷90 000 nm



by K. Kozak IFJ, 21.06.2012

Transportation of Radon ^{222}Rn in soil air

Diffusion – concentration gradient

Convection – pressure gradient

Advection – temperature gradient

The concentration of Radon in the soil air is a function of wind speed, soil heat flux and air temperature

^{222}Rn in the soil air

RI – Radon Index

Risk level from radon (low, medium, high)

RP – Radon Potential of a building site

$$\mathbf{RP = (C_{Rn} - 1) / (-\log k - 10)}$$

C_{Rn} – concentration of Radon in soil [kBq/m^3]
k – permeability [m^2]

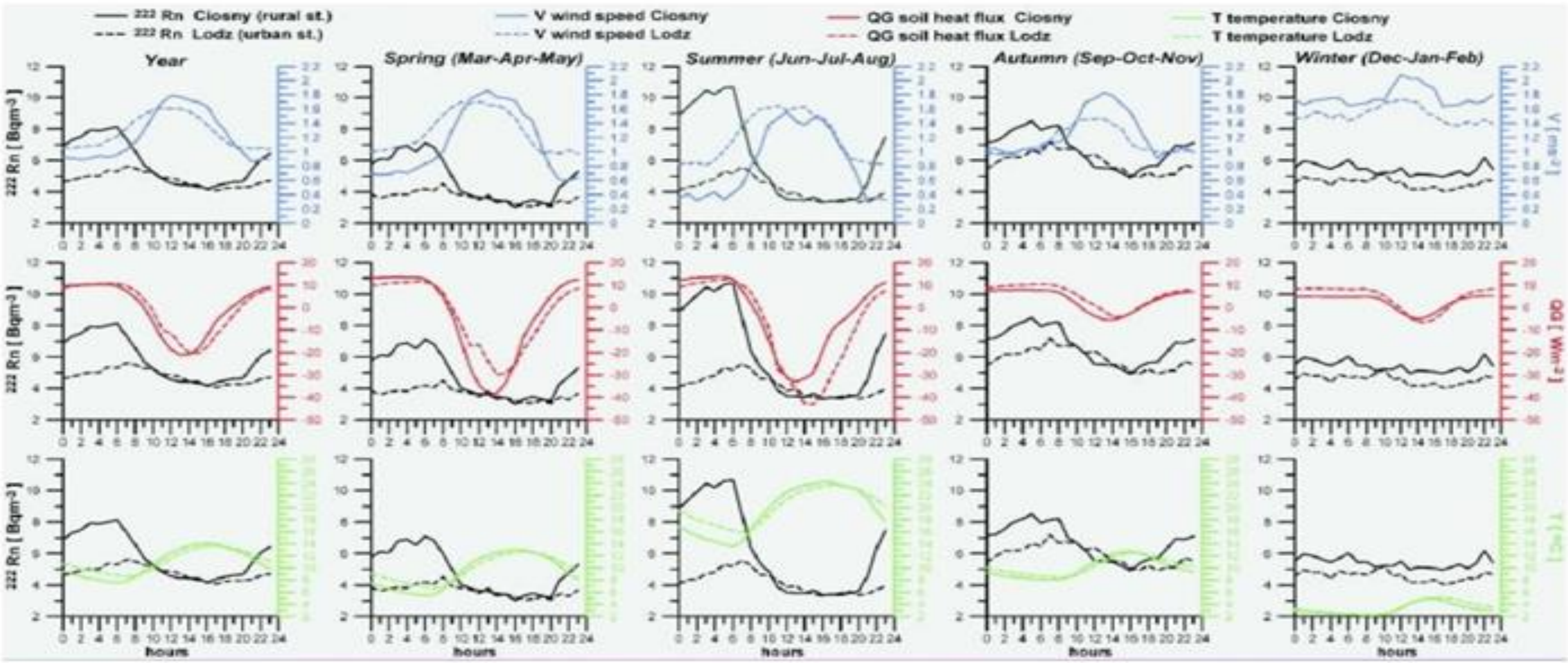
RI low	RP < 10
RI medium	10 ≤ RP < 35
RI high	RP ≥ 35

by K. Kozak IFJ, 21.06.2012

^{222}Rn in the atmospheric air

Concentration of ^{222}Rn

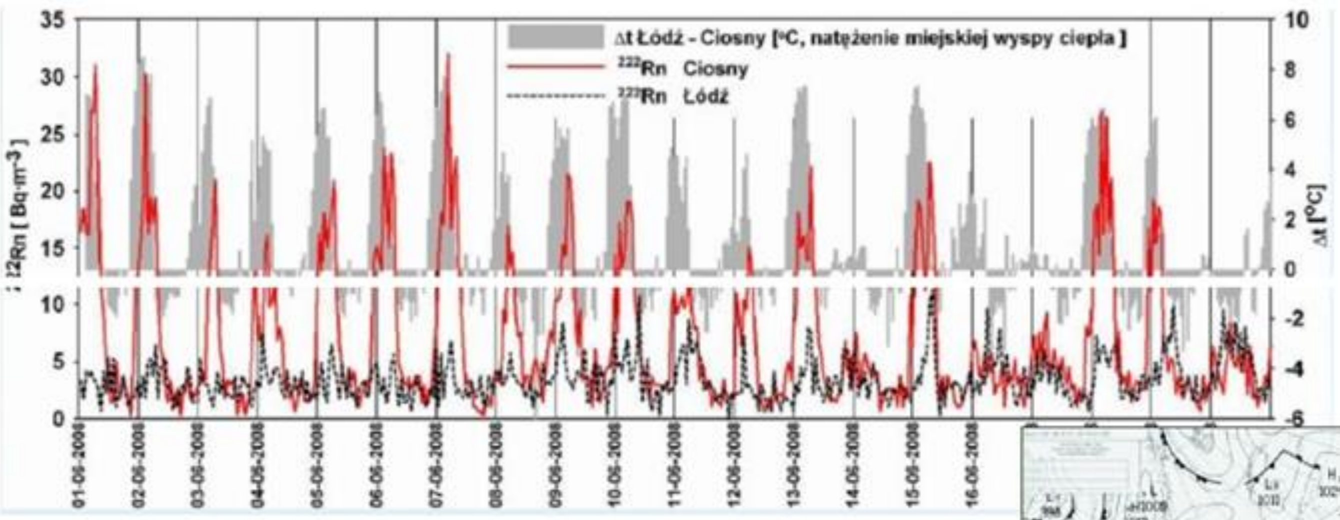
S_{Rn} = f(wind speed, soil heat flux, air temperature)

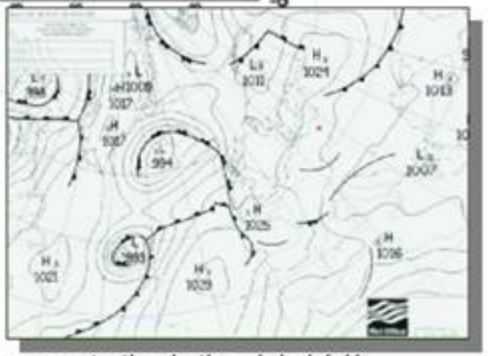


A.Podstawczyńska, **K.Kozak**, W.Pawlak, J.Mazur, *Seasonal and diurnal variation of outdoor radon (222Rn) concentrations in urban and rural area with reference to meteorological conditions*, **NUKLEONIKA 55(4) (2010)** 543–547;

^{222}Rn in the atmospheric air

CONCENTRATION ^{222}Rn = f(global meteorological phenomena)





The period of occurrence of the intensive phenomenon of the urban heat island with a maximum intensity of 8°C and with the maximum negative radon differences Rn <-25 Bq/m^3 (urban area and outside urban area)

A.Podstawczyńska, **K.Kozak,** *Preliminary results of measurements of radon (222Rn) concentration in the air in Łódź,* **Climate and bioclimate of urban areas**, eds K. Kłysik et al., WUL, ISBN: 978-83-7525-243-9 (2008) pp. 467-476

A.Podstawczyńska, **K.Kozak**, J.Mazur, *Urban-rural differences of radon (22Rn) concentration in the air surface layer with reference to meteorological conditions - preliminary analysis,* **Acta Agrophysica. Rozprawy i monografie. Atmospheric heat and mass exchange research**, red. B.H. Chojnicki, Lublin (Wyd. Inst. Agrofizyki PAN), ISSN 1234-4125, 179 (2010)

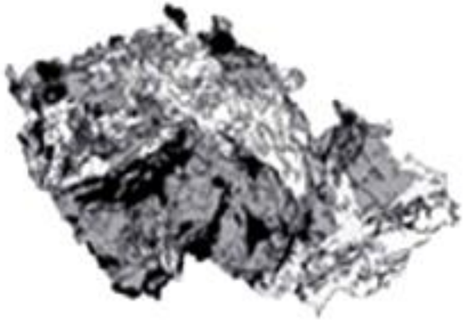
by K. Kozak IFJ, 21.06.2012

Radon concentration in selected countries

(the darker the colour, the higher the risk)

USA

CZECH REPUBLIC



GERMANY

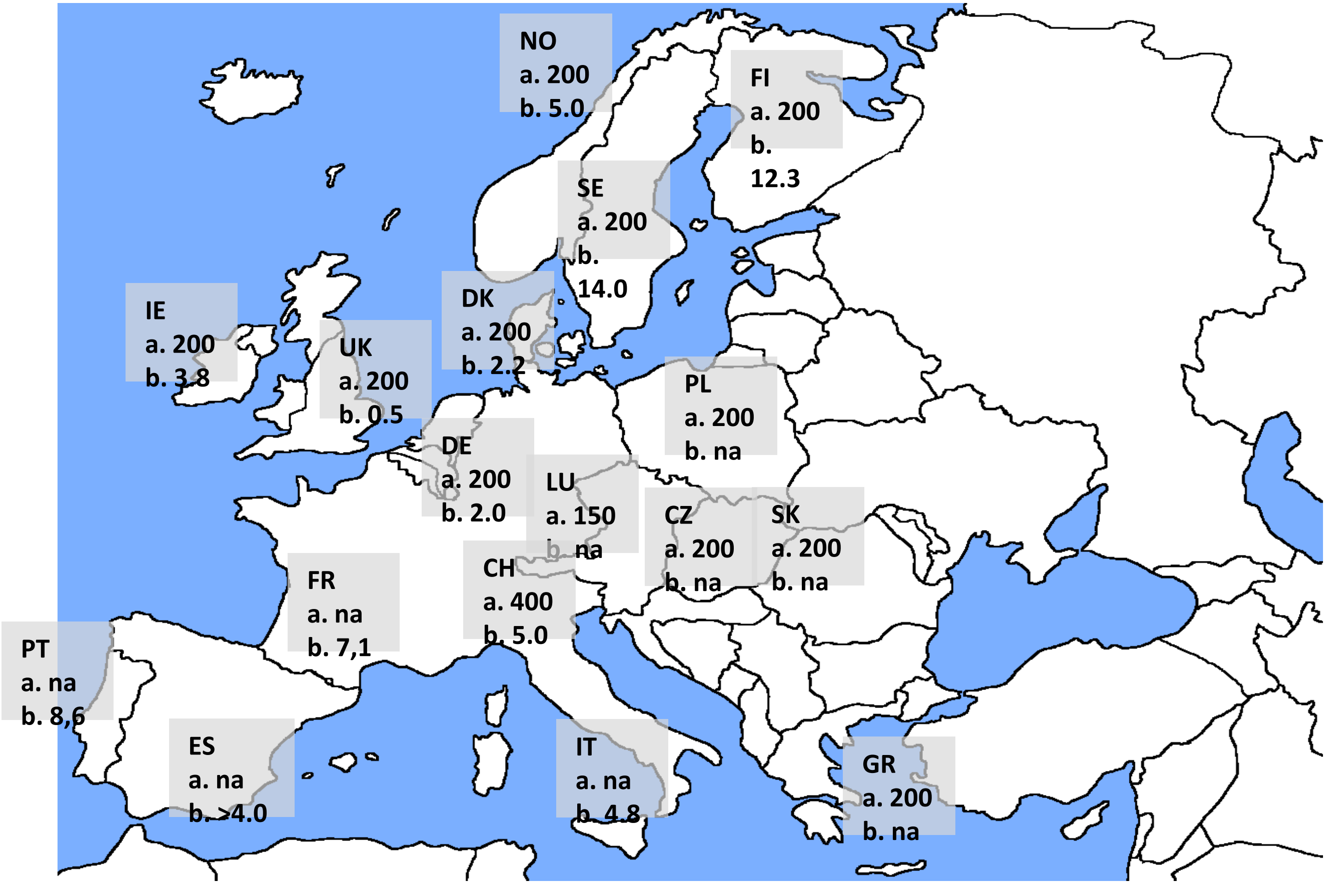
SWITZERLAND

ENGLAND and WALES

POLAND

Radon concentration in selected countries in Europe

a – allowable concentration [Bq/m^3], b – buildings with concentration above 200 Bq/m^3 [%], na – data not available



Source:WHO Air Quality Guidelines – Second Edition

^{222}Rn in the atmospheric air

by K. Kozak IFJ, 21.06.2012

^{222}Rn in the atmospheric air




Results of measurements
(1-, 3-monthly)

Correction factors

Yearly dose




^{222}Rn in the atmospheric air

Correction factors

A – moderate warm, dry
B – warm, moderate warm, dry
C – warm, humid
D – warm, humid,
(Sudety mountains, Radon prone area

Region A: 28 (bs), 4 (no-bs), 32

Region B: 14 (bs), 9 (no-bs), 23

Region C: 36 (bs), 18 (no-bs), 54

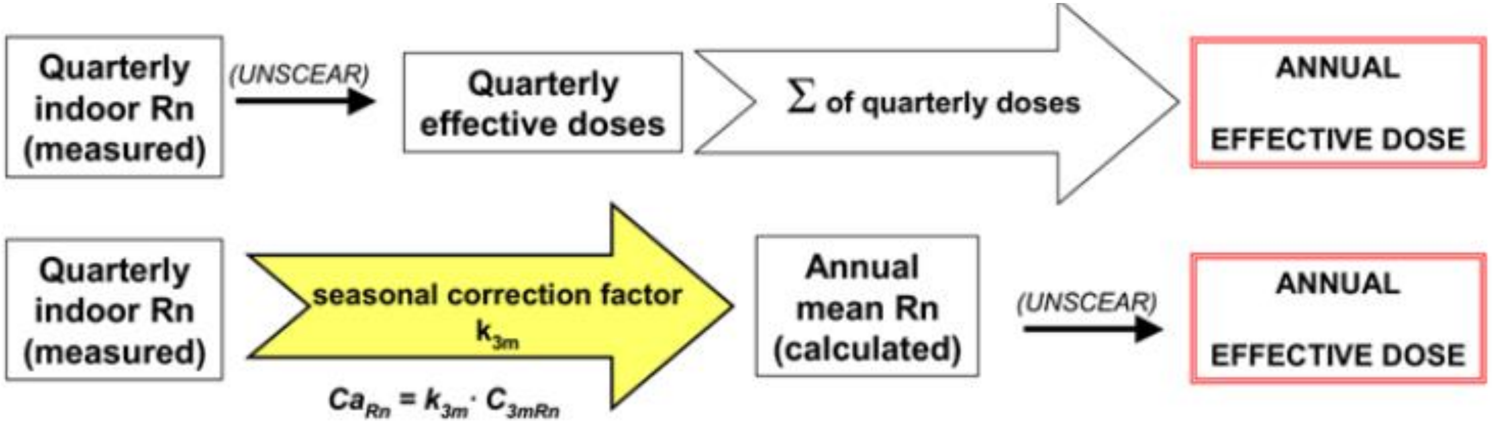
Region D: 15 (bs), 8 (no-bs), 23

$$k_{1m_i} = \frac{GM_Y}{GM_{m_i}} \qquad k_{3m_i} = \frac{k_{1m_i} + k_{1m_{i+1}} + k_{1m_{i+2}}}{3}$$

K.Kozak, et al., *Correction factors for determination of annual average radon concentration in dwellings of Poland resulting from seasonal variability of indoor radon*, **Applied Radiation and Isotopes, 69 (2011)**

^{222}Rn in the atmospheric air

"Ways" of calculations
buildings without a basement, area: Sudety region (D)



Point	QUARTERLY INDOOR Rn (measured) [Bq/m^3]				QUARTERLY DOSES [mSv]				ANNUAL DOSES [mSv]	
	I quarter	II quarter	III quarter	IV quarter	I	II	III	IV	1st way	2nd way
D-1	309	292	299	280	1,9	1,8	1,9	1,8	7,4	8,7
D-2	328	224	218	218	2,1	1,4	1,4	1,4	6,2	6,5
D-3	511	237	283	280	3,2	1,5	1,8	1,8	8,3	8,5

K.Kozak, et al., *Correction factors for determination of annual average radon concentration in dwellings of Poland resulting from seasonal variability of indoor radon*, **Applied Radiation and Isotopes, 69 (2011)**

by K. Kozak IFJ, 21.06.2012

Radon in buildings

Exposure to radon in buildings and workplaces is responsible for about 1/3 of the total dose of ionizing radiation (and about half the dose from natural sources) to which we are exposed. It is worth adding that radon is a natural factor, but its high concentrations in human constructions are not!

Radon – a natural carcinogenic factor at work stations

According to the data of the World Health Organization, radon is the main carcinogen that threatens non-smokers. For tobacco smokers, radon on the list of carcinogenic factors ranks second, but only because cigarette smoke is in the first place. Simultaneous exposure to tobacco smoke and radon has a synergistic effect, significantly increasing the risk of developing cancer.

Sources

The main source of radon in buildings is soil, in addition: building materials, water and natural gas. Construction of a house requires a "penetration" of the topsoil and reaching its deeper layers, where radon concentrations are very high. Pressure difference occurring between the environment and the interior of the building causes "suction" of radon from the ground (so-called chimney effect).

Sources

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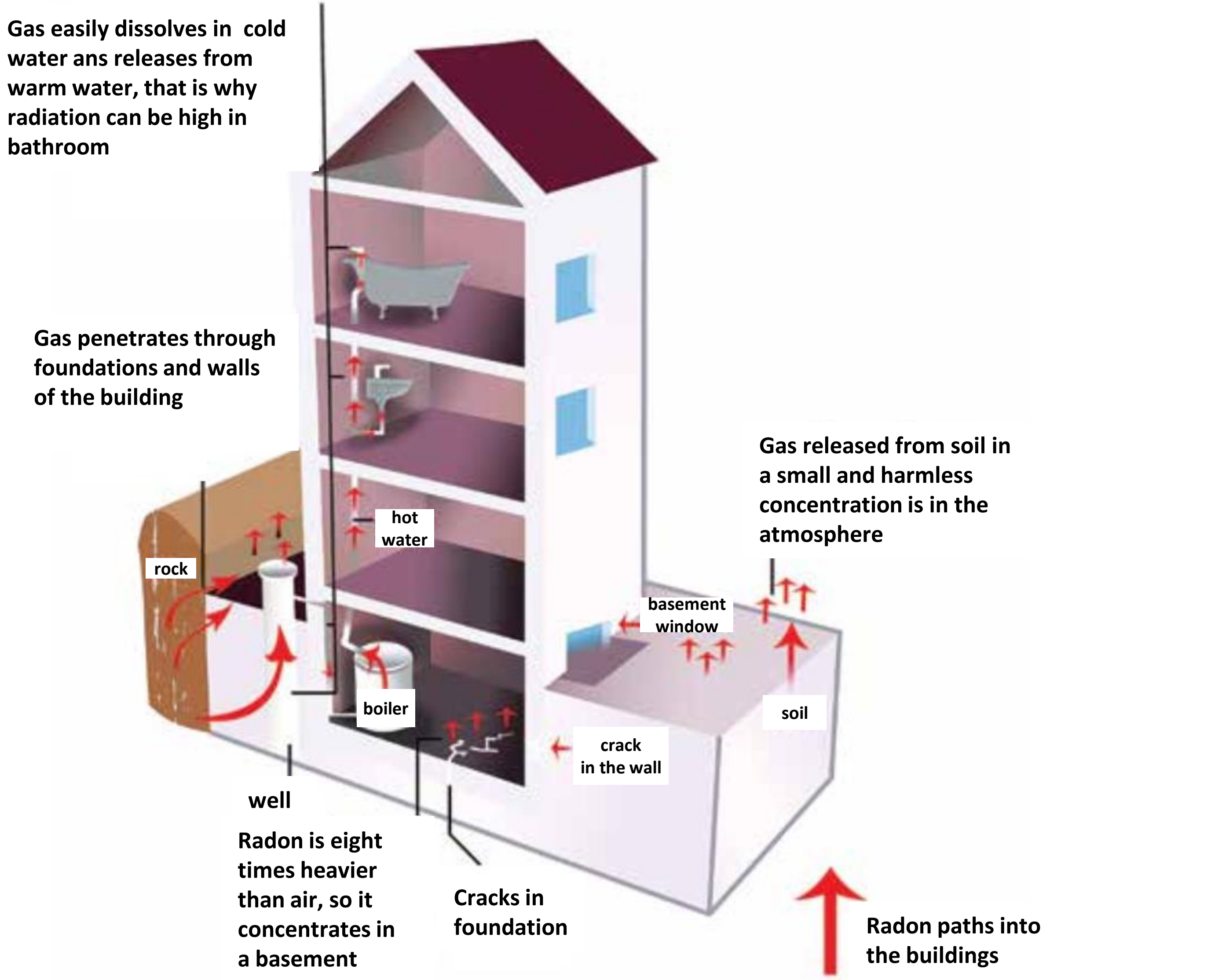


by K. Kozak, IFJ PAN

Sources

The higher the level, the greater the influence on the concentration of radon in the air inside the building. Material sources include that which the walls and ceilings of the building are made from and the type of covering of the walls. The technology of building a house is important. The penetration of radon into the interior of buildings can be facilitated by commonly used gravitational ventilation and the chimney effect during the heating season. The heated air, released from the building through micro-openings in the windows and through ventilation grilles **causes a reduction in the pressure** in the building and the suction of air from the lower parts of the building, including the basements. This makes it easier for air from the radon-containing soil to enter into the basements. In this way, the concentration of radon can reach high values even in some buildings located in areas where the concentration of radon in the soil is small, but there is, for example, high ground permeability or tectonic faults.

Harmful effect on man

Radon as gas remains a relatively short time in our lungs, but we are constantly exposed to it. Radon rapidly disintegrates (half-life time is 3.8 days), and the derivatives of this decay combine with the dust present in the air, penetrate into the respiratory system and lungs, posing a threat of respiratory cancer. Radon derivatives do not uniformly deposit in the respiratory system – the depth of penetration of the particle depends on its size.

by K. Kozak IFJ PAN

Harmful effect on man

Aerosols in the inhaled air are often retained in the upper parts of the respiratory system or the pulmonary epithelium, from where they can be removed within a few hours. Only the smallest particles (diameter less than 0.1 µm) reach the alveoli. These particles may be months or years there, leading to the irradiation of internal organs. The lungs are, therefore, the most exposed to radon. The dose obtained by the lungs as a result of inhalation of radon depends primarily on the concentration of radon in the inhaled air, the concentration of dust present in this air (especially with the smallest diameters) and the breathing rate (which is particularly important in the case of physical work).

by K. Kozak IFJ PAN

Basic safety standards for Radon

The latest directive 2013/59/EURATOM2 regulates the level of radon concentration, above which the increase in risk is so significant that it requires taking steps to lower this concentration in the room. In this document, the average annual concentration of radon equal to 300 Bq/m^3 was assumed as the reference level, which should not be exceeded. This level applies to both work places and residential homes. The directive's recommendations were to be incorporated into national law by February 2018.

Basic safety standards for Radon

In Poland, a draft amendment to the Atomic Law was prepared in connection with the necessity to implement the directive. The project included important proposals from the point of view of exposure to radon in workplaces. One of the provisions stipulates that the employer provides measurement of radon concentration or the concentration of potential energy of alpha short-lived radon decay products in workplaces located underground and associated with the treatment of water extracted from underground sources.

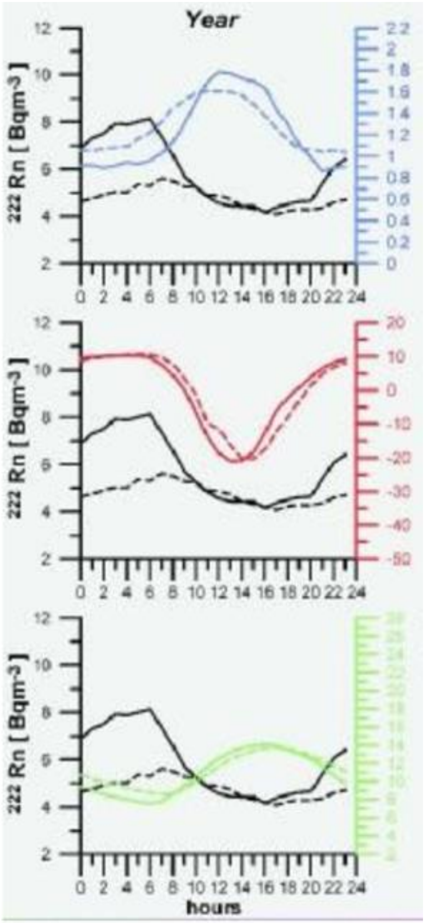
Such measurements must also be carried out in workplaces at the ground floor or basement level in areas where the average annual radon concentration in the air in a significant number of buildings may exceed the reference level.

Basic safety standards for Radon

In accordance with the draft new regulations regarding radon in residential houses, the buyer or tenant of a building, premises or room intended for human stays has the right to demand from the seller or landlord information on the value of the average annual concentration of radon. The legislator imposes on the Minister of Health the obligation to create the so-called radon plan for Poland (radon action plan).

Basic safety standards for Radon

For this purpose you need, among others recognition of the "radon situation", i.e. identification of areas where in a large number of buildings the radon concentration reference level can be exceeded. This also includes the collection of the results of previous measurements, the implementation of screening measurements, and, above all, the **information campaign** in the municipalities, including training for local authorities, residents and for construction companies and developers.



by K. Kozak IFJ PAN

Basic safety standards for Radon

Projected annual doses of ionizing radiation due to radon inhalationc

Radon concentration [Bqm^{-3}]	Work time yearly [hours]	Yearly dose effective [mSv]	Radiation exposure category
300	1,000	0.9	No exposure
300	2,000	1.9	Category B
1,000	1,000	3	Category B
1,000	2,000	6	Category A
2,000	2000	13	Category A
3,000	2,000	19	Category A: radiation exposure category the annual dose limit may be exceeded
8,000	2,000	50	the annual dose limit exceeded the annual dose limit may be exceded in an individual year 50 mSv

Categories of exposure to ionizing radiation in relation to the whole body

Yearly dose effective D [mSv]	Radiation exposure category
D ≤ 1	No exposure
1 < D ≤ 6	Category B
D > 6	Category A
D = 20	effective dose limit in each individual year
D = 50	effective dose limit in each individual year, provided that the average annual dose over the next 5 years does not exceed 20 mSv

by K. Kozak IFJ PAN

Basic safety standards for Radon – spa

Service of spas with radon waters and spas with thermal waters Radon released from water into the air can be a source of danger for employees working with mineral and thermal waters. **The content of radon can be very variable**, depending on the season and climate conditions. In Poland, the highest concentration of radon was recorded in Świeradów Zdrój, amounting to approx. 3,000 Bq/dm^3 (max. 14,000, min. 350 Bq/dm^3), whereas in Jachymov in Czech Republic the concentration is more than 60,000 Bq/dm^3, and in Germany's Bad Brambach, over 250,000 Bq/dm^3.

by K. Kozak IFJ PAN

Basic safety standards for Radon

Noefer Institute of Occupational Medicine in Łódź carried out research for the threat posed by radon **for workers in Polish spas**. In 2 spas, concentrations exceeding 1,000 Bq/dm^3 were found, which means that employees can receive annual doses exceeding 6 mSv. In four spas, concentrations ranging from 500 to 1000 Bq/dm^3 were found, and in the next 7 spas, concentrations from 200 to 500 Bq/dm^3 were noted. The employees of these spas (about 160 people in total) may be exposed to radiation doses that are important from the point of view of radiological protection and require systematic assessment of exposure to radon. In the remaining 63 spas studied, average monthly concentrations of radon did not exceed 200 Bq/dm^3. The next study covered 9 spas and only in 1 was it possible for employees to receive a dose of 3 mSv per year (category of radiation exposure B). In other spas, the doses per year did not exceed 0.6 mSv – and, therefore, these were completely safe in terms of Radon exposure.

mSv – miliSivert

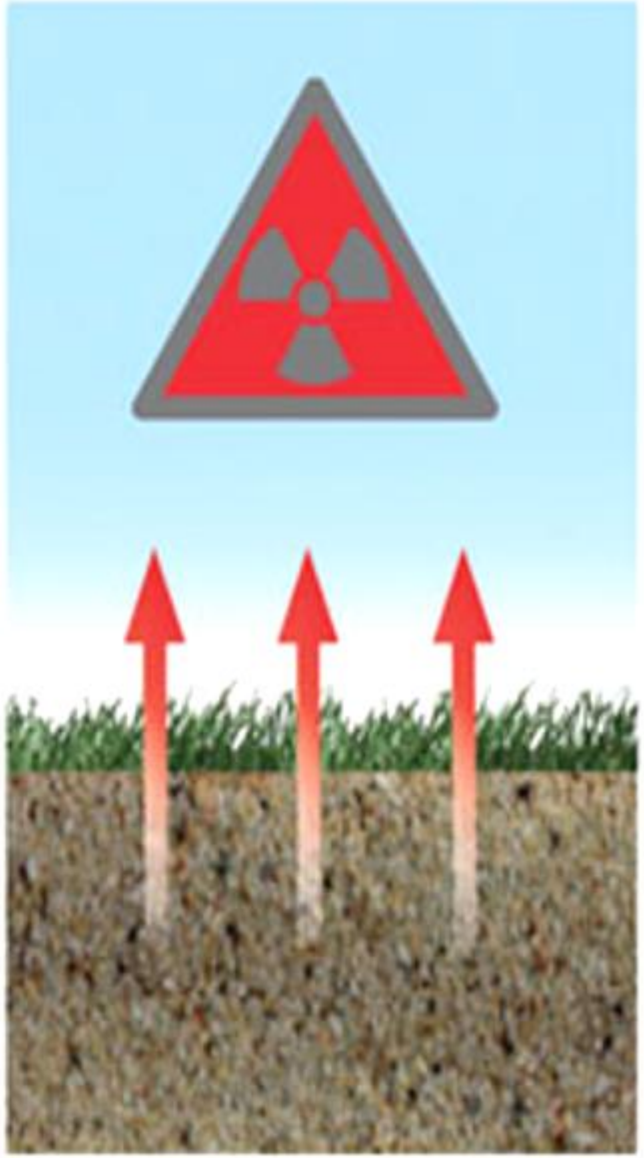
by K. Kozak IFJ PAN

Basic safety standards for Radon

The Institute of Nuclear Physics of the Polish Academy of Sciences in Krakow was involved in the measurement of radon concentration in spas with thermal waters in Podhale (Rabka Zdrój, Bukowina Tatrzańska and Szaflary). Radon concentrations in the thermal waters were within the range of 0.1÷4.9 Bq/dm^3, and in the indoor air of these objects from 20 to 92 Bq/dm^3. This does not lead to radiological hazards for employees and patients. It should be expected that after passing changes in Polish nuclear law, specific employer obligations with regard to radon as a carcinogenic factor in the working environment will be determined. Screening carried out by scientific institutes and by authorized laboratories are already indicating which employers this may apply to.

by K. Kozak IFJ PAN

- Radioactive, colourless, odourless gas,
- Its source is radioactive uranium ore located in the Earth's crust,
- It gets out of the earth's interior to its surface, migrates in the air,
- It is about 7.5 times heavier than air, therefore, it accumulates in basements and on lower floors of residential buildings,
- As a result, decay products (radioactive metals as dangerous as Radon), are inhaled, where they emit deadly ionizing radiation as solid bodies and are difficult to expel from the human body,
- Radon and radioactive metals are 20 times more harmful than X-rays!



by K. Kozak IFJ PAN

Increased incidence of malignant lung cancer

The International Agency for the Fight against Cancer (IARC) in 1988 recognized radon as the highest carcinogenic substance – I class

by K. Kozak IFJ PAN

Studies carried out in the USA have shown that radon radiation causes in the USA.

About 10,000 cases a year for lung cancer, i.e. 5% of all cases.

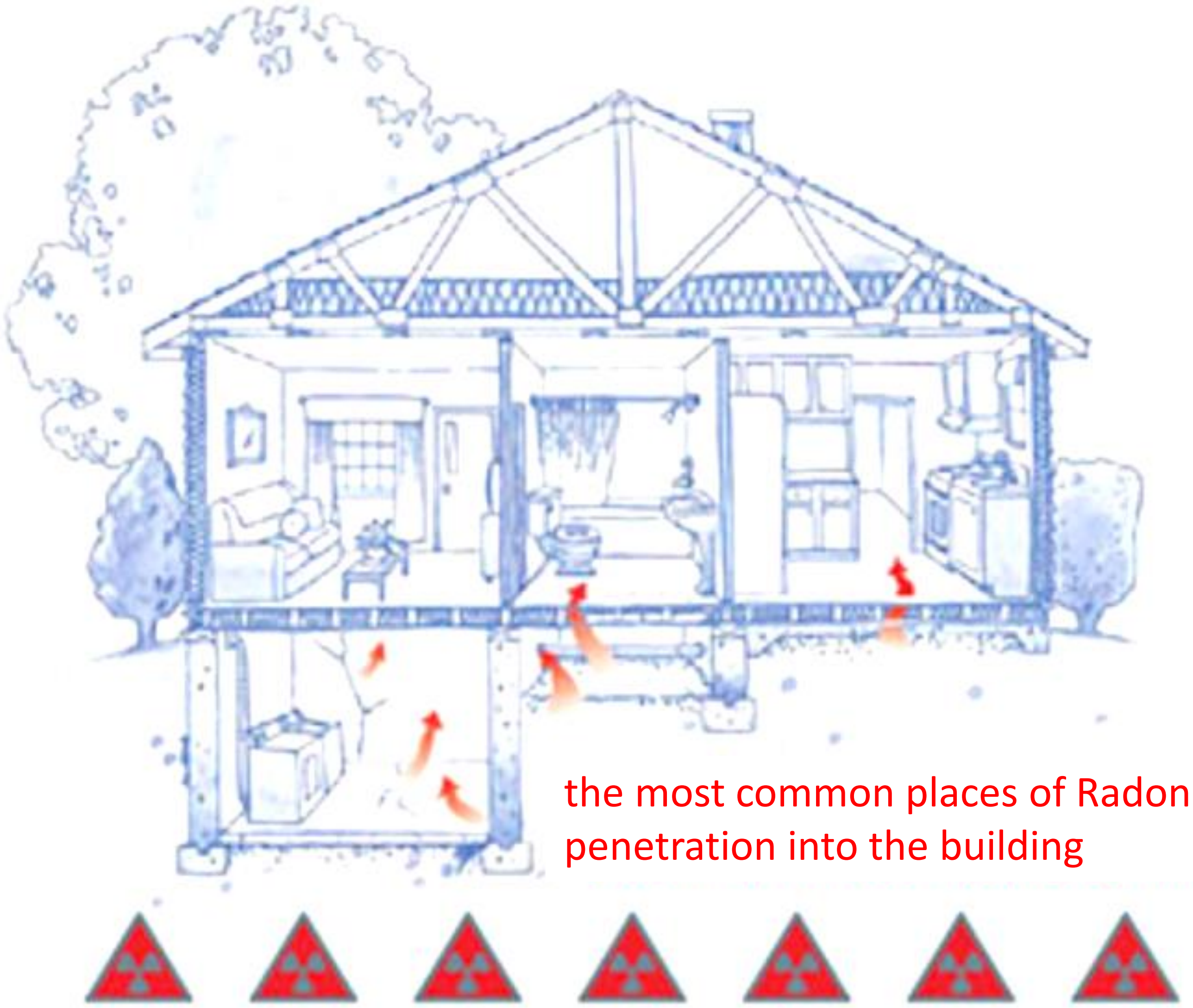
In the European Union, radon gathering in homes causes the deaths of about 20,000 people a year.

Combined with lung cancer, it accounts for about 2% of all cancer cases.

- Radon enters the human body with inhaled atmospheric air.
- It accumulates in our lungs in the form of aerosols (liquid and solid particles in suspended air). It also enters the blood system (it dissolves well in water and organic substances), emitting ionizing radiation in the body.
- 80% get to the building through a badly secured foundation.

The remaining 20% comes from:

- the water used at home,
- natural gas used for fuel, cooking,
- building materials used to build a house.



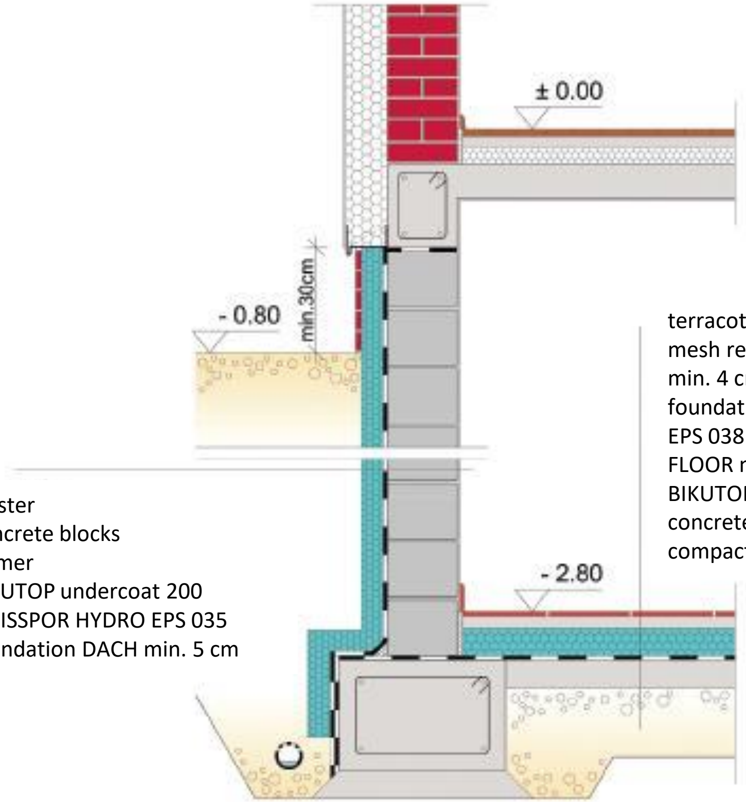
the most common places of Radon penetration into the building

Solution? Hope?

Radon is a natural radioactive gas inside the earth, resulting from the decay of uranium, which, if passed through the foundations to buildings, contributes to an increased incidence of lung cancer.

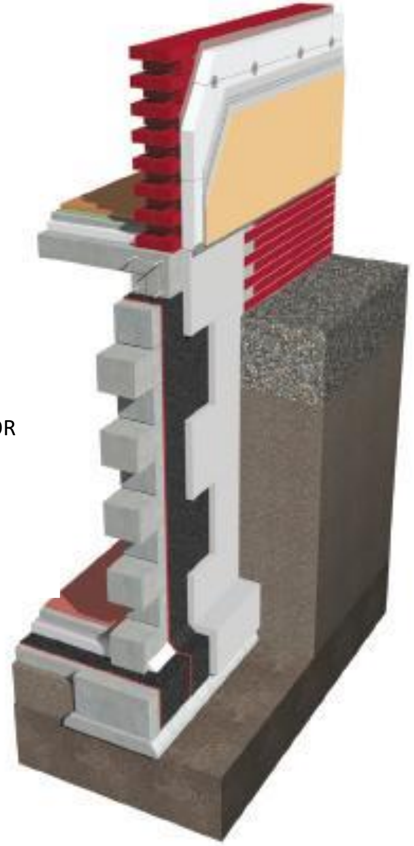
The simplest and most effective way to reduce its level is the use of anti--radon and anti-fog barriers in the construction of foundations.

„Papa” with an anti-radon barrier



plaster
concrete blocks
primer
BIKUTOP undercoat 200
SWISSPOR HYDRO EPS 035
foundation DACH min. 5 cm

terracotta
mesh reinforced concrete,
min. 4 cm
foundation DACH/SWISSPOR
EPS 038 DACH
FLOOR min. 10 cm
BIKUTOP undercoat 200
concrete screed 10 cm
compacted sand 30 cm



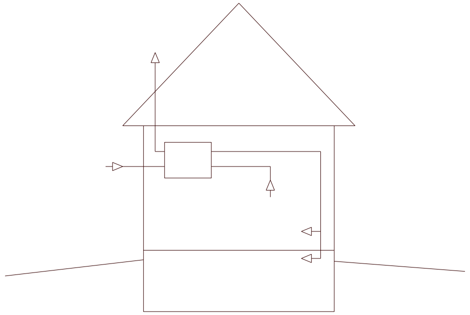
- Radon accumulates in buildings, where its concentration increases due to the lack of ventilation.
- This takes place especially at night and in the morning, in the lower floors of buildings – when household members are sleeping.

Effective home protection against radon radiation is ensured by:

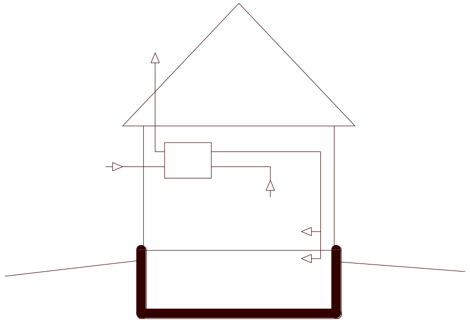
- Appropriate design and construction of tight foundations with an anti-Radon barier,
- Suitable installation systems (water pipes, sewage pipes, electrical and gas lines),
- The right ventilation system of the building.

Effective home protection against radon radiation is ensured by:

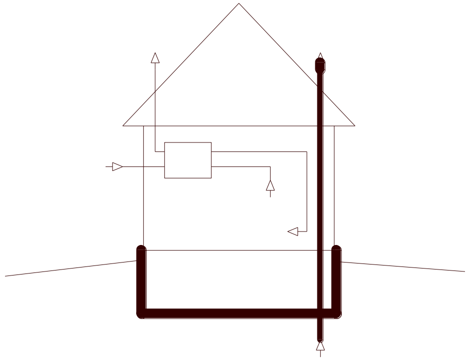
- ventilation system, ensuring effective removal of contaminated air and inflow of atmospheric air from the outside, diluting the concentration of radon indoors,



- mechanical barrier in the form of gas-tight insulation of the entire underground part of the building and sealing of all openings, channels, crevices, cracks, etc.,



- lowering the pressure in the ground under the building and in its surroundings, by inserting a suction duct under the floor and using fans to release some of the air from ground gases to the atmosphere; a variation of this method may be increasing air pressure in interior rooms adjacent to the ground.

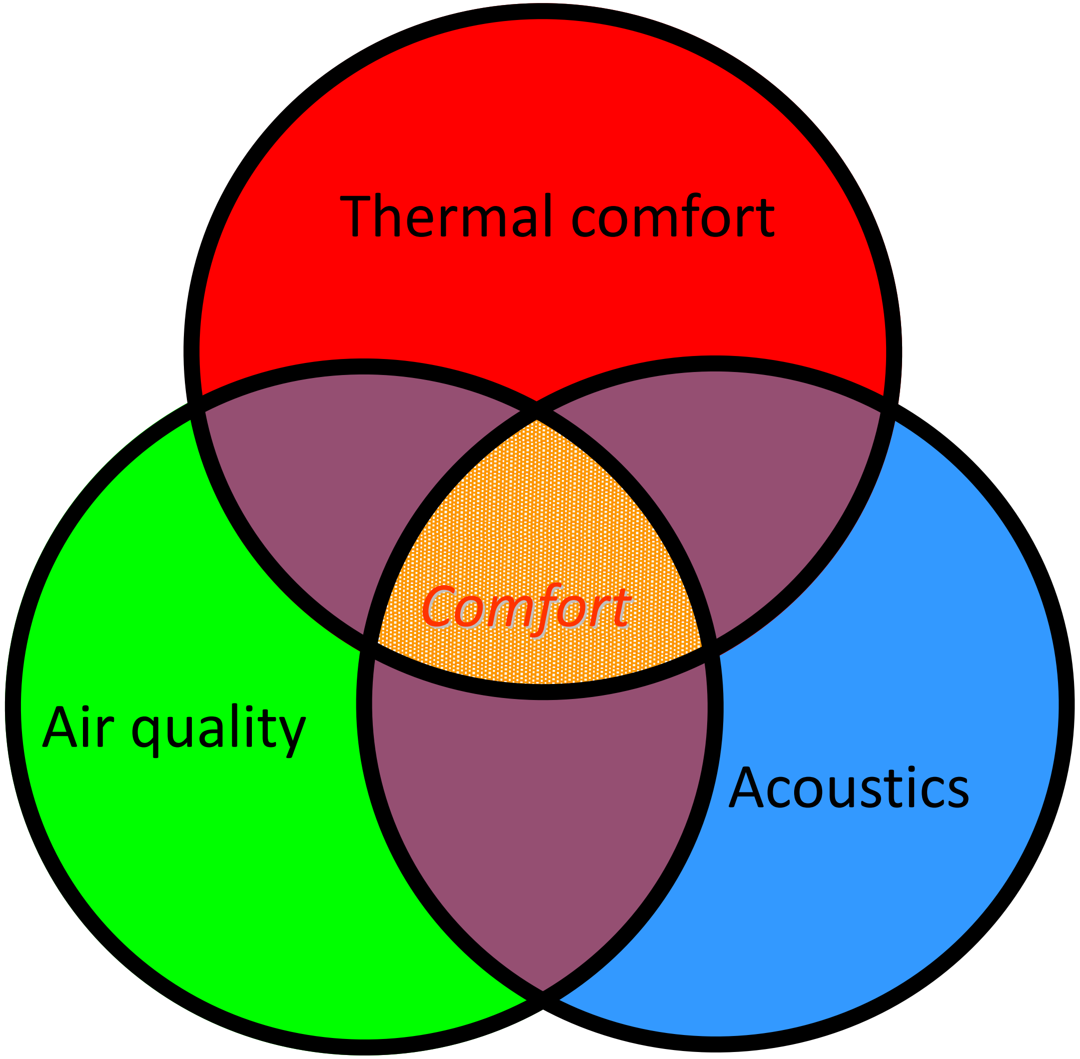


Part 3

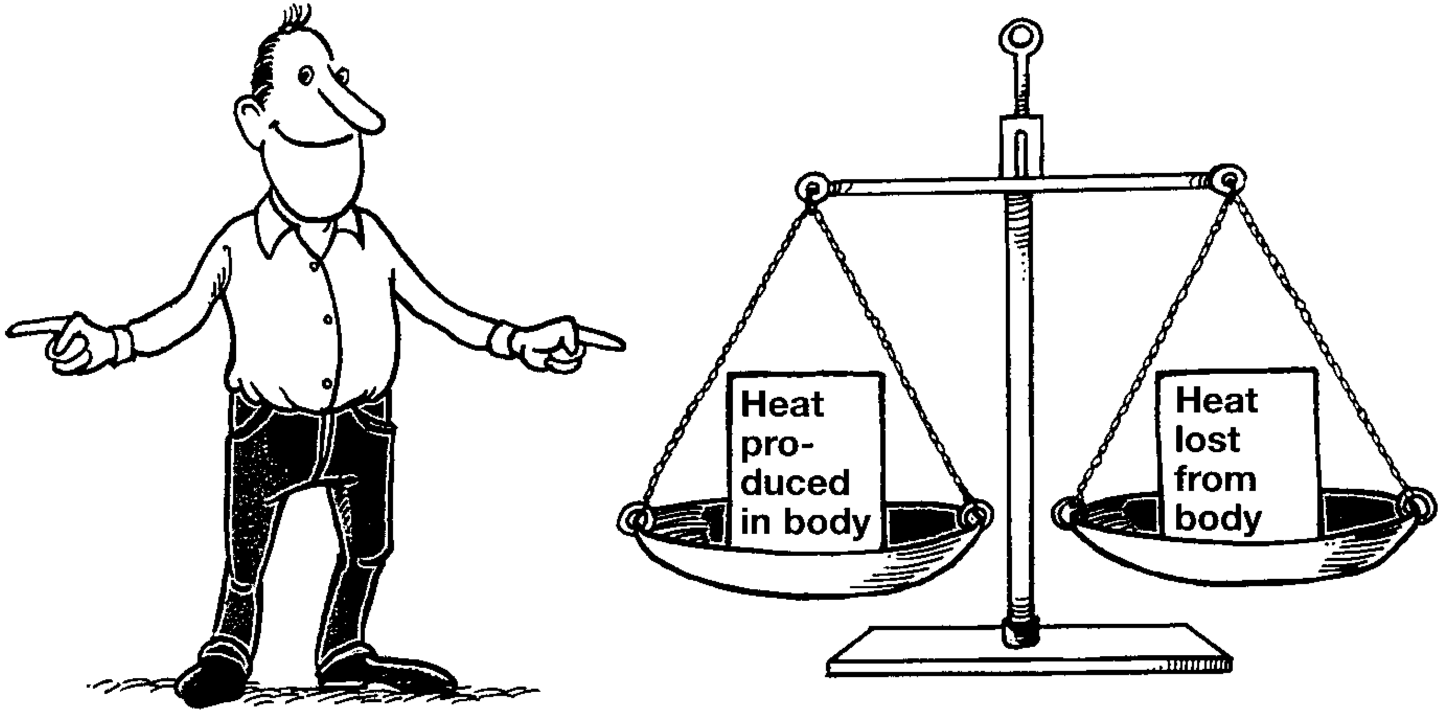
Comfort

JAROSŁAW MÜLLER

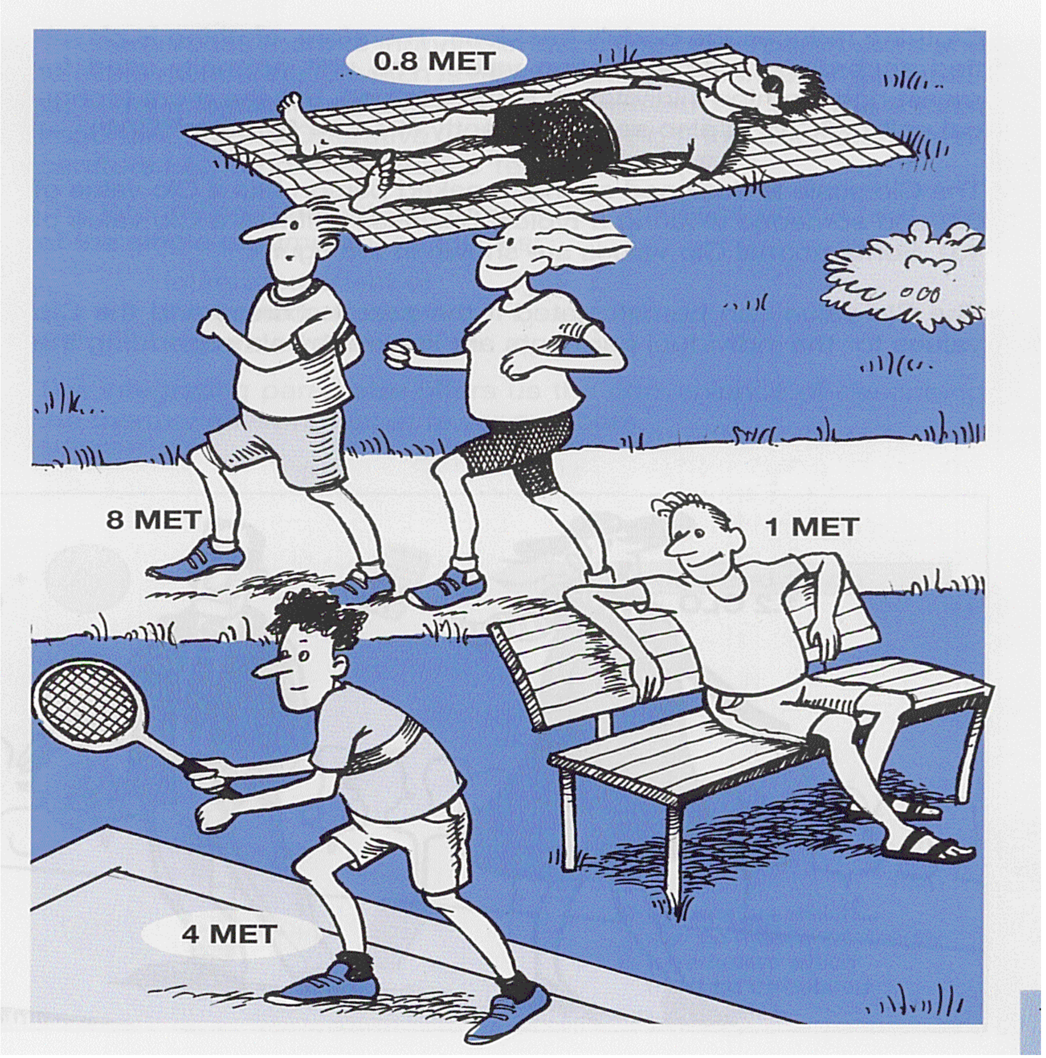
Room comfort



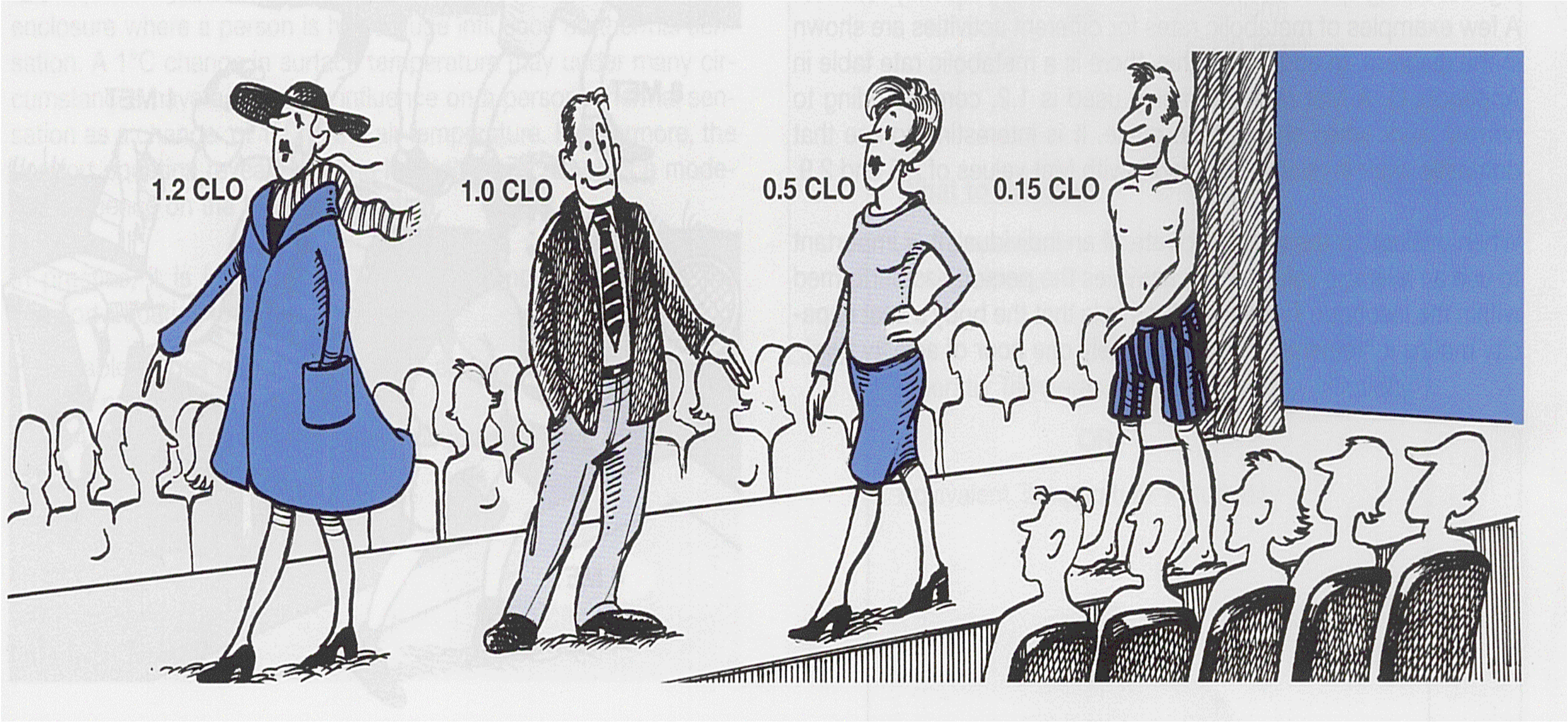
Heat balance = thermal comfort



Metabolic rate



Clothing (CLO)



Thermal comfort parameters:

- air velocity (draught)
- air temperature
- temperature difference with height (gradient)
- thermal radiant temperature
- humidity
- activity
- clothing

Thermal comfort in buildings basic concepts (acc.: EN 7730)

Thermal comfort – the main objective of the air conditioning system design

Subjective assessment of comfort:

PMV (*Predicted Mean Vote*):

+3 – hot
+2 – warm
+1 – slightly warm
0 – neutral
–1 – slightly cool
–2 – cool
–3 – cold

and

PPD (*Predicted Percentage of Dissatisfied*)

Thermal comfort in buildings basic concepts (acc.: EN 7730)

Thermal comfort – statistics but measurable

$$PMV = \{0{,}303 \cdot \exp(-0{,}036 \cdot M) + 0{,}028\} \cdot$$

$$\begin{Bmatrix} (M-W) - 3{,}05 \cdot 10^{-3} \cdot [5733 - 6{,}99 \cdot (M-W) - p_a] - 0{,}42 \cdot (M-W) - 58{,}15] \\ -1{,}7 \cdot 10^{-5} \cdot M \cdot (5867 - p_a) - 0{,}0014 \cdot M \cdot (34 - t_a) \\ -3{,}96 \cdot 10^{-8} \cdot f_{cl} \cdot [(t_{cl} + 273)^4 - (\bar{t}_r + 273)^4] - f_{cl} \cdot h_c \cdot (t_{cl} - t_a) \end{Bmatrix}$$

$$t_{cl} = 35{,}7 - 0{,}028 \cdot (M - W) - I_{cl} \cdot \{3{,}96 \cdot 10^{-8} \cdot f_{cl} \cdot [(t_{cl} + 273)^4 - (\bar{t}_r + 273)^4] + f_{cl} \cdot h_c \cdot (t_{cl} - t_a)]\}$$

where:

$$t_{cl} = 35.7 - 0.028\,(M - W) - I_{cl}\{3.96 \text{ x } 10^{-8} f_{cl} \text{ x } [(t_{cl} + 273)^4 - (t_r + 273)^4] + f_{cl}\, h_c\, (t_{cl} - t_a)\}$$

$$h_c = \begin{cases} 2.38(^{t_{cl}-t_a})^{0,25} & \text{dla} \quad 2.38(^{t_{cl}-t_a})^{0.25} > 12.1\sqrt{v_a} \\ 12.1\sqrt{v_a} & \text{dla} \quad 2.38(^{t_{cl}-t_a})^{0.25} < 12.1\sqrt{v_a} \end{cases}$$

$$f_{cl} = \begin{cases} 1.00 + 1.290 I_{cl} & \text{dla} \quad I_{cl} \leq 0.078\ [\mathrm{m}^2 \cdot {}^\circ\mathrm{C/W}] \\ 1.05 + 0.645 I_{cl} & \text{dla} \quad I_{cl} > 0.078\ [\mathrm{m}^2 \cdot {}^\circ\mathrm{C/W}] \end{cases}$$

Thermal comfort in buildings basic concepts (acc.: EN 7730)

$$\text{PPD} = 100 - 95 \cdot e^{-(0.03353 \cdot PMV^4 + 0.2179 \cdot PMV^2)}$$

Notifications:

M – Metabolic energy production [W/m^2], (46 to 232 W/m^2 – 0.8 to 4.0 met)

W – Rate of mechanical work, (normally 0) [W/m^2].

I_{cl} – basic clothing insulation [m^2 ^{o}C/W], (0.0 to 0.31 m^2 ^{o}C/W – 0.0 to 2.0 clo)

f_{cl} – rate of area of the body covered to uncovered

t_a – air temperature [^{o}C], (10 to 30^{o}C)

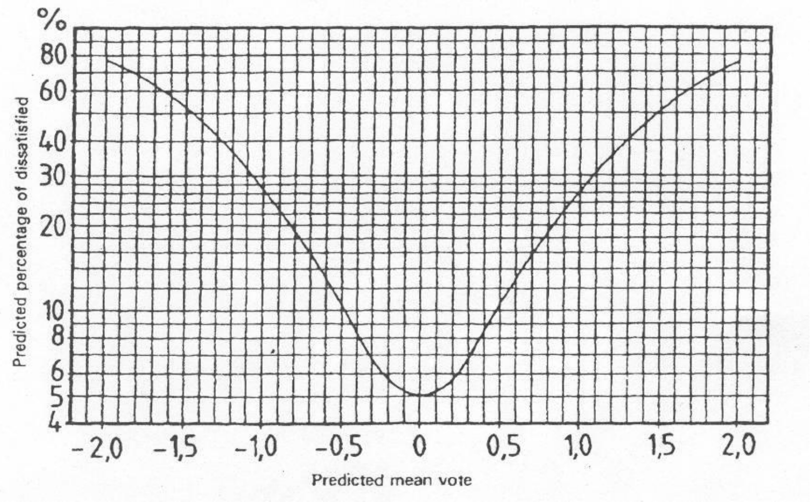
t_r – mean radiant temperature [^{o}C], (10 to 30^{o}C)

v_a – air velocity [m/s], (0.0 to 1.0 m/s)

p_a – partial water vapour pressure [Pa]

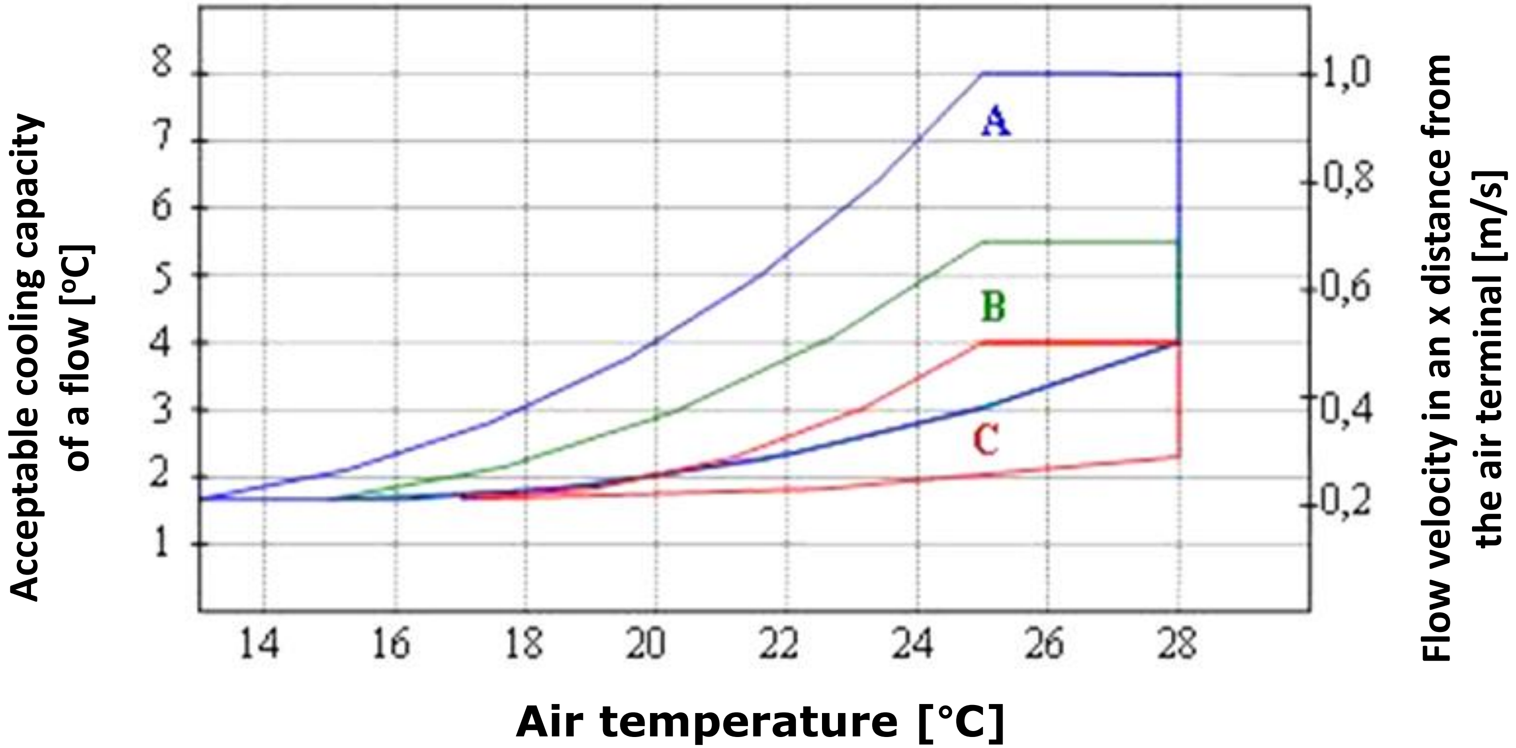
h_c – convection heat exchange coefficient [W/m^2 ^{o}C]

Tu – turbulence intensivity



Airflow cooling capacity

$$\upsilon_a = 8 \cdot v_a + \Delta t_a$$



Cooling capacity of airflow as a function of air temperature and air velocity in an occupied zone for different activity level:
A – high activity. B – medium activity. C – low activity

Airflow cooling capacity

Standard EN 7730:
(„Draught”)

$$DR = (34 - t_a) \cdot (v_a - 0.05)^{(0.62)} \cdot (0.37 \cdot v_a \cdot Tu + 3.14)$$

Thermal comfort in buildings

Standard EN 15251: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality. thermal environment. lighting and acoustics.

Comfort category	PPD [%]	PMV	DR [%]
I	< 6	–0.2 < PMV < +0.2	< 15
II	< 10	–0.5 < PMV < +0.5	< 20
III	< 15	–0.7 < PMV < +0.7	< 25
IV	–	beyond categories	

Recommended thermal comfort indicators for different room categories

Thermal comfort in buildings Classification criteria (acc.: EN 15251)

Recommended room temperatures based on PMV – PPD

Type of room (activity)	Class	Calculation temperature for winter (1.0 clo)	Calculation temperature for summer (up to 0.5 clo)
Offices. conference rooms. auditoriums. restaurants. coffe shops… (1.2 met)	I	21.0–23.0°C	23.5–25.5°C
	II	20.0–24.0°C	23.0–26.0°C
	III	19.0–25.0°C	22.0–27.0°C
Supermarkets… (1.6 met)	I	17.5–20.5°C	22.0–24.0°C
	II	16.0–22.0°C	21.0–25.0°C
	III	15.0–25.0°C	20.0–26.0°C

Thermal comfort in buildings Classification criteria (acc.: EN 15251)

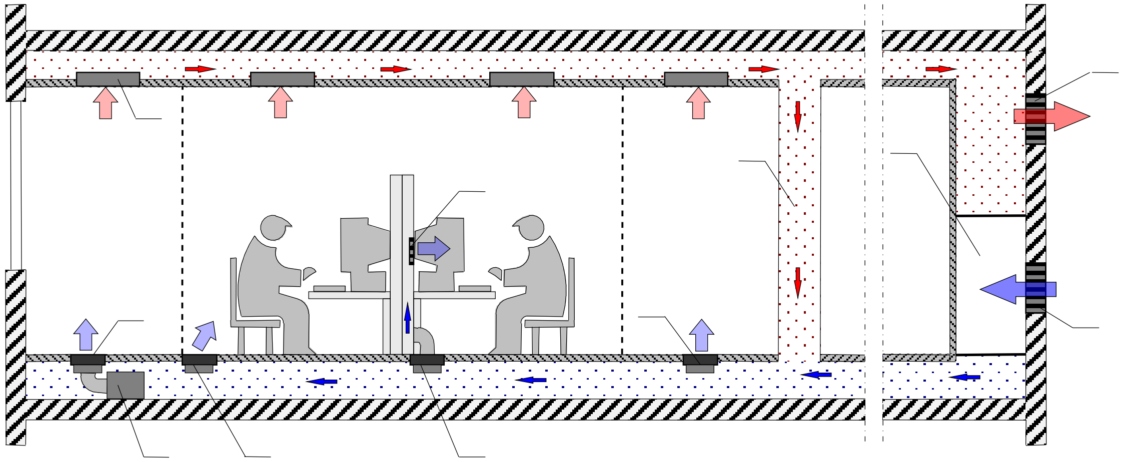
Comfort criteria – air velocity

Type of room	Comfort Category	Summer season	Winter season
Office. conference room	I	0.18	0.15
	II	0.22	0.18
	III	0.25	0.21
Open space office	I	0.18	0.15
	II	0.22	0.18
	III	0.25	0.21
Auditorium	I	0.18	0.15
	II	0.22	0.18
	III	0.25	0.21
Restaurant. coffe schop	I	0.18	0.15
	II	0.22	0.18
	III	0.25	0.21
Shops	I	0.16	0.13
	II	0.20	0.15
	III	0.23	0.18

Where to effectively supply ventilation air to the room?

Directly to the user

Ventilation effectivity



Personalized ventilation

Ventilation effectivity (occupied zone) (acc.: EN 13779)

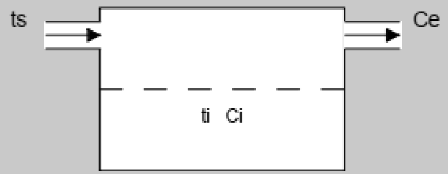
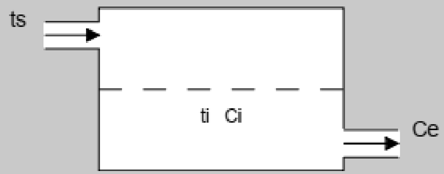
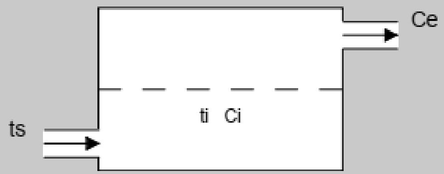
$$\varepsilon_v = \frac{c_{EHA} - c_{SUP}}{c_{IDA} - c_{SUP}}$$

where:

ε_v	ventilation effectivity
c_{EHA}	concentration of pollutants in the exhaust air
c_{IDA}	concentration of pollutants in the occupied zone
c_{SUP}	concentration of pollutants in the suply air

The higher the value. The better the ventilation system values ε_v can (should) be greater than 1.

Ventilation effectivity examples

Mixing ventilation		Mixing ventilation		Displacement ventilation	
					
temperature difference ts - ti °C	Ventilation effectivity	temperature difference ts - ti °C	Ventilation effectivity	temperature difference ts - ti °C	Ventilation effectivity
< 0 0 ÷ 2 2 ÷ 5 > 5	0.9 ÷ 1.0 0.9 0.8 0.4 ÷ 0.7	< -5 -5 ÷ 0 >0	0.9 0.9 ÷ 1.0 1.0	< 0 0 ÷ 2 > 2	1.2 ÷ 1.4 0.7 ÷ 0.9 0.2 ÷ 0.7

Do the plants purify the air?

SANSEVIERIA
One of the most durable plants in the world. Cleans air from benzene, formaldehyde, trichloroethylene, xylene and toluene. A unique feature is oxygen production during the night.

SPATIPHYLLUM
Thanks to the large surface of the leaves. It efficiently cleanses the air of benzene, formaldehyde, trichloroethylene, xylene, toluene and ammonia. It blooms often and its white buds persist for a long time.

ARECA
Cleans air from xylene, formaldehyde and toluene. Its leaves do not contain any irritating substances. Thanks to which it can grow among young children.

EPIREMNUM
A jungle climber that absorbs benzene, formaldehyde, xylene and toluene.

by M. Lechowski

Internal gardens purifying the air

Bad air influences on our health

TRICHLOROETHYLENE
Symptoms associated with short term exposure include excitement, dizziness, headache, nausea and vomiting followed by drowsiness and coma.

XYLENE
Symptoms associated with short term exposure include irritation to mouth and throat, dizziness, headache, confusion, heart problems, liver and kidney damage and coma.

FORMALDEHYDE
Symptoms associated with short term exposure include irritation to nose, mouth and throat, and in severe cases, swelling of the larynx and lungs.

AMMONIA
Symptoms associated with short term exposure include eye irritation, coughing and sore throat.

BENZENE
Symptoms associated with short term exposure include irritation to eyes, drowsiness, dizziness, increase in heart rate, headaches, confusion and in some cases can result in unconsciousness.

Plants purifying the air

Examples




by M. Lechowski

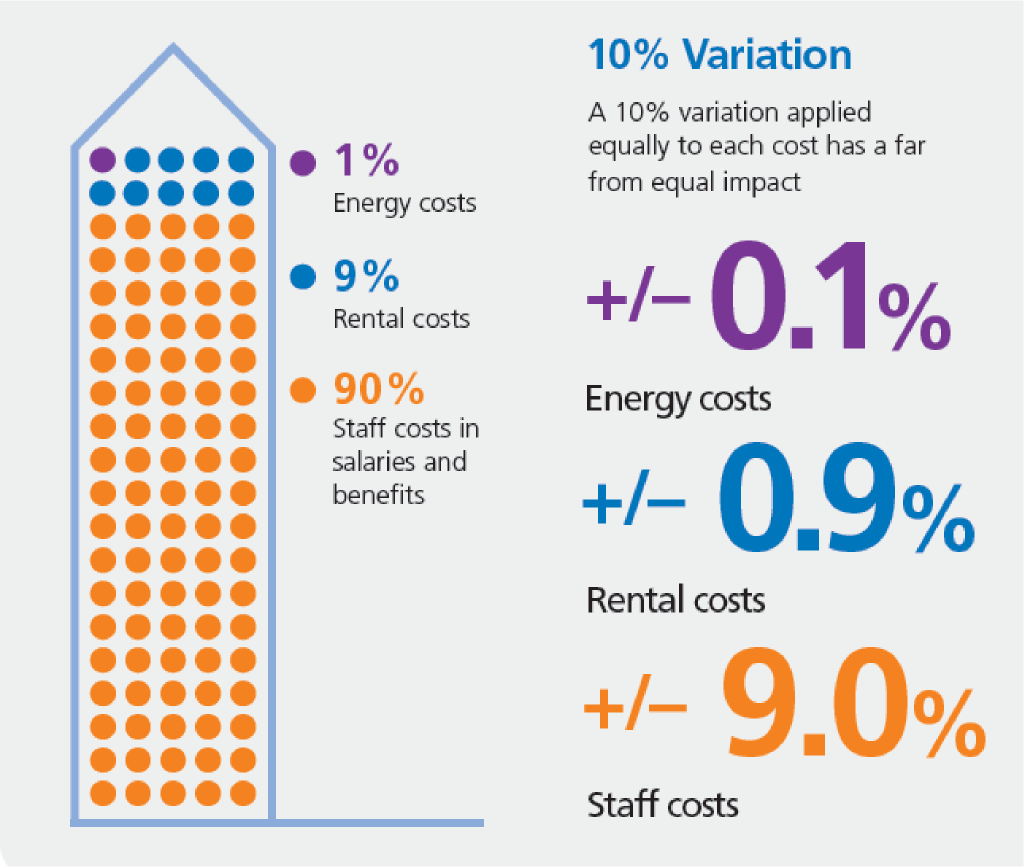
TVOC – Total Volatile Organic Compounds (Mølhave. 1990)

TVOC total amount of volatile organic compounds measured using a gas chromatograph with flame ionization detector calibrated against toluene.

TVOC concentration – predictable effects

< 200 µg/m^3	comfort level
200÷3,000 µg/m^3	level of possible discomfort with the presence of other factors
3,000÷25,000 µg/m^3	discomfort level
> 25,000 µg/m^3	toxic zone

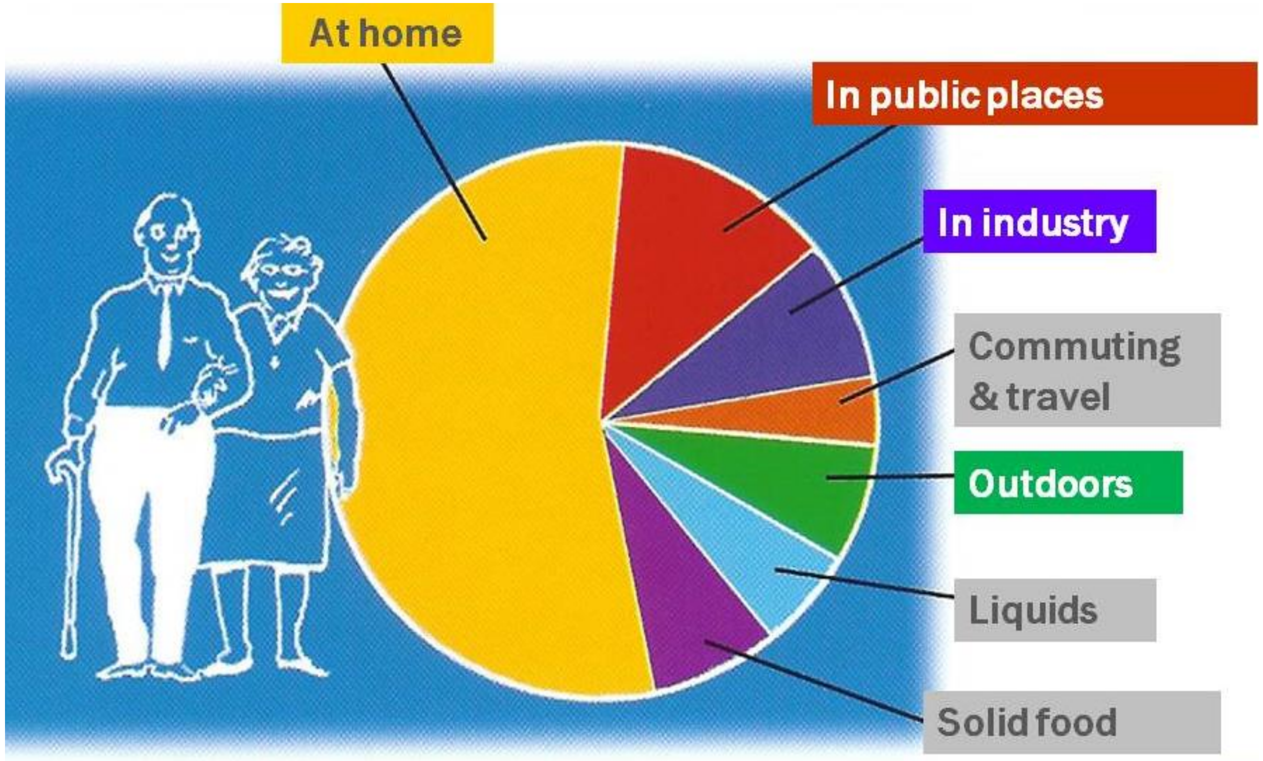
Standard costs incurred for the maintenance of office buildings



Based on a typical split of business operating costs, modest gains in staff health and wellbeing can deliver significant financial savings.

Source: World Green Building Council (2014)

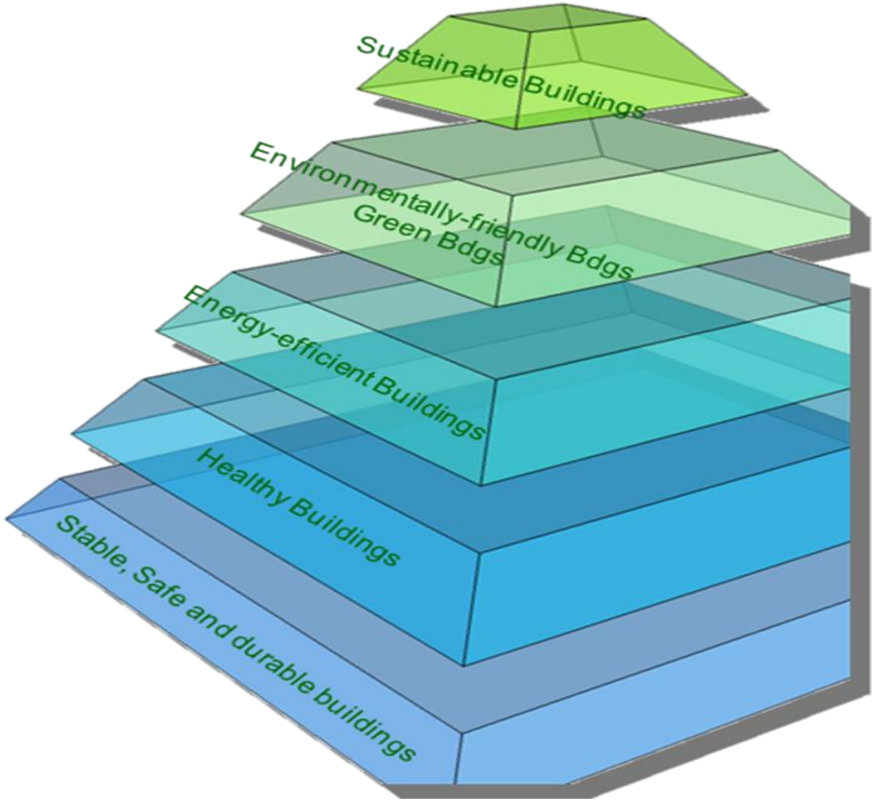
Staying in buildings greatly affects mutagen and chemical exposure throughout life. As well as general health conditions and well-being



by P. Wargocki

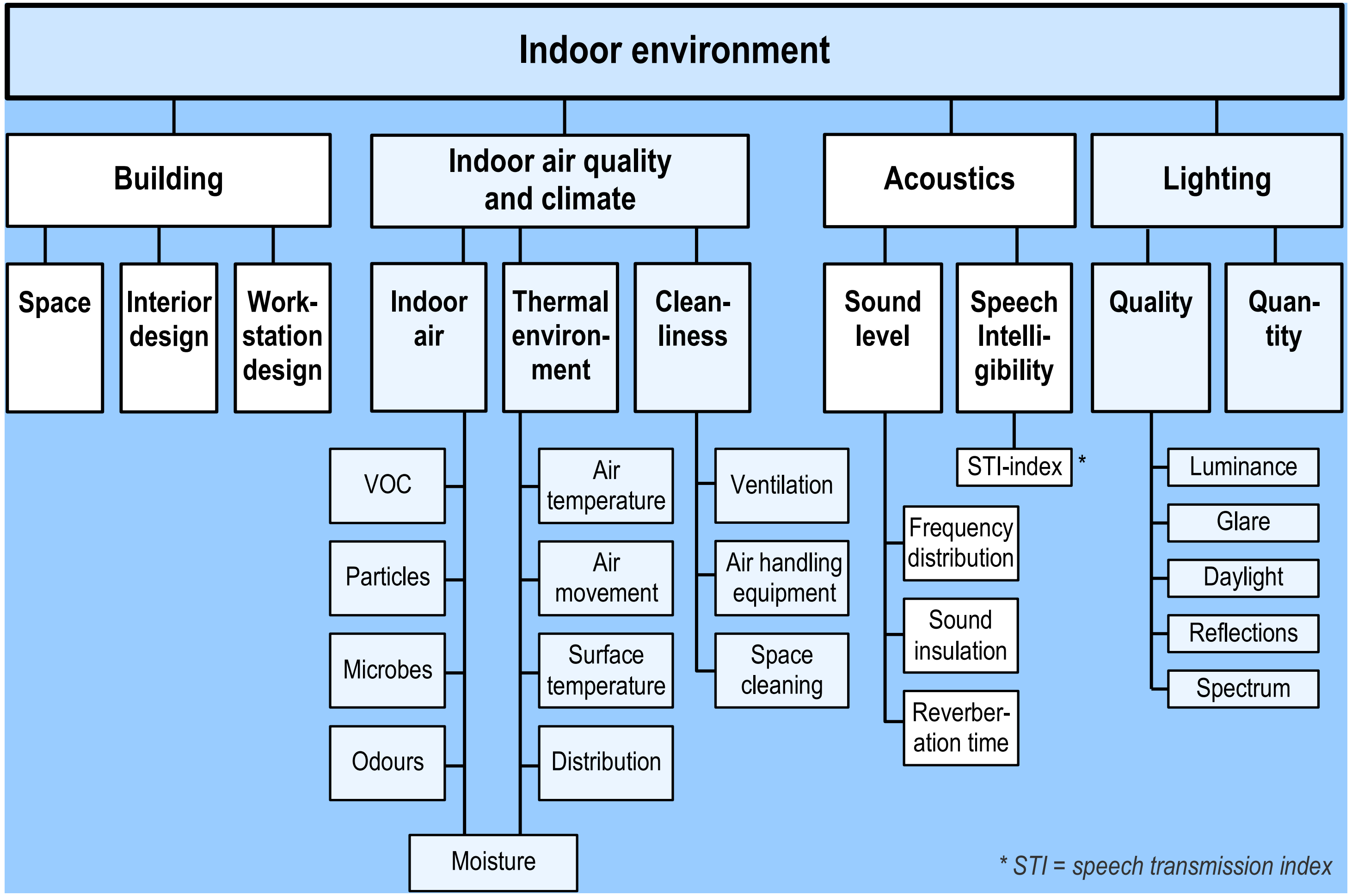
Buildings are for people

- They must create health-enhancing conditions, then be energy-efficient and balanced, not the reverse.
- Significant consequences if you do not follow the above instructions.
- People use energy – not buildings, and affect the indoor climate to a much greater extent than it is realised.

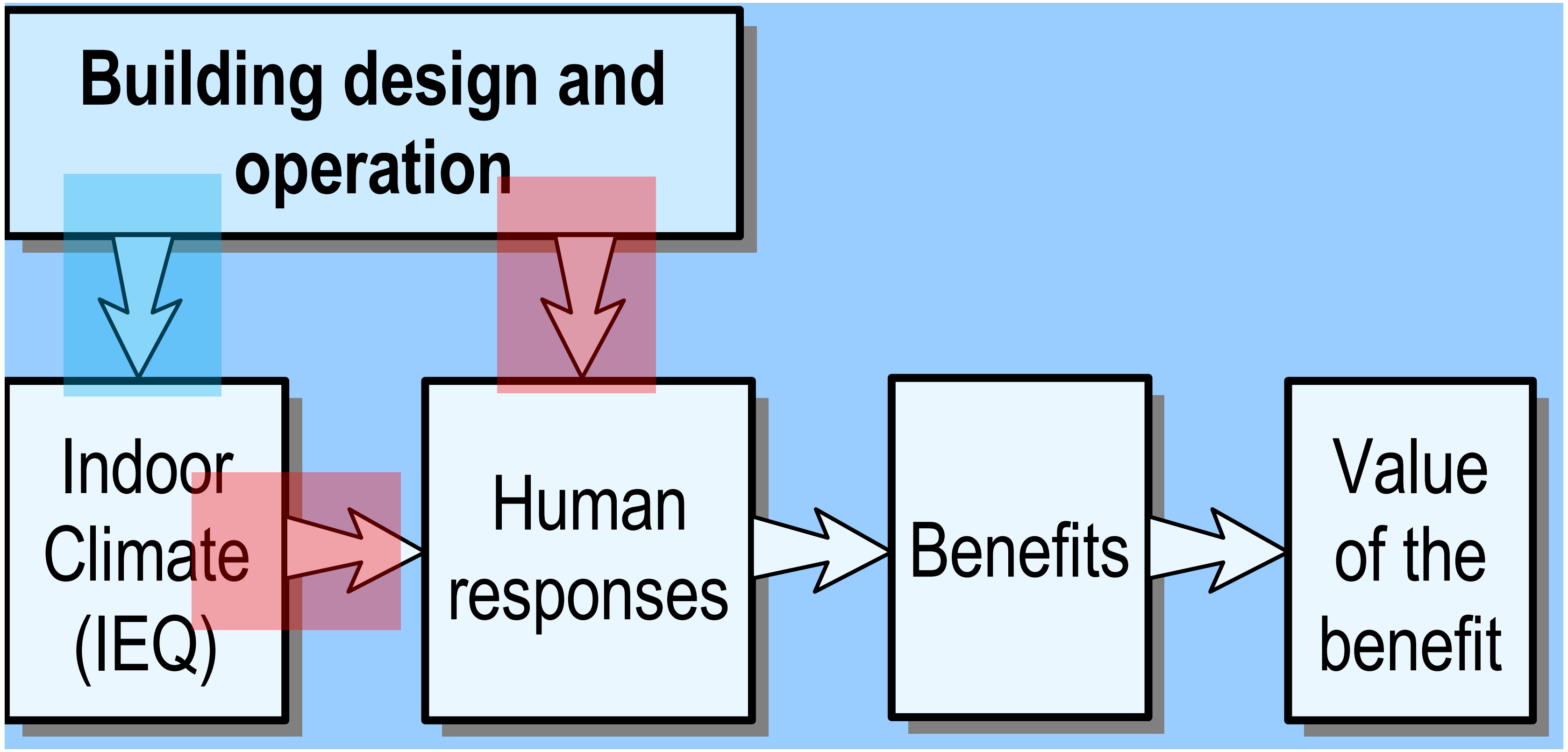


Source: University of Porto

What are the conditions of the indoor climate?



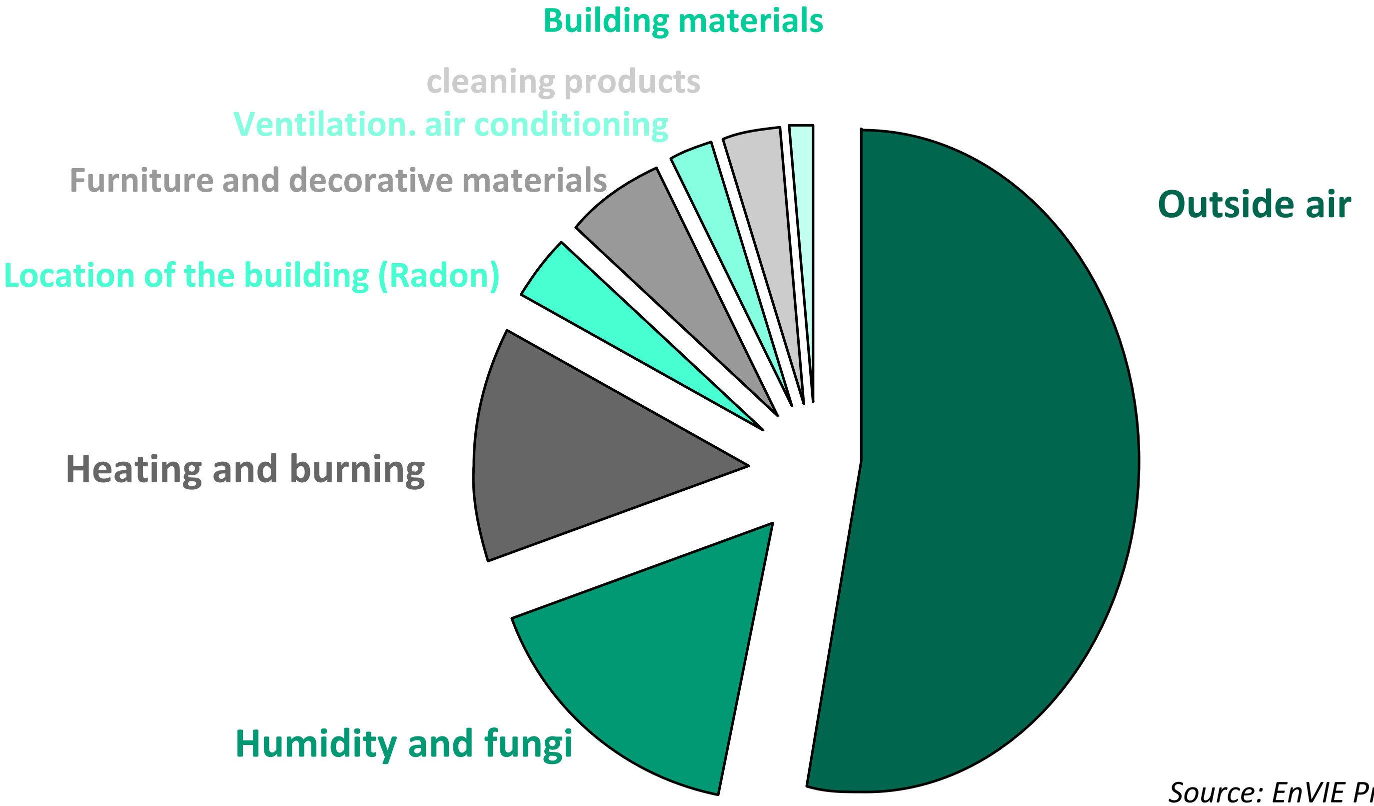
Relationship between internal climate conditions and benefits (economic)



What influences do buildings have?

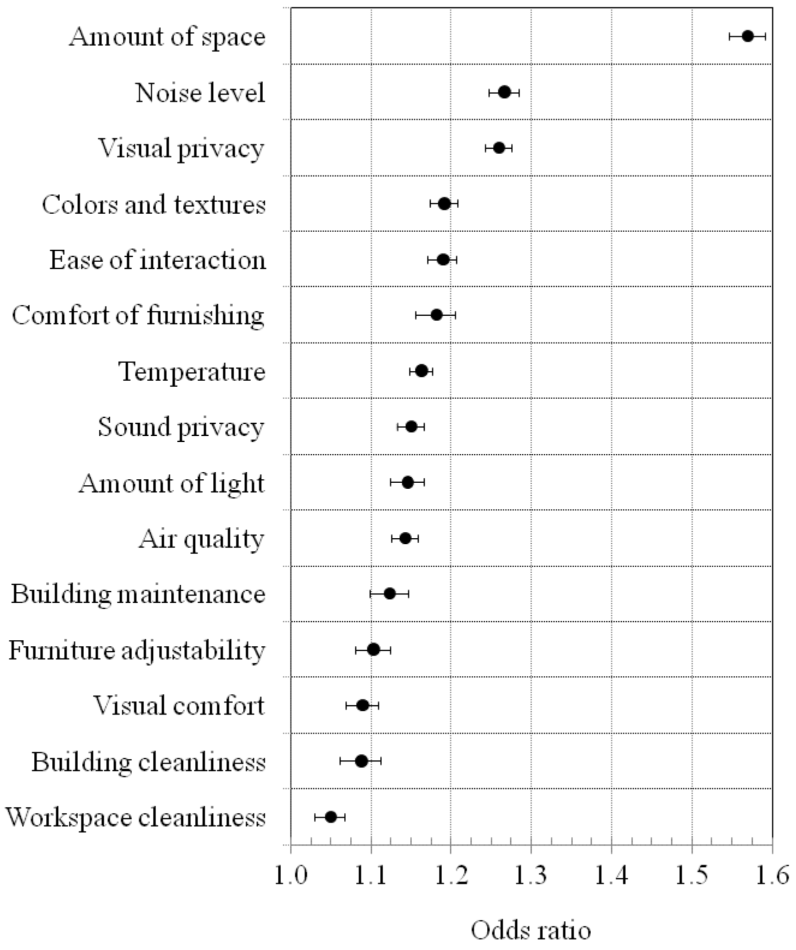
- on health conditions
- on comfort/satisfaction
- on the quality of work and progress in learning

It is estimated that in the EU. exposure to pollution in buildings leads to a loss of 2,000,000 „healthy years” annually (excluding smoking)



Source: EnVIE Project (2009)

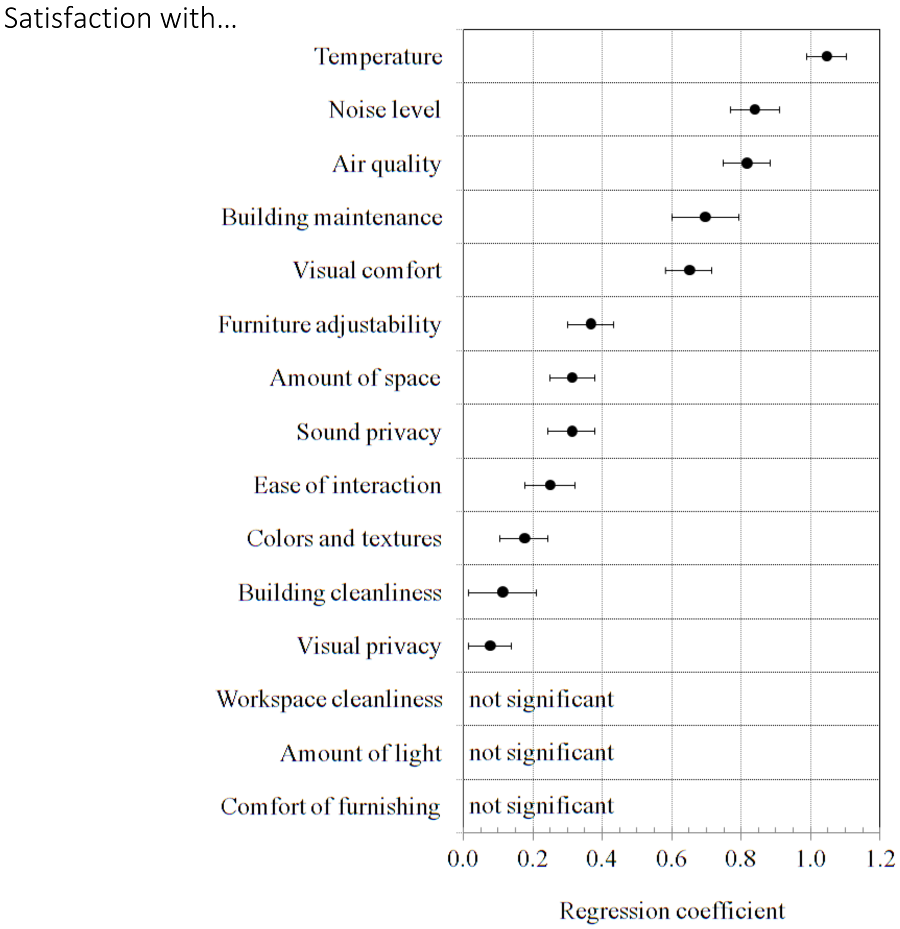
Factors affecting the comfort conditions at workplaces



- All factors are significant.
- The most important is the amount of office space regardless of age, gender, office type (open or one person), distance from the window.
- In addition, the following are important: noise levels, intimacy, colours, furniture, etc.
- Indoor climate conditions are not the most important for comfort/satisfaction with working conditions.

Source: Frontczak et al. (2011)

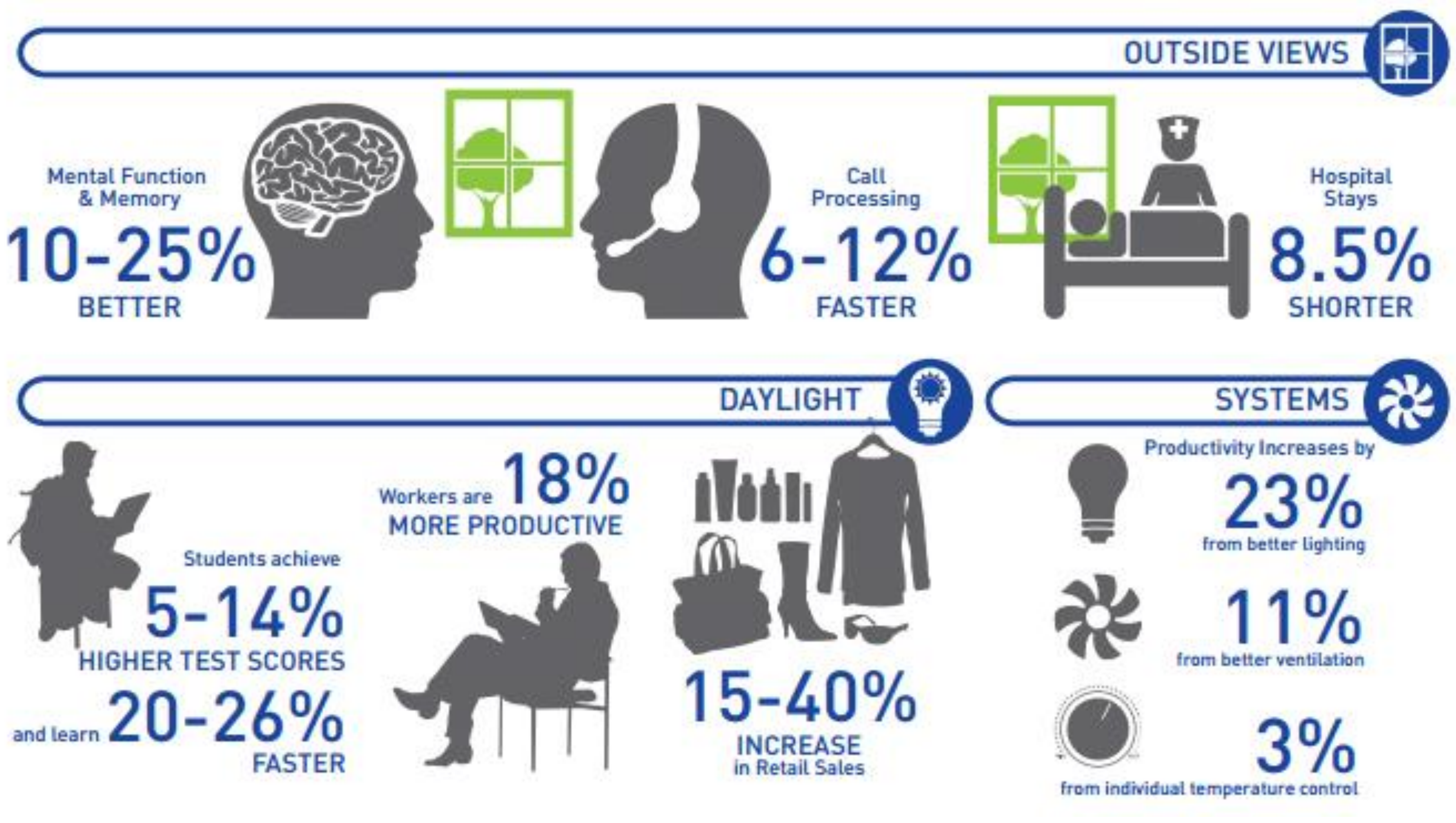
Factors influencing the self-assessment of office productivity



- Satisfaction with temperaturę, noise, air quality or satisfaction with indoor climate conditions.
- For example, ~15% increase in satisfaction with thermal conditions (temperature) is estimated at approx, 1% increase in self-evaluated work efficiency.

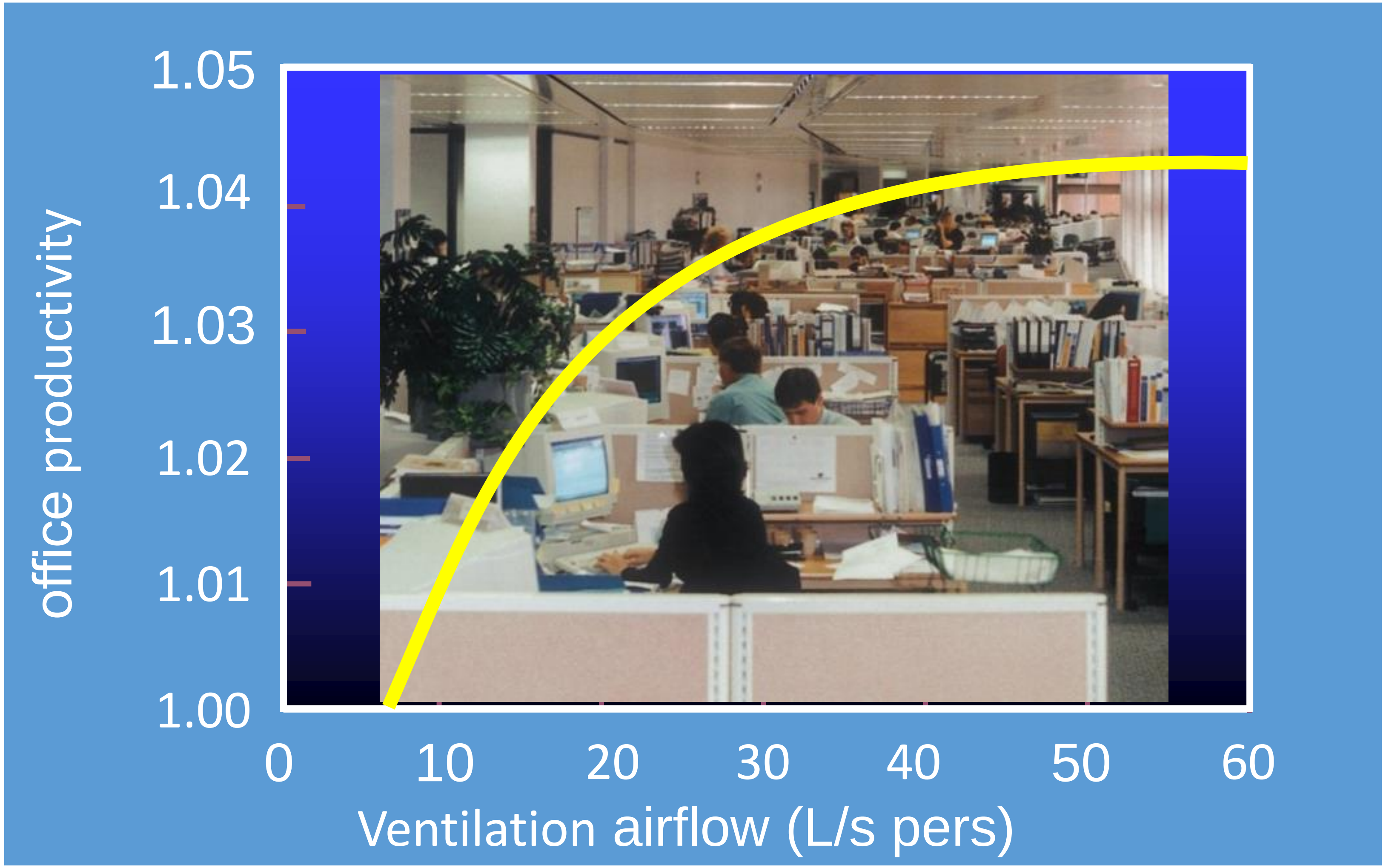
Source: Wargocki et al. (2012)

Poor indoor climate has a negative effect on work efficiency



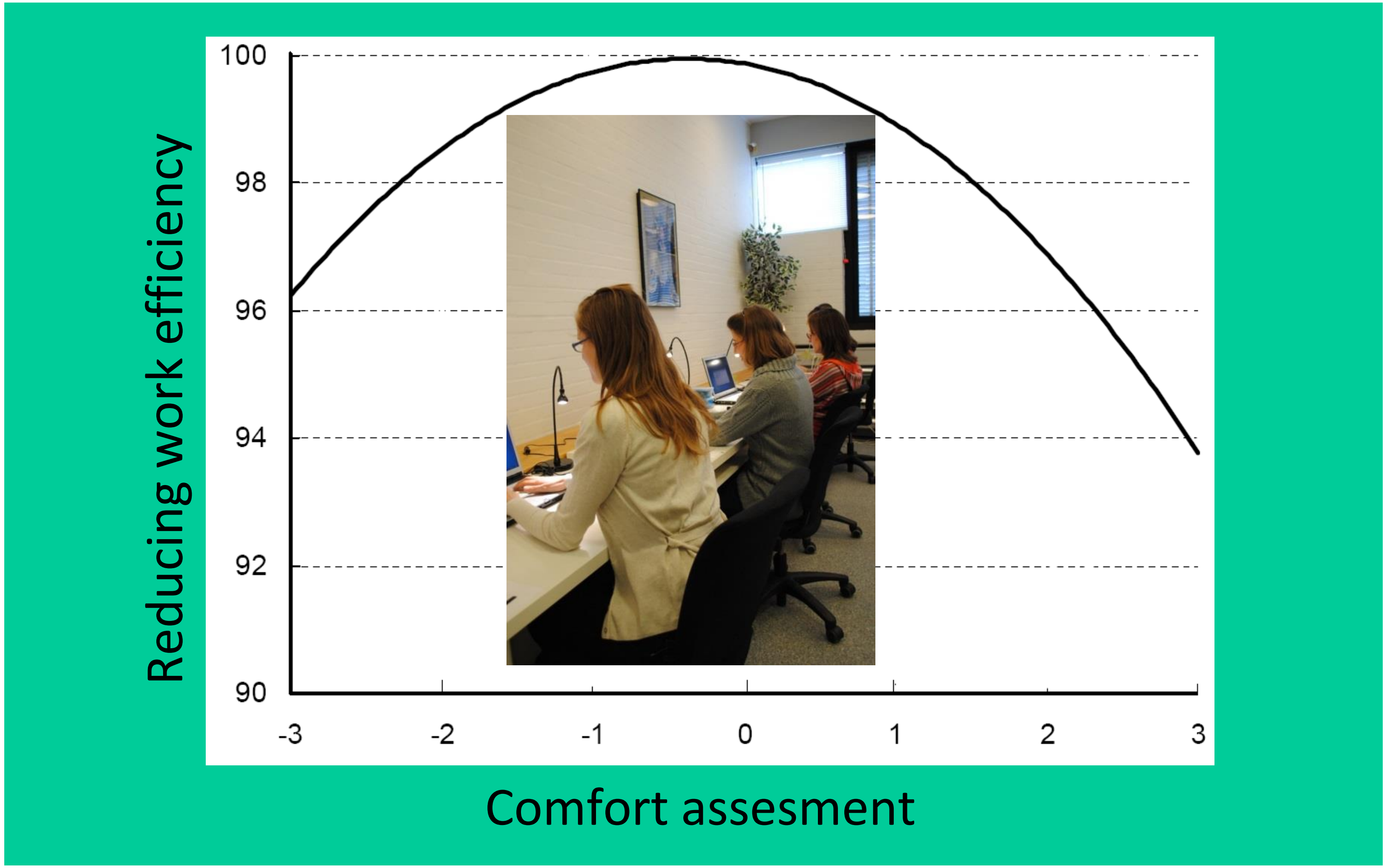
Source: World Green Building Council (2014)

Ventilation airflow and office productivity



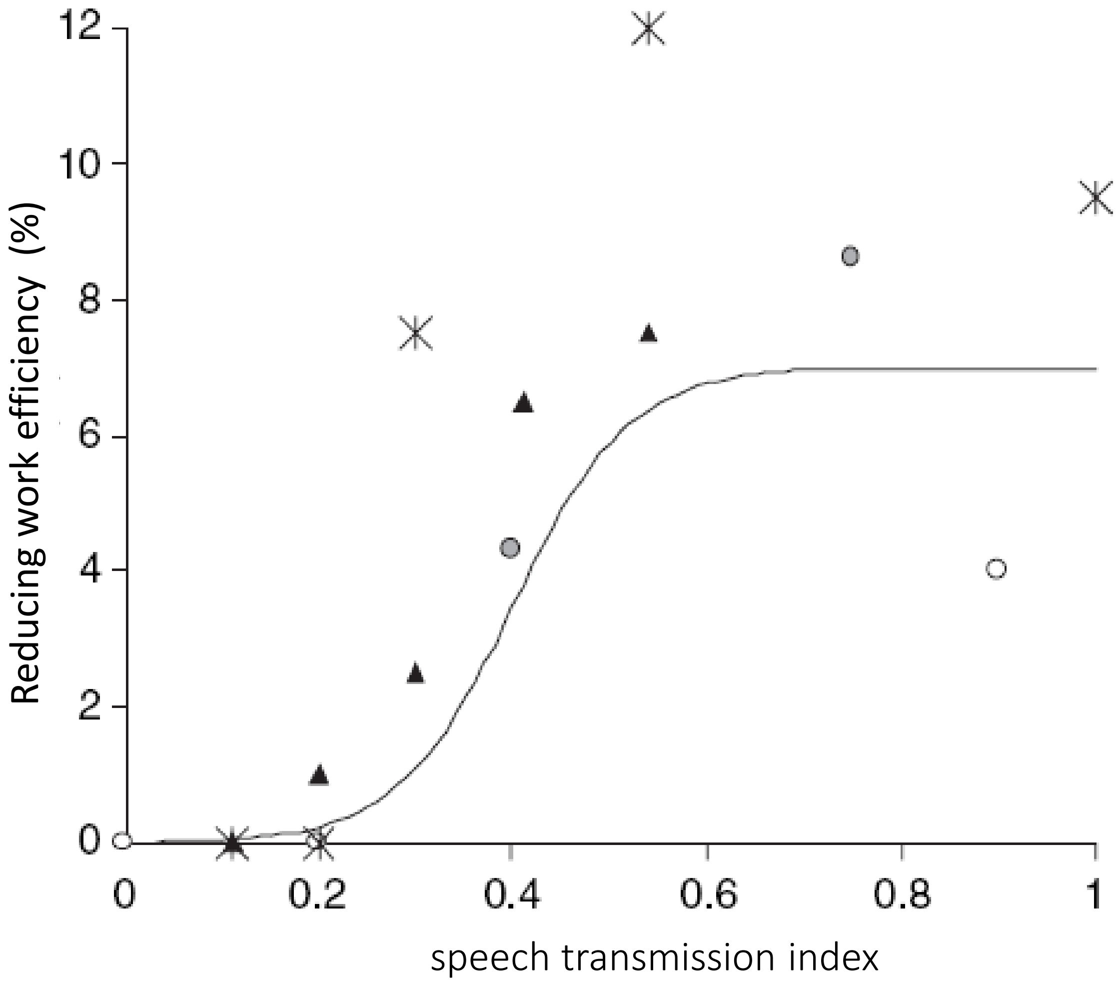
Source: Wargocki and Seppanen (2006)

Thermal comfort and office productivity



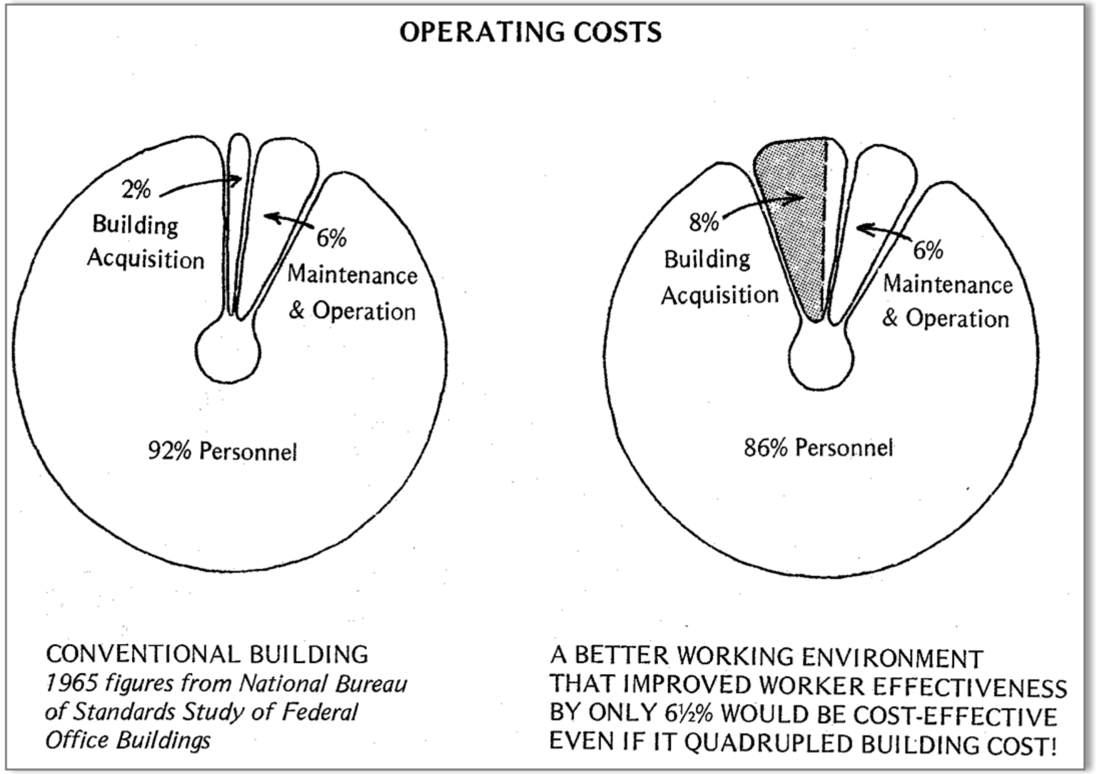
Source: Lan et al. (2011)

Noise disturbance and office productivity



Source: Hongisto et al. (2005)

It can be assumed with a high degree of probability that a 1% increase in work efficiency will be economically effective



Source: Building Value. Energy Design Guidelines for State Buildings
Office of the State Architect. California (1976)

Estimated payback time

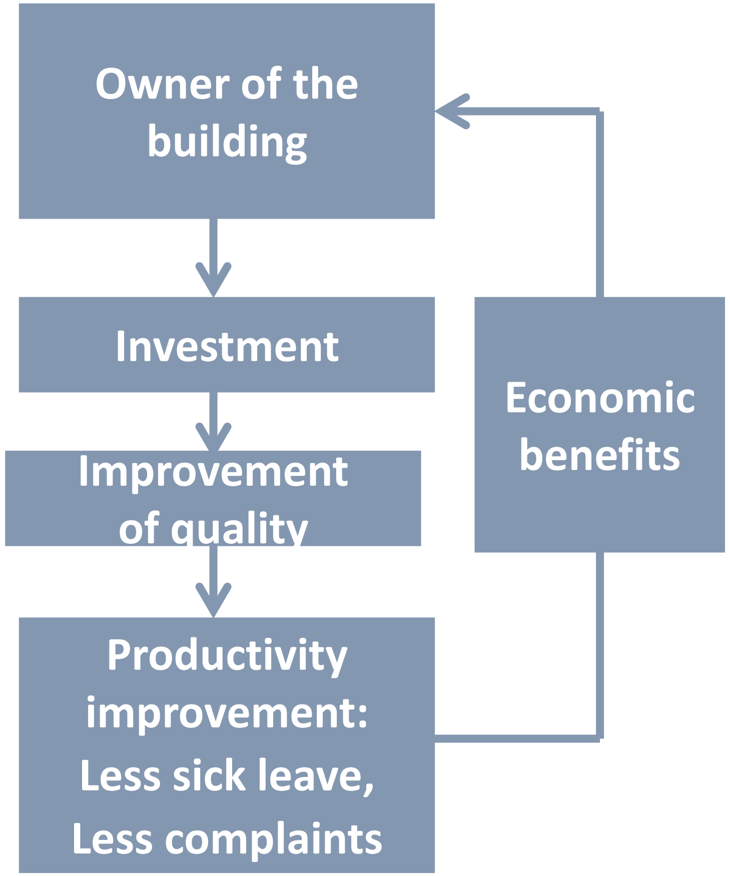
- Total profits – $62.7 billion per year
- Work productivity = $54.7 billion
  - Saving on health expenditures = $8 billion: sudden respiratory diseases = $1.2 billion; diseases related to exposure in the dorms (eg fever in connection with the use of humidifiers) = $0.8 billion; diseases related to air quality including SBS = $6 billion)
  - Total costs – $87.9 billion (initial) (in 40% buildings in USA not meeting the requirements of standards)

    + 4.8 billion per year(operating costs)

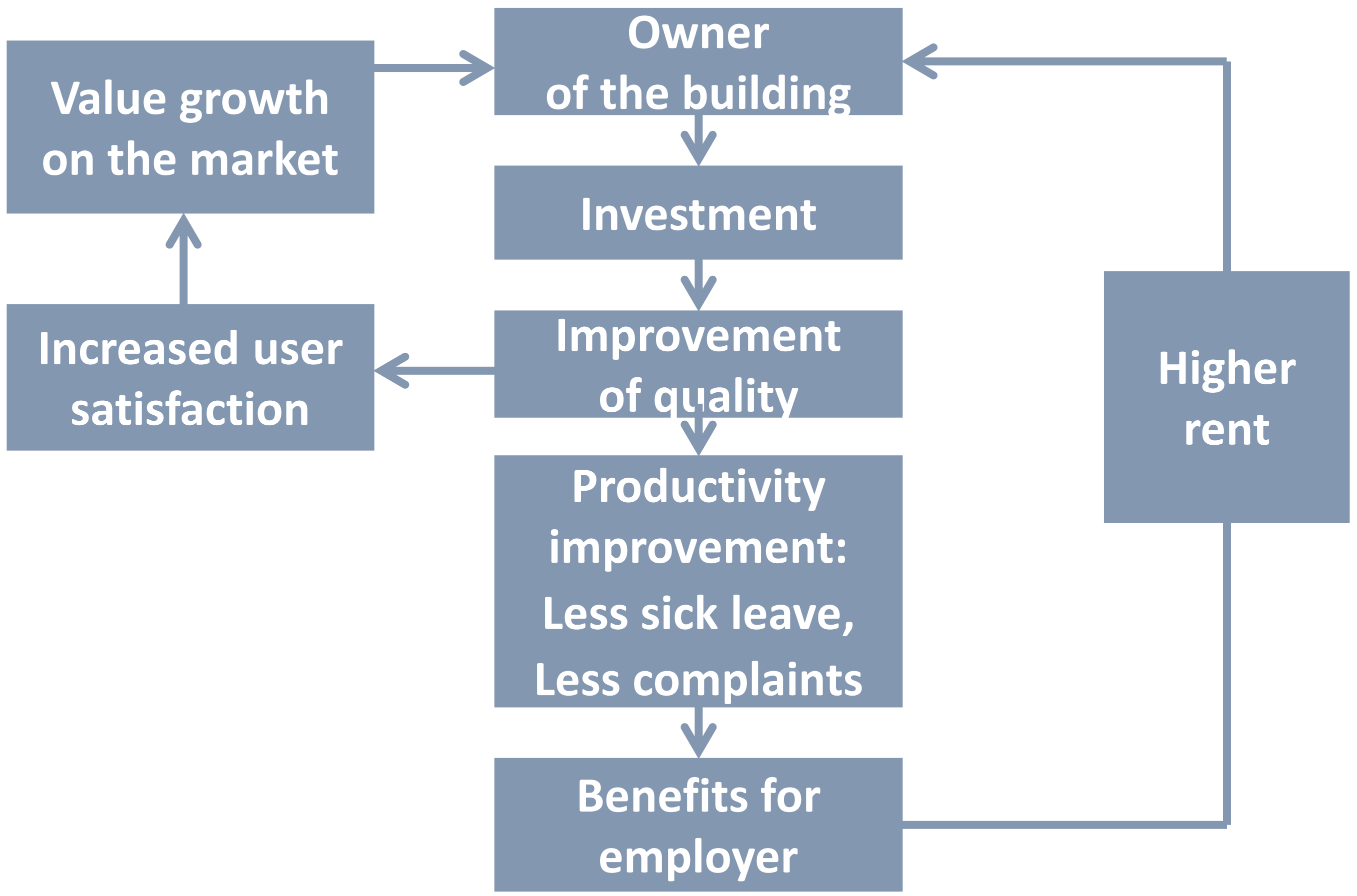
Payback time = 1.4 years

Source: Dorgan et al. (1998)

Factors that encourage investment in improving the indoor climate in the building



Factors that encourage investment in improving the indoor climate in buildings



SBS – Sick Building Syndrome

Ailments associated with staying in a building and breathing contaminated air inside it:

- fatigue, or performance degradation
- irritability, or conflict
- shortness of breath, or need to take work breaks
- headaches and dizziness, or visits to doctors
- lowering concentration, or increased errors
- fainting, or breaks in work and increased absence
- respiratory problems, or hospitalizations and sicknesses
- allergies, or sickness and absences
- mass infection (influenza), or mass sickness

Energy-efficient buildings and work efficiency

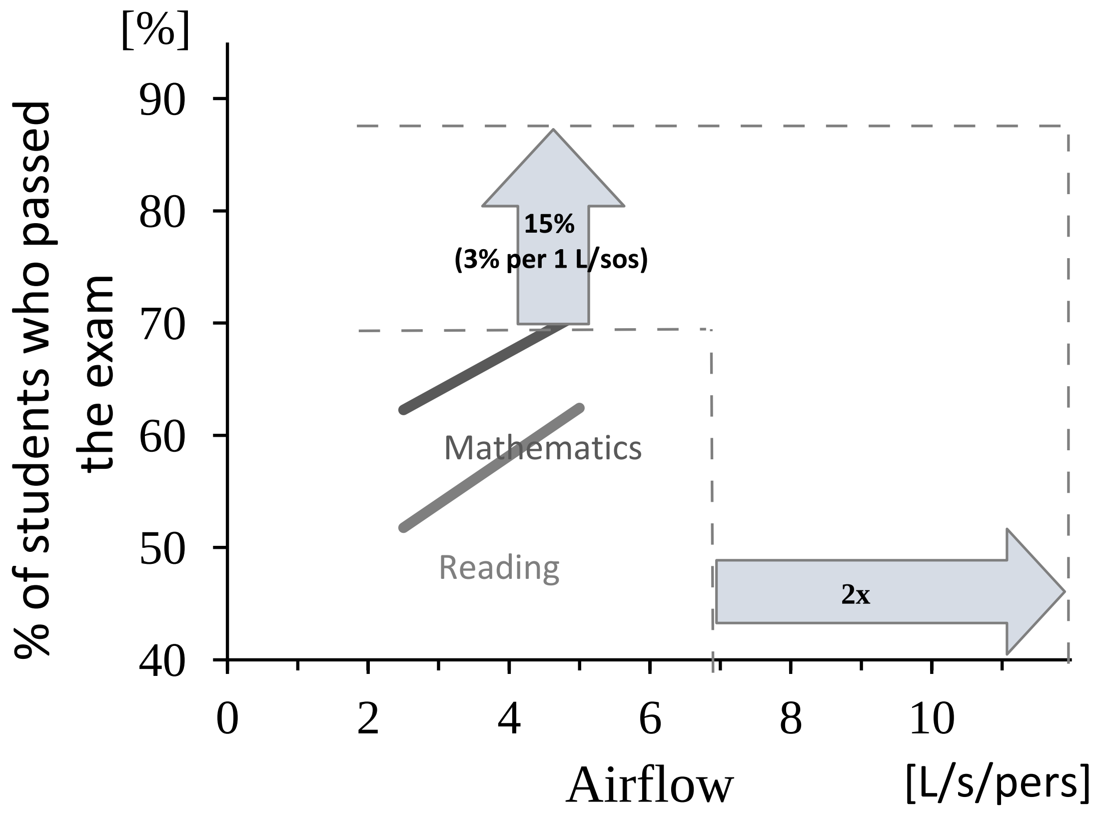
- 37 scientific articles and 12 reports,
- Self-efficacy of work generally higher in energy-efficient buildings (n = 14),
- in n = 3 tests – the reverse effect. Improvement of 2–16%,
- Reduced sick leave in the amount of 5–39%,
- No information about whether these benefits persist after years of work in an energy-efficient building or are only short-term.

Source: da Silva (2015)

Disbelief in the increase in work efficiency in energy-efficient buildings

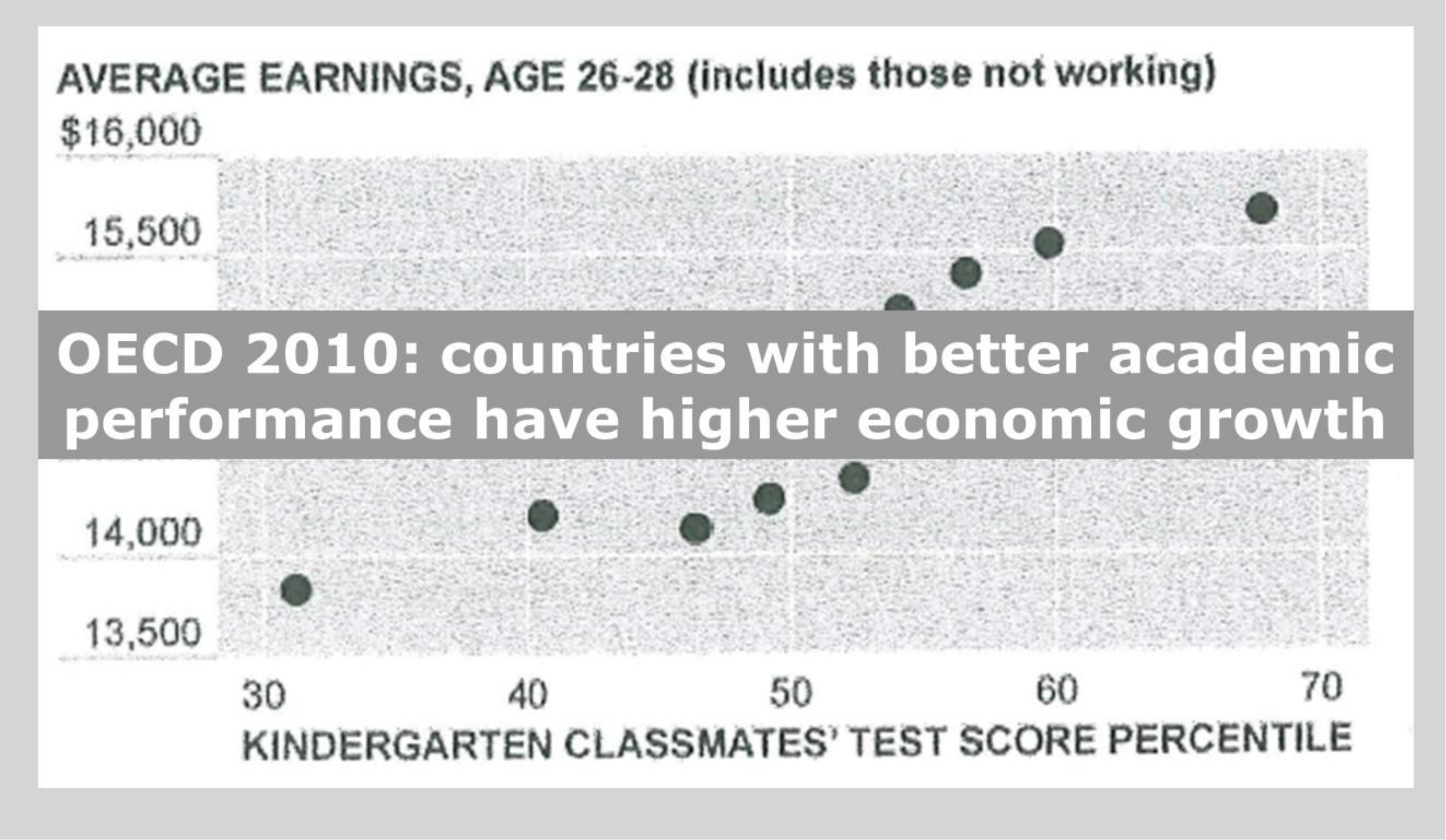
- The study population consisted of "shareholders" in buildings (n = 112, unrepresentative sample) including owners. tenants. service staff and designers who understand the impact of internal air quality and related energy costs.
- Asked about benefits and costs related to filter replacement (G3 => F6) and an increase in the ventilation air stream (9.5 to 19 L/s per person).
- Only 45% indicated improved work efficiency, reduced sick leave (23%) and health benefits (39%).
- Estimates of energy costs 2–4 times higher than estimates using modeling.
- Respondents in energy-efficient buildings did not report more often the benefits of improving air quality and were less willing to pay for it.
- Most were not sure or did not believe in benefits and overestimated costs – lack of proper education.

Class ventilation and learning progress (% of students who passed the exam)



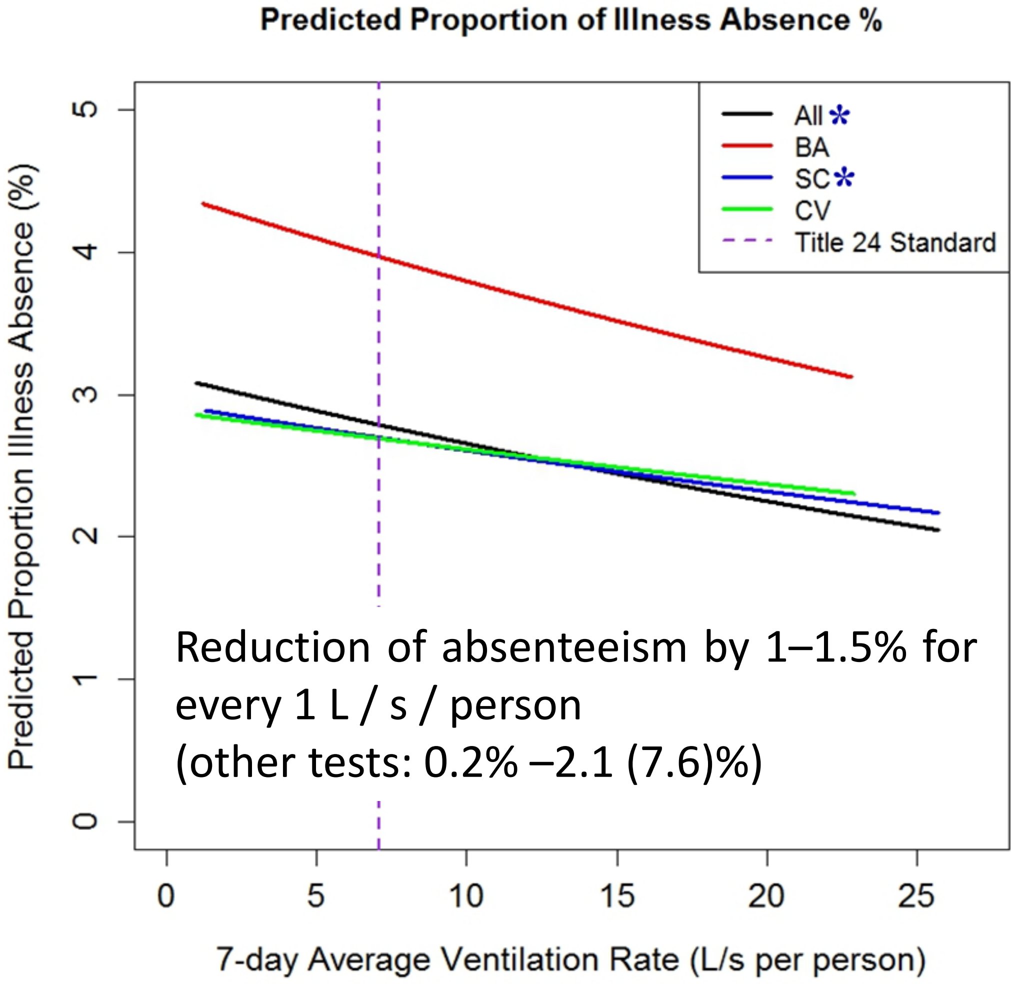
Source: Haverinen-Shaughnessy et al. (2013)

Socio-economic consequences



Source: Chetty et al. (2010)

Ventilation in classes and sickness absence



Reduction of absenteeism by 1–1.5% for every 1 L / s / person
(other tests: 0.2% –2.1 (7.6)%)

Source: Mendell et al. (2013)

Estimated costs

- An increase in the ventilation expenditure by 1 L/s per person corresponds to a reduction in sickness absence of approx. 1–1.5%.
- Average absenteeism in Denmark is around 3.6% => approx. 7.4 days a year (data from 2011).
- At 200 school days, ventilation increase from 6 L/s/pers (DK) to 8.4 L/s/ person (Sweden) will reduce the average absence by one-fourth of a year.

Residential buildings

Sleep quality and work efficiency the next day

Improving the air quality in the bedrooms:

- The air felt fresh,
- Improving the quality of sleep,
- Better mood the next day, less sleepiness, better concentration,
- Better results on mental tests (logical thinking).

Source: Strøm-Tejsen et al. (2015)

Conclusions

- Systematic results of studies document that there is a close relationship between the quality of the indoor climate and work performance and learning progress. This may result in high economic benefits.
- It is presumed that these benefits also apply to residential buildings due to the fact that a lot of office work is currently carried out at home and the quality of sleep affects the performance of the next day's work.

Let’s remember

Air quality/temp/noise/light

5–10%

Economic losses
Health costs
Short payback time < 2 years

Air quality/temp/noise/light

>15%

Socio-economic benefits (in future)
Cost concern teachers

?

?

Potentially very high

Context, challenges

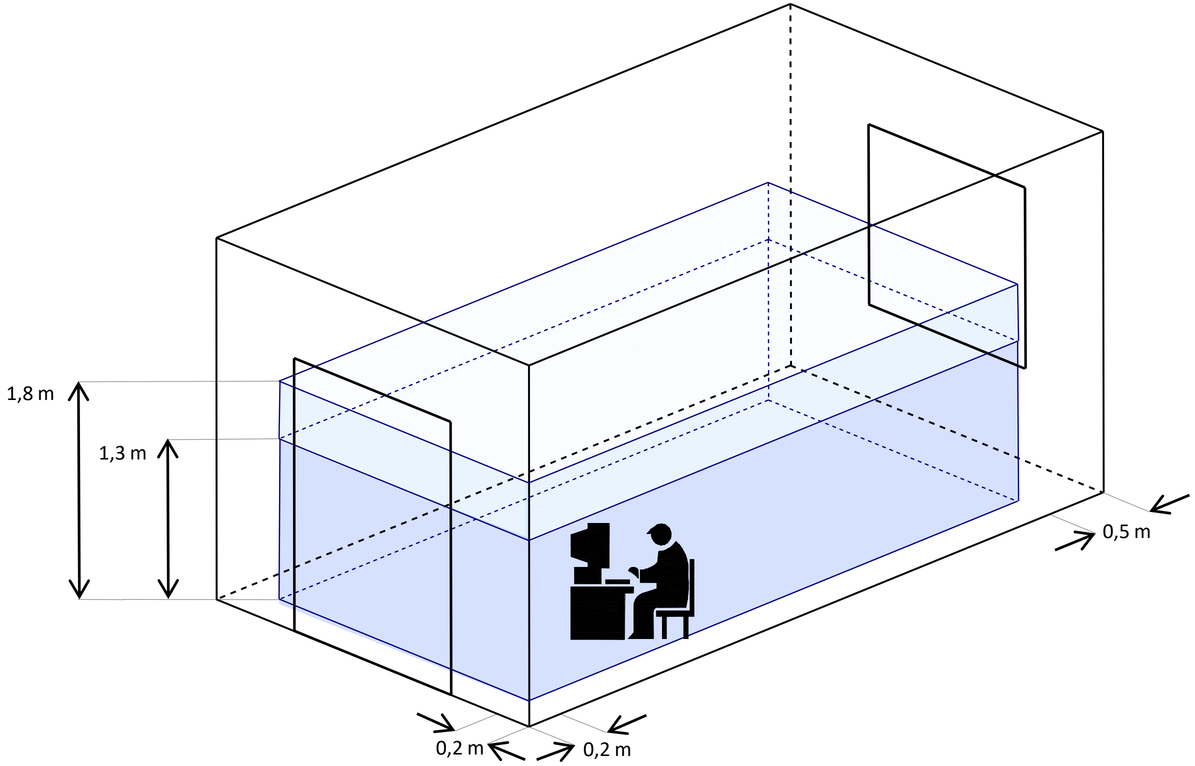
- **Climate change:** severe weather events. new pollutants that appear naturally (new allergens), increased probability of a pandemic.
- **Changes in construction**: newly erected and thermo-modernized buildings with low energy consumption in order to reduce CO_2 emissions ("green" buildings), adaptation of existing buildings.
- **New impurities produced by humans:** compounds that disrupt the endocrine system (hormones), retardants, phthalates, etc. in most cases without knowledge of their toxicity, abuse of products that produce odours.
- **The presence and re-emergence of persistent organic pollutants** in existing buildings.
- **Rapidly growing hypersensitivity (lack of tolerance) to pollution** in the general population and especially in the younger generation.
- **Aging generation and longer life expectancy**.

Part 4

Energy saving in ventilation systems

JAROSŁAW MÜLLER

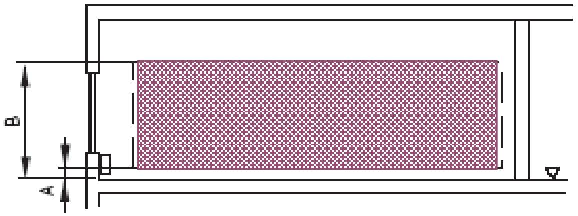
The occupied zone

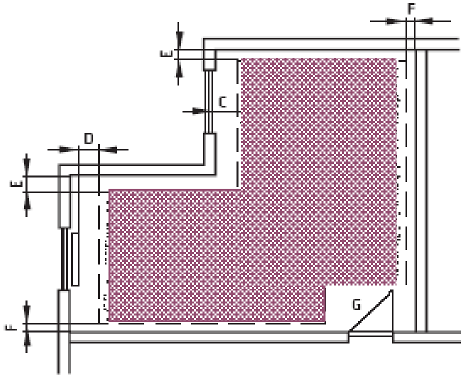


- The occupied zone is defined depending on the needs.
- The values given above are exemplary values.

Occupied zone definitione (acc. EN 13779)

Distance from:		Range [m]	Standard value [m]
Floors (bottom border)	A	0.00 do 0.20	0.05
Floors (top border)	B	1.30 do 2.00	1.80
Windows, external door	C	0.50 do 1.50	1.00
Air-conditioning devices	D	0.50 do 1.50	1.00
External walls	E	0.15 do 0.75	0.50
Internal walls	F	0.15 do 0.75	0.50
Internal door	G	indyvidually	



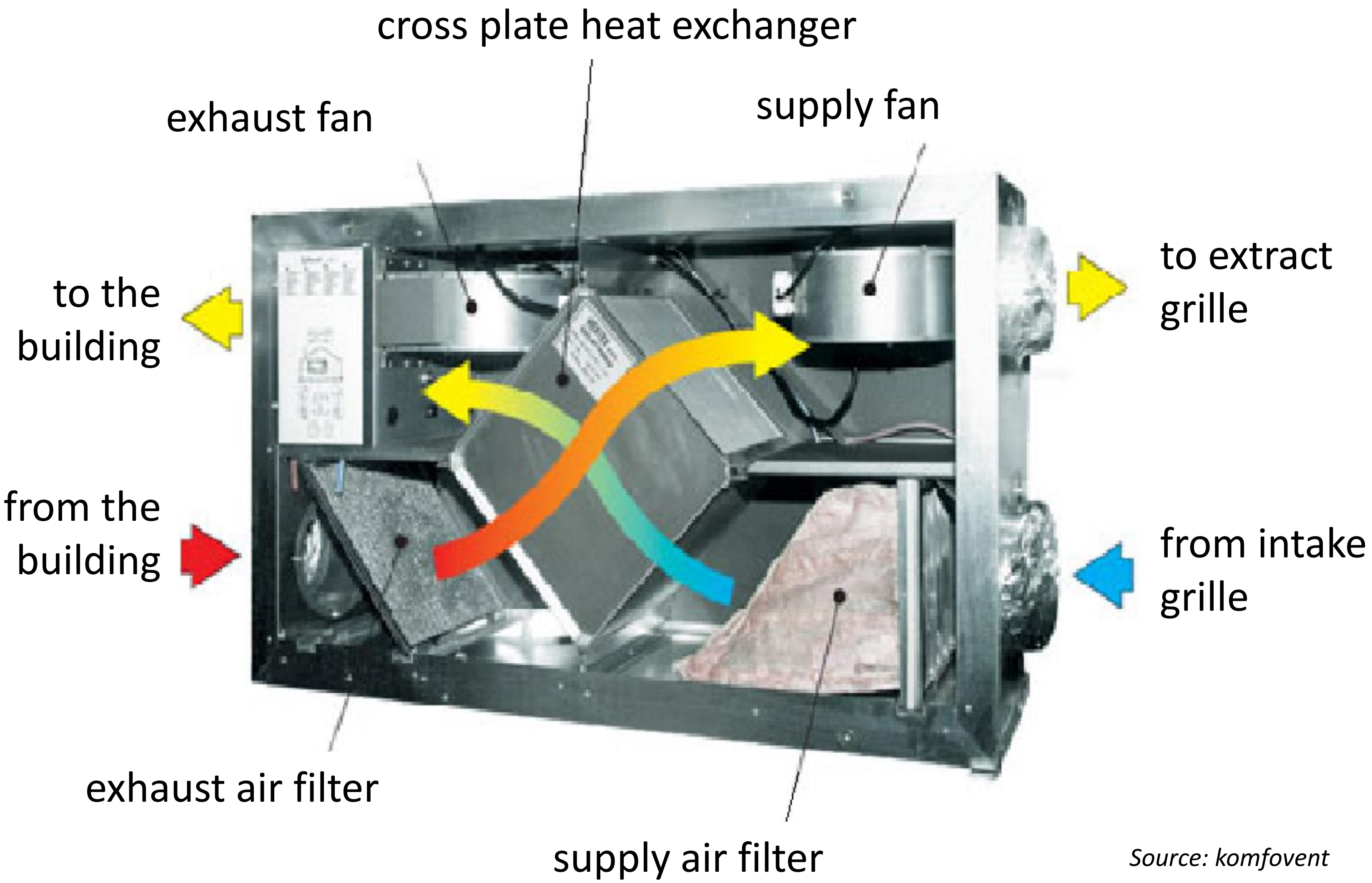


Ventilation Ducts

Pressure losses and perimeter

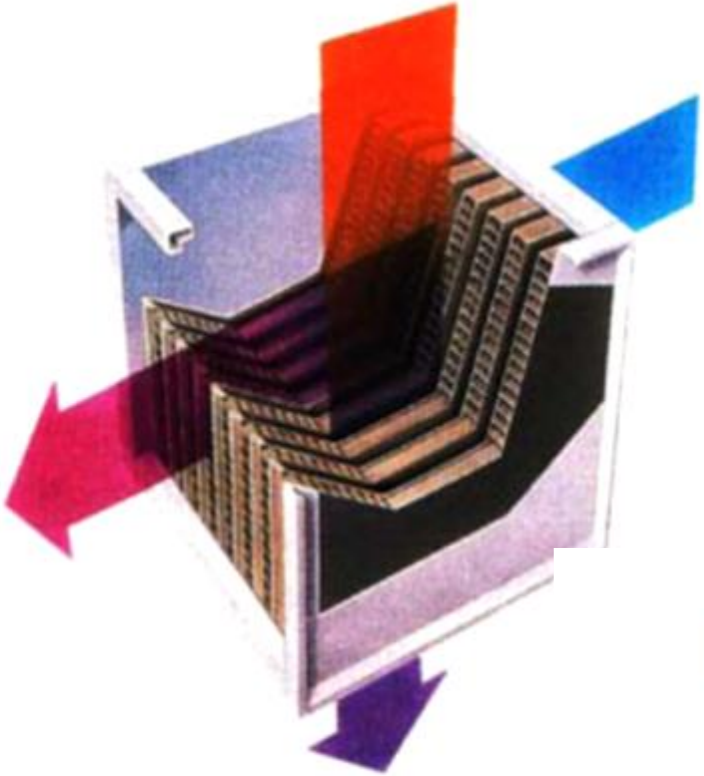
perimeter %	Duct shape		% Pressure loss
100	r = 200		100
103	r = 150, 180		106
111	a = 350, b = 350	a/b = 1.0	118
119	a = 250, b = 500	a/b = 2.0	128
156	a = 150, b = 830	a/b = 5.5	177
214	a = 100, b = 1250	a/b = 12.5	260

Heat recovery



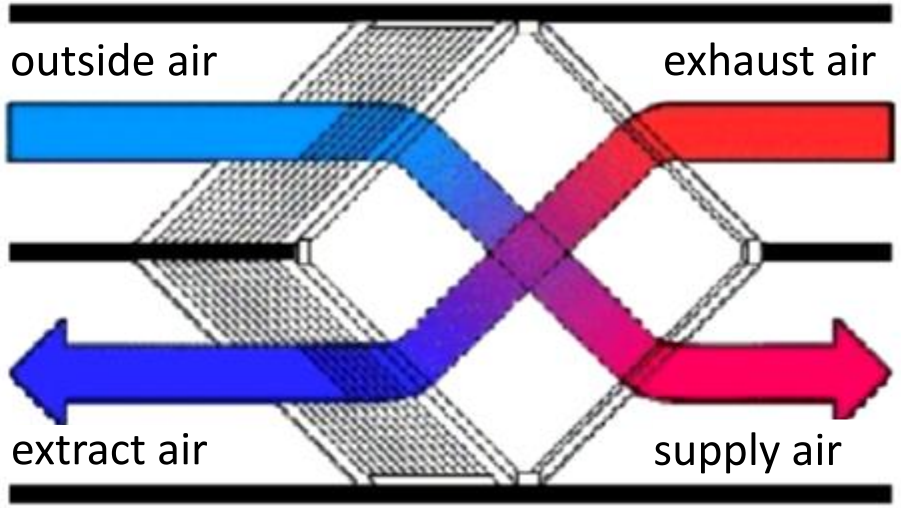
Source: komfovent

Cross-plate recuperator



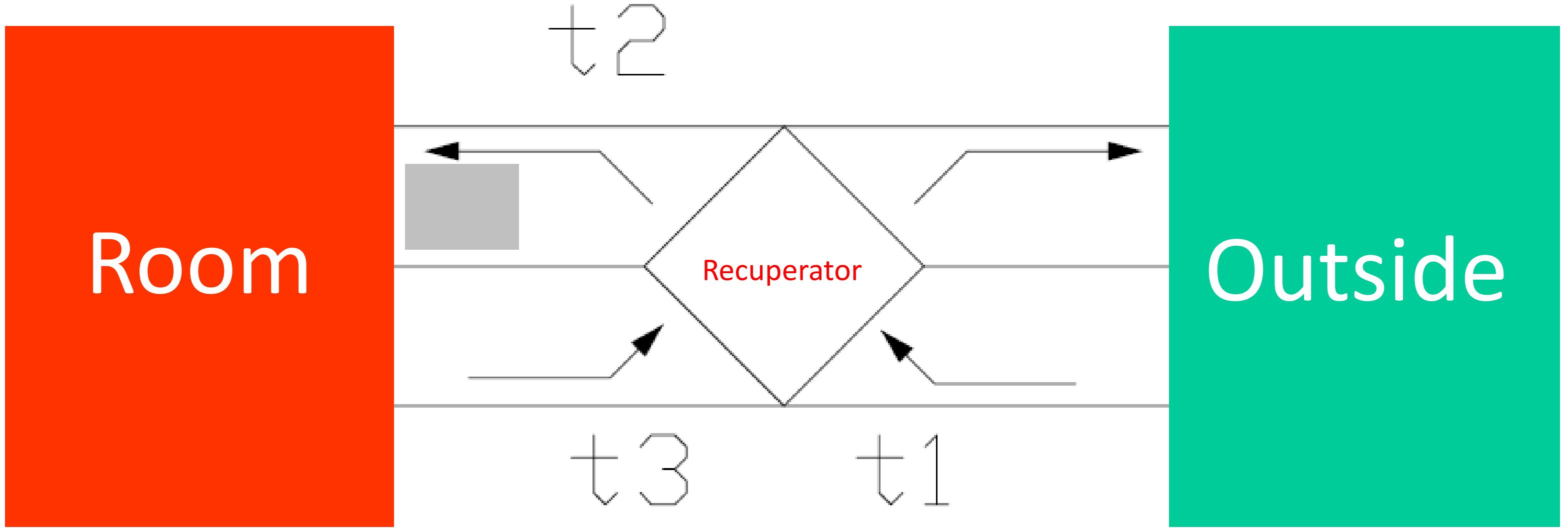
$$\eta = 70 \div 85\%$$

$$\eta = \text{min } 68\%$$



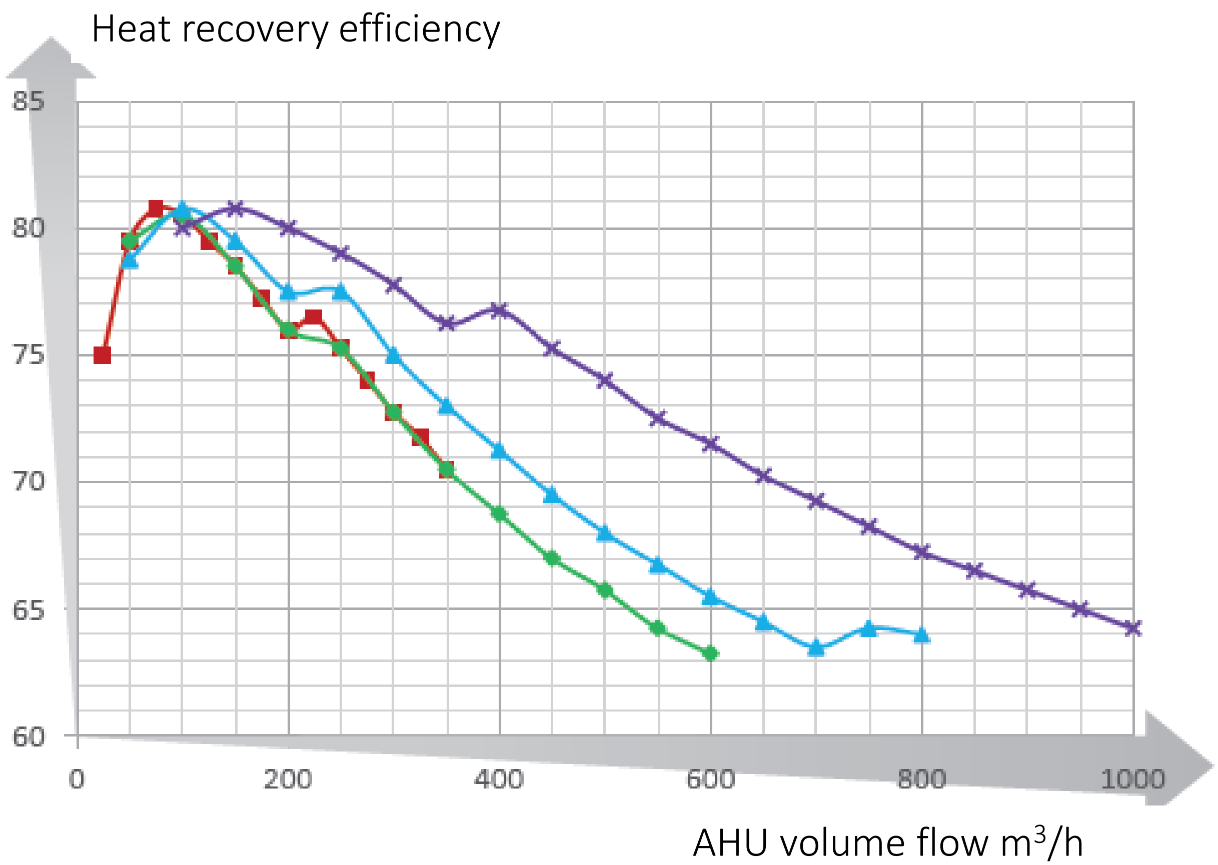
Source: komfovent

Heat recovery efficiency



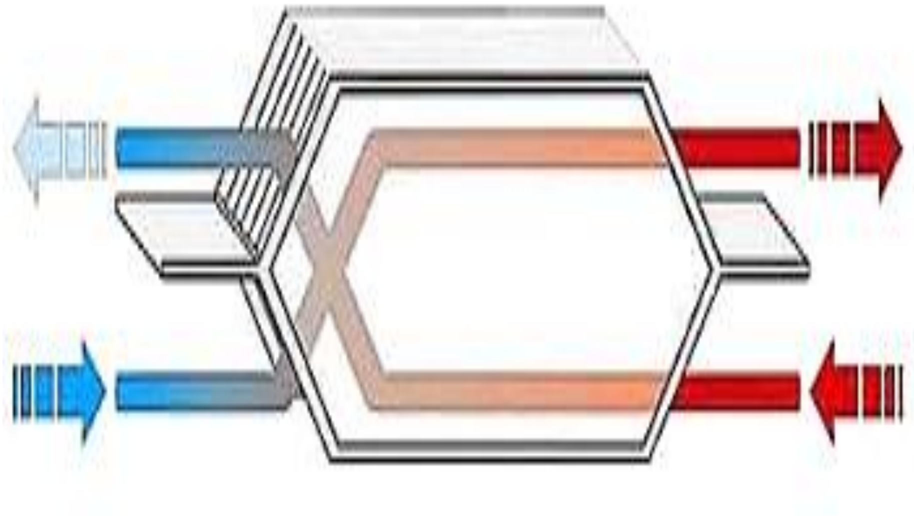
$$\eta_{RK} = \frac{V_{w,Naw} \cdot \rho \cdot c_p \cdot (t_2 - t_1)}{V_{w,Wyw} \cdot \rho \cdot c_p \cdot (t_3 - t_1)} \cong \frac{(t_2 - t_1)}{(t_3 - t_1)}$$

Cross-plate recuperator



Cross-plate recuperator

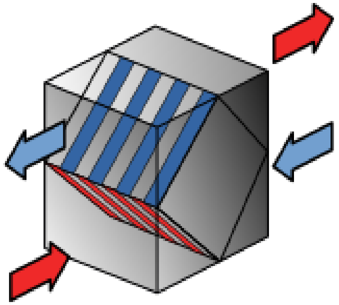
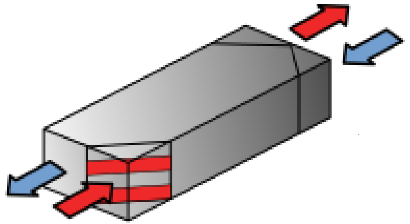
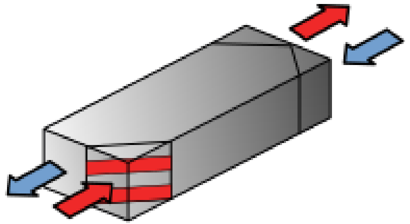
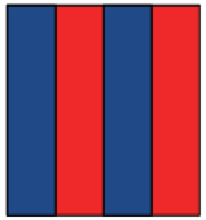
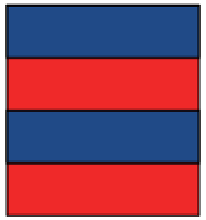
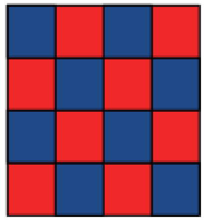
Cross-flow



Counter-current flow

Source: komfovent

Heat exchangers

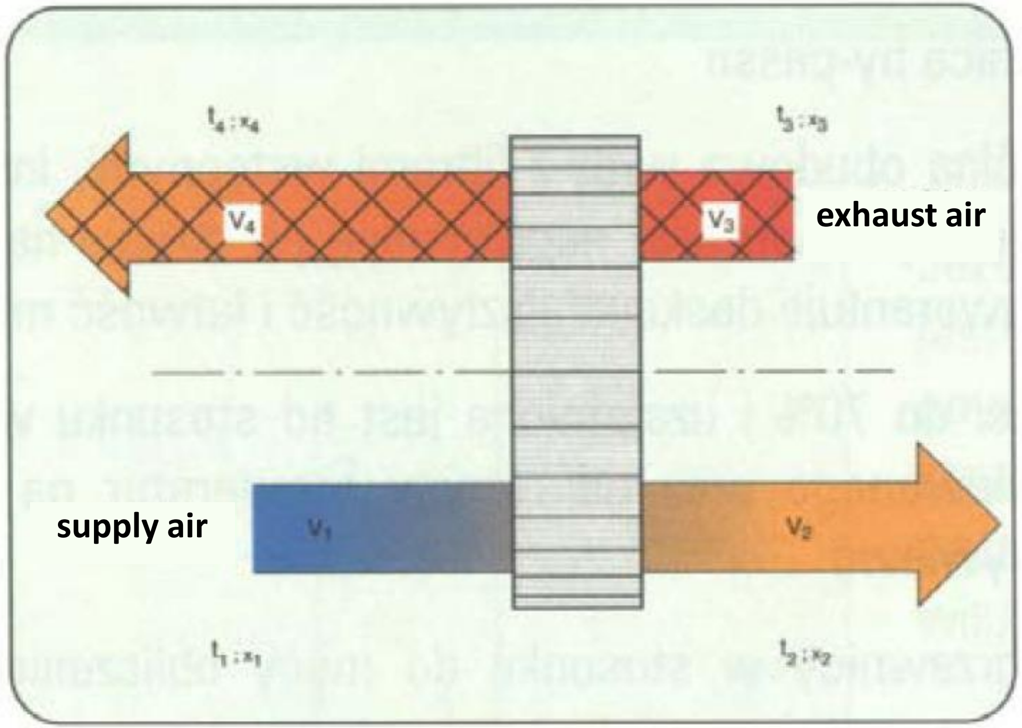
Principle			
Profile			
Counter current Heat exchanger	Vertical flat panel	Horizontal flat panel	Cellular
Efficiency	50 – 70 %	70 – 80 %	85 – 99 %

Source: wikipedia.org

Cross-plate recuperator

Cross-plate recuperator – the attic

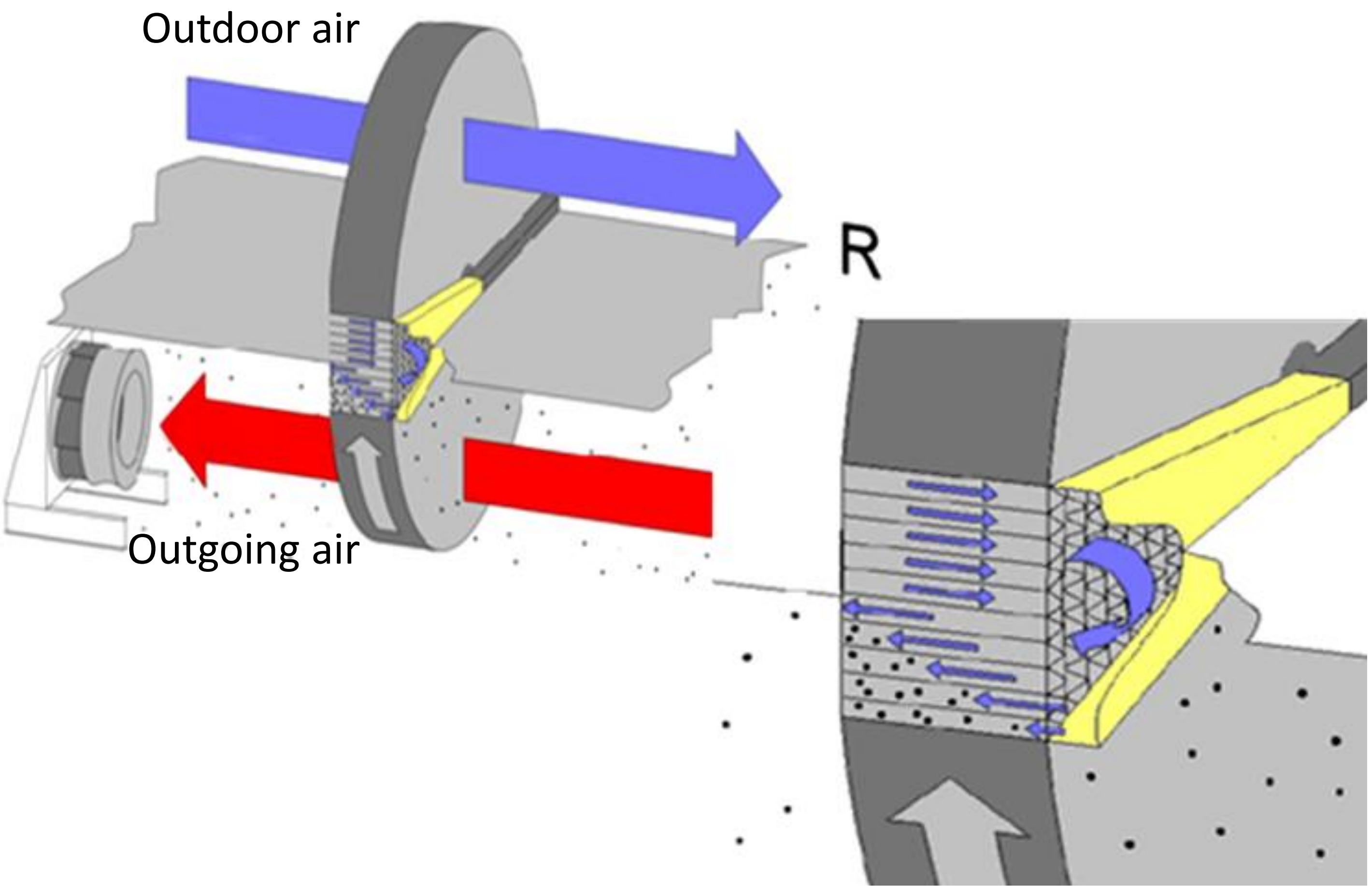
Rotary HX – mass and heat recovery



η = 70÷90%

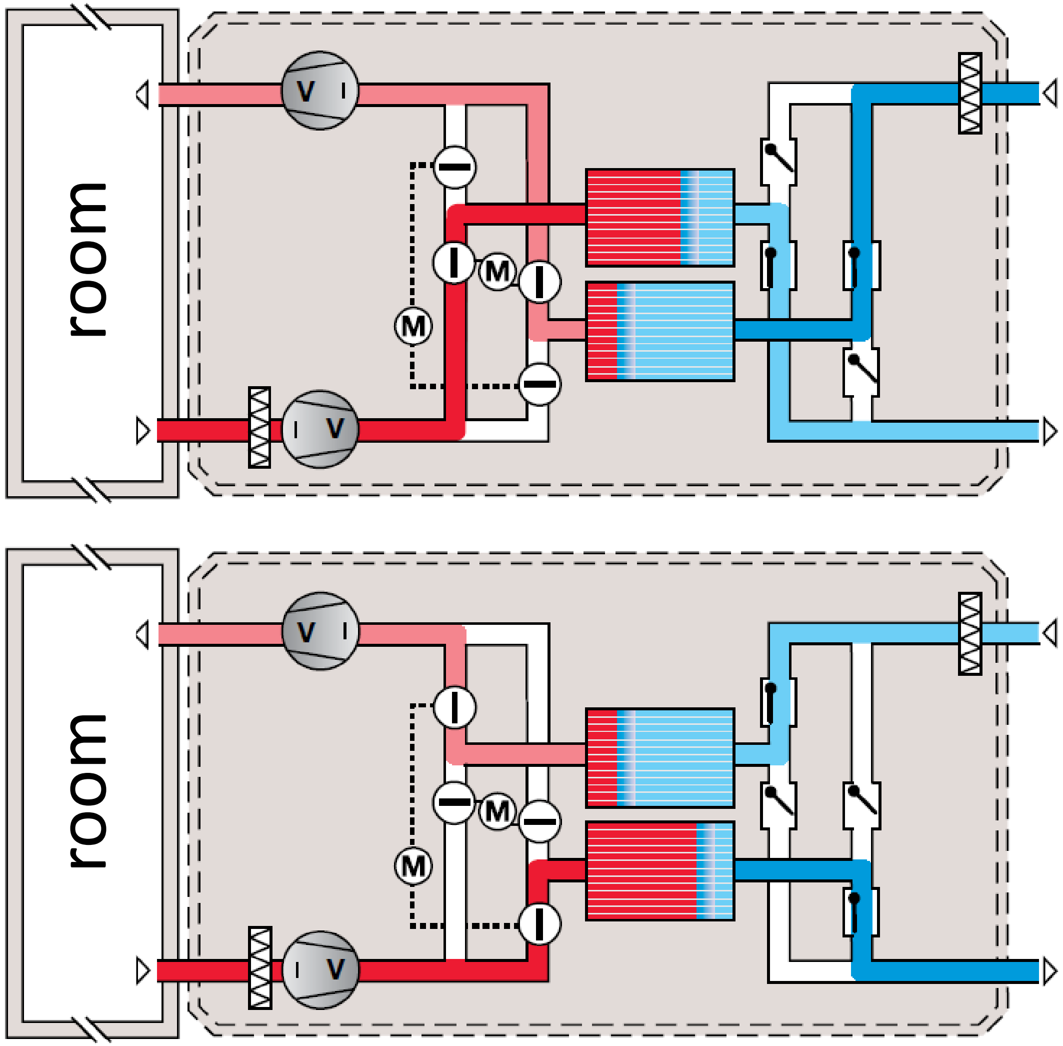
$$\eta = \frac{t_2 - t_1}{t_3 - t_1} \qquad \eta_x = \frac{x_2 - x_1}{x_3 - x_1}$$

Rotary HX – mass and heat recovery



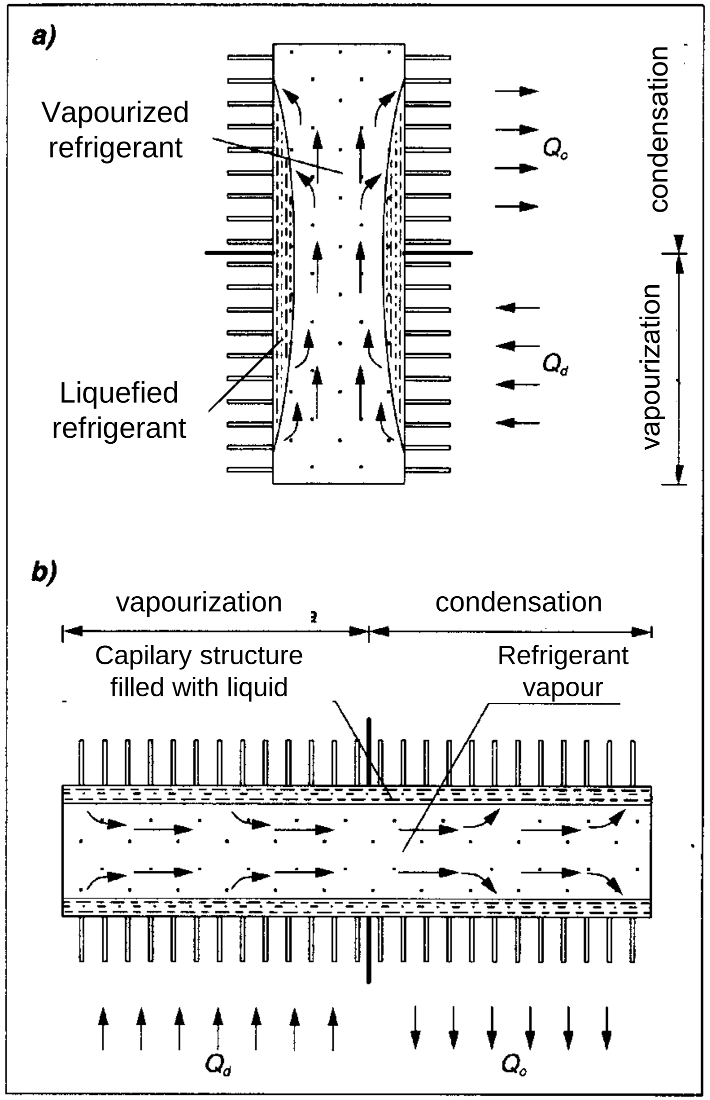
Source: lautner.eug

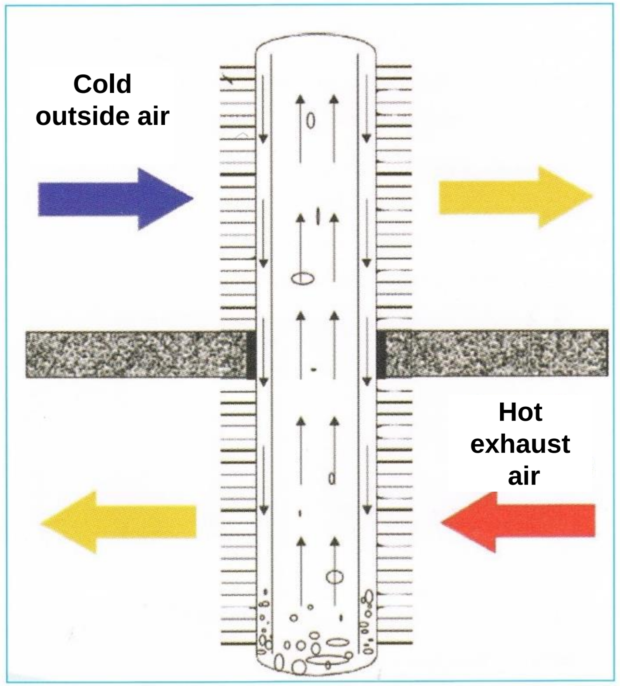
Solid HX



Source: rekuperatory.pl

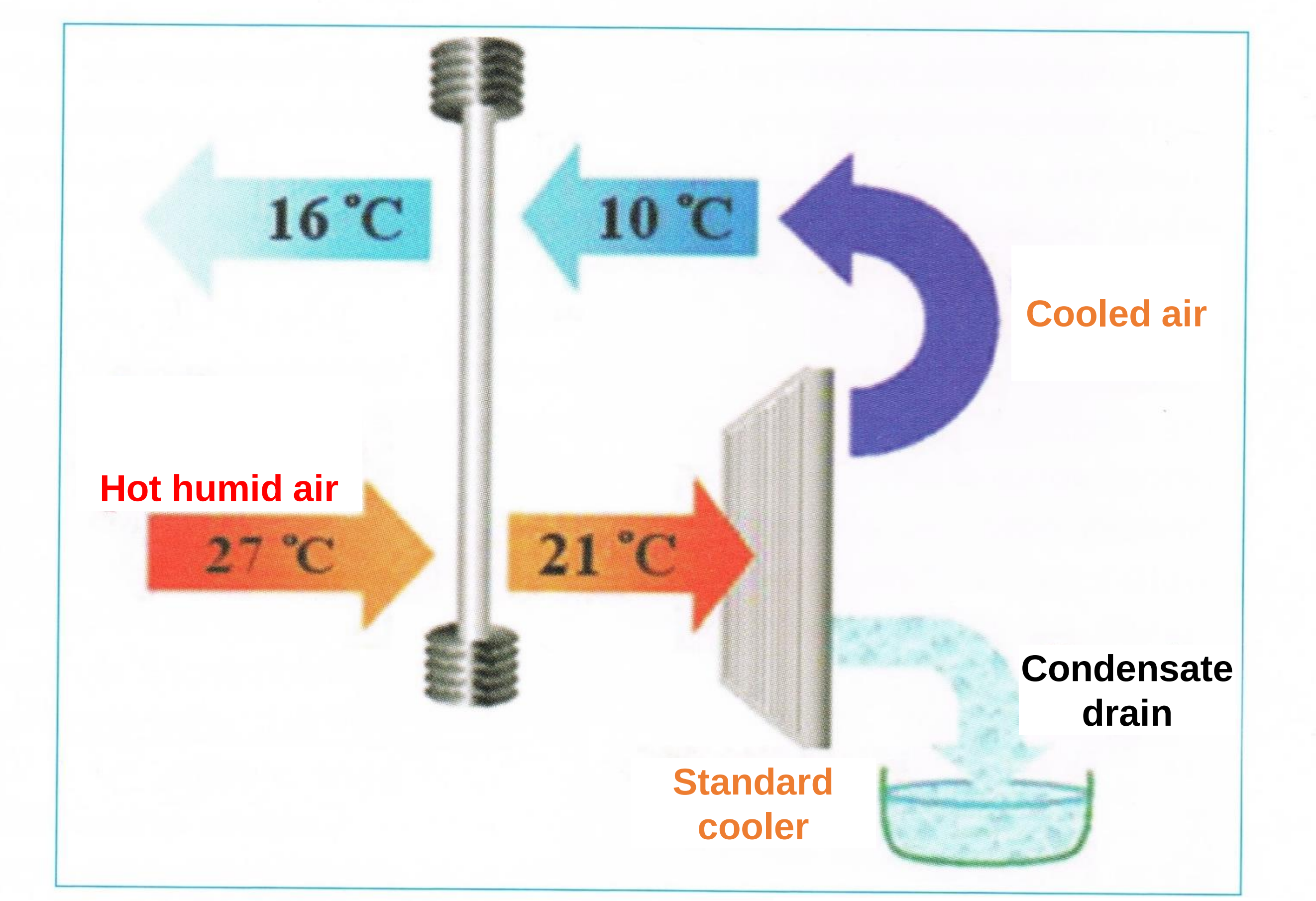
Heat pipe





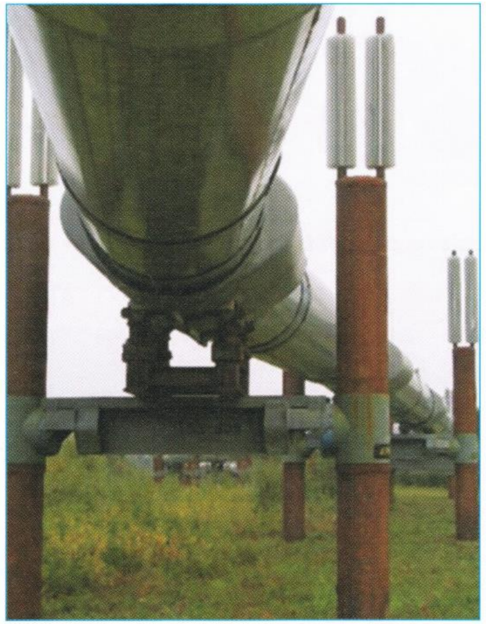
Source: chlodnictwoklimatyzacja.pl
Ł. Adrian

Heat pipe – Air dehumidification

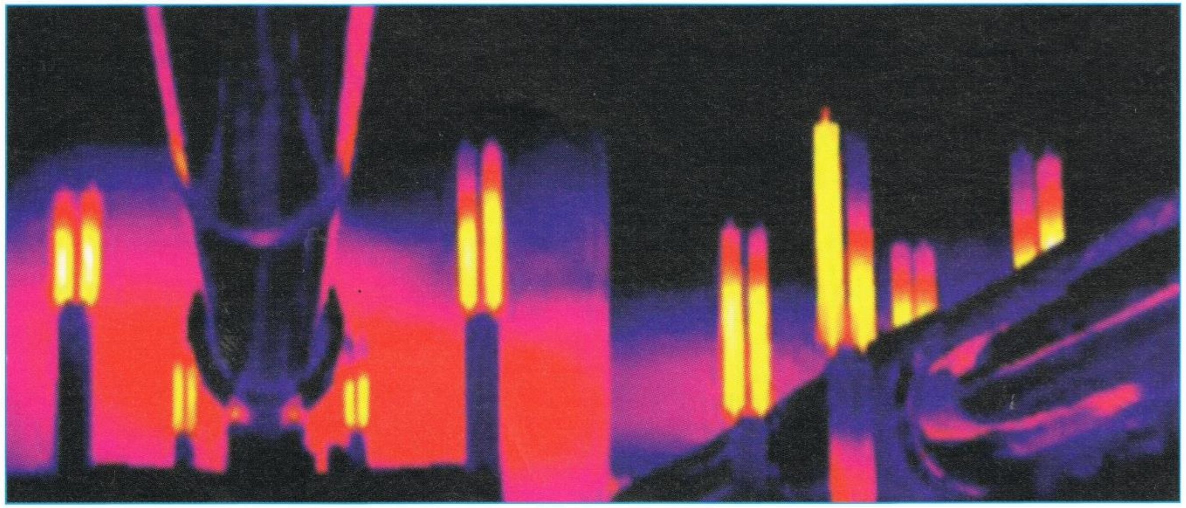


Source: chlodnictwoklimatyzacja.pl
Ł. Adrian

Heat pipe – protection of foundation



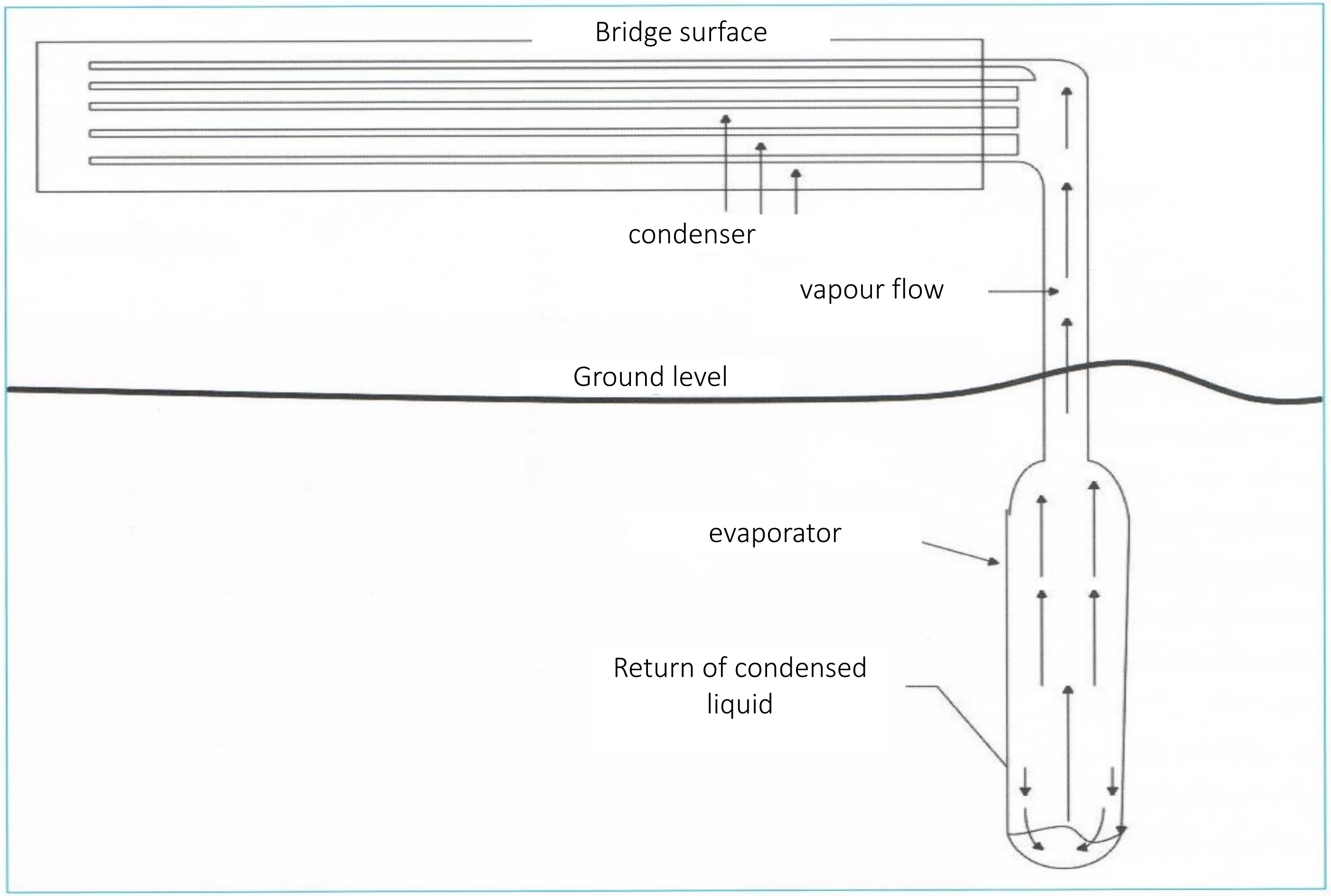
Trans-alaska pipeline



Trans-alaska pipeline

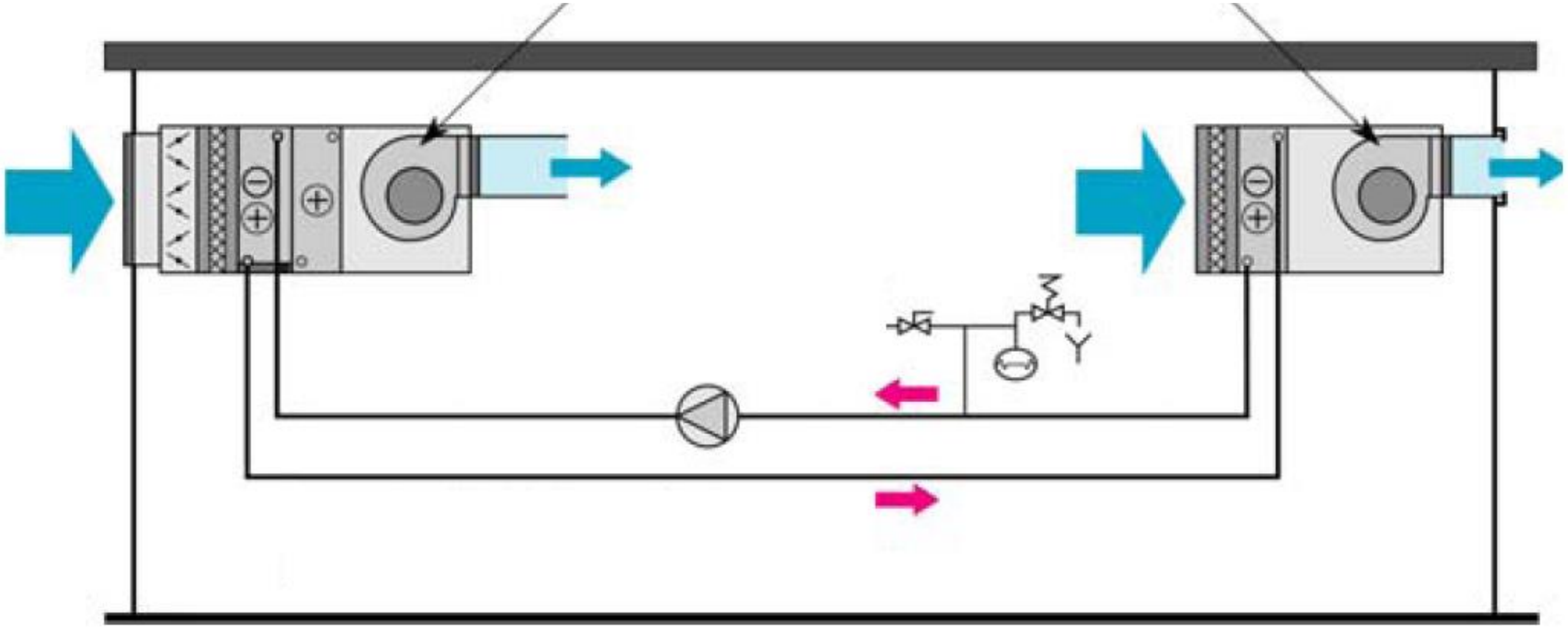
Source: chlodnictwoklimatyzacja.pl
Ł. Adrian

Heat pipe – passive ice protection of bridges



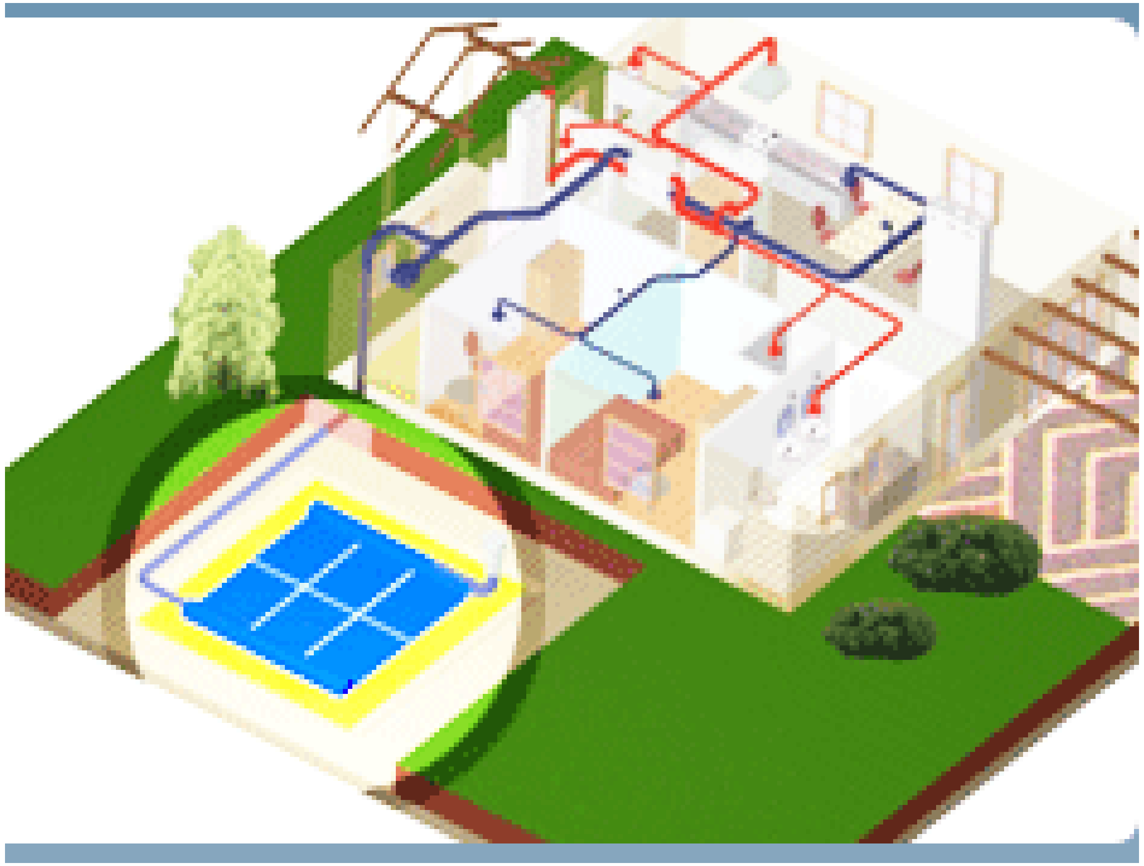
Source: chlodnictwoklimatyzacja.pl

Heat Transfer Fluid (HTF) heat recovery



Source: Frapol

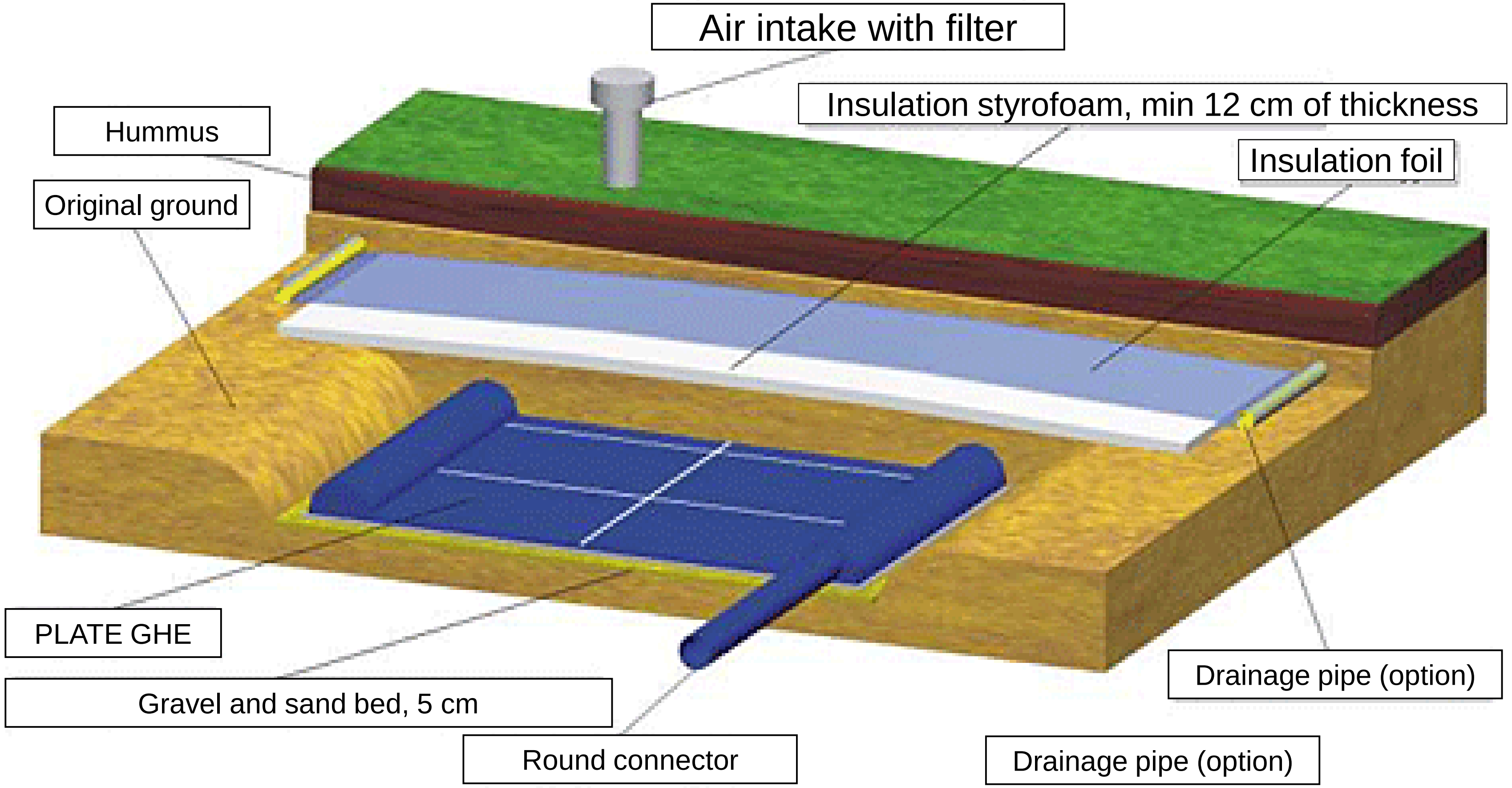
Ground source heat exchanger



Source: provent

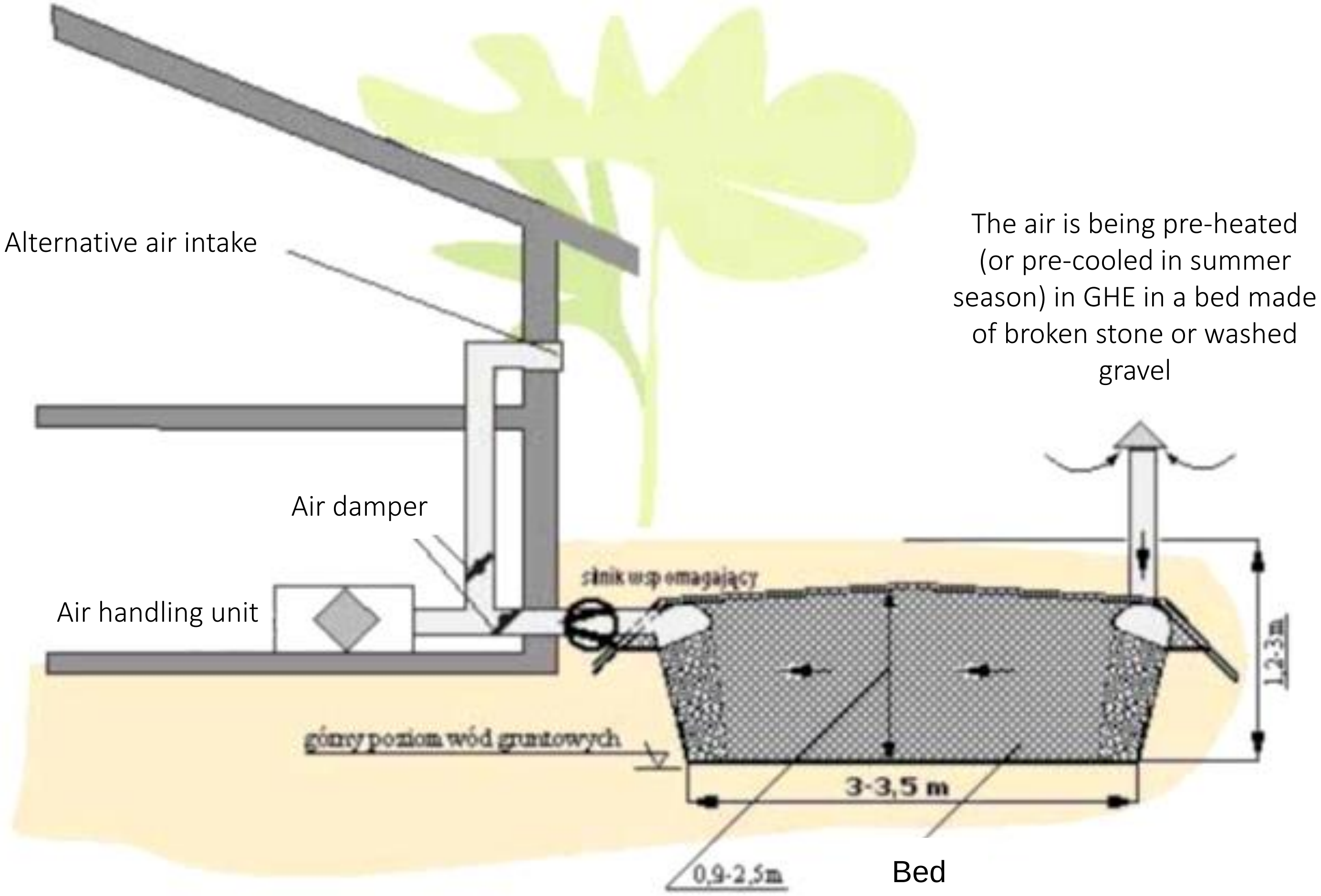
Ground source heat exchanger

Cross-section of provent – geo heat exchanger



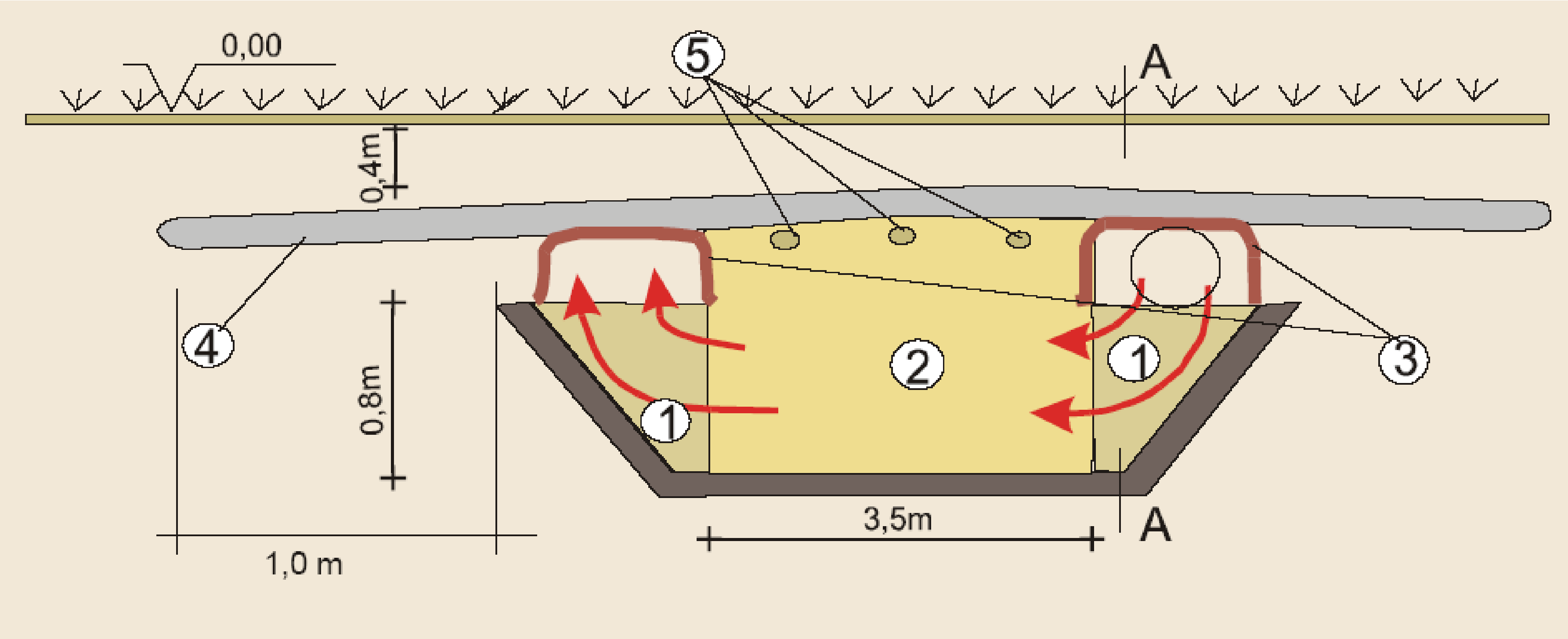
Source: provent

Ground source heat exchanger



Source: instalacje.pl

Ground source heat exchanger – gravel

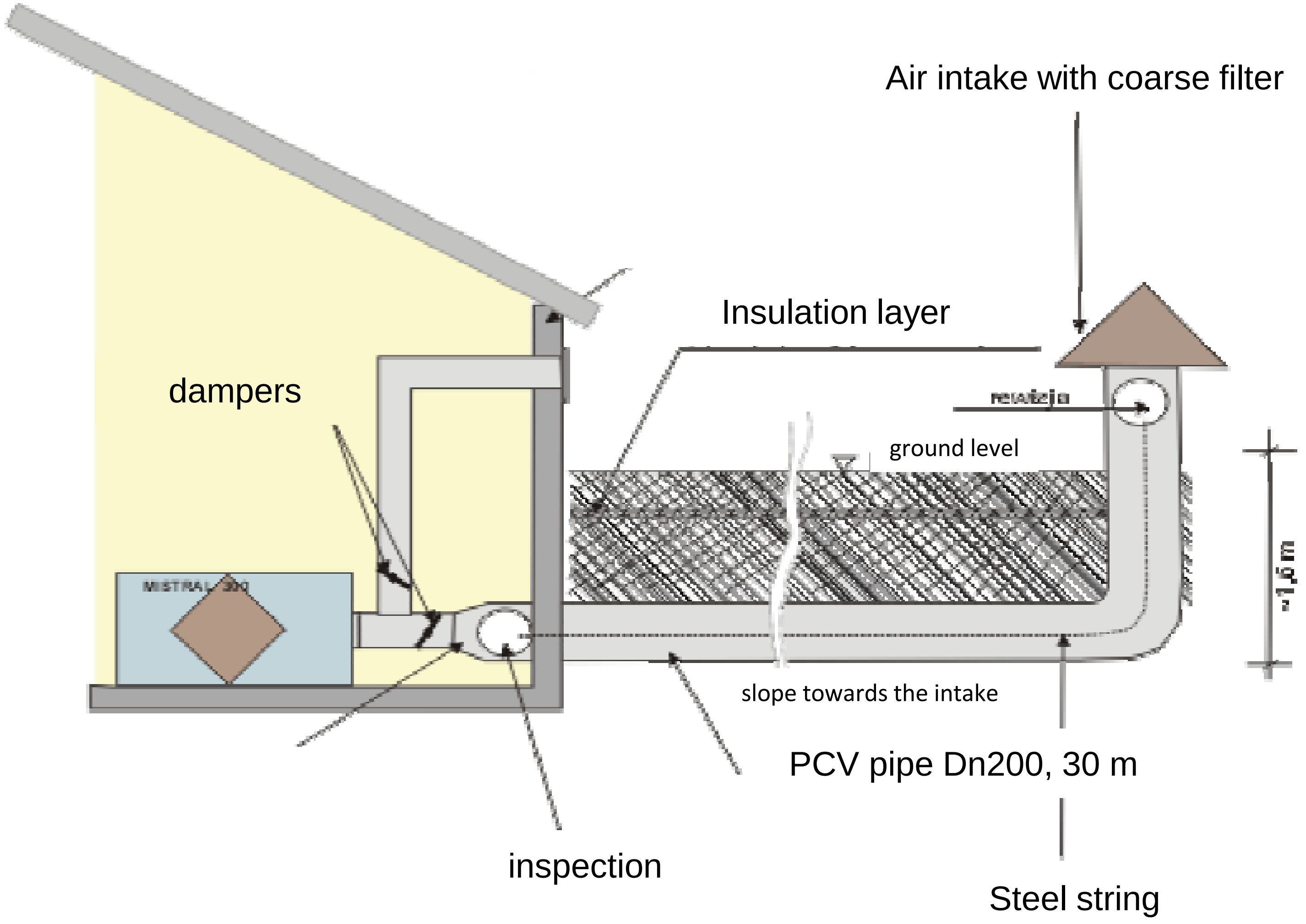


1. Granulated stone 60–90 mm
2. Gravel 30–50 mm
3. Concrete bed
4. Insulation 10 cm
5. Spray tubes

Watch for Radon!

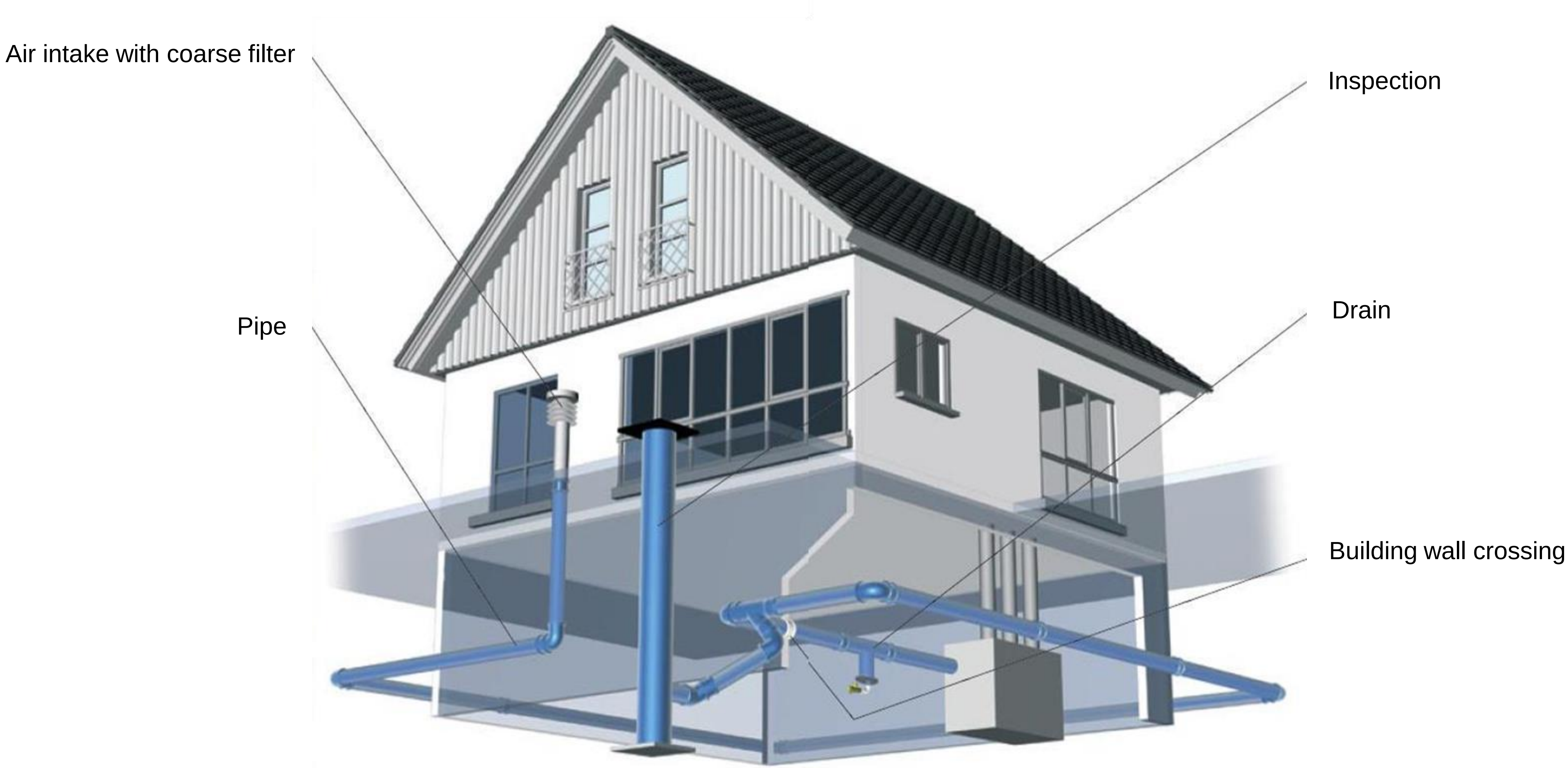
Source: instalacje.pl

Ground source heat exchanger – pipe



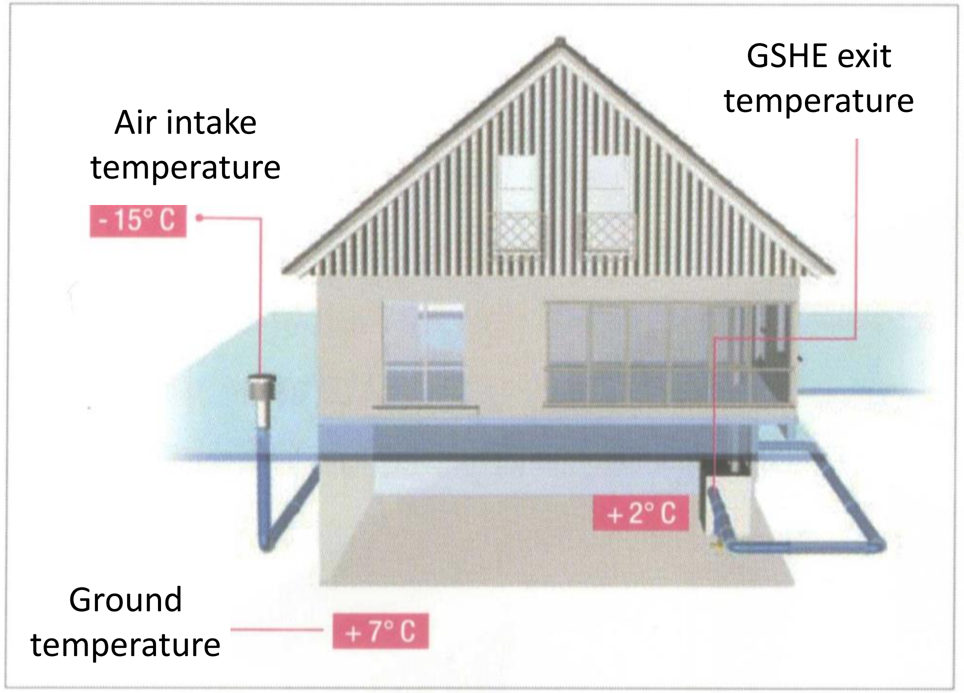
Source: instalacje.pl

Ground source heat exchanger



Source: Rehau

Ground source heat exchanger



Air velocity 1 m/s

Diameter Dn 200

Air flow 120 m^3/h

Heat capacity 680 W

Lenght 70 m

Effect 10 W/mb

Gas furnace, efficiency 90%

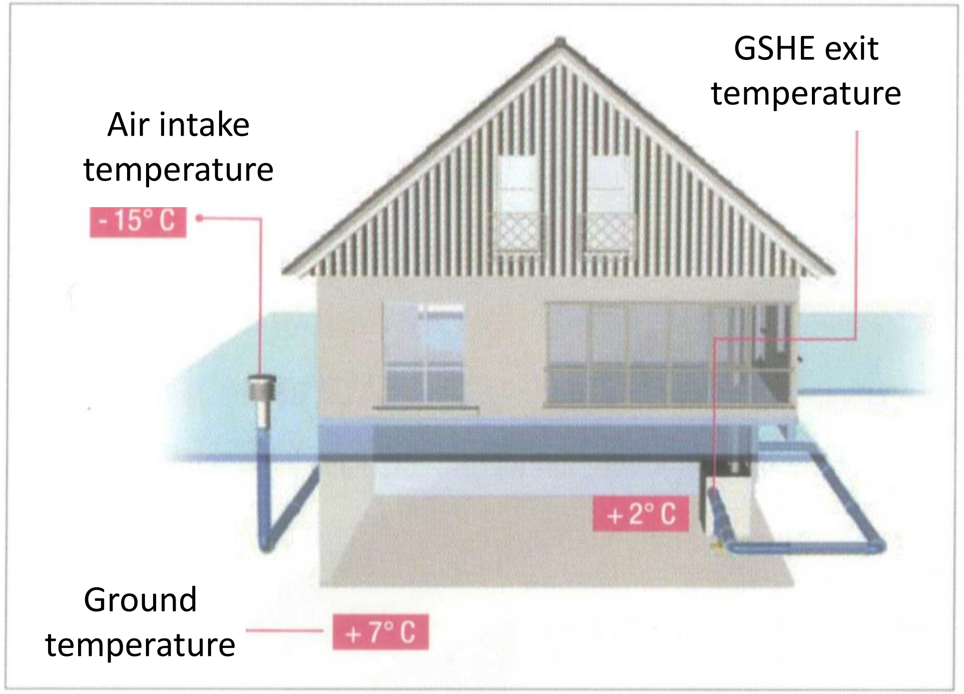
K = 0.176 PLN/kWh

Heat amount in heating season

K = 31.0 kWh/(m^3/h)

G = m*c_p*Dt*5000 h
= 0.04*1.005*17*5328 = **3641kWh**
G*price = 3641*0.176 PLN/kWh = 640 PLN/season
Cost GSHE 15,000 zł
Payback. 23.5 years

Ground source heat exchanger



Air velocity 1 m/s

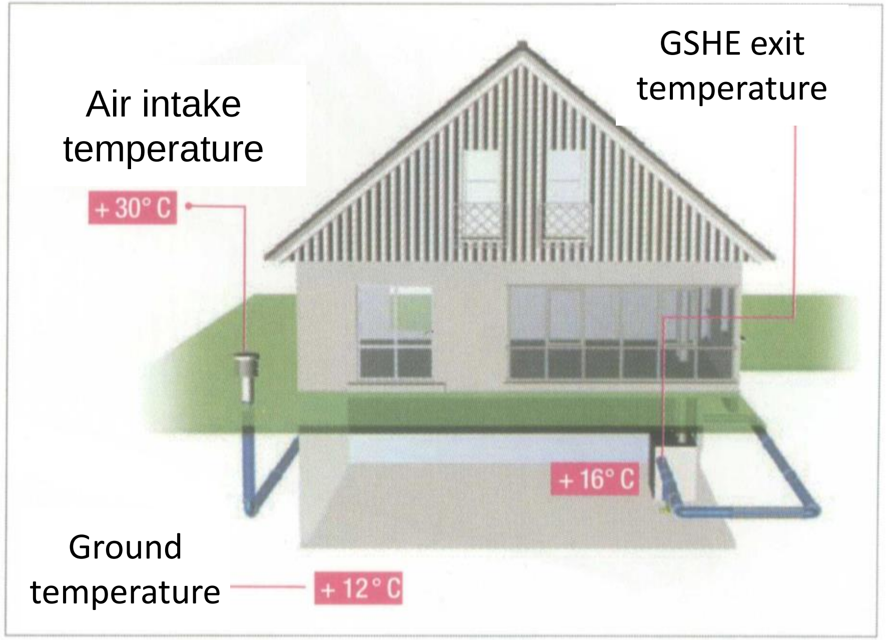
Diameter Dn 200

Air flow 120 m^3/h

Summer operation only

Payback time 27 years

Compared to split system



Source: Rehau

Ground source heat exchanger

Source: Instalacjebudowlane.pl

Commission Regulations

Commission Regulation (EU) No 1253/2014 of 7 July 2014 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for ventilation units.

Commission Delegated Regulation (EU) No 1254/2014 of 11 July 2014 supplementing Directive 2010/30/EU of the European Parliament and of the Council with regard to energy labelling of residential ventilation units.

Commission Regulations

- All systems must have heat recovery.
- The recovery must have a bypass.
- Multi-speed fan (preferably linear control).
- Mandatory indication of filter contamination (from 2018).

Ecodesign

Heat recovery efficiency
Starting January 2018

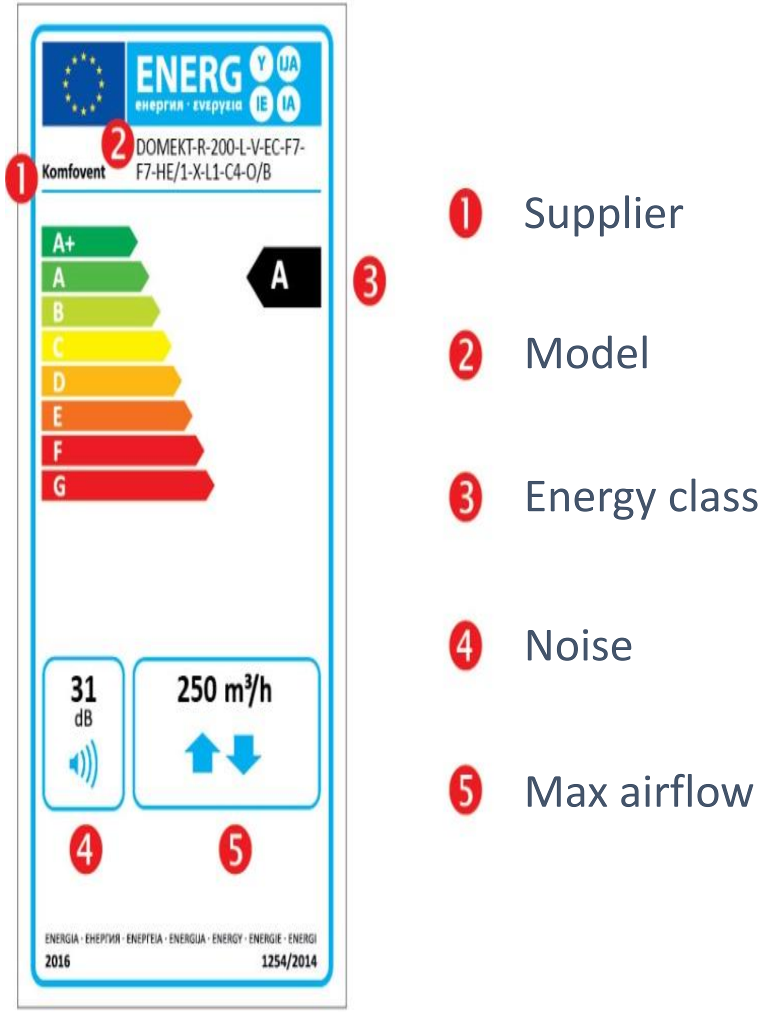
minimum thermal efficiency η_{t_swnm} of all recuperators, except for HTF must be 73% (from 2016 → 67%)

minimum thermal efficiency η_{t_swnm} of all recuperators, must be 68% (from 2016 → 63%)

Directions for residential AHU (SWM)

The obligation to have an energy label

- The label should contain the following information for each producer: supplier's name or trademark, supplier's model designation, energy class, sound power level (LWA) in dB rounded to the nearest whole number, maximum airflow in m^3/h (at 100 Pa).
- By presenting these parameters in an unambiguous way, the devices proposed by different manufacturers can be compared.



Ecodesign

- In addition, the manufacturer of the ventilation unit should prepare a product sheet containing more detailed information about the device, such as thermal efficiency of heat recovery, type of heat recovery system (UOC), unit power consumption (JPM) or annual energy consumption (RZE).

An example of a device card fragment

Supplier's name or trade mark		KOMFOVENT
Model identifier provided by the supplier		DOMEKT-R-250-L-V-EC-F7-F7-HE/1-X-L1-C4-O/B
Specific energy consumption (JZE) given for each climate zone used	kWh/m^2/year	A -83/-39.5/-14.6
Declared type		Two-way
Drive type installed		variable fan speed control system
Type of heat recovery system		regenerative
Efficiency of heat recovery system	%	86
Maximum airflow	m^3/h	285
Fan power consumption at maximum airflow	W	60
Sound power level L_WA	dBA	32
Airflow reference value	m^3/s	0.056
Pressure difference reference value	Pa	50
Unit power consumption	W/(m^3/h)	0.26

Part 5

Cleanroom air conditioning

JAROSŁAW MÜLLER

Cleanrooms

- Introduction
- Standards
- Air handling principles
- Aplications

What is a cleanroom?

- Federal Standard 209E defines a cleanroom as a room in which the concentration of airborne particles is controlled to **specified limits**.

- British Standard 5295 defines a cleanroom as a room with control of particulate contamination, constructed and used in such a way as to minimize the **introduction, generation and retention** of particles inside the room and in which the temperature, humidity, air flow patterns, air motion and pressure are controlled.

- Biotechnology and pharmaceutical cleanrooms are designed to meet current Good Manufacturing Practices (cGMPs).

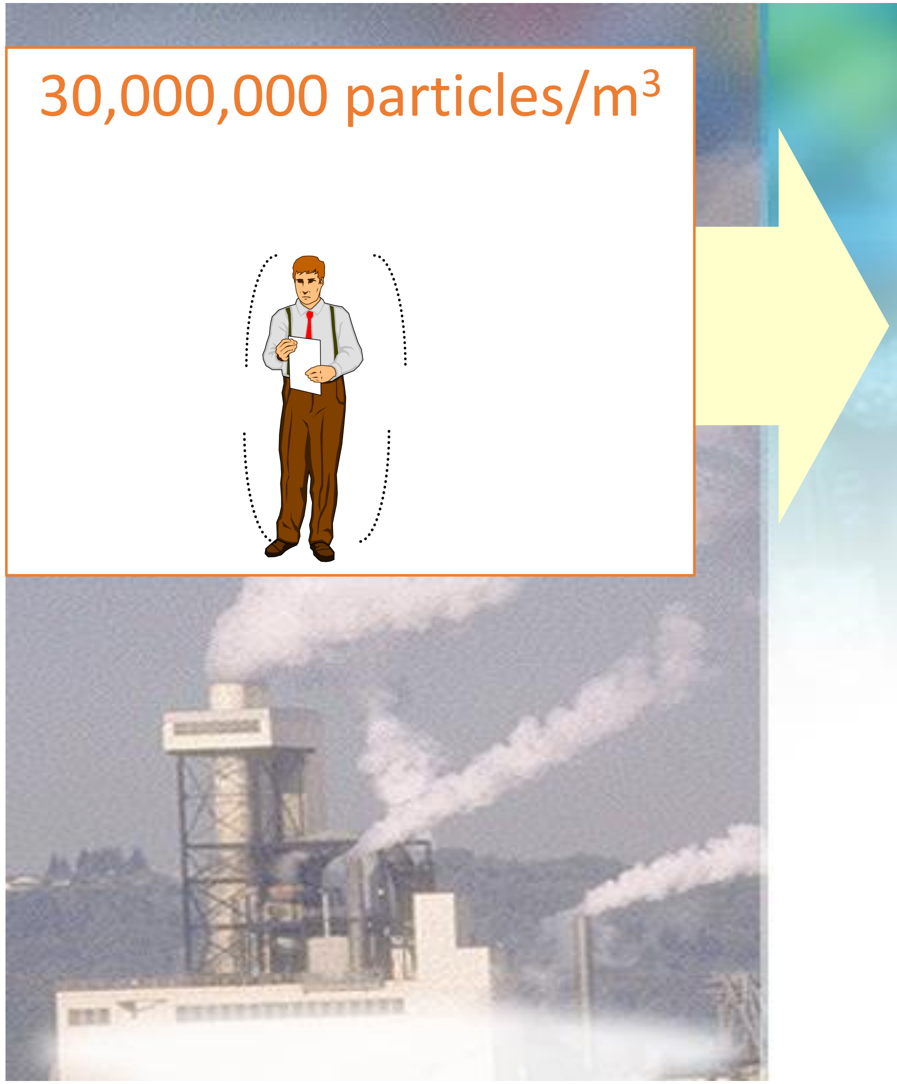
Cleanrooms

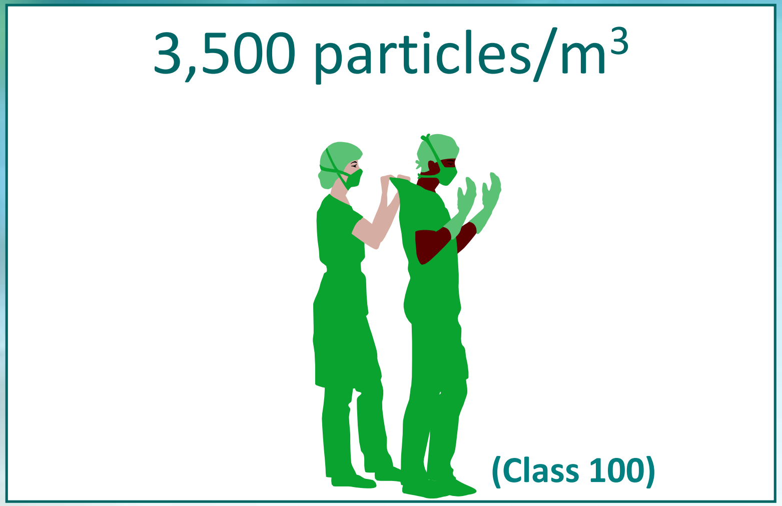
Errors

Pollution

- **mechanical**
  failure reduction
  production increase
- **biological**
  avoiding bacterial infection

Cleanrooms





- **Architecture**
- **Operating**
- **Air conditioniing**
  - **Outdoor air and recirculation**
  - **T and RH%**
  - **Pressure cascade**
  - **Air supply**
  - **Filtration**

Cleanrooms – standards

Number of particles ≥ 0,5 µm/m³	US Fed. Std 1992		EN ISO 14644-1	FRANCE AFNOR NFx44,101 NF x 44,101 1981	CEE Pharma. industry Guide BPF 1997	Number of particles ≥ 0,1µm/m³
	209D	209E				
			ISO 1			10
1						35
4			ISO 2			100
10		M1				350
35	1	M1,5	ISO 3			1 000
100		M2				3 500
353	10	M 2,5	ISO 4			10 000
1 000		M3				35 000
3 530	100	M3,5	ISO 5	4 000	A* et B**	100 000
10 000		M4				350 000
35 300	1000	M4,5	ISO 6			1 000 000
100 000		M5				
353 000	10 000	M5,5	ISO 7	400 000	B*** et C**	
1 000 000		M6				
3 530 000	100 000	M6,5	ISO 8	4 000 000	C*** et D**	

ISO standards

ISO 14644-1: Classification of air cleanliness

ISO/DIS 14644-2: Specifications for testing and monitoring to prove continued compliance with ISO 14644-1

ISO/DIS 14644-3: Test methods

ISO/DIS 14644-4: Design, Construction, and Start-up

ISO/DIS 14644-10: Classification of Surface Cleanliness by Chemical Concentration

Standards and pollutions

Cleanliness class (FS 209 D)	100	10,000	100,000
Separated zones in hospitals	Zone 4 (very high risk)	Zone 3 (high)	Zone 2 (medium)

Note the lack of clear function between particle number and microorganism number.
Classification of cleanrooms does not reflect the cleanliness of the room but rather the effectivness of the air handling system.

ISO/DIS 14698: BIOCONTAMINATION CONTROL
– **14698.1: General principles and methods**
– **14698.2: Evaluation and interpretation of biocontamination data**

TYPICAL APPLICATIONS

<table>
<tr><th></th><th>ISO 3</th><th>ISO 4</th><th>ISO 5</th><th>ISO 6</th><th>ISO 7</th><th>ISO 8</th></tr>
<tr><td></td><td colspan="4">MICRO-ELECTRONICS</td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td colspan="2">CHEMISTRY</td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td colspan="3">AUDIO/VIDEO EQUIPMENT</td><td></td></tr>
<tr><td></td><td></td><td></td><td colspan="4">PHARMACEUTICS/OPERATION ROOMS</td></tr>
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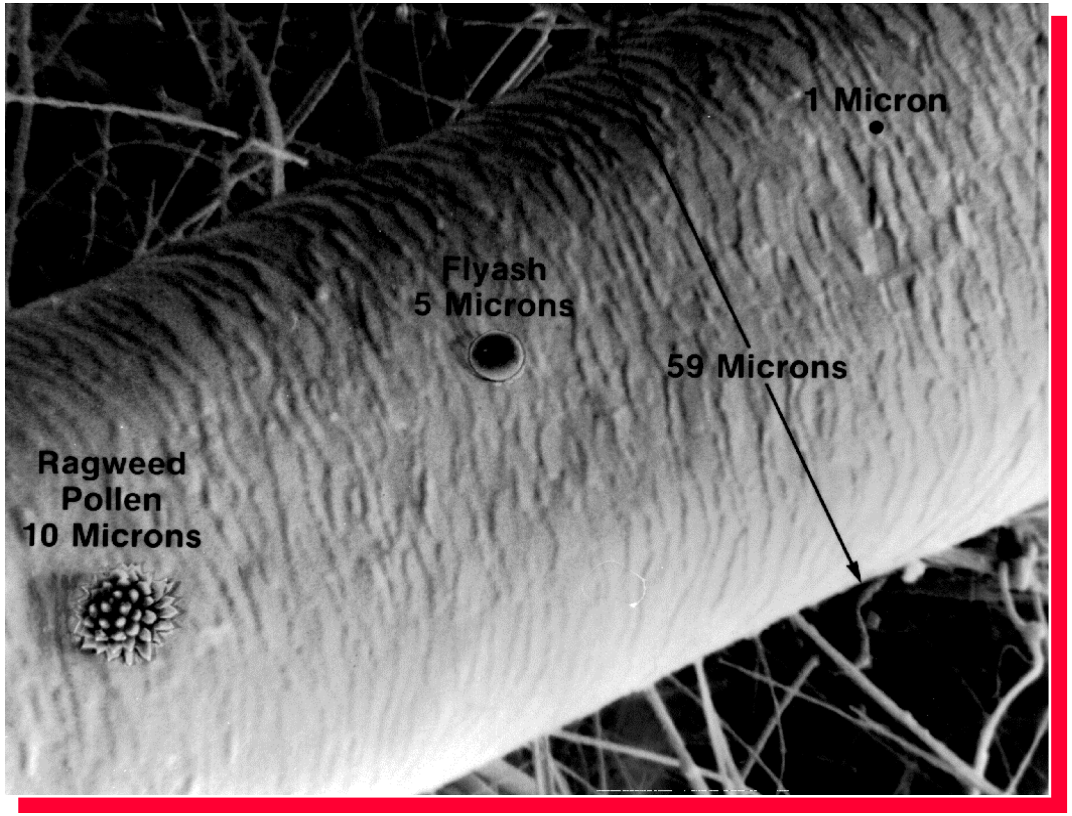
<tr><td></td><td></td><td></td><td></td><td colspan="3">MICRO-MECHANICS</td></tr>
<tr><td></td><td></td><td></td><td></td><td colspan="3">FOOD INDUSTRY</td></tr>
<tr><td></td><td></td><td></td><td></td><td colspan="3">AVIATION INDUSTRY</td></tr>
<tr><td></td><td></td><td></td><td></td><td colspan="3">CAR INDUSTRY</td></tr>
<tr><td></td><td></td><td></td><td></td><td colspan="3">OTHER</td></tr>
</table>

Source: Camfil

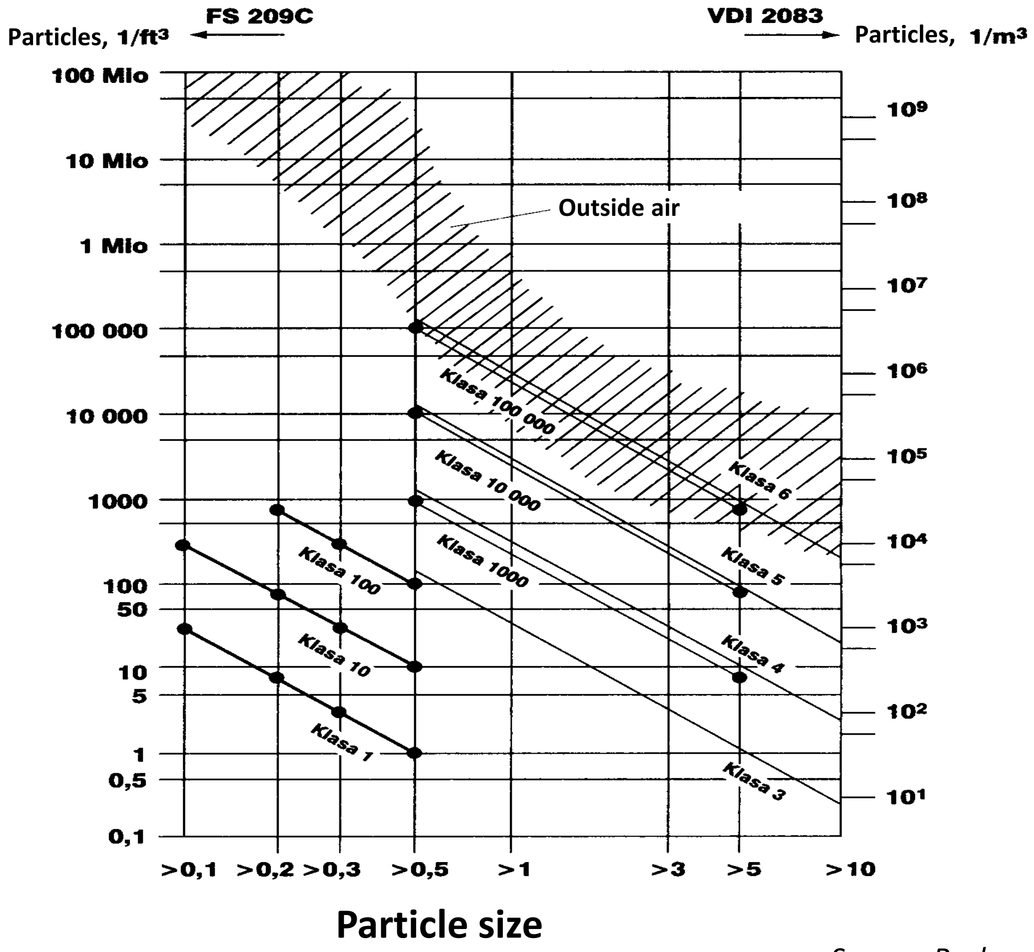
Size of microparticles



Microparticles size: bacteria 0.05 to 10 µm, virus 0.002 to 0.08 µm, Air < 0.008 µm. Naked eye vision > 30 µm

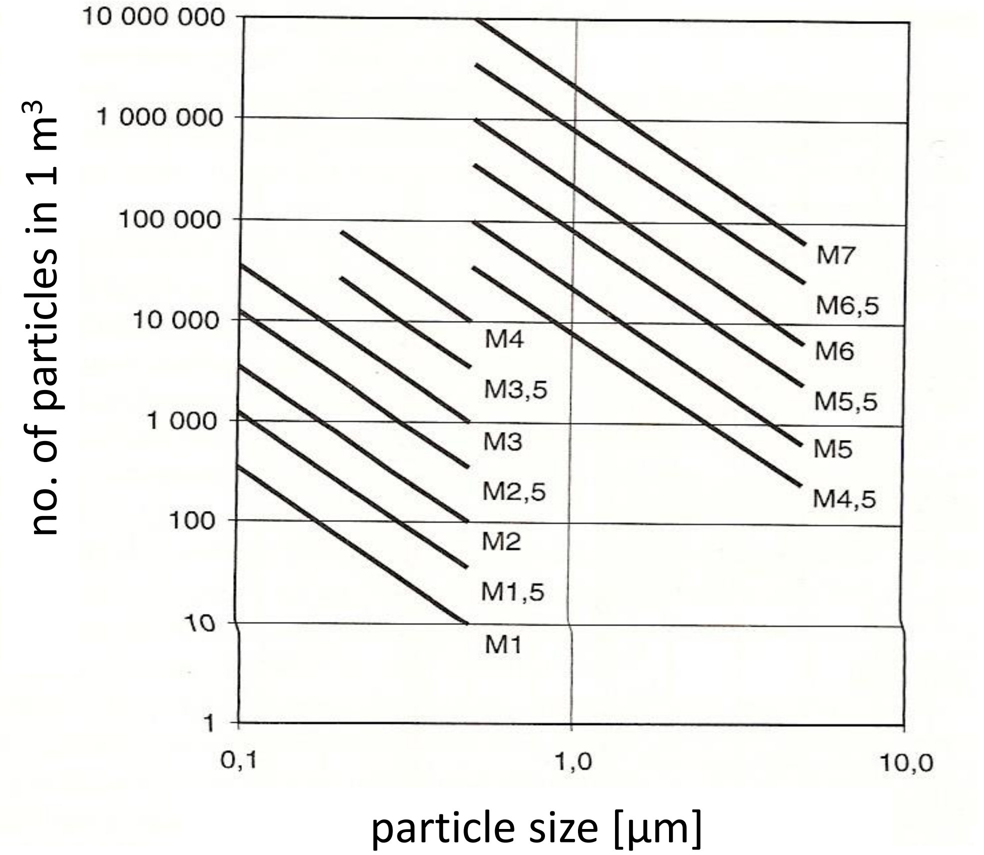
Source: pinterest.com

Outdoor air pollutions and cleanroom class

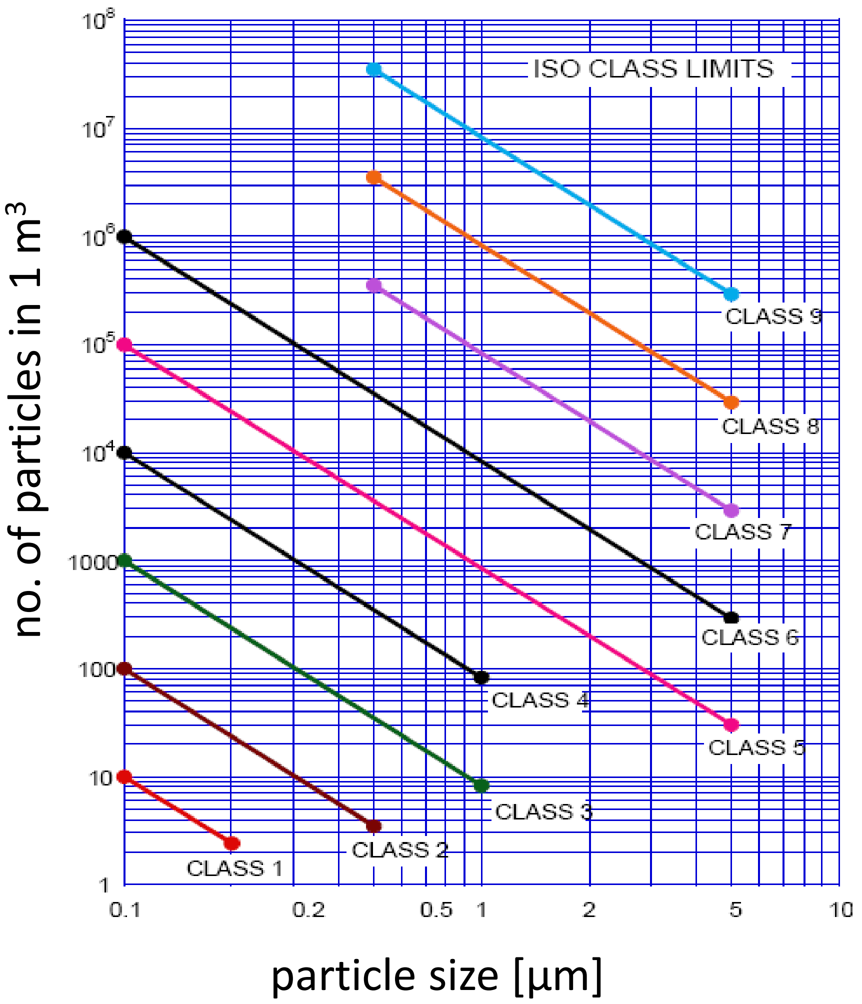


Source: Recknagel

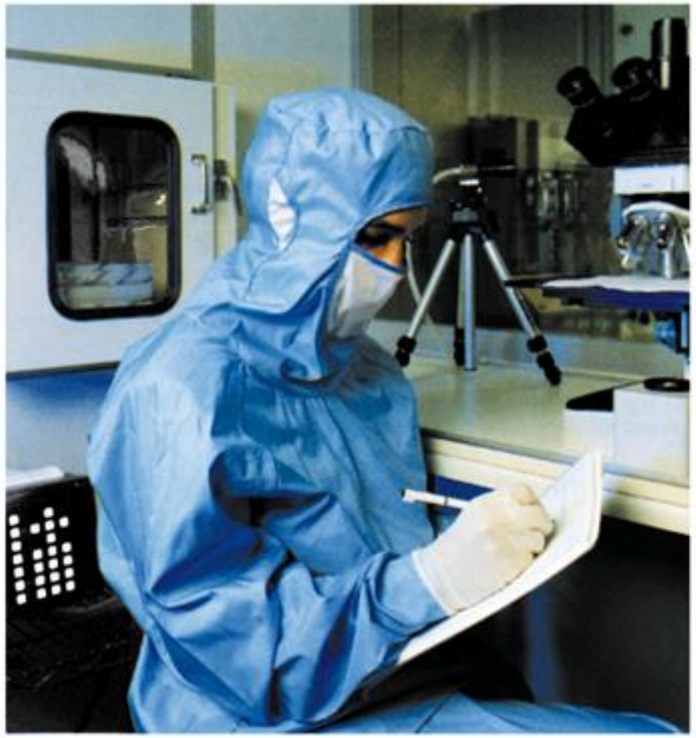
Graphical presentation of cleanroom class according to Federal Standard 209e



Classification of cleanrooms EN ISO 14644-1



Architecture and system operation



ARCHITECTURE

- room
- building

OPERATION

- protective clothing
- maintenance
- training

Recommended air change rate for cleanrooms

Important control precautions include:

1. Walls, floors, ceiling tiles, lighting fixtures, doors, and windows are construction materials that must be carefully selected to meet clean room standards.
2. People must wear appropriate clothing to minimize the release of particles into the space. The type of garment depends on the level of cleanliness required by the industrial process/activity. Smocks, coveralls, gloves, and head and shoe covers are clothing accessories commonly used in clean spaces.
3. Materials and equipment must be cleaned before entering the clean room.
4. Room entrances such as air locks and pass-through are used to maintain pressure differentials and reduce contaminants.
5. Air showers are used to remove contaminants from personnel before entering the clean space.

Cleanrooms

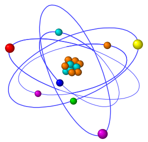
HVAC Design Considerations

Temperature and Humidity

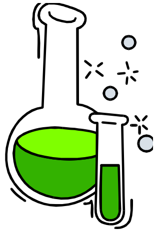
- Most cleanroom require **year-round cooling** as a result of the fan energy associated with high cleanroom airflow as well as the heat generated by the process, people, and lighting within the facility. Temperature control is required to provide **stable conditions** for materials, instruments, and personnel comfort. Human comfort requirements typically call for temperatures in the range of 22 to 24°C, since workers frequently wear cleanroom garments over street clothes.
- Humidity control is necessary to prevent corrosion, condensation on work surfaces, eliminate static electricity, and provide personnel comfort. The human comfort zone is generally in the range of 30 to 70% relative humidity.
- Both temperature and humidity are controlled with alarm signals recorded.

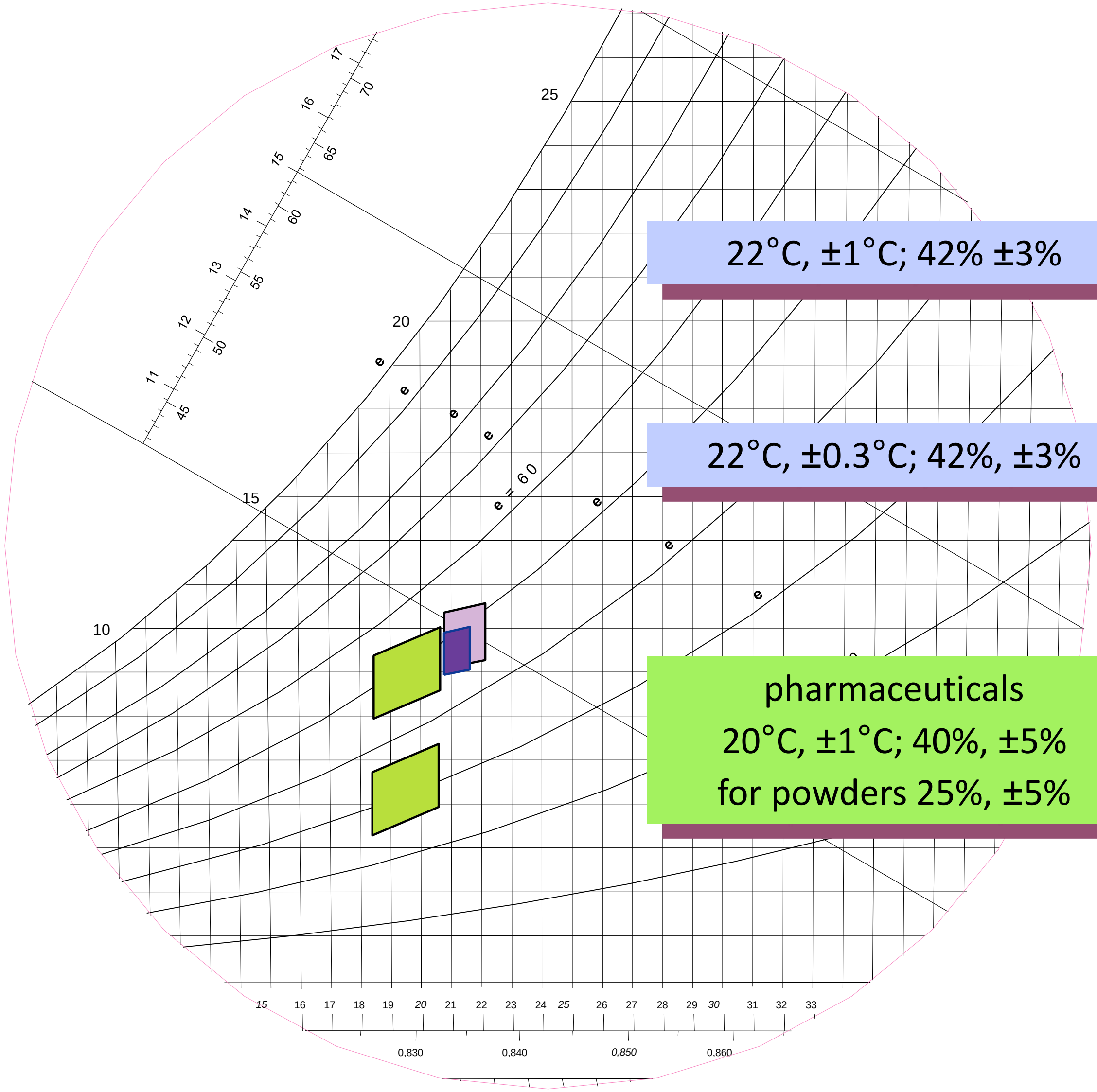
T° i RH%

Micro-electronics



Pharmaceutical industry





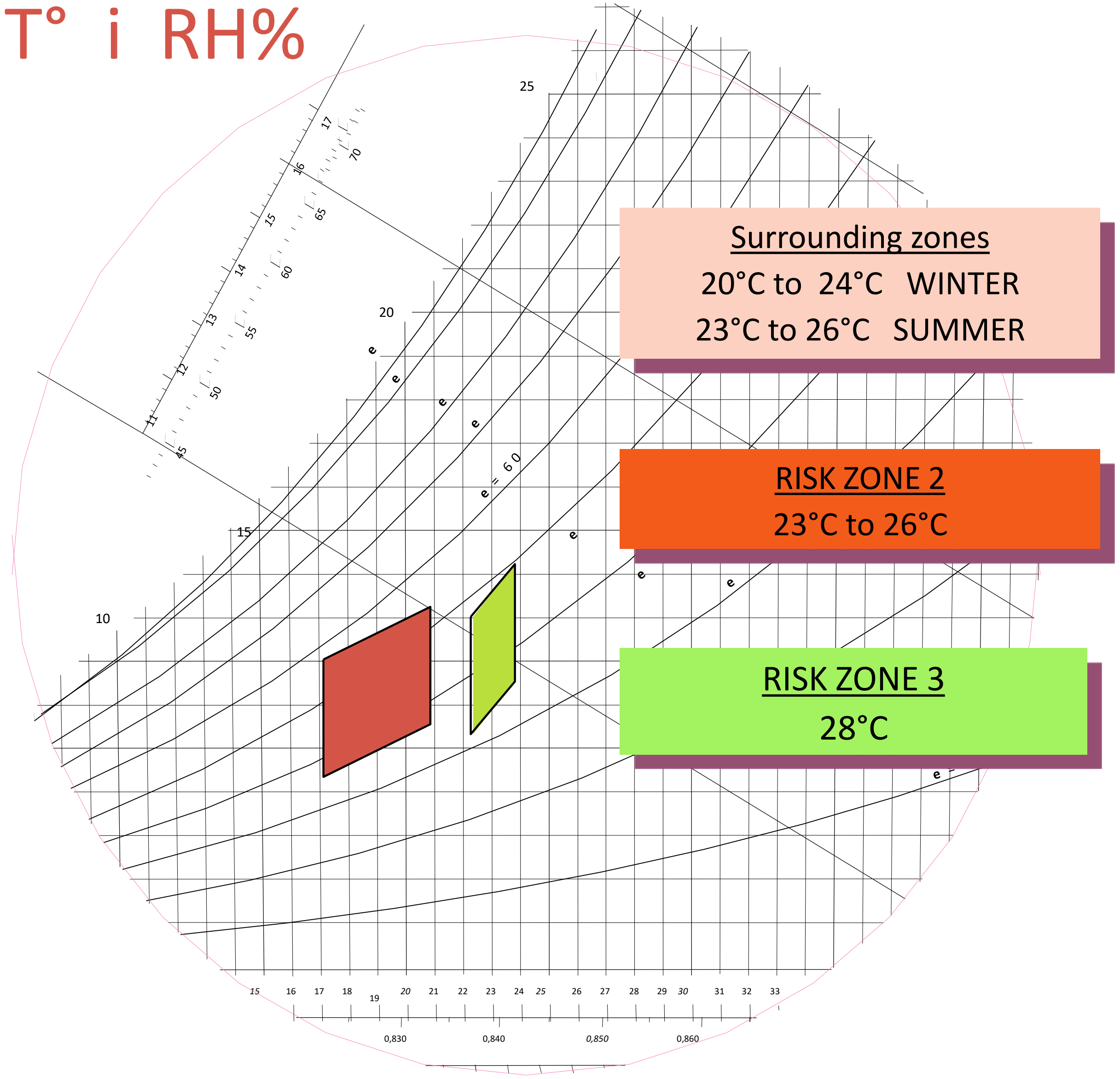
22°C, ±1°C; 42% ±3%

22°C, ±0.3°C; 42%, ±3%

pharmaceuticals
20°C, ±1°C; 40%, ±5%
for powders 25%, ±5%

T° i RH%

HOSPITALS



RH: 40 to 60%

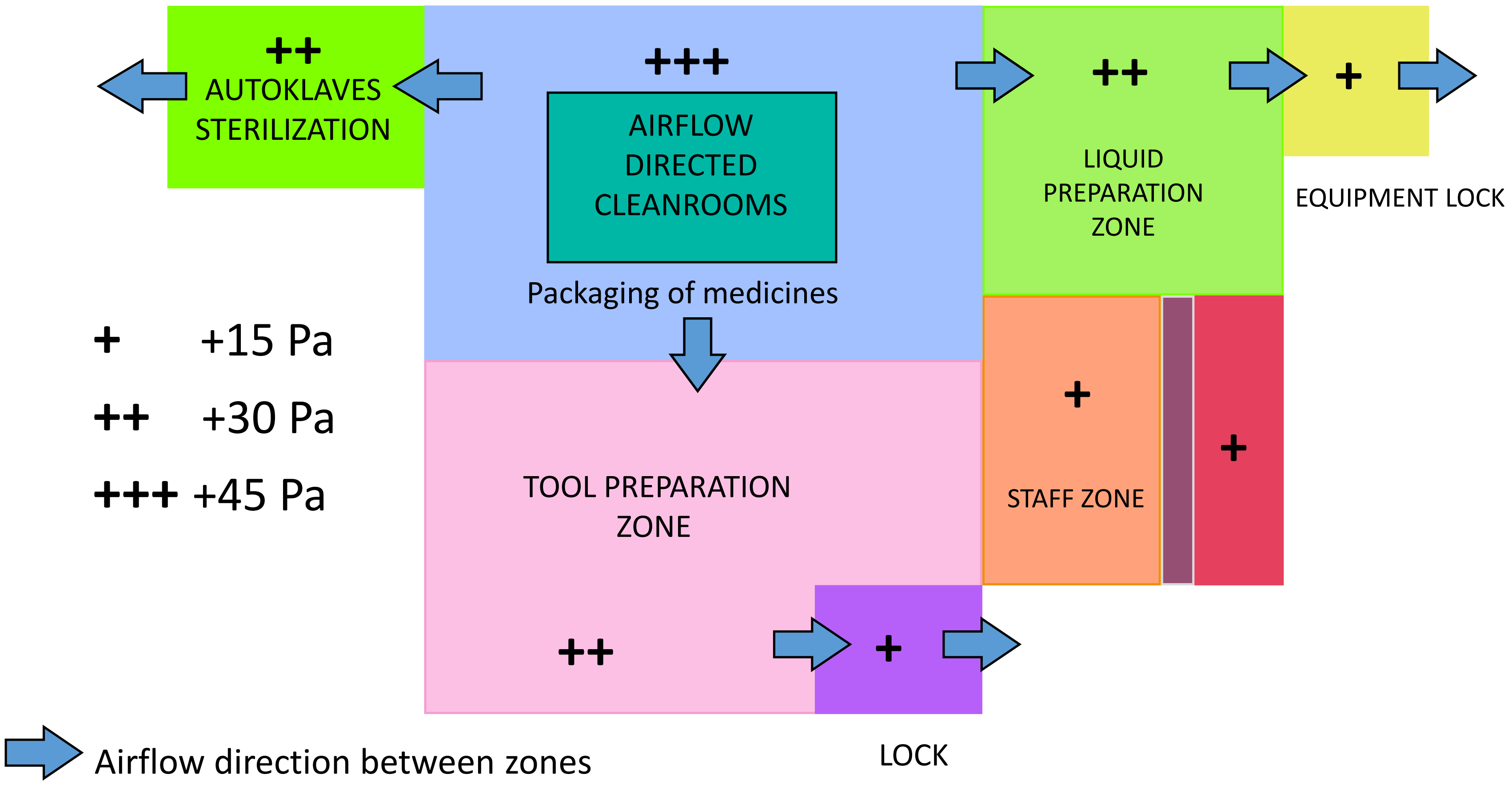
- **COMFORT**
- **CONDENSATION PREVENTION**

HVAC Design Considerations

Pressurization

A cleanroom facility may consist of multiple rooms with different requirements for contamination control. Rooms in a clean facility should be maintained at static pressures higher than atmospheric to prevent infiltration by wind. Positive differential pressures should be maintained between the rooms to ensure air flows from the cleanest space to the least clean space. The only exception to using a positive differential pressure is when dealing with specific hazardous materials where the room is required to be at a negative pressure. In high precision rooms the control system must be responsive enough to maintain the differential pressure when doors are opened.

Pressurization

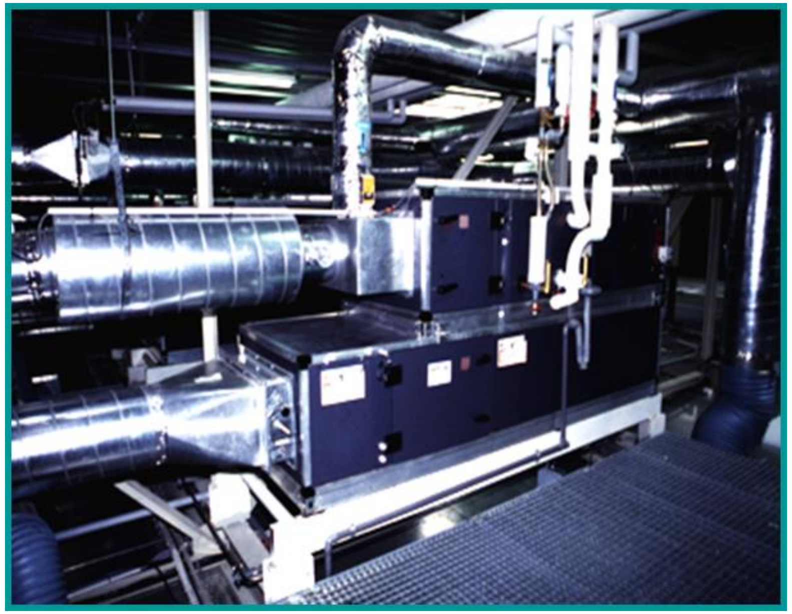


Airflow direction between zones
Preventing from pollution inflow
Avoiding infection spread

HVAC Design Considerations

Ventilation and Air Handling

Ventilation and air handling are dictated by the amount required to maintain indoor air quality, replace process exhaust and for building pressurization. This provides assurance that carbon dioxide and oxygen remain in balance, that formaldehyde and other vapours given off by building materials and furniture are diluted, and that air changes occur with sufficient frequency to minimize the chance for high concentration of airborne pollutants within the building.

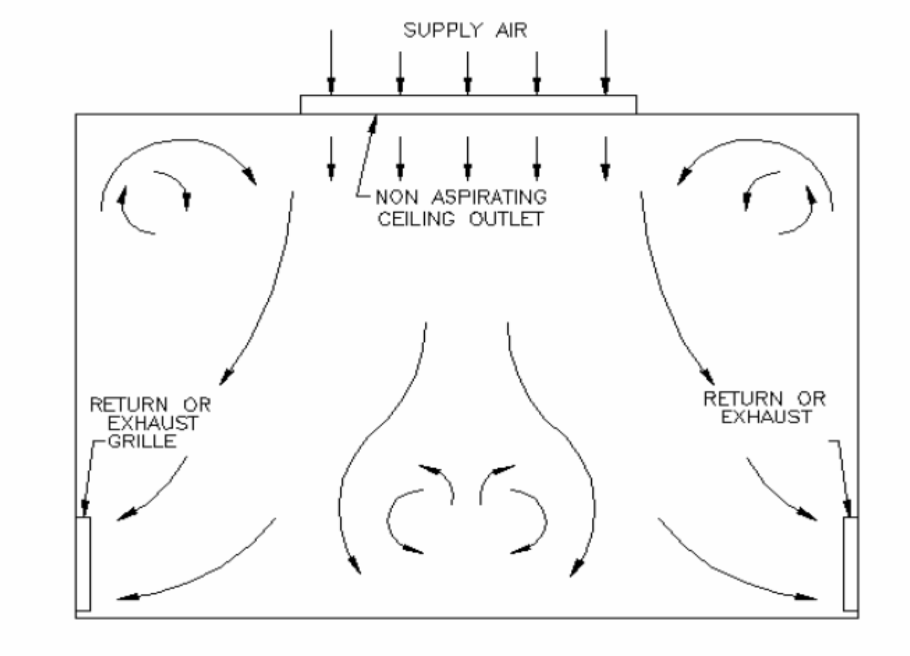


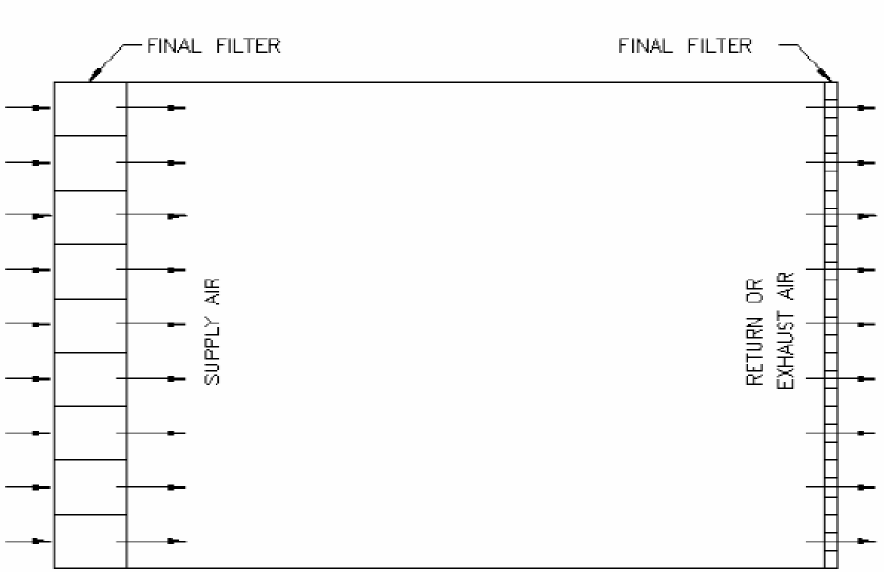
Air handling principles:

- Recirculation and outdoor air
- T [°C]   i   RH [%]
- pressure cascade
- filtration
- air supply
- heat recovery

Architecture and system operation

Cleanrooms have evolved into two major types which are differentiated by their method of ventilation. These are turbulent air flow and laminar air flow cleanrooms.

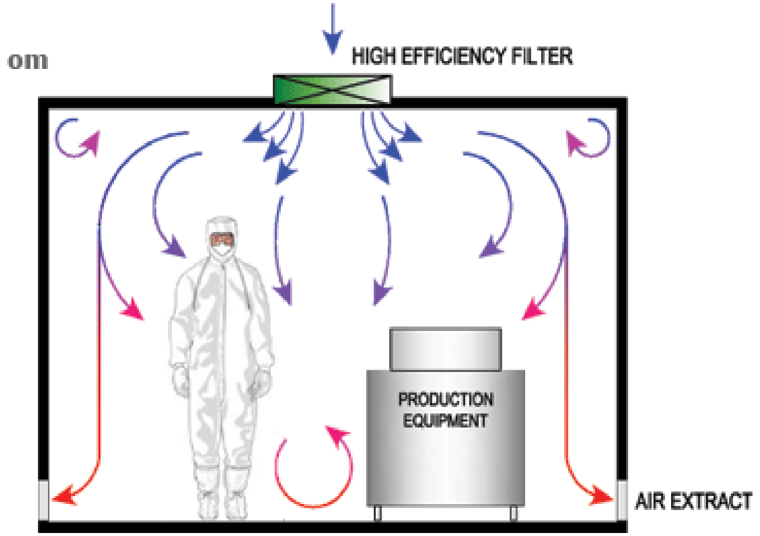




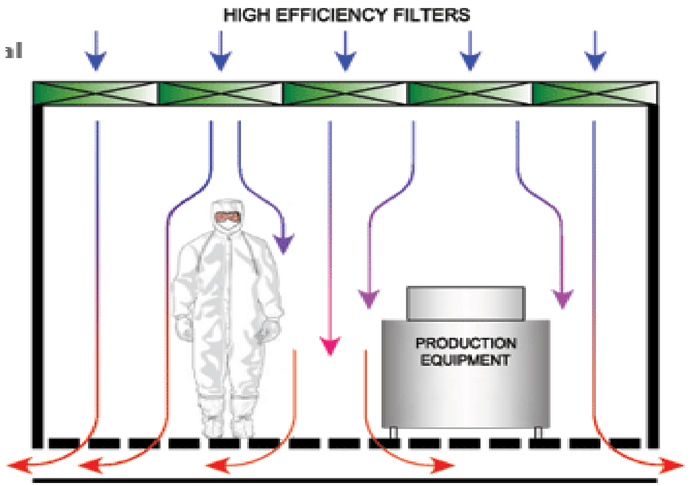
Tunnel or vertical

Architecture and system operation

Risk of draft
Mixing and diluting
the pollution



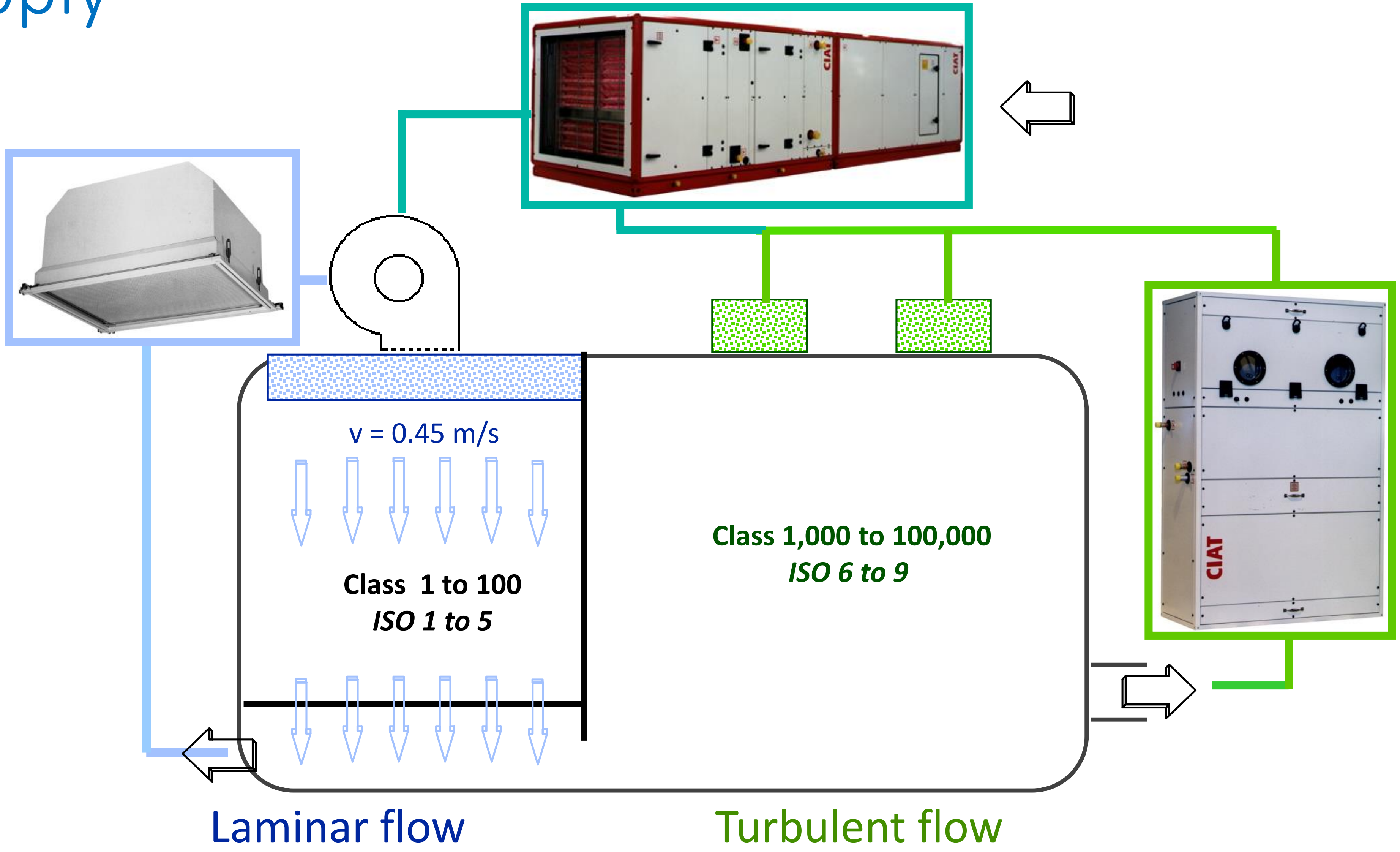
0.45 m/s
High air change rates



Particles of different sizes behave differently as air moves through a room. For example, in an 2.4 m high room, a particle in the 50 micron range might take 60 seconds to settle, while a 1 micron particle might take 15 hours to settle. Particles larger than 5 microns tend to settle quickly unless air blown.

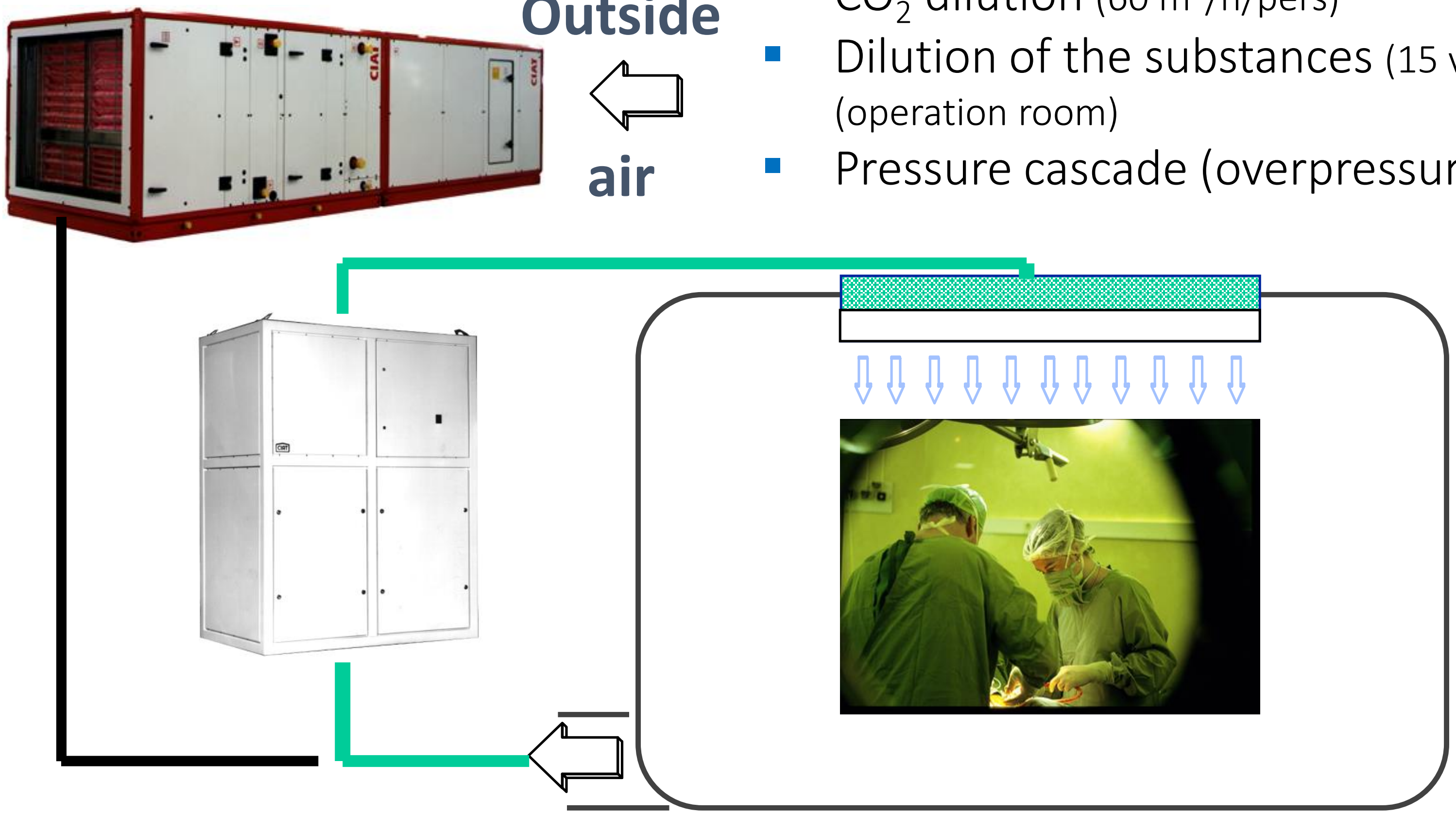
Source: spaceindustries.co.uk

Air supply



v = 0.45 m/s
Class 1 to 100
ISO 1 to 5
Class 1,000 to 100,000
ISO 6 to 9
CIAT
Laminar flow
Turbulent flow

- CO_2 dilution (60 m^3/h/pers)
- Dilution of the substances (15 vol/h) (operation room)
- Pressure cascade (overpressure)



Recirculated air

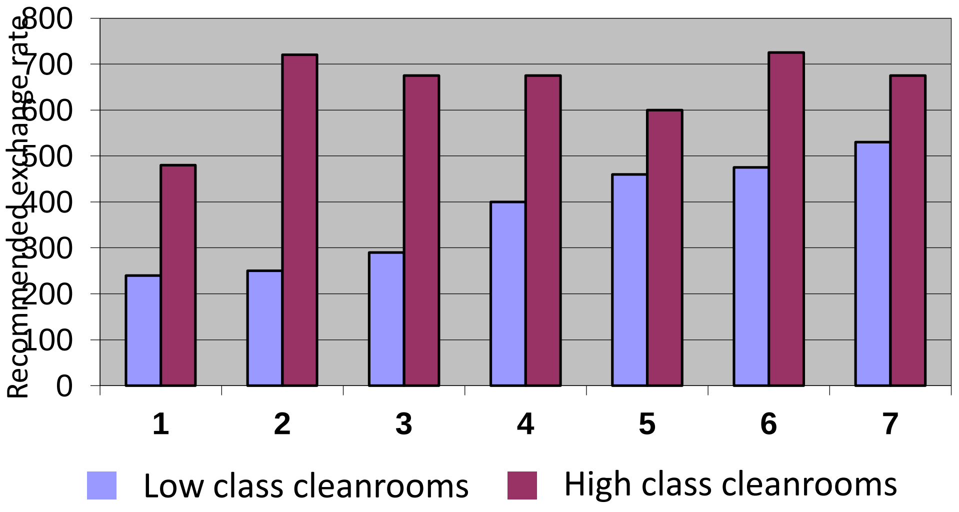
US Fed Std 209D	EN ISO 14644-1	RE-CIRCULATION RATE
1	3	> 600
10	4	600
100	5	200 to 600
1 000	6	50 to 100
10 000	7	30 to 50
100 000	8	15 to 30

Outside air

The amount of outside air required is a function of:

- Equipment exhausts and exhaust through toilets/kitchen/pantry/battery rooms etc.
- Leakage through pass through, conveyor openings, strip curtains, air locks, door undercuts etc.
- Duct leakage, wall and ceiling leakages.
- Level of positive pressurization required.

Recommended exchange rate for cleanrooms



1. IEST Considerations in Cleanroom Design (IEST RP-CC012.1)
2. Raymond Schneider, Practical Cleanroom Design
3. Cleanrooms equipment supplier
4. Faulkner, Fisk and Walton, “Energy Management in Semiconductor Cleanrooms”
5. California-based designer and cleanrooms instructor
6. Federal Standard 209B (superseded by ISO/DIS 14644)
7. National Environment Balancing Bureau, “Procedural Standards for Certified Testing of Cleanrooms”, 1996

Recommended air change rate for cleanrooms

Human occupants are the **primary source** of internal contamination. Once a cleanroom is vacated, lower air changes per hour to maintain cleanliness are possible allowing for setback of the air handling systems. Setback of the air handling system fans can be achieved by manual setback, timed setback, use of occupancy sensors, or by monitoring particle counts and controlling airflow based upon actual cleanliness levels.

Particle emission of people in cleanrooms

Emission particles/min	Activity
100,000	Stillness in sitting or standing position
500,000	Sitting position – slight movements of the head, the hand or forearm
1,000,000	Sitting position – average body movement
2,500,000	Standing up with full body movemet arms and legs
5,000,000	Slow walking about 3.5 km/h
7,500,000	Walking about 6 km/h
15,000,000–30,000,000	Slow excercises, sport games

Filtration

WHITBY 's

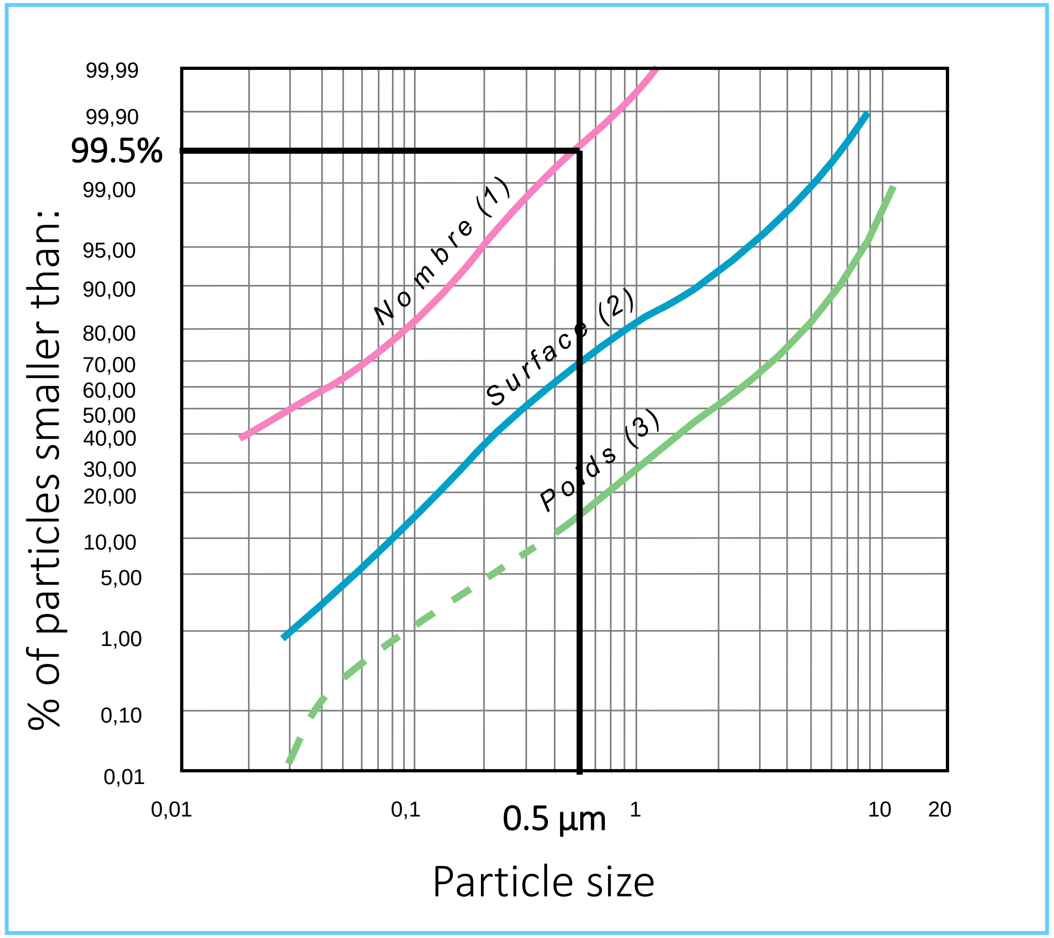
Diagram

99.5%

Particles in air

are smaller than 0.5 µm

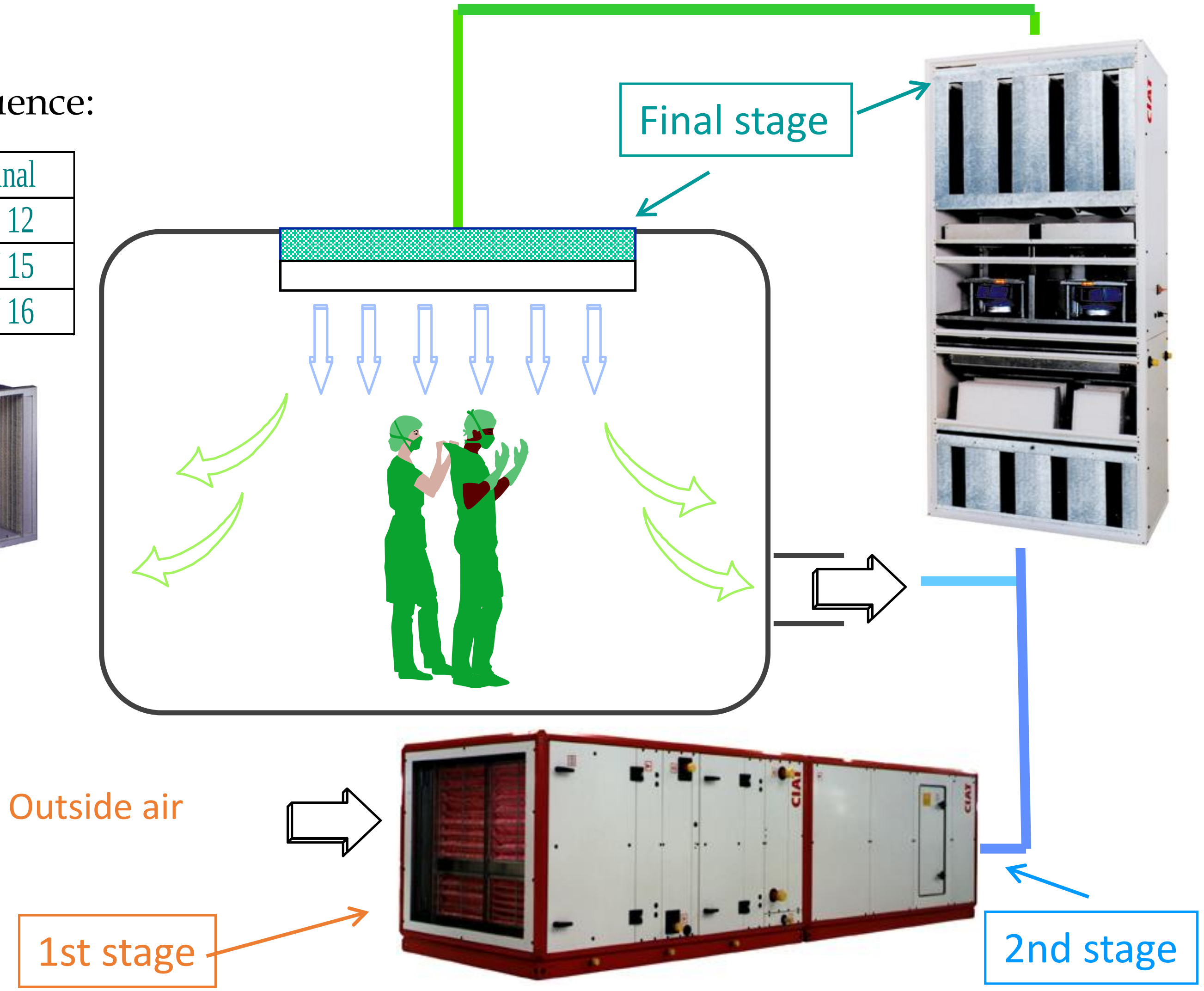
Distribution of particles in atmospheric air



Filtration sequence

Example of filtration sequence:

Class	1st	2nd	Final
10 000 / ISO 7	G 4 + F 7	F 9	H 12
1 000 / ISO 6	F 7	H 10	U 15
100 / ISO 5	F 9	H 12	U 16



Efficiency comparision Pre filtration – 1st stage

Particles	1 µm			0,5 µm		
filter type	Efficiency	Penetration	Cleaning effect	Efficiency	Penetration	Cleaning effect
90% GRAVI (G4)	10%	90%	1,1	5%	95%	1,05
50% OPACI (F5)	30%	70%	1,4	10%	90%	1,1
65% OPACI (F6)	45%	55%	1,8	25%	75%	1,3
85% OPACI (F7)	85%	15%	6,6	70%	30%	3,3
95% OPACI (F8/9)	95%	5%	20	90%	10%	10

Pre filtration must be at least F7

(G4 is unsufficient)

Air does not support microorganisms – particles do so

Efficiency comparision High efficiency filters

Class EN 1822	Efficiency MPPS	Cleaning efficiency
H 10	85%	6.7
H 11	95%	20
H 12	99.5%	200
H 13	99.95%	2,000
H 14	99.995%	20,000
U 15	99.9995%	200,000
U 16	99.99995%	2,000,000
U 17	99.999995%	20,000,000

AHU

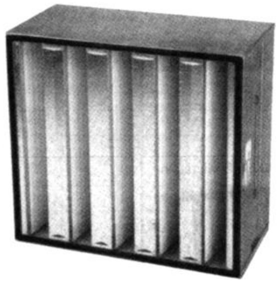
End – filter

H: H.E.P.A.: High efficiency particulate air filter

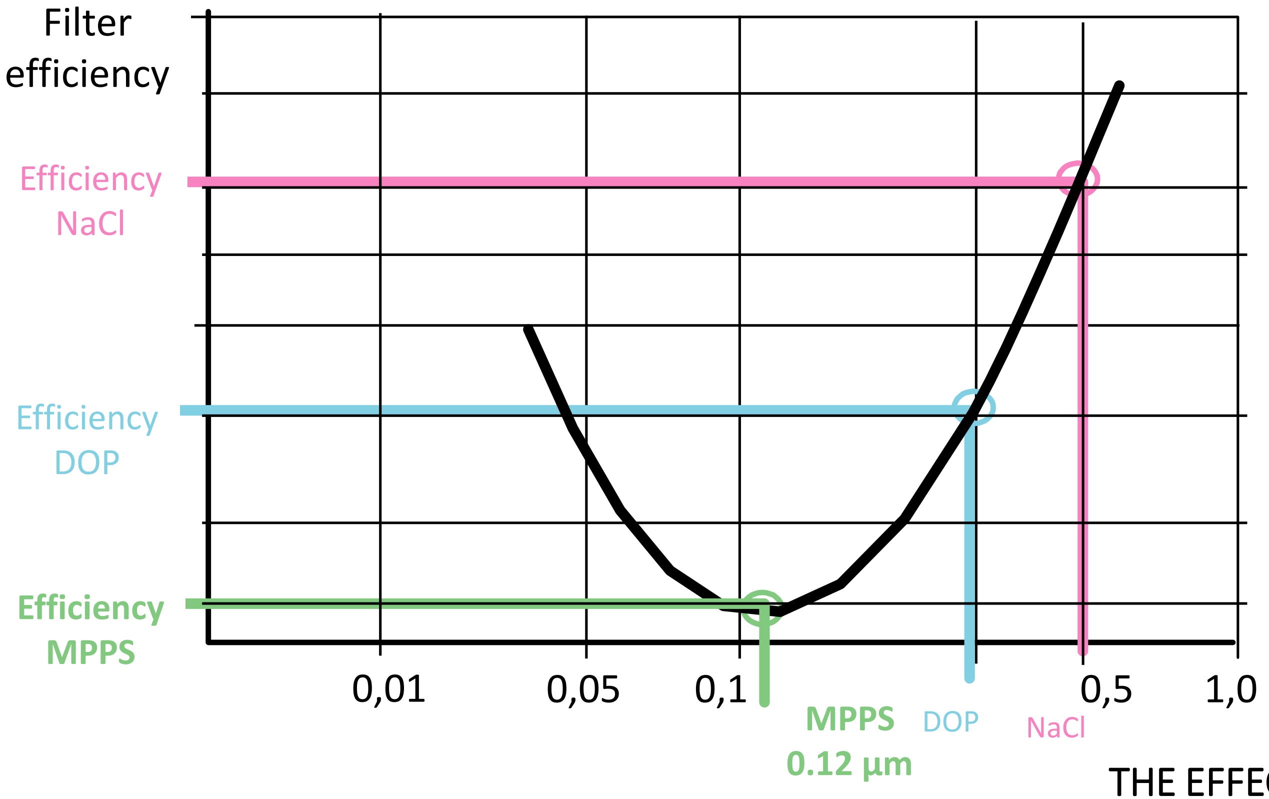
U: U.L.P.A.: Ultra low penetration air filter

Efficiency = concentration before/concentration after

M.P.P.S.: Most Penetrating Particle Size

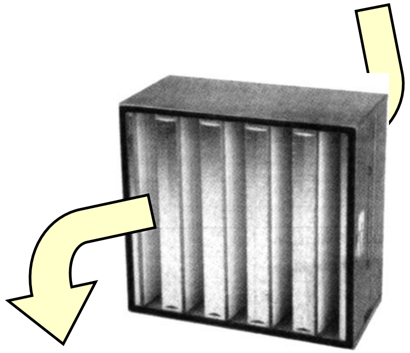


Efficiency M.P.P.S. (for HEPA and ULPA filters)



M.P.P.S.

Most Penetrating Particle Size



THE EFFECTS ON THE FILTER

- Direct penetration
- Accumulation of particles
- Diffusion penetration

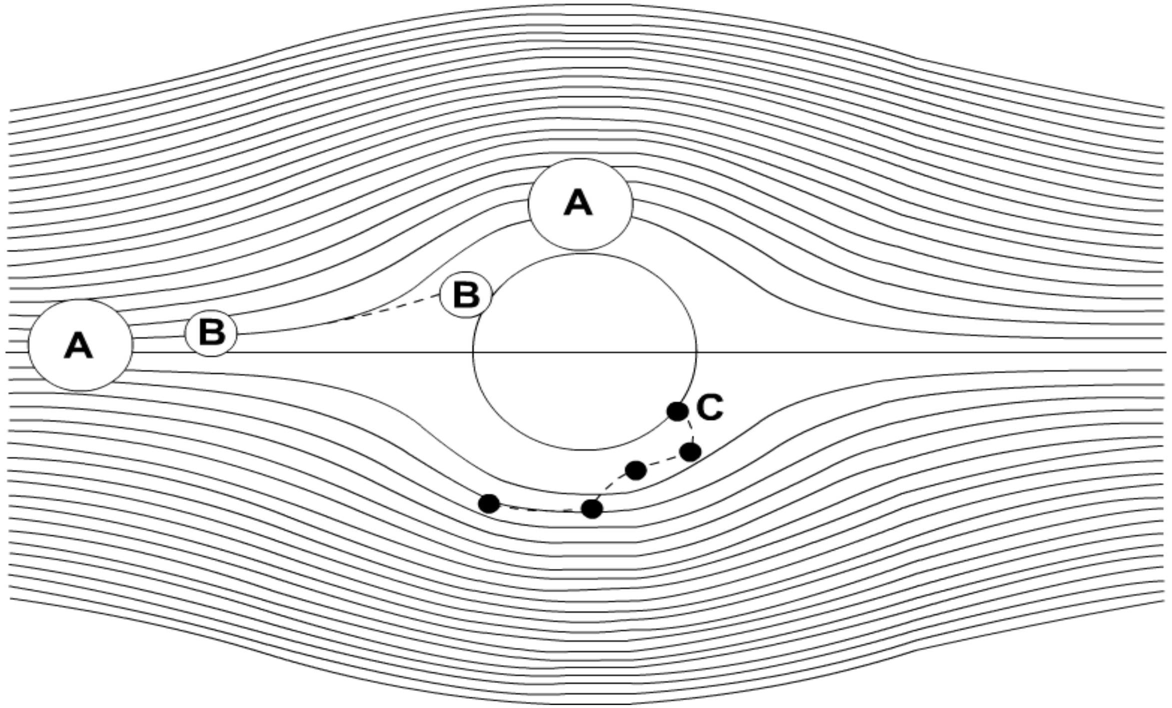
Comparison of filter classification

Country	Poland		Germany	Europe	USA
Standard	PN-B-76003	PN-EN 779 PN-EN 1822-1	DIN 24 185 DIN 24 183 DIN 24 184	EN 779 EN 1822-1	ASHRAE 52.2-1999
Pre-filters (Coarse)	A1 A2	G1	EU1	G1	MERV 1
Medium filters	B1	G2	EU2	G2	MERV 2 – MERV4
	B2	G3	EU3	G3	MERV 5 – MERV 6
		G4	EU4	G4	MERV 7 – MERV 8
Medium Filters	C	M5	EU5	F5	MERV 9 – MERV 10
		M6	EU6	F6	MERV 11 – MERV 12
Fine filters		F7	EU7	F7	MERV 13
		F8	EU8	F8	MERV 14
Absolute filters	Q	F9	EU9	F9	MERV 15
		H10		H10	–
	R	H11	EU10	H11	–
	S	H12	EU11	H12	–
		H13	EU12	H13	–
		H14	EU13	H14	–
		U15	EU14	U15	–
		U16		U16	–
		U17		U17	–

Filtration efficiency of different kinds of air contaminants

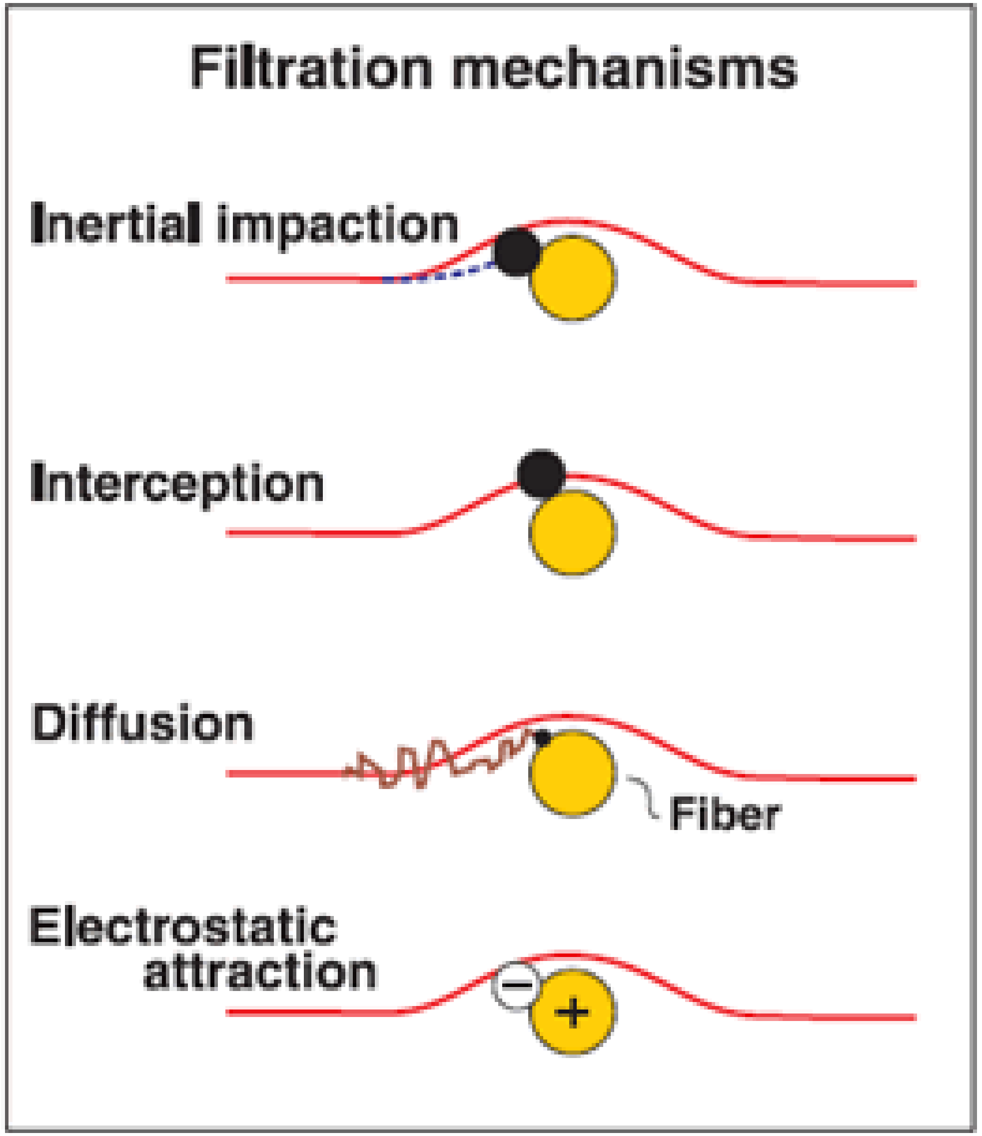
Filter groups EN 779, EN 1822-1	Filter class EN 779 EN1822-1	Test aerosol / Particle size	Type of retained contaminants	
			Very good efficiency	Limited efficiency
Coarse filters	**G1**	Synthetic powder **< 80 µm**	**insects, fiber eg. cotton, sand**	
	G2		**larger pollen**	
	G3			
	G4		**larger pollen, thick metallurgical dust**	**Smoke, sooth, oil mist**
Medium filters	**M5**	Test aerosol **0,5–20 µm**	**pollen, thick metallurgical dust**	**Smoke, sooth, oil mist**
	M6			
Fine filters	**F7**		**All kinds of dust, sooth, oil mist, fungal spores**	**Cigarette smoke, bacteria**
	F8		**Sooth, oil mist, bacteria**	**Cigarette smoke**
	F9			
HEPA	**H10**	Liquid aerosol DEHS, DOP Or paraffin oil aerosol **0,04–1 µm**	**bacteria, cigarette smoke, all kinds of smoke and aerosols**	
	H11			
	H12			
	H13		**bacteria, radioactive dust, cigarette smoke, all kinds of smoke and aerosols good efficiency for most viruses**	
	H14			
ULPA	**U15**			
	U16			
	U17			

Filtraction mechanisms



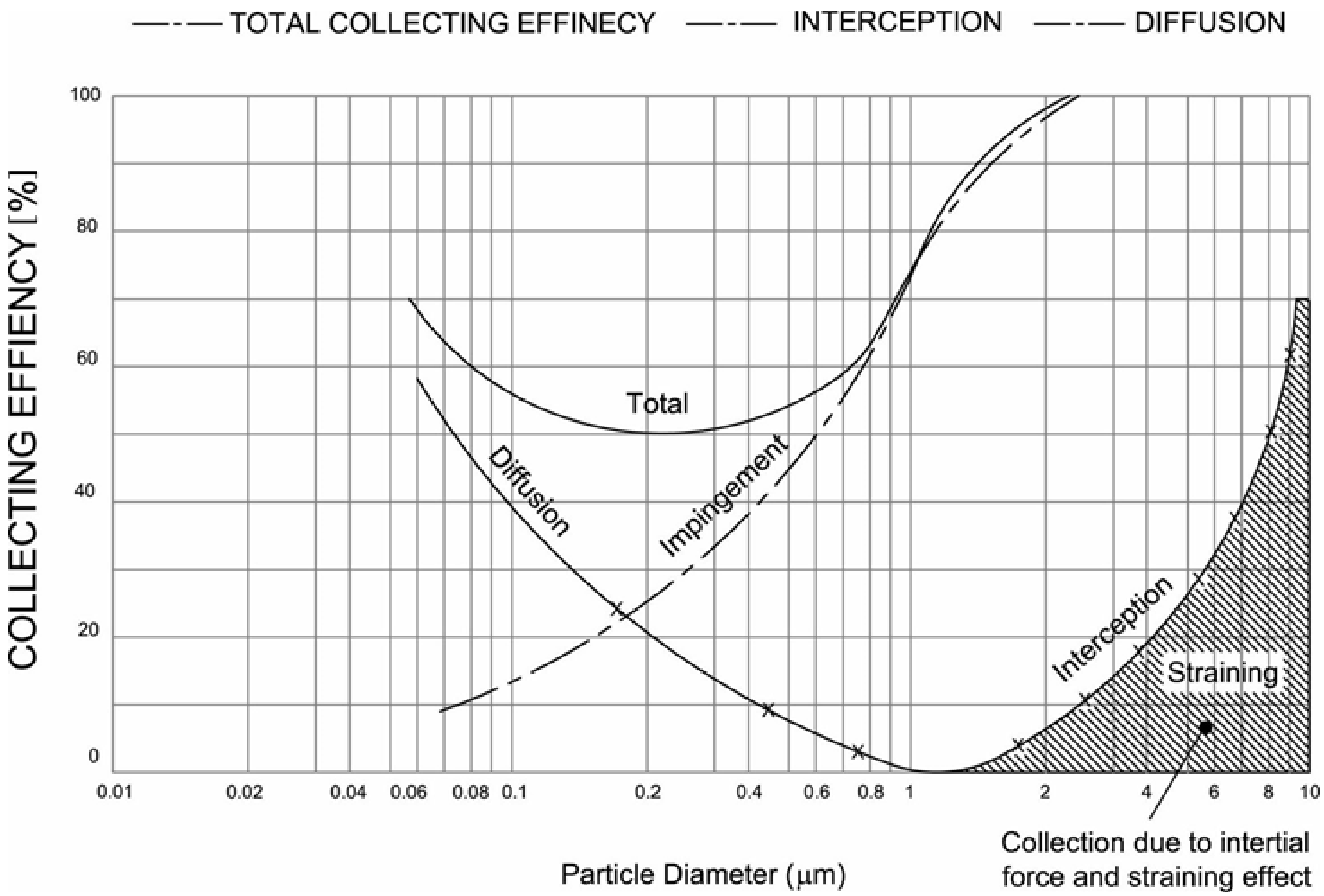
A – interception
B – inertial impaction
C – diffusion

Source: 1 filter.pl

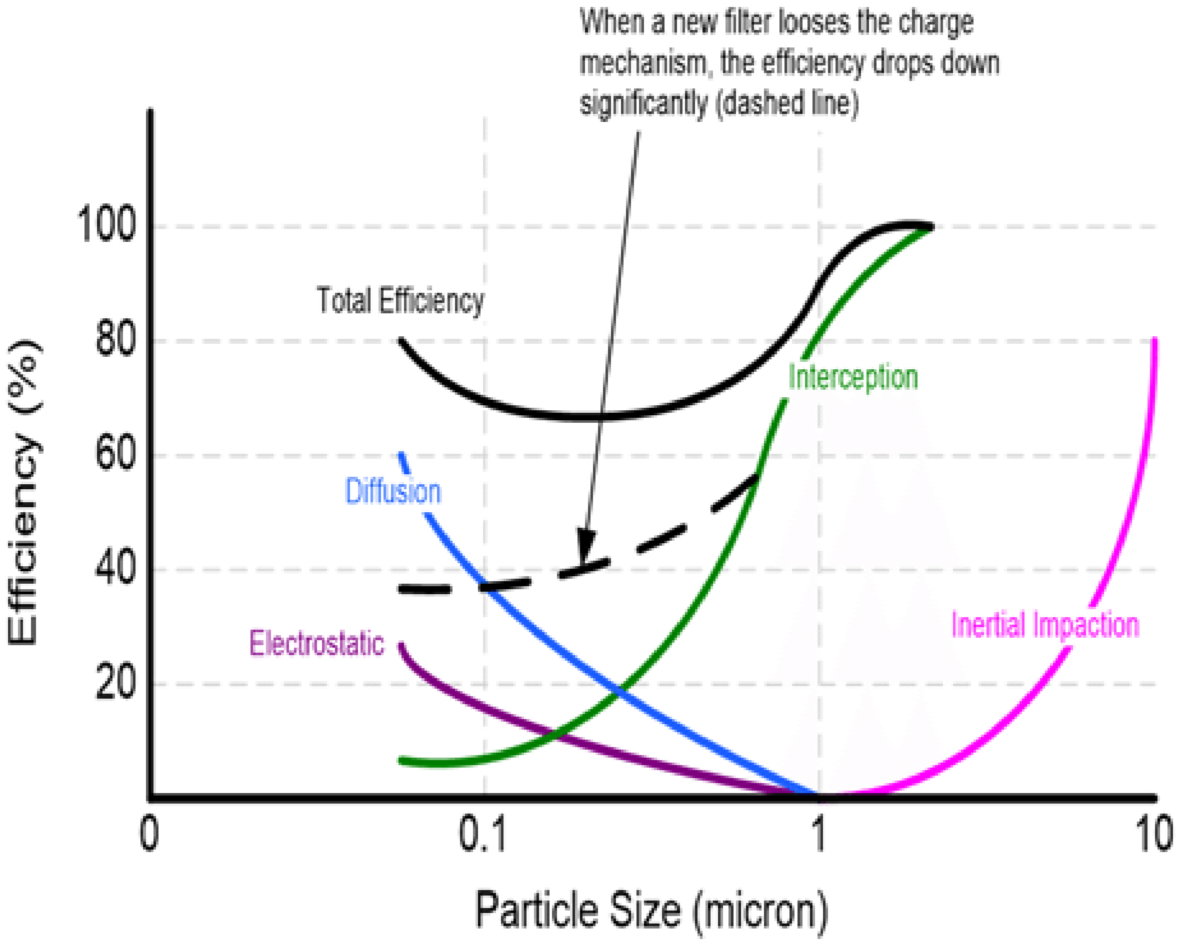


Source: semantischolar.org

Filtration mechanisms and efficiency



Filtration mechanisms and efficiency



Source: Researchgate

Methods of testing filters – standards

Particulate air filters (coarse, medium and absolute):
DIN 24185

Suspension filters:
DIN 24184 – tests with paraffin oil mist or flame fotometer

Suspension filters – other tests:
- Sodium flame test British Standard 1831
- DOP test (aerosol) –MIL – Standard 282 (USA) FS 209C

Methods of testing filters

Dust filters – coarse and fine filters:
DIN 24185

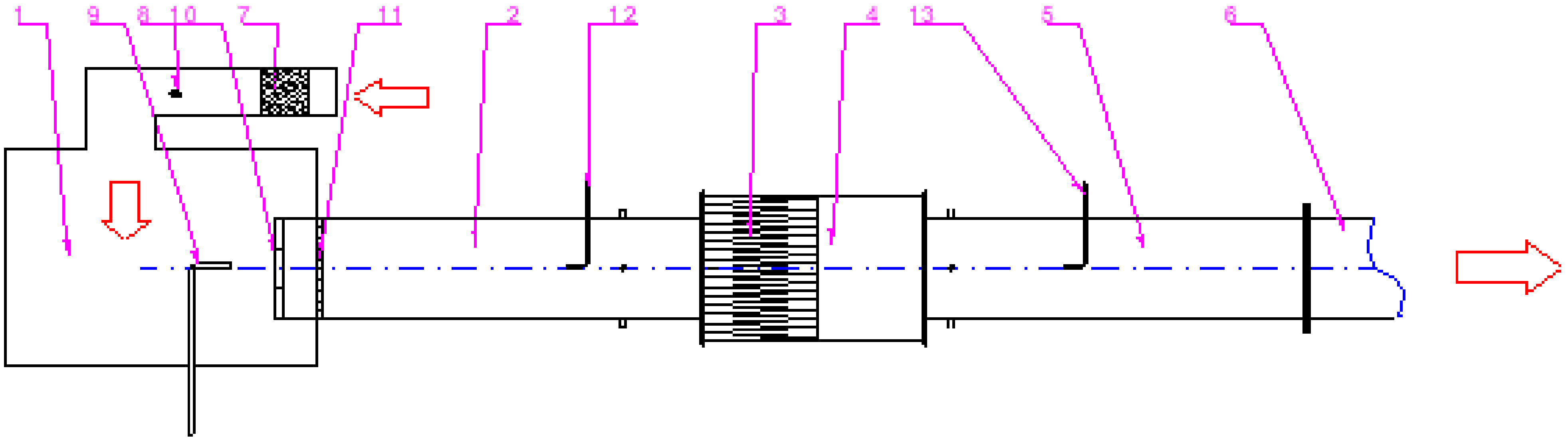
- Volumetric air flow
- Initial and final pressure drop
- Arrestance – A
- Efficiency – E
- Dust holding capacity

Methods of testing filters

Absolute filters (suspension):
DIN 24184

- aerosol 1 – paraffin oil mist (particles < 1 µm)
- aerosol 2 – natural atmospheric aerosol marked with Tor B isotope (particles < 0.3 µm)
- aerosol 3 – fresh made quartz dust (particles < 5 µm)

Filter testing rig (EN 779)



Legend: 1, 2, 5, 6 – duct section of a test rig, 3 – tested filter, 4 – duct with the tested filter, 7 – HEPA filter (at least H13), 8 – inlet point of DEHS particles, 9 – injection nozzle, 10 – mixing orifice, 11 – perforated plate, 12 – probe before tested filter, 13 – probe after tested filter

Methods of testing filters (EN 779)

Efficiency *E* for a given size range of particles:

$$E = \left(1 - \frac{n_i}{N_i}\right)100$$

where:

n_i – number of particles after the tested filter

N_i – number of particles before the tested filter

Methods of testing filters (EN 779)

Parameters measured or calculated after every dust feeding stage

Stage	Parameter			
	Efficiency	Dust arrestance	Dust holding capacity	Pressure drop
Preliminary, before dust fed	Yes	No	No	Yes
After 30 g of dust (first feed for estimating initial dust arrestance)	Yes	Yes	No	Yes
At the end of every intermediate increase	Yes	Yes	No	Yes
After the last increase (final pressure drop)	Yes	Yes	Yes	Yes

Methods of testing filters (EN 779)

Dust arrestance

$$A_j = \frac{1 - m_j}{M_j} \cdot 100\%$$

where:

m_j – mass of dust missed by tested filter (increase of mass of measuring filter D_{mff} and dust after the device m_d in feeding stage „j”)

M_j – mass of dust fed D_m in feeding stage „j”

Methods of testing filters (EN 779)

Efficiency

$$E_{i,j} = (E_{1,j} + \ldots + E_{6,i}) / 6$$

where:

$E_{1,j}$ … $E_{6,i}$ – unit efficiencies for dust size range „i” after feeding stage

$E_{1,j}$ – average efficiency for dust size range „i” after feeding stage „j”

Methods of testing filters (EN 779)

Average efficiency

$$E_{m,i} = \frac{1}{M}\sum_{j=1}^{n}\left(\frac{E_{i,(j-1)} + E_{i,j}}{2} \cdot M_j\right)$$

where:

$E_{m,i}$ – average efficiency for the size range of particles „i" for all stages of dust feeding

$E_{i,j}$ – average efficiency for the size range of particles „i" after feeding stage „j"

M_j – quantity of dust fed during feeding stage „j"

M – $\sum_{j=1}^{n} M_j$

N – number of feeding stages

Dust holding capacity

Dust holiding capacity for a given final pressure drop is calculated as total mass of the dust fed multiplied by average dust arrestance.

The total mass is corrected by the loss before the tested filter.

Airborne Molecular Contamination Control

AMC covers a wide range of chemical contaminants in form of gases, vapors or aerosols that can be a results of outdoor air, manufacturing processes, fugitive emissions from process equipment and chemical supply lines, cross-contamination between manufacturing areas, chemical storage areas, off-gassing of construction and building materials, accidental spills, and bio-effluents from cleanroom personnel.

Gas phase chemical filtration systems or scrubbing systems

Performance during tests and in real operation greatly depend on:

- Final pressure drop,
- Media air velocity,
- Type of dust loading,
- Humidity/weather conditions/season,
- Flow pattern of airstreams used,
- Mechanical forces (vibration),
- Forces between filter and particles (adhesive coatings, electrostatic charges).

Classification EN 779:2012

Filter Type	New EN779 classification	Average Arrestance (%)	Average Efficiency (%) @ 0,4 µm	Final pressure drop (Pa)	Minimum Efficiency @ 0,4 µm
Coarse Filter	G1 G2 G3 G4	50≤Am<65 65≤Am<80 80≤Am<90 90≤Am		250 250 250 250	
Medium Filter	M5 M6		40≤Em<60 60≤Em<80	450 450	
Fine Filter	F7 F8 F9		80≤Em<90 90≤Em<95 95≤Em	450 450 450	35 55 70

Eurovent Certify all – Energy rating system

- Eurovent Certify All program – certifies filter ranges according to EN 779:2012
- Criteria certification program – filter class according to EN 779:2012 and initial pressure drop must be in correspondence with public data and technical information
- Each filter certified by Eurovent has an energy label. Energy label is set up by filter class
- Energy rating will be done on the filter classes M5 up to F9

Classification EN 779:2012

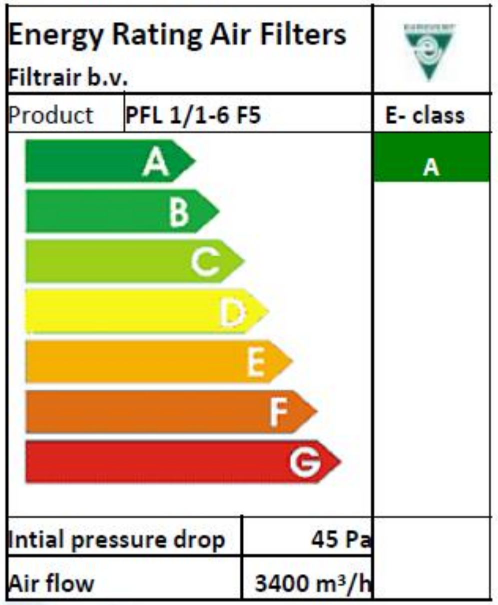
Energy Consumption, the Cost of Clean Air

- Energy costs grow steadily in all countries
- Energy costs of air filters in the total system is approximately 30%
- Select a correct filter with lowest optimized pressure drop
  This filter will create significant savings on energy
- 1 additional Pa over an air filter adds 1 euro in extra energy costs
- This principle shows the difference between a good or bad filter even if they have the same filter class
- With the energy consumption principle, filters can be sold on technical performance

Classification EN 779:2012

Energy Rating System for Air Filters

- Eurovent will introduce in 2012 to the certification program; air filters Class M5-F9 an ENERGY RATING SYSTEM FOR AIR FILTERS
- Same type of rating system as white goods, i.e refrigerator, washing machines, television, cars etc.



Classification EN 779:2012

Eurovent Certification program

Eurovent Certification programs - Air filters Class M5-F9 (certify all)

- Eurovents accreditation can be used as quality label (similar to DIN)
- DIN geprűft is product certification according EN779:2012
- All filters M5-F9 will be certified (total group certification)
- Certification according EN779:2012
- Eurovent sent filters at independent labs – SP Sweden / VTT Finland
- Eurovent checks test data of independent lab with the given data by the filter manufacturer
- Validity of certificate – 1 year
- Every year group audit by Eurovent
- All certified filters are present on website of Eurovent
- 2012 introduction Energy Rating System in Certification program Air Filters M5-F9

Classification EN 779:2012

Eurovent Energy Rating System

Energy Rating System is based on;

- EN779:2012 classification system
- EN779 data for G, M and F filters
- Average pressure drop G filters @ 350 g Ashrae dust,
- M filters @ 250 g Ashrae dust and F filters @ 150 g Ashrae dust
- Energy rating is based on the energy consumption in kWh

$$E\,(kWh) = \frac{V \cdot \Delta P \cdot t}{\eta * 1000}$$

E: energy consumption (kWh)
V: Air flow(m3/s)
ΔP: Average pressure drop of the filter during life time
t: operation time (h)
η: efficiency of the fan

Eurovent Energy Rating System

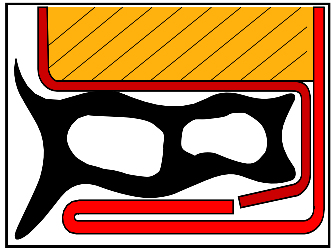
Energy Rating System per Filter Class ; G4-M5-M6-F7-F8-F9

Medium filters Threshold M5-M6 filters

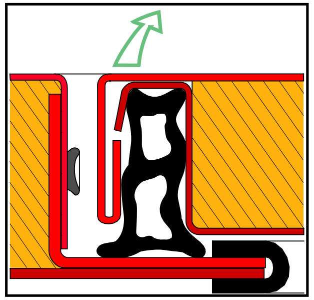
Filter Class	M5	M6	M5	M6
IPA Intiial Efficiency @ 0,4 µm	n.a.	n.a	n.a	n.a
Eurovent Energy label	Ave. ΔP @ 250 g. Ashrae dust		Energy @ 250 g Ashrae dust	
A	0-57 Pa	0-71 Pa	0-650 kWh	0-800 kWh
B	57-69 Pa	71-84 Pa	650-780 kWh	800-950 kWh
C	69-80 Pa	84-97 Pa	780-910 kWh	950-1100 kWh
D	80-92 Pa	97-110 Pa	910-1040 kWh	1100-1250 kWh
E	92-103 Pa	110-124 Pa	1040-1170 kWh	1250-1400 kWh
F	103-115 Pa	124-137 Pa	1170-1300 kWh	1400-1550 kWh
G	>115 Pa	>137 Pa	>1300 kWh	>1550 kWh

Air tightness of AHU

Housing: *Class B (EN 1886)*



Standard doors



Pressure doors

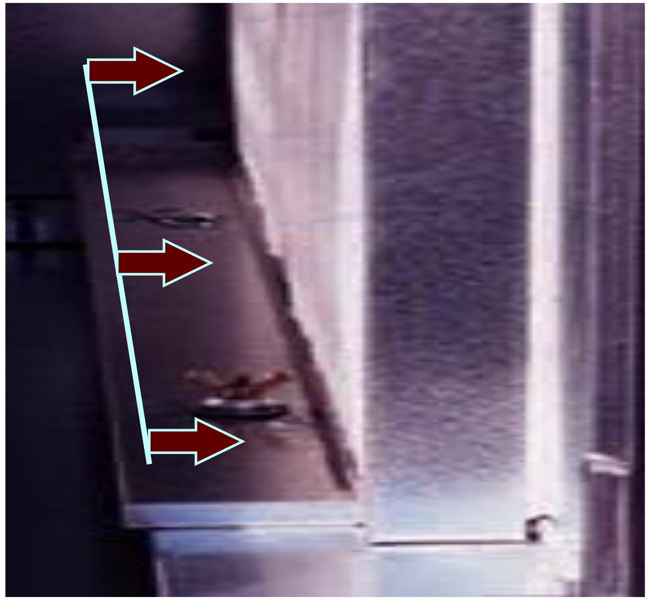
Pressure sensors connections

„Chokes"

Seals

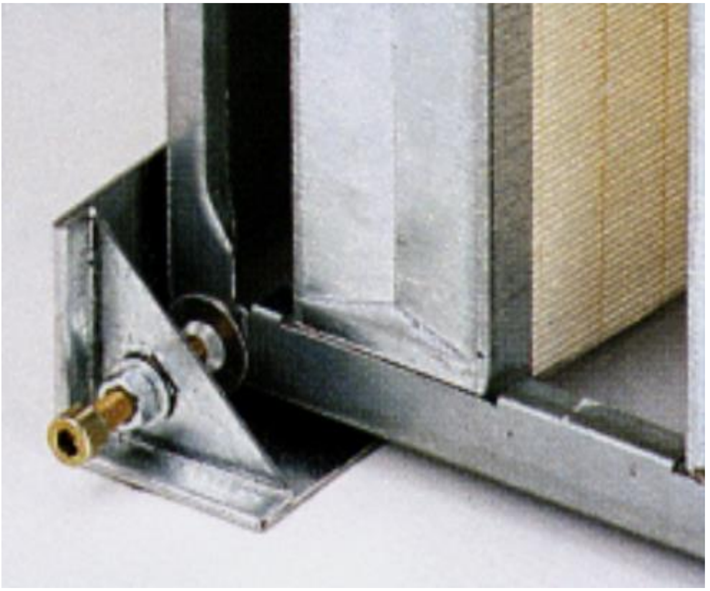
Air tightness

Filter mounting:
Class F9 (EN 1886)



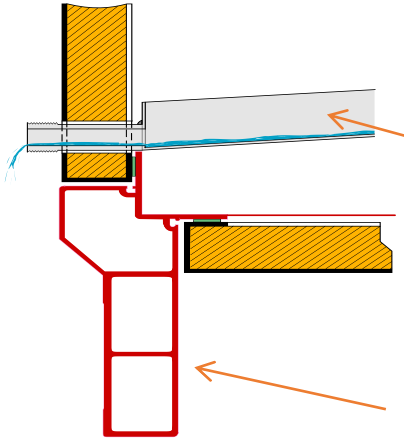
Pressure mounting
of pre – filters

Filter cartriges
Standard size
(24" x 24" / 12" x 24")



Frame
For high efficiency filters

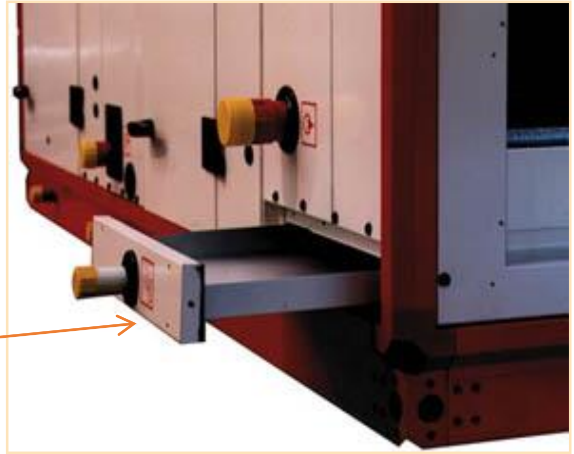
Cleaning maintenance

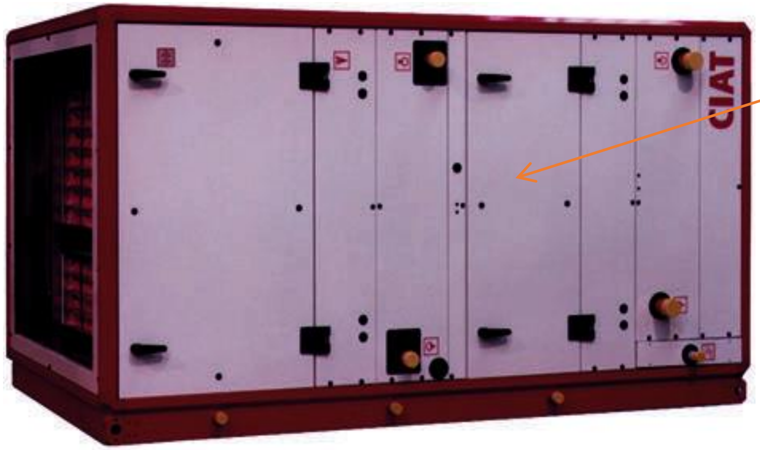


Sloped Tray

Take – out tray

Integrated AHU frame

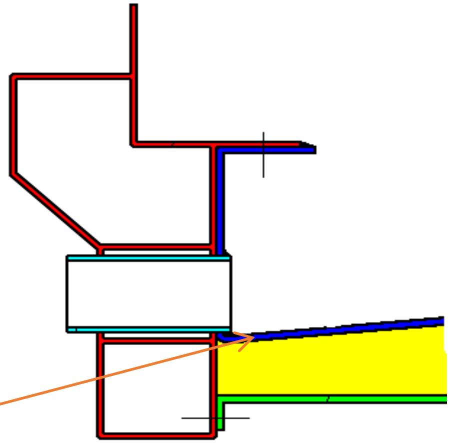




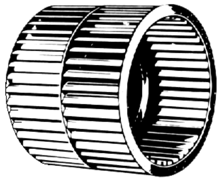
System – finishing

Empty section for inspection

Sloped base-board

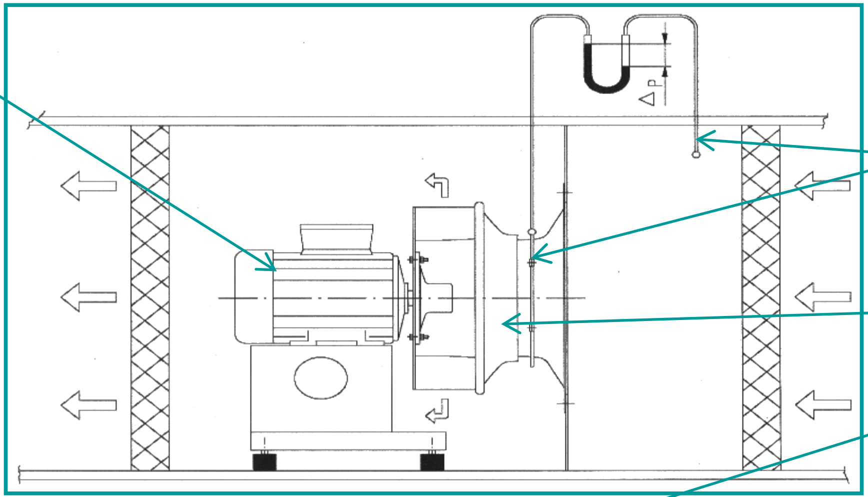


Fans

	Belt drive		Direct drive		
	BP	MP	BP	MP	TURBINE
	 				
Rotor efficiency	38 to 74%	60 to 85%			
Total efficiency	29 to 56%	46 to 65%	10 to 48%	10 to 55%	41 to 62%
Balance	G 6,3		G 2,5		
Acoustics	+ +	+++	++	++	+++

Ventilation

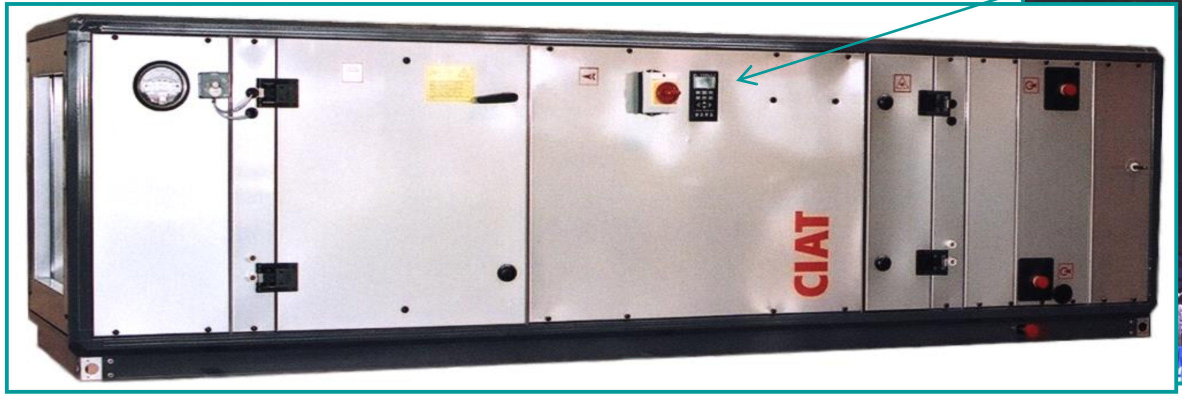
Motor with built-in or separate inverter

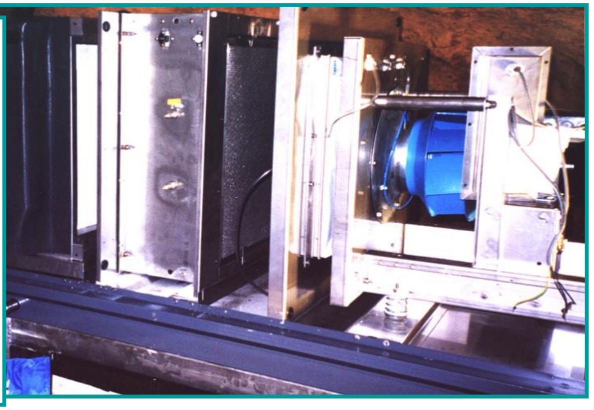


Connections to pressure diff. sensor

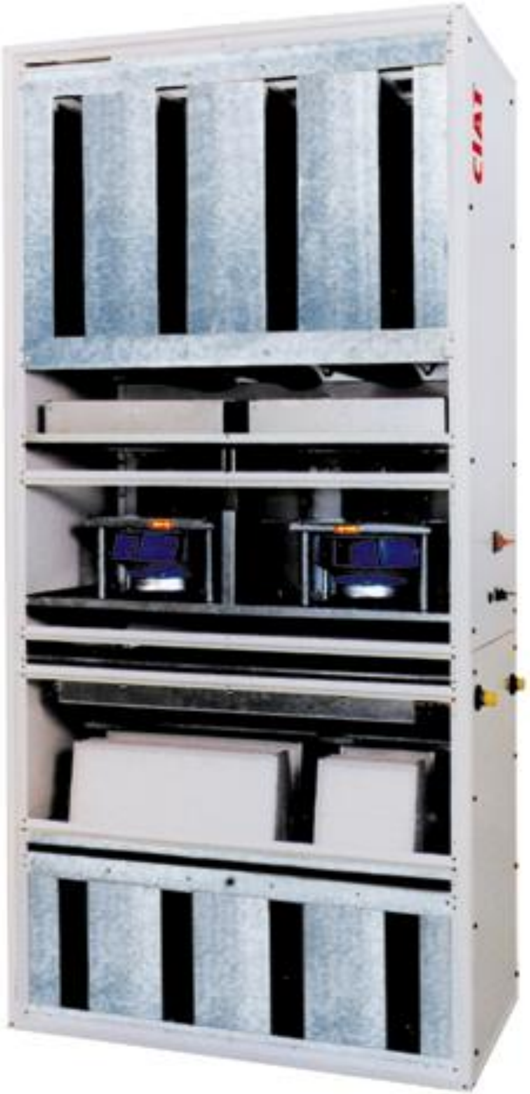
Turbine vent.

Inverter display





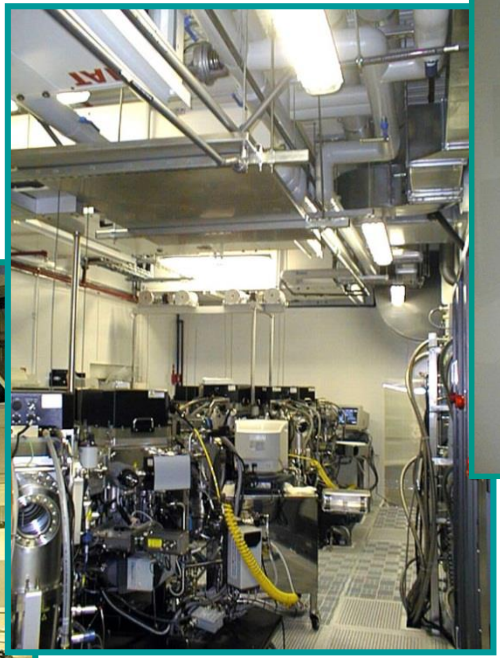
Recycler



- HORIZONTAL OR VERTICAL
- MONO- OR MULTI – PART
- TURBINE FAN
- INVERTER
- SILENCERS
- PRE-FILTER
- AIR DAMPER
- AIR-COOLER
- CONTROLS

Source: CIAT

Recycler Custom – made product

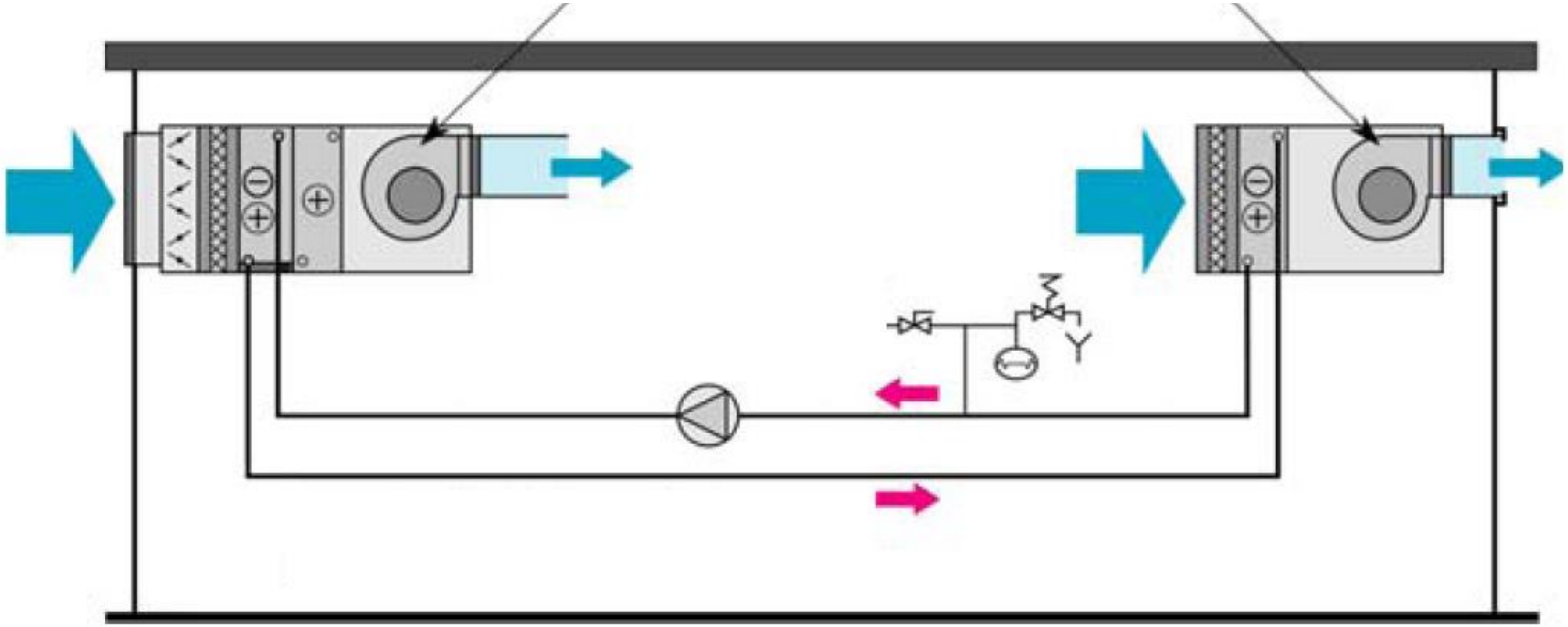




- Horizontal – vertical
- Custom sizes
- Custom – configuration

Module ventilation – filtration

- For air-flows from 1000 to 2100 m^3/h Filters H14, U15 or U16
- All kinds of power supply (1-phase, 3-phase, DC, other)
- Pressure or speed control
- Low noise

Heat recovery



Source: Frapol

- Separated air streams
- Reduced efficiency compared to other types
- Heat pump as an alternative

Part 6

Energy certificates of buildings

JAROSŁAW MÜLLER

Engineer

– it sounds proud!

But the air conditioning engineer knows that

a person can live 30 days without food, 8 days without drinking, but only **3 minutes** without air.

Quantity and quality

The following definition is given in the English text of the CIBSE standard: Indoor air quality may be acceptable if less than 50% of users experience an unpleasant odour, less than 20% experience discomfort, less than 10% suffer from mucosal irritation, less than 5% experience irritation in less than 2% of residence time.

The European CEN standard defines its ventilation requirements by dividing room occupants into three groups satisfied with indoor air quality: A – 85%, B – 80% and C – 70%.

The German DIN standard, with analytical methods, establishes three groups of satisfied users: 90, 80 and 70%.

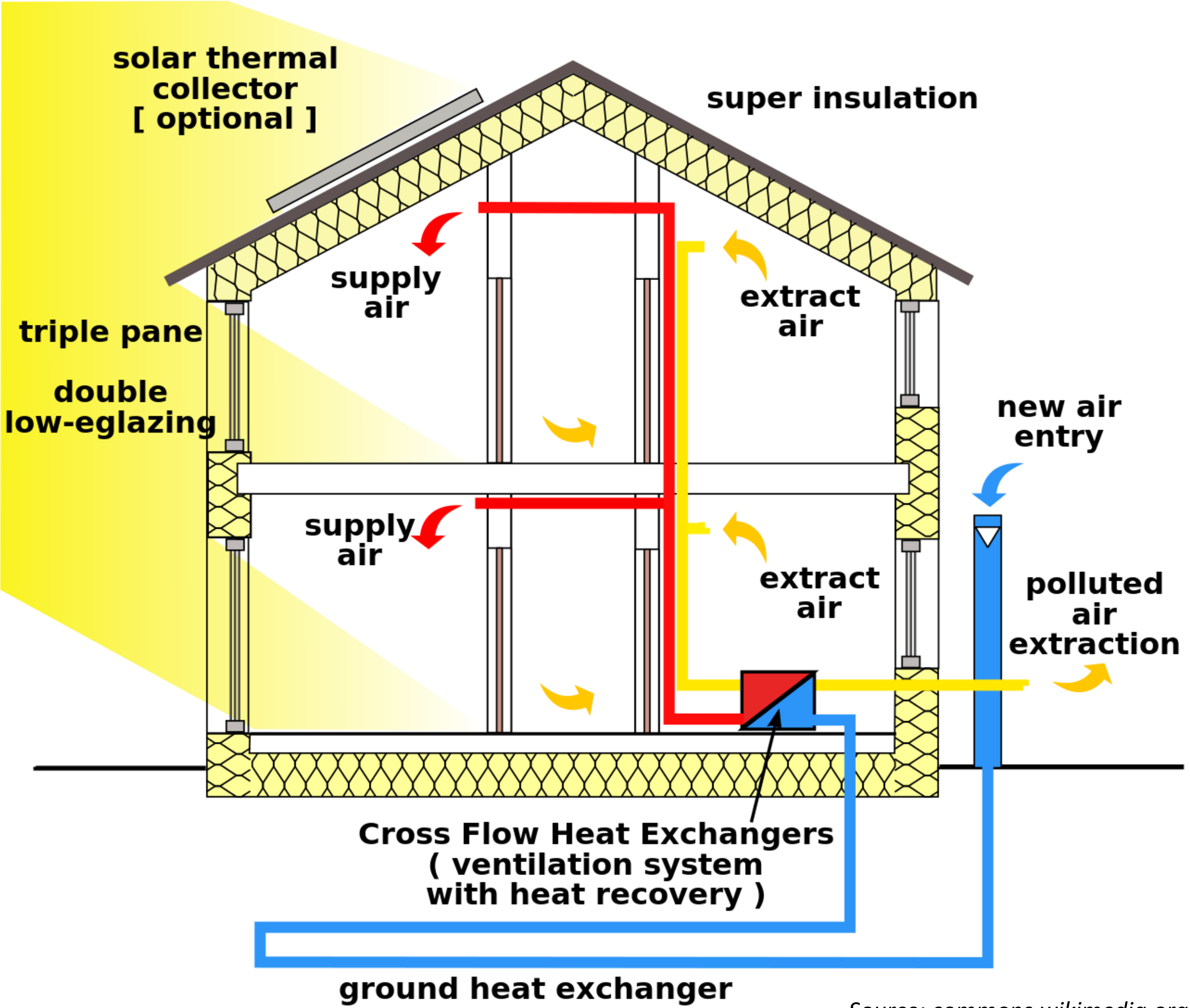
Criteria to choose from

Passive house (Passivhaus)

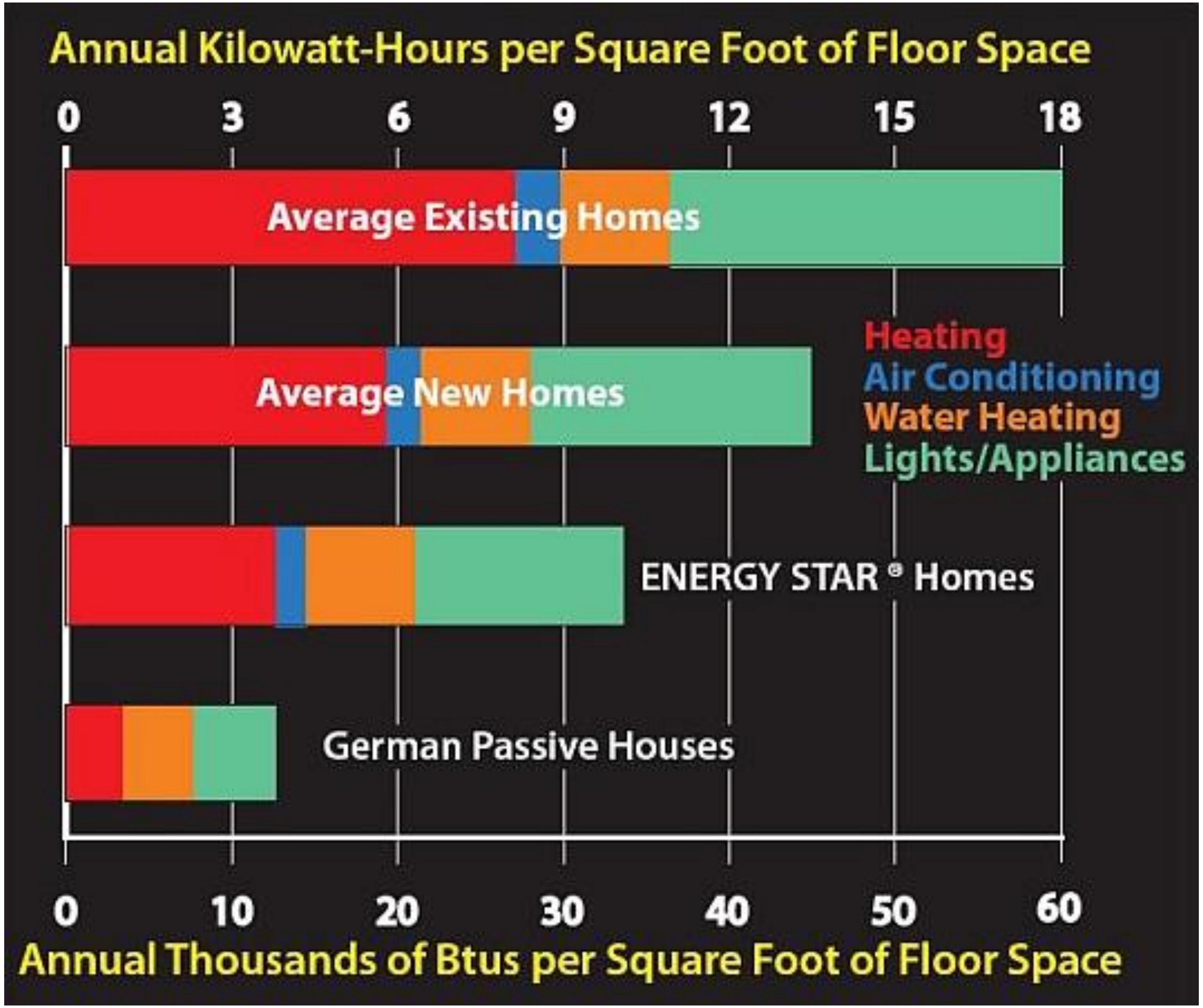
Green building

BREEAM Building Research Establishment Environmental Assessment Method

LEED Leadership in Energy and Environmental Design



Source: commons.wikimedia.org

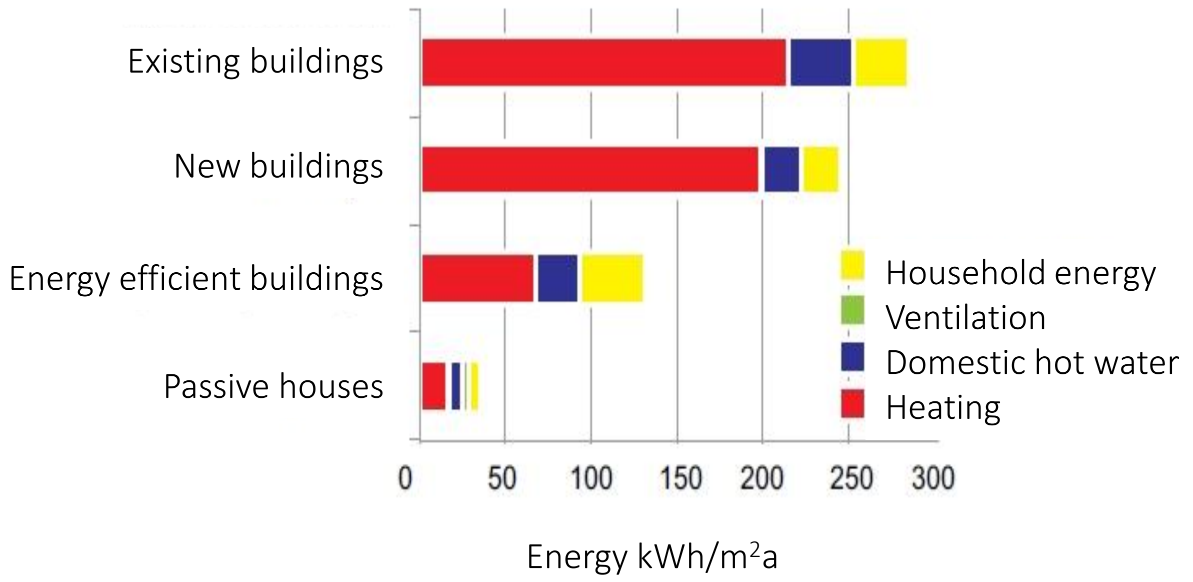


Source: pasivhaus

Passive house

Converting the amount of energy needed to heat the minimum fresh air per one person ($30\ m^3/h$) by 10 degrees (eg from +10 to +20°C), for three winter months (90 days).

$(30/3600) * 1.2\ kg/m^3 * 1.005\ kJ/kgK * 10 * 24 * 90 = 217.08\ kWh$



Source: pasivhaus

Definition

LEED Leadership in Energy and Environmental Design is an international eco--building certification system that tests whether a building or housing estate has been designed and built using strategies to improve the performance of all parameters that have a real impact on the environment: design and internal microclimate energy saving, rationalization of consumption water, reduction of CO_2 emissions, minimization of waste generation and location of the building.

Definition

Developed by the US Green Building Council (USGBC), the LEED certificate provides building owners and developers with a concise framework for identifying and implementing practical and measurable green solutions for the design, construction, operation and maintenance of a building.

The certificate can be obtained on four levels:

certified, silver, gold, platinum.

Features

LEED is flexible and applicable to all types of buildings – commercial and residential. Consideration is made of the entire life cycle of the building – design and construction, operation and maintenance, interior design and modernization.

It is not flexible: only ASHRAE
although 117 countries

ASHRAE standard 62.1

(ventilation for acceptable indoor air quality)

ASHRAE standard 90.1

(energy standard for buildings except low rise residential buildings)

Features

Mandatory criteria

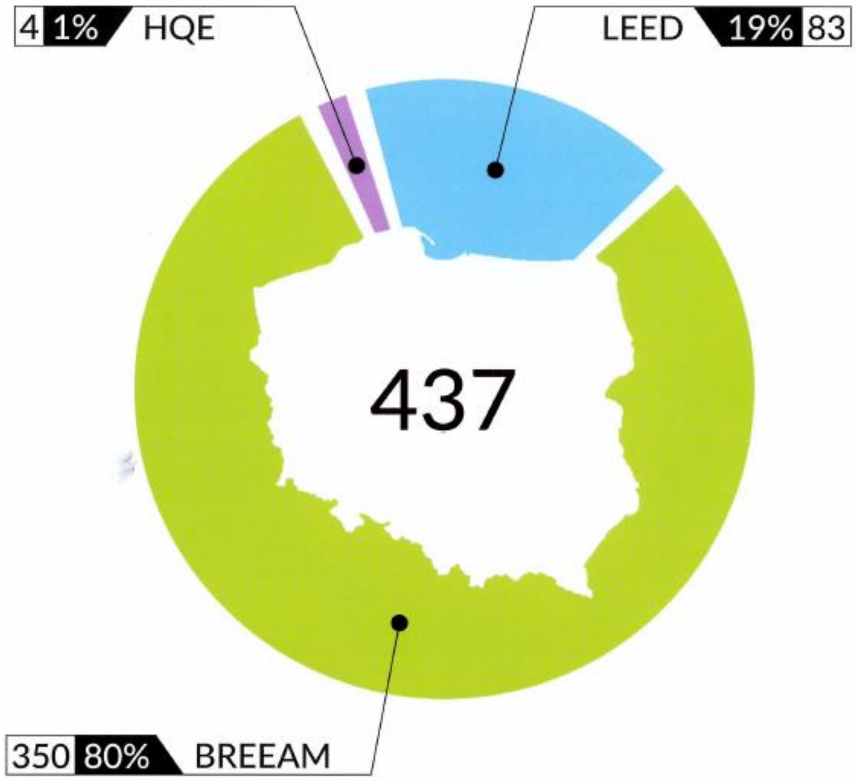
- Sustainable location
- Effective use of water resources
- Energy and atmosphere
- Materials and resources
- Indoor air quality

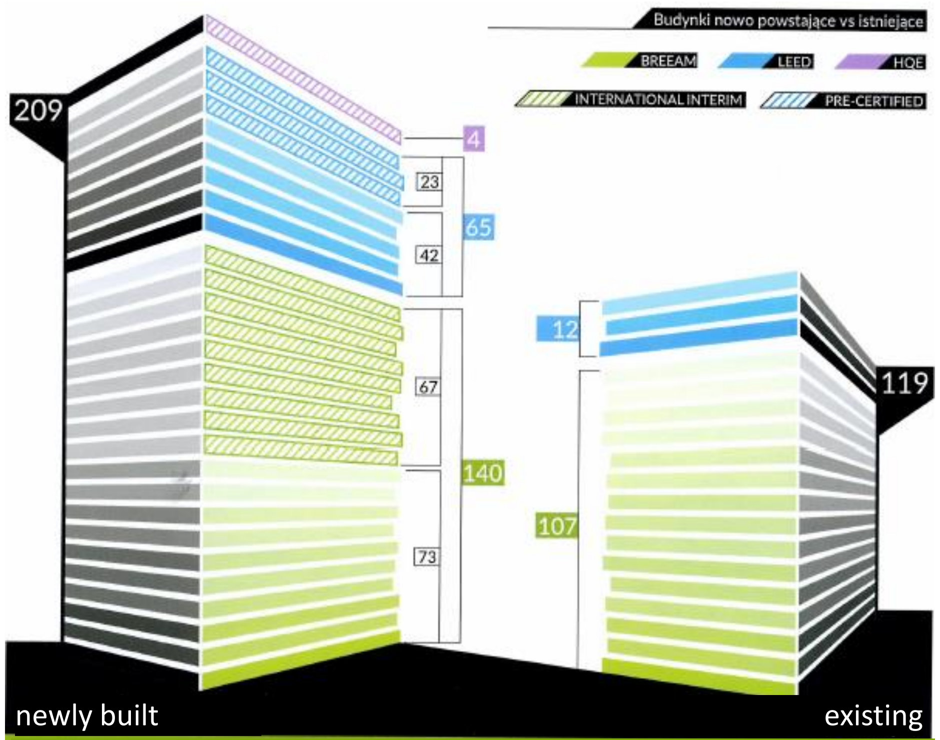
Features

Criteria "welcome but not necessary"

- Innovation
- Regional priorities

Sustainable buildings in Poland 2016





There are 115 newly built certified facilities, and 94 pre-certified (LEED) and interim (BREAM) in the design / construction phase (including four buildings certified in HQE), while older buildings with certification currently have 119

Source: PLGBC – Certyfikacja zielonych budynków w liczbach – Raport 2016

Building assessment systems – LEED

7 main areas of assessment

- Sustainable Sites
- Water Efficiency
- Energy and Atmosphere
- Materials and Resources
- Indoor Environmental Quality
- Innovation and Design
- Regional Priority

LEED 2009 for Core and Shell Development
Project Checklist

Project Name
Date

Y	?	N	Sustainable Sites	Possible Points: 28
Y			Prereq 1 Construction Activity Pollution Prevention	
			Credit 1 Site Selection	1
			Credit 2 Development Density and Community Connectivity	5
			Credit 3 Brownfield Redevelopment	1
			Credit 4.1 Alternative Transportation—Public Transportation Access	6
			Credit 4.2 Alternative Transportation—Bicycle Storage and Changing Rooms	2
			Credit 4.3 Alternative Transportation—Low-Emitting and Fuel-Efficient Vehicl	3
			Credit 4.4 Alternative Transportation—Parking Capacity	2
			Credit 5.1 Site Development—Protect or Restore Habitat	1
			Credit 5.2 Site Development—Maximize Open Space	1
			Credit 6.1 Stormwater Design—Quantity Control	1
			Credit 6.2 Stormwater Design—Quality Control	1
			Credit 7.1 Heat Island Effect—Non-roof	1
			Credit 7.2 Heat Island Effect—Roof	1
			Credit 8 Light Pollution Reduction	1
			Credit 9 Tenant Design and Construction Guidelines	1

			Water Efficiency	Possible Points: 10
Y			Prereq 1 Water Use Reduction—20% Reduction	
			Credit 1 Water Efficient Landscaping	2 to 4
			Credit 2 Innovative Wastewater Technologies	2
			Credit 3 Water Use Reduction	2 to 4

			Energy and Atmosphere	Possible Points: 37
Y			Prereq 1 Fundamental Commissioning of Building Energy Systems	
Y			Prereq 2 Minimum Energy Performance	
Y			Prereq 3 Fundamental Refrigerant Management	
			Credit 1 Optimize Energy Performance	3 to 21
			Credit 2 On-Site Renewable Energy	4
			Credit 3 Enhanced Commissioning	2
			Credit 4 Enhanced Refrigerant Management	2
			Credit 5.1 Measurement and Verification—Base Building	3
			Credit 5.2 Measurement and Verification—Tenant Submetering	3
			Credit 6 Green Power	2

Y	?	N	Materials and Resources	Possible Points: 13
Y			Prereq 1 Storage and Collection of Recyclables	
			Credit 1 Building Reuse—Maintain Existing Walls, Floors, and Roof	1 to 5
			Credit 2 Construction Waste Management	1 to 2
			Credit 3 Materials Reuse	1
			Credit 4 Recycled Content	1 to 2
			Credit 5 Regional Materials	1 to 2
			Credit 6 Certified Wood	1

			Indoor Environmental Quality	Possible Points: 12
Y			Prereq 1 Minimum Indoor Air Quality Performance	
Y			Prereq 2 Environmental Tobacco Smoke (ETS) Control	
			Credit 1 Outdoor Air Delivery Monitoring	1
			Credit 2 Increased Ventilation	1
			Credit 3 Construction IAQ Management Plan—During Construction	1
			Credit 4.1 Low-Emitting Materials—Adhesives and Sealants	1
			Credit 4.2 Low-Emitting Materials—Paints and Coatings	1
			Credit 4.3 Low-Emitting Materials—Flooring Systems	1
			Credit 4.4 Low-Emitting Materials—Composite Wood and Agrifiber Products	1
			Credit 5 Indoor Chemical and Pollutant Source Control	1
			Credit 6 Controllability of Systems—Thermal Comfort	1
			Credit 7 Thermal Comfort—Design	1
			Credit 8.1 Daylight and Views—Daylight	1
			Credit 8.2 Daylight and Views—Views	1

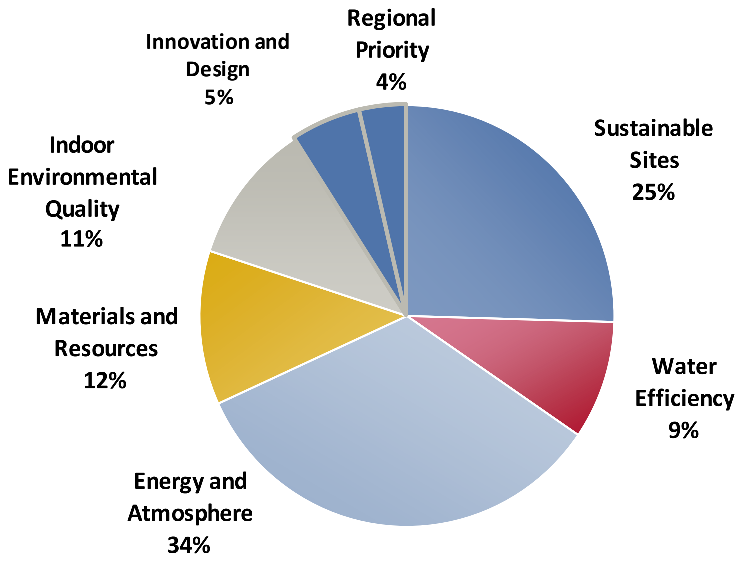
			Innovation and Design Process	Possible Points: 6
			Credit 1.1 Innovation in Design: Specific Title	1
			Credit 1.2 Innovation in Design: Specific Title	1
			Credit 1.3 Innovation in Design: Specific Title	1
			Credit 1.4 Innovation in Design: Specific Title	1
			Credit 1.5 Innovation in Design: Specific Title	1
			Credit 2 LEED Accredited Professional	1

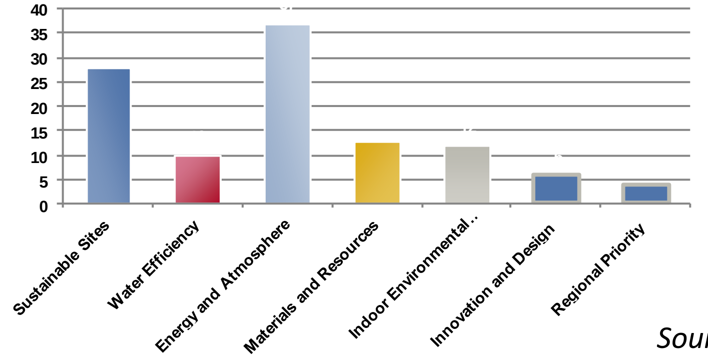
			Regional Priority Credits	Possible Points: 4
			Credit 1.1 Regional Priority: Specific Credit	1
			Credit 1.2 Regional Priority: Specific Credit	1
			Credit 1.3 Regional Priority: Specific Credit	1
			Credit 1.4 Regional Priority: Specific Credit	1

			Total	Possible Points: 110

Certified 40 to 49 points Silver 50 to 59 points Gold 60 to 79 points Platinum 80 to 110

Distribution of credits LEED CS 2009





Source: USGBC

LEED v4 for BD+C: New Construction and Major Renovation

Project Checklist

Project Name:

Date:

Y	?	N			
			Credit	Integrative Process	1

0	0	0	Location and Transportation		16
			Credit	LEED for Neighborhood Development Location	16
			Credit	Sensitive Land Protection	1
			Credit	High Priority Site	2
			Credit	Surrounding Density and Diverse Uses	5
			Credit	Access to Quality Transit	5
			Credit	Bicycle Facilities	1
			Credit	Reduced Parking Footprint	1
			Credit	Green Vehicles	1

0	0	0	Sustainable Sites		10
Y			Prereq	Construction Activity Pollution Prevention	Required
			Credit	Site Assessment	1
			Credit	Site Development - Protect or Restore Habitat	2
			Credit	Open Space	1
			Credit	Rainwater Management	3
			Credit	Heat Island Reduction	2
			Credit	Light Pollution Reduction	1

0	0	0	Materials and Resources		13
Y			Prereq	Storage and Collection of Recyclables	Required
Y			Prereq	Construction and Demolition Waste Management Planning	Required
			Credit	Building Life-Cycle Impact Reduction	5
			Credit	Building Product Disclosure and Optimization - Environmental Product Declarations	2
			Credit	Building Product Disclosure and Optimization - Sourcing of Raw Materials	2
			Credit	Building Product Disclosure and Optimization - Material Ingredients	2
			Credit	Construction and Demolition Waste Management	2

0	0	0	Indoor Environmental Quality		16
Y			Prereq	Minimum Indoor Air Quality Performance	Required
Y			Prereq	Environmental Tobacco Smoke Control	Required
			Credit	Enhanced Indoor Air Quality Strategies	2
			Credit	Low-Emitting Materials	3
			Credit	Construction Indoor Air Quality Management Plan	1
			Credit	Indoor Air Quality Assessment	2
			Credit	Thermal Comfort	1
			Credit	Interior Lighting	2
			Credit	Daylight	3

Source: USGBC

0	0	0	**Water Efficiency**		**11**
Y			Prereq	Outdoor Water Use Reduction	Required
Y			Prereq	Indoor Water Use Reduction	Required
Y			Prereq	Building-Level Water Metering	Required
			Credit	Outdoor Water Use Reduction	2
			Credit	Indoor Water Use Reduction	6
			Credit	Cooling Tower Water Use	2
			Credit	Water Metering	1

0	0	0	**Energy and Atmosphere**		**33**
Y			Prereq	Fundamental Commissioning and Verification	Required
Y			Prereq	Minimum Energy Performance	Required
Y			Prereq	Building-Level Energy Metering	Required
Y			Prereq	Fundamental Refrigerant Management	Required
			Credit	Enhanced Commissioning	6
			Credit	Optimize Energy Performance	18
			Credit	Advanced Energy Metering	1
			Credit	Demand Response	2
			Credit	Renewable Energy Production	3
			Credit	Enhanced Refrigerant Management	1
			Credit	Green Power and Carbon Offsets	2

			Credit	Quality Views	1
			Credit	Acoustic Performance	1

0	0	0	**Innovation**		**6**
			Credit	Innovation	5
			Credit	LEED Accredited Professional	1

0	0	0	**Regional Priority**		**4**
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1

0	0	0	**TOTALS**	Possible Points:	**110**

Certified: 40 to 49 points, Silver: 50 to 59 points, Gold: 60 to 79 points, Platinum: 80 to 110

Source: USGBC

Final grade


U.S. GREEN BUILDING COUNCIL
LEED CERTIFIED
USGBC
CERTIFIED
40-49 points
U.S. GREEN BUILDING COUNCIL
LEED SILVER
USGBC
SILVER
50-59 points
U.S. GREEN BUILDING COUNCIL
LEED GOLD
USGBC
GOLD
60-79 points
U.S. GREEN BUILDING COUNCIL
LEED PLATINUM
USGBC
PLATINUM
80+ points

7 dimensions of LEED

Dimension evaluated	Criteria
Sustainable sites	Encourages strategies that minimize impact on the ecosystem during the building implementation and approaches fundamental issues of large urban centers, such as the reduction of car use and heat islands
Water efficiency	Promotes innovations for the rational use of water, focusing on the reduction of drinking water consumption and resources treatment and reuse alternatives

7 dimensions of LEED

Energy & atmosphere	Promotes energy efficiency in buildings through simple and innovative strategies, such as energy simulations, measurements, commissioning of systems and efficient use of equipment and systems
Materials & resources	Encourages the use of low environmental impact materials (recycled, regional, recyclable, reuse, etc.) and reduces the waste generation, besides promoting conscious disposal, deviating waste volume generated from sanitary landfills

7 dimensions of LEED

Indoor c	Promotes indoor environmental air quality, essential for environments with high permanence for people, focusing on the choice of materials with low emission of volatile organic compounds, controllability of systems, thermal comfort and prioritization of areas with outdoor view and natural light
Innovation in design or innovation in operations	Encourages the pursuit the knowledge about Green Buildings, as well as the creation of project measures which are not described in the categories of LEED. Exemplary performance points are enabled for this category
Regional priority credits	Encourages credits defined as regional priorities for each country, in accordance with environmental, social and economic differences existent in each location. Four points are available for this category

Criteria

0	0	0	**Location and Transportation**		**16**
			Credit	LEED for Neighborhood Development Location	16
			Credit	Sensitive Land Protection	1
			Credit	High Priority Site	2
			Credit	Surrounding Density and Diverse Uses	5
			Credit	Access to Quality Transit	5
			Credit	Bicycle Facilities	1
			Credit	Reduced Parking Footprint	1
			Credit	Green Vehicles	1

0	0	0	**Sustainable Sites**		**10**
Y			Prereq	Construction Activity Pollution Prevention	Required
			Credit	Site Assessment	1
			Credit	Site Development - Protect or Restore Habitat	2
			Credit	Open Space	1
			Credit	Rainwater Management	3
			Credit	Heat Island Reduction	2
			Credit	Light Pollution Reduction	1

LEED

Criteria

0	0	0	Materials and Resources		13
Y			Prereq	Storage and Collection of Recyclables	Required
Y			Prereq	Construction and Demolition Waste Management Planning	Required
			Credit	Building Life-Cycle Impact Reduction	5
			Credit	Building Product Disclosure and Optimization - Environmental Product Declarations	2
			Credit	Building Product Disclosure and Optimization - Sourcing of Raw Materials	2
			Credit	Building Product Disclosure and Optimization - Material Ingredients	2
			Credit	Construction and Demolition Waste Management	2

0	0	0	Indoor Environmental Quality		16
Y			Prereq	Minimum Indoor Air Quality Performance	Required
Y			Prereq	Environmental Tobacco Smoke Control	Required
			Credit	Enhanced Indoor Air Quality Strategies	2
			Credit	Low-Emitting Materials	3
			Credit	Construction Indoor Air Quality Management Plan	1
			Credit	Indoor Air Quality Assessment	2
			Credit	Thermal Comfort	1
			Credit	Interior Lighting	2
			Credit	Daylight	3
			Credit	Quality Views	1
			Credit	Acoustic Performance	1

LEED

Criteria

0	0	0	**Water Efficiency**		11
Y			Prereq	Outdoor Water Use Reduction	Required
Y			Prereq	Indoor Water Use Reduction	Required
Y			Prereq	Building-Level Water Metering	Required
			Credit	Outdoor Water Use Reduction	2
			Credit	Indoor Water Use Reduction	6
			Credit	Cooling Tower Water Use	2
			Credit	Water Metering	1

0	0	0	**Energy and Atmosphere**		33
Y			Prereq	Fundamental Commissioning and Verification	Required
Y			Prereq	Minimum Energy Performance	Required
Y			Prereq	Building-Level Energy Metering	Required
Y			Prereq	Fundamental Refrigerant Management	Required
			Credit	Enhanced Commissioning	6
			Credit	Optimize Energy Performance	18
			Credit	Advanced Energy Metering	1
			Credit	Demand Response	2
			Credit	Renewable Energy Production	3
			Credit	Enhanced Refrigerant Management	1
			Credit	Green Power and Carbon Offsets	2

LEED

Cost and results

- From 3 to 30,000 USD
- The later, the more expensive
- And worse, e.g.:
    - Using installation and lighting solutions with lower power consumption,
    - Providing the best thermal insulation
    - Ensuring efficient air conditioning
    - Providing protection against excessive heat caused by sunlight

LEED

Mandatory conditions for HVAC

- Timer control of room temperature
- At least 10% lower energy demand compared to a standard building

Fulfilling the requirements of ASHRAE for:

  - *Heat transfer coefficients*
  - *Coefficients of efficiency of heat and cold sources*
  - *SFP indicators*

- Demand Controled Ventilation (DCV) for area more than 50 m^2 and for number of people over 40 per 100 m^2

LEED

Mandatory conditions for HVAC

- No harmful refrigerants
- No smoking – or designation of a special room
- Unit power of lighting up to 11 W/m^2
- Providing an appropriate fresh air stream according to ASHRAE

LEED

Conditions (extra) for HVAC

- CO_2 monitoring for the number of people over 25/100 m^2
- Use of local renewable energy sources, "green, renewable suppliers"
- Individual measurement of tenant energy/water use, excluding energy charges from rent, systematic analysis of trends
- At least 12% lower energy demand compared to the standard building confirmed by the Energy Model

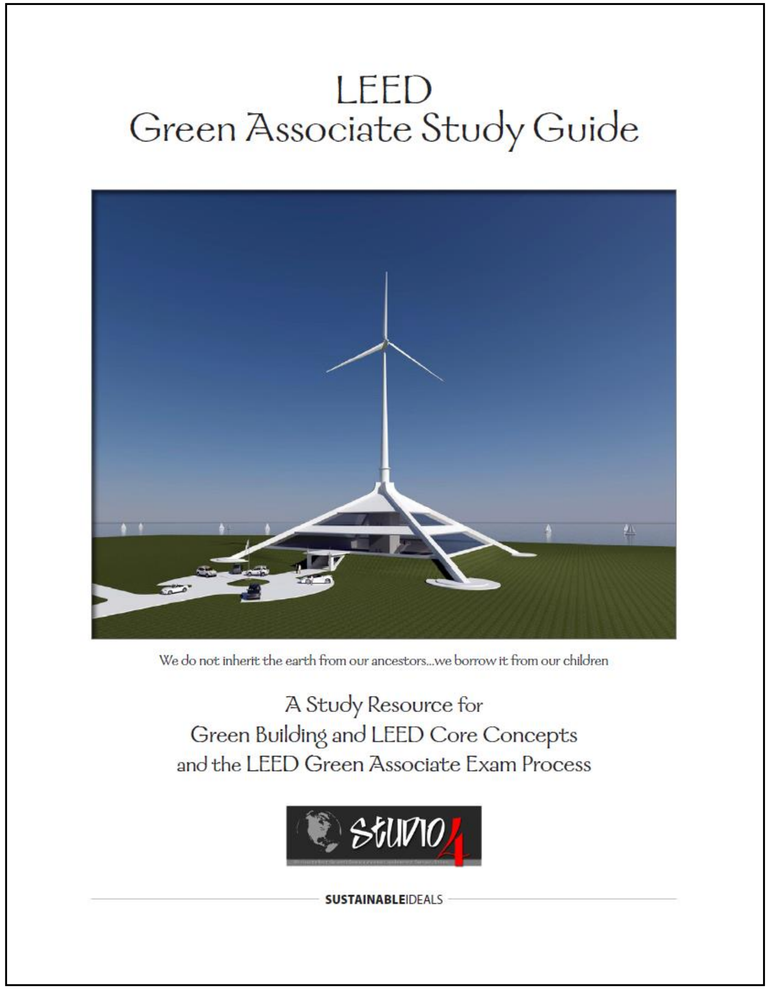
LEED

Conditions (extra) for HVAC

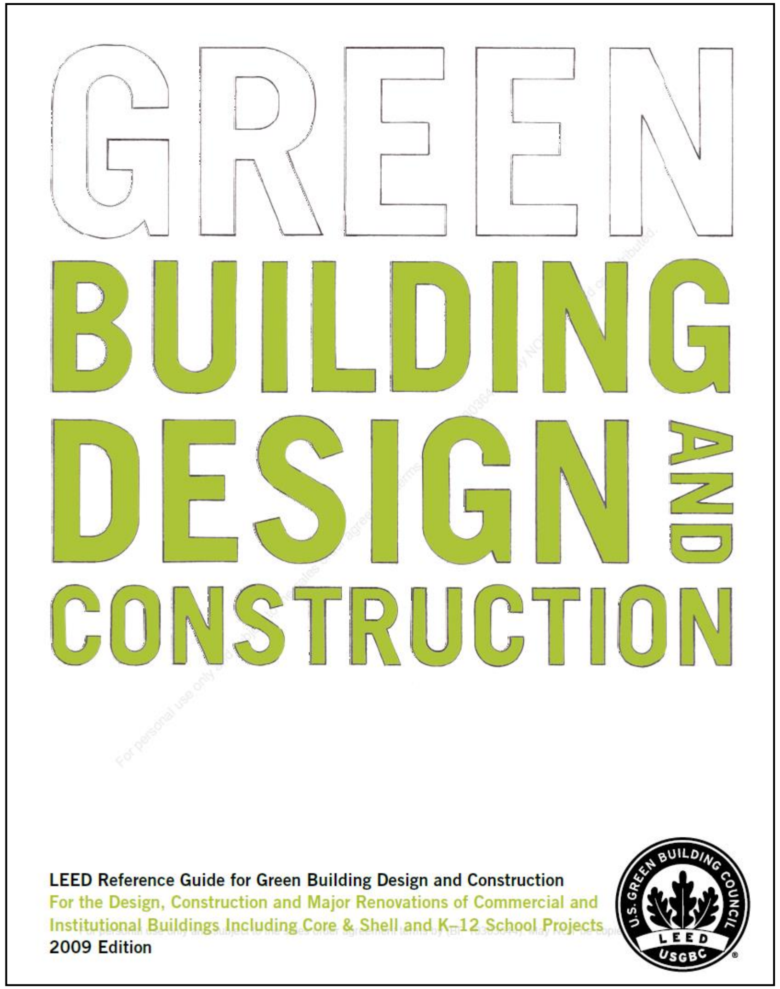
- Providing a suitable fresh air stream 30% above ASHRAE, monitoring
- Maintaining a negative pressure in rooms housing a source of pollution
- Filters at least F7 for supply
- Providing individual control of comfort conditions for at least 50% of users
- Meeting comfort conditions according to the clothing and physical activity

LEED

Guides



LEED
Green Associate Study Guide
We do not inherit the earth from our ancestors...we borrow it from our children
A Study Resource for
Green Building and LEED Core Concepts
and the LEED Green Associate Exam Process
STUDIO4
SUSTAINABLEIDEALS

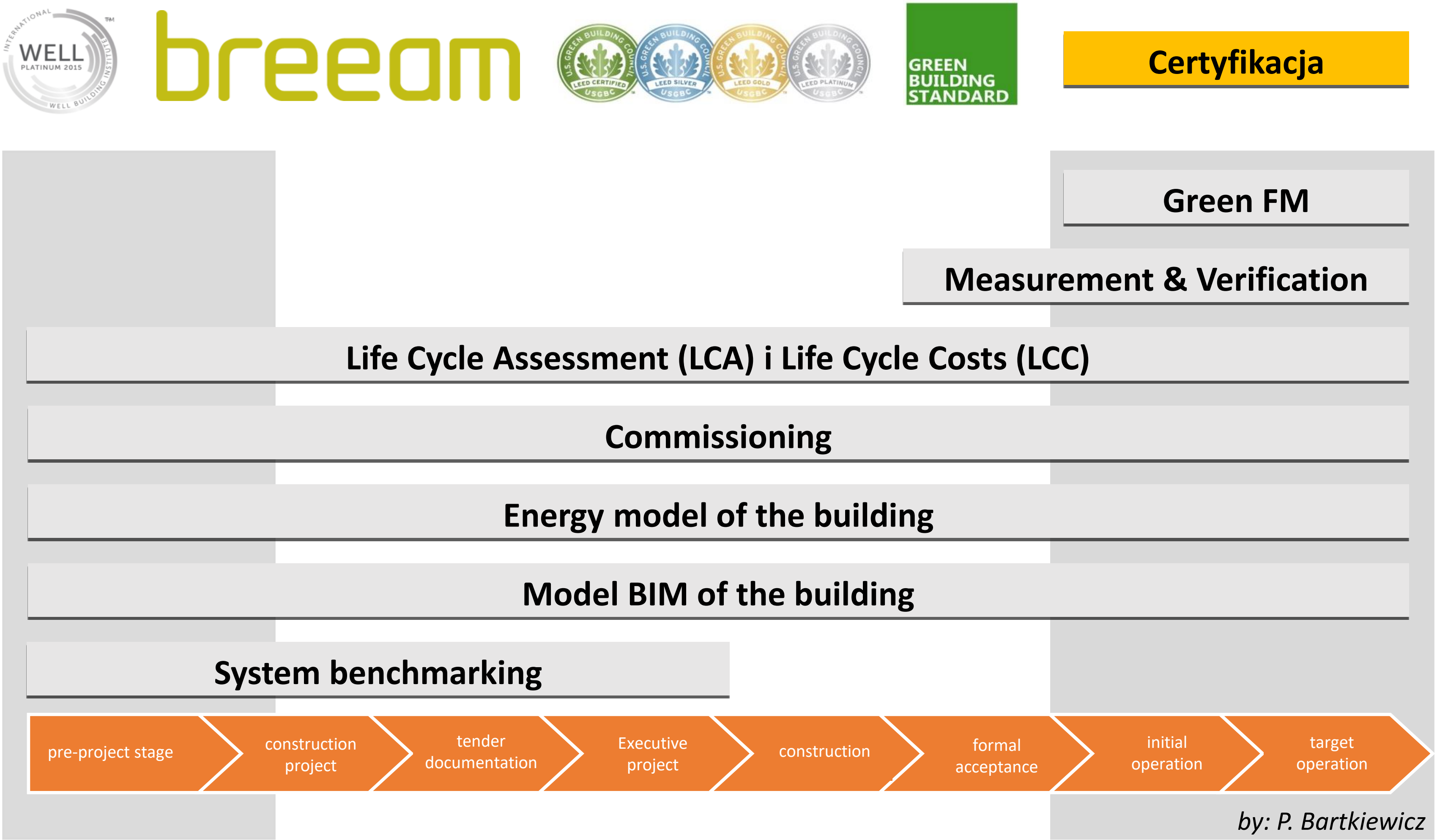


GREEN
BUILDING
DESIGN AND
CONSTRUCTION
LEED Reference Guide for Green Building Design and Construction
For the Design, Construction and Major Renovations of Commercial and
Institutional Buildings Including Core & Shell and K–12 School Projects
2009 Edition

Example

Alchemia – Gdańsk

Comprehensive building analysis as supporting processes



Sustainable construction in Poland

Koszalin – Październik 2016

Ogłoszenia

Kategoria: Ogłoszenia
Opublikowano: czwartek, 13, październik 2016 10:53
Artur Szczybelski
Odsłony: 35

II.4) Krótki opis przedmiotu zamówienia *(wielkość, zakres, rodzaj i ilość dostaw, usług lub robót budowlanych lub określenie zapotrzebowania i wymagań)* **a w przypadku partnerstwa innowacyjnego - określenie zapotrzebowania na innowacyjny produkt, usługę lub roboty budowlane:** 1. Przedmiotem zamówienia jest wykonanie w formule "zaprojektuj i wybuduj" zadania inwestycyjnego „Budowa nowej siedziby Wojewódzkiego Funduszu Ochrony Środowiska i Gospodarki Wodnej w Szczecinie Oddział w Koszalinie", od etapu dokumentacji projektowej (projekt budowlany i wykonawczy), dokonania rozbiórki istniejącego budynku, wykonania robót budowlanych, wraz z zagospodarowaniem terenu i małą architekturą, aż do uzyskania pozwolenia na użytkowanie, uzyskanie certyfikatu finalnego BREEAM na poziomie co najmniej VERY GOOD, zgodnie z Programem Funkcjonalno – Użytkowym, zwanym dalej PFU, stanowiącym załącznik nr 10 do SIWZ. 2. Dodatkowo do obowiązków Wykonawcy należeć będzie uzyskanie w imieniu Zamawiającego wszystkich decyzji o pozwoleniu na budowę (wraz ze wszystkimi niezbędnymi opiniami i pozwoleniami), wykonanie zaprojektowanych robót budowlanych, przeprowadzenie procedur odbiorowych, sprawowanie nadzoru autorskiego, rozruch instalacji i obowiązki umowne w okresie udzielonej gwarancji.

Sustainable construction in Poland

UCHWAŁA NR XVII/408/16
RADY MIASTA SZCZECIN
z dnia 22 marca 2016 r.

w sprawie zwolnienia od podatku od nieruchomości przedsiębiorców realizujących inwestycje początkowe

Na podstawie art. 18 ust. 2 pkt 8, art. 40 i art. 42 ustawy z dnia 8 marca 1990 r. o samorządzie gminnym (Dz. U. z 2015 r., poz.1515; zm: Dz.U.z 2015r. poz.1045 i poz. 1890) oraz art. 7 ust. 3 ustawy z dnia 12 stycznia 1991 r. o podatkach i opłatach lokalnych (Dz. U. z 2014 r. poz. 849; zm: Dz U. z 2015 r. poz. 528, poz. 699, poz. 774, poz.1045,poz. 1283, poz.1777 i poz. 1890) **Rada Miasta Szczecin uchwala, co następuje:**

Rozdział 1.
Postanowienia ogólne

§ 1. 1. Zwalnia się od podatku od nieruchomości na okres do trzech lat grunty, nowo wybudowane budynki lub ich części, nowo wybudowane budowle stanowiące inwestycję początkową, zajęte na prowadzenie działalności gospodarczej.

2. Zwolnieniu od podatku od nieruchomości, o którym mowa w ust. 1, podlegają:

- powierzchnie biurowe o wysokim standardzie w nowo wybudowanych budynkach,
- powierzchnie konferencyjne w nowo wybudowanych budynkach,

oraz budowle związane z tymi budynkami.

3. Zwalnia się od podatku od nieruchomości grunty, nabyte po dniu wejścia w życie niniejszej uchwały, na których zrealizowano inwestycję początkową.

4. Nowo wybudowany budynek podlega zwolnieniu od podatku od nieruchomości w całości, jeżeli co najmniej 90% jego powierzchni użytkowej stanowią powierzchnie, o których mowa w § 1 ust. 2.

5. Nowo wybudowany budynek podlega zwolnieniu od podatku od nieruchomości w całości, jeżeli co najmniej 60% jego powierzchni użytkowej stanowią powierzchnie, o których mowa w § 1 ust. 2, a jednocześnie posiada certyfikat LEED na poziomie Gold lub certyfikat BREEAM na poziomie very good.

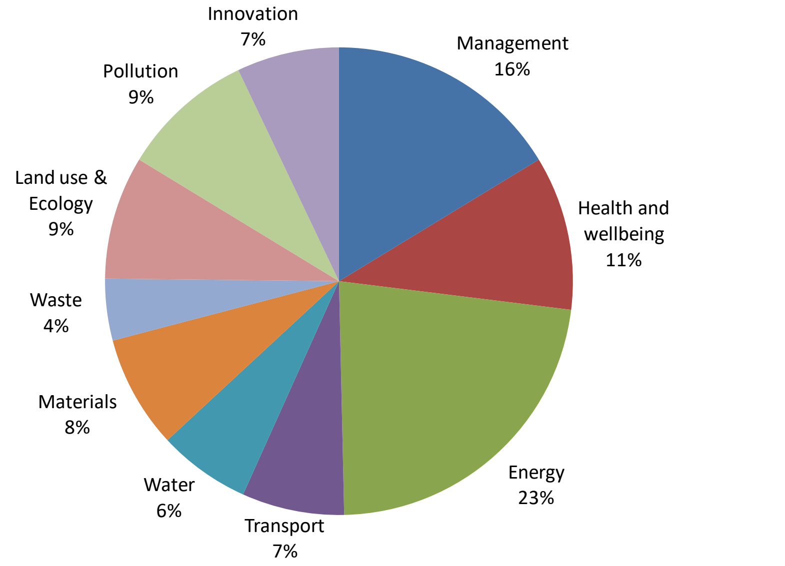
Building assessment systems – BREEAM

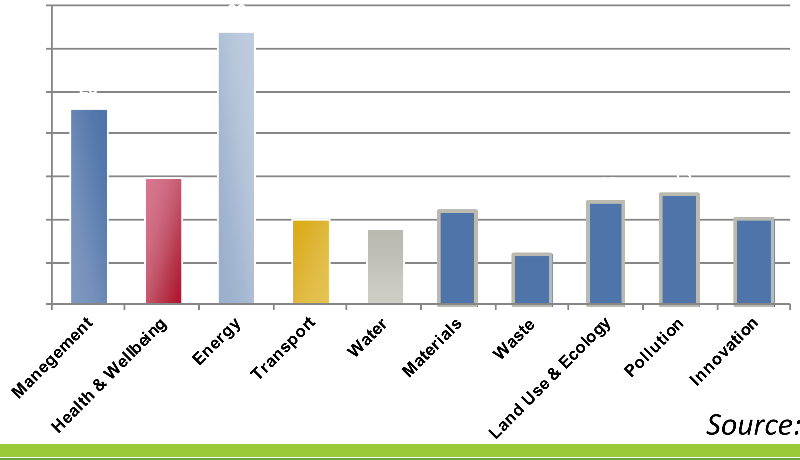
10 main assessment areas

- Management
- Health & Wellbeing
- Energy
- Transport
- Water
- Materials
- Waste
- Land Use & Ecology
- Pollution
- Innovation

- **Energy**: operational energy and carbon dioxide (CO_2)
- **Management**: management policy, commissioning, site management and procurement
- **Health and Wellbeing**: indoor and external issues (noise, light, air quality etc)
- **Transport**: transport-related CO_2 and location-related factors
- **Water**: consumption and efficiency inside and out
- **Materials**: embodied impacts of building materials, including lifecycle impacts like embodied carbon dioxide
- **Waste**: construction resource efficiency and operational waste management and minimisation
- **Land Use**: type of site and building footprint
- **Pollution**: external air and water pollution
- **Ecology**: ecological value, conservation and enhancement of the site

Credit distribution BREEAM International 2013





Source: BREEAM

The future of systems – WELL

WELL Building Standard® – a certification system dedicated to the indoor environment of the building.

WELL in numbers – over 500 registered and certified projects in 30 countries in total with a total area of about 10 million m^2. Already 44 certificates awarded.

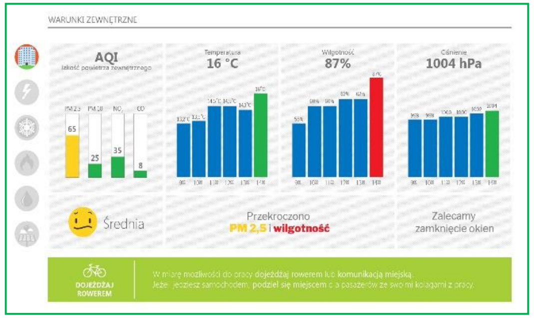
WELL in Poland – 9 registered projects (including 1 pre-certified).

WELL v2 – works on the v2 version are underway, and its debut is planned for Q1 2018.

Source: WELL Building Institute, Go4Energy

The future of systems – WELL

INTERNATIONAL WELL BUILDING INSTITUTE™



- AIR
- WATER
- NOURISHMENT
- LIGHT
- FITNESS
- COMFORT
- MIND

Source: WELL Building Institute, Go4Energy

The future of systems – GBS

GREEN BUILDING STANDARD

OSWBZ.org

Users

Comfort and quality of the internal environment

- The building provides for users of min. category III (PN / EN 15251: 2012):
    - thermal comfort,
    - stream of ventilation,
    - quality of ventilation air,
    - maintaining humidity,
    - acoustic comfort,
    - visual comfort.
- Analysis of access of daylight to rooms
- Analysis of the possibilities of providing users with a window view, from every workplace.

Building

Energy

- A building notified to the GBS Certification Process must use 20% less energy than the reference building expressed in energy costs.
- The analyzes concern usable, final and primary energy.

Action plan at the operational stage

Procedures for the care of the quality of the internal environment

- **Training for users**
- **Training for building service**

Liabilities

Action plan at the operational stage

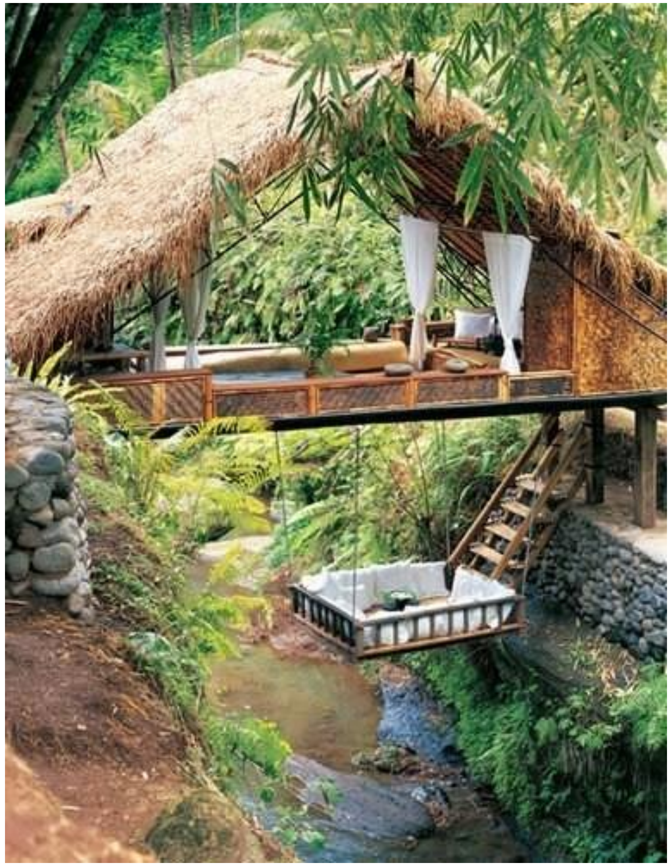
Procedures for rational energy consumption

Investor

GREEN BUILDING STANDARD

Source: OSWBZ

- EcoHomes is one of the environmental classification of residential buildings completed in Great Britain.
- It was a version of the more well-known BREEAM method – Building Research Establishment Environmental Assurancement Method – for housing development.
- In April 2008 it was replaced by Code for Sustainable Homes.



- At the same time, BRE introduced the voluntary certificate „The Home Quality Mark" (HQM) – addressed to construction companies as well as owners and users of new residential buildings.
- HQM – the certificate aims to demonstrate high standards in the existing housing market. At the same time, it will ensure owners and users the assurance that the purchased product is designed and implemented to a high standard, and at the same time is effective in terms of obtained costs of use.

HOME QUALITY MARK

It defines a rigorous, evidence-based, relevant and independent voluntary standard for new homes, and is built on tried and tested processes commonly used in the UK and the rest of the world.

The Home Quality Mark (HQM) is a customer- focused, third-party assessment and certification scheme. It recognises new homes where performance meets best-practice standards that are often significantly above those required by regulation.

HOME QUALITY MARK

- Allows consumers to compare new homes in terms of their likely running costs and environmental footprint (effect), as well as providing a measure of a healthier home. It helps them to make informed choices when buying or renting a home.
- Allows home-builders to evaluate their operations and set their new homes apart from others by supporting performance claims and explaining the benefits of new homes to their customers and others.
- Allows public and private sector landlords to set priorities and monitor performance against these priorities in new build properties throughout the design and construction phases, making sure that the properties they take on, meet their expectations and their tenants' needs.

HOME QUALITY MARK

- Allows the financial service providers to more accurately reflect in their lending or affordability criteria, the effect the cost of running a new home has on a home owner's financial outgoings. This helps to guide lending decisions by taking into account the likely reduction in spending for customers living in better- performing homes.
- Reassures planners, designers, communities and other stakeholders that objectives relating to sustainability and quality of developments are being achieved and robustly monitored.

HOME QUALITY MARK

Our Surroundings

1 Transport and Movement	1.1 Public Transport Availability	15
	1.2 Sustainable Transport Options	17
	1.3 Local Amenities	16
2 Outdoors	2.1 Identifying Ecological Risks and Opportunities	07
	2.2 Managing Impacts on Ecology	09
	2.3 Ecological Change and Enhancement	12
	2.4 Long Term Ecological Management and Maintenance	08
	2.5 Recreational Space	22
3 Safety and Resilience	3.1 Flood Risk	19
	3.2 Managing Rainfall Impacts	19
	3.3 Security	09

HOME QUALITY MARK

My Home

4 Comfort	4.1 Indoor Pollutants	12
	4.2 Daylight	13
	4.3 Noise Sources	04
	4.4 Sound Insulation	09
	4.5 Temperature	17
	4.6 Ventilation	13
5 Energy	5.1 Energy and cost	60
	5.2 Decentralised Energy	08
	5.3 Impact on Local Air Quality	15
6 Materials	6.1 Responsible Sourcing	25
	6.2 Environmental Impact of Materials	25
	6.3 Life Cycle Costing	12
	6.4 Durability	07
7 Space	7.1 Drying Space	03
	7.2 Access and Space	11
	7.3 Recyclable Waste	10
8 Water	8.1 Water Efficiency	17

My Cost	
Provides an indication of the overall costs of living in the home. This takes account of the following. – Energy costs – How long materials are likely to last – Maintenance – Performance of the home in extreme weather – Access to transport and amenities such as GP surgeries, cash points, pharmacies, supermarkets and so on. – Higher quality homes This indicator could influence mortgages, insurance and financing for development.	

HOME QUALITY MARK

My Wellbeing

Provides an indication of how the home will affect the occupier's health and wellbeing. This takes account of the following.

- Quality of living space (indoor air, temperature, light and noise)
- Local amenities such as GP surgeries, cash points, pharmacies, supermarkets and so on.

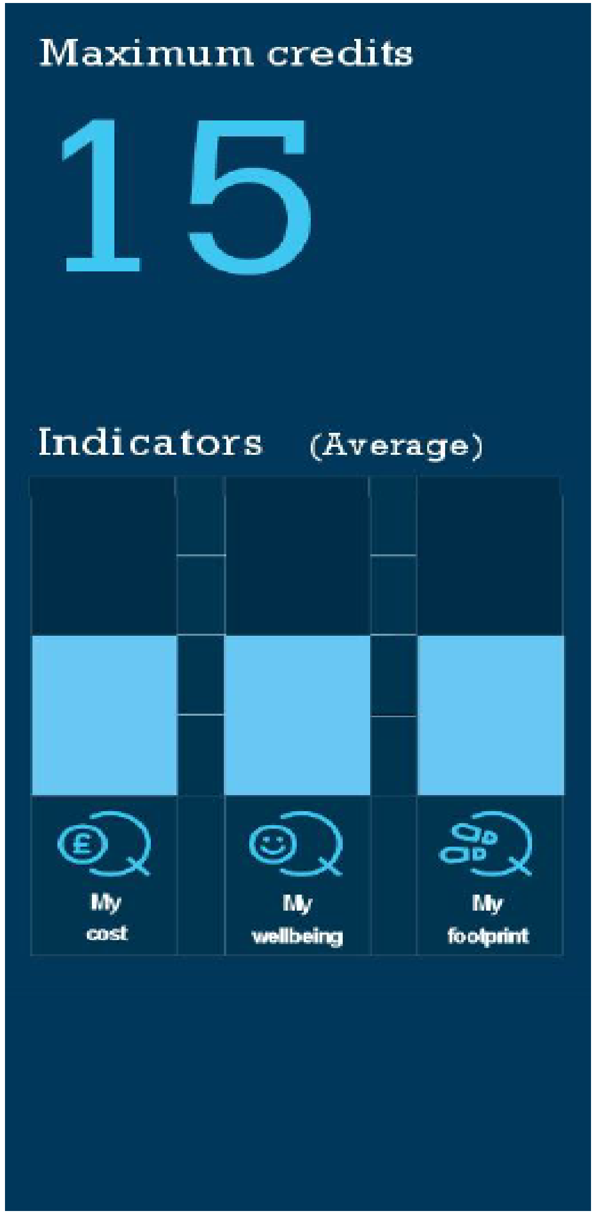
My Footprint

Provides an indication of how the home will affect the environment both during its construction and when it is being used. This takes account of the following.

- Local and global emissions to the environment when the home is being used
- Environmental impact of constructing the home
- Protecting and enhancing ecology

An Excellent new home. Achieving this Mark means that the home is designed and built to have very low running costs, many positive impacts upon your health and wellbeing, all with an extremely low impact upon our environment.

Public Transport Availability



Aim

To recognise and encourage developments which are close to public transport networks. This will give consumers a choice and mean they are not as dependent on their cars, which will reduce associated emissions.

Benefit

- Promotes activity and empowerment.
- Future-proofs developments for changes in transport practices and in the population, including an ageing population.
- Reduces occupants' carbon footprint.
- Provides cost savings when compared with the cost of owning and running a car[6].

Context

Transport accounts for a quarter of UK greenhouse-gas emissions, significantly affecting air quality. Public transport helps reduce transport-related greenhouse-gas emissions, as emissions per passenger mile resulting from trains and buses can be up to eight times lower than those from private cars.

New housing development has a large part to play in making sure that sustainable and public transport facilities are in place and are suitable for the number of people a development is designed for. Including the necessary infrastructure at an early planning stage is the most cost-effective way to help build communities and improve accessibility, and can also help improve existing local transport links.

Indoor Pollutants

Aim

To increase comfort for occupants and minimise negative impacts on health arising from indoor air pollutants emitted from the building and its materials.

Benefit

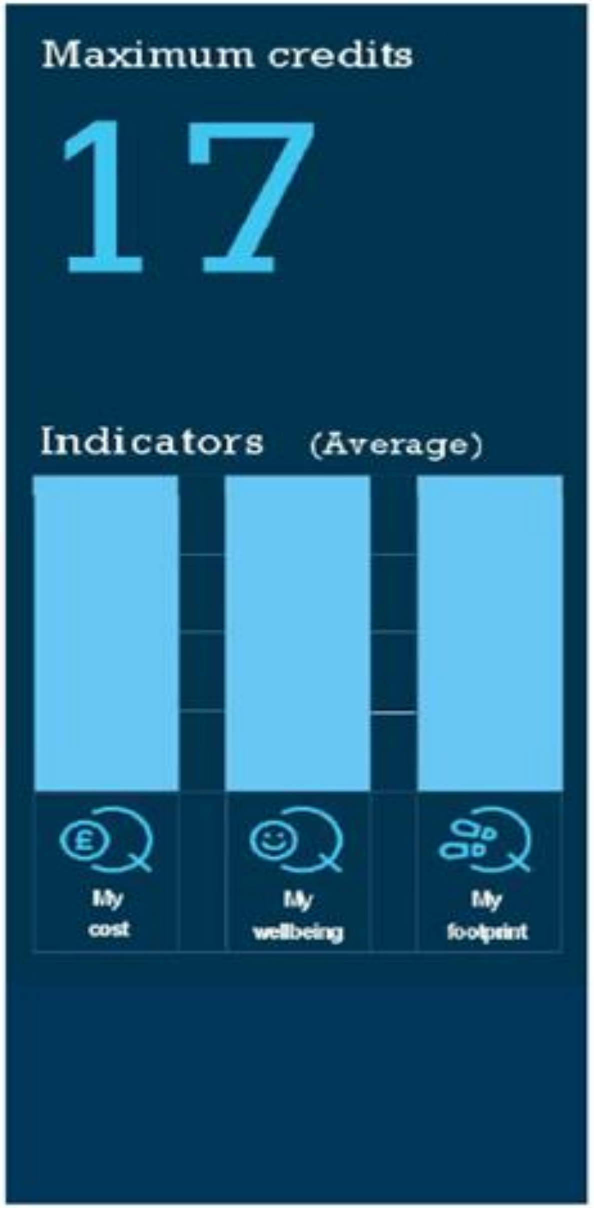
- Reduces the risk of pollutants released from a new home which negatively affect an occupant's health and wellbeing.
- Makes occupants more aware of indoor pollutants so they can make better choices with building materials, decorative products, furnishings or cleaning products.

Context

Building materials, coatings and furnishings are significant sources of indoor air pollution, in particular, formaldehyde and volatile organic compounds (VOCs). Building materials can release a wide range of VOCs, especially during the first two years of a new building[39]. The amount of pollution released into indoor air can be reduced by selecting building materials, coatings and furnishings with low pollutant content.

Household products (such as air fresheners, cleaning fluids, polishes) and cosmetics (such as deodorants, powders, and bathing products) are also potential significant sources of indoor air pollution, but are not covered by HQM.

Termperature



Aim

To minimise the risk of uncontrollable high temperatures happening as a result of current and projected future climate scenarios by recognising that this needs to be considered early in the design process.

Benefit

- Reduces the risk to occupants' comfort, health and wellbeing from uncontrollably high indoor temperatures.
- Helps to 'future-proof' homes by making them able to withstand climate change, which will protect the home's long-term value.
- Reduces the impact on the environment and running costs caused by wasted heat or the need for air-conditioning.

Context

A key part of achieving a comfortable home environment is regulating temperature effectively and reducing the risk of excessive or prolonged exposure to high temperatures (overheating).

Homes are becoming increasingly at risk of overheating [87], due to a number of reasons, including climate change, increased development, high-rise construction and high standards of energy efficiency[88]

New homes are at particular risk of overheating as they are becoming more airtight and are built using better insulation, which results in less air getting in and out and so gives people less control over temperature.
If the risk of a home overheating is not managed appropriately, the results can be very harmful to health and could be fatal for more vulnerable occupants[89].

This issue recognises effective temperature regulation that allows for seasonal changes, occupier preferences and global climate change, which are expected throughout the lifetime of the home.

Ventilation

Aim

To achieve a high standard of air quality in the home to avoid environments that could damage the health and wellbeing of people living in it.

Benefit

- Encourages designs that reduce the risk of pollutants and the health risks associated with this.
- Encourages design that reduces moisture build up in the home and associated respiratory health risks resulting from condensation and mould growth.
- Makes sure that ventilation systems are easy to control so improving effectiveness and usability, occupant understanding and reducing costs.
- Improves access for maintenance access to maintain high performance levels from mechanical and mixed-mode ventilation systems.

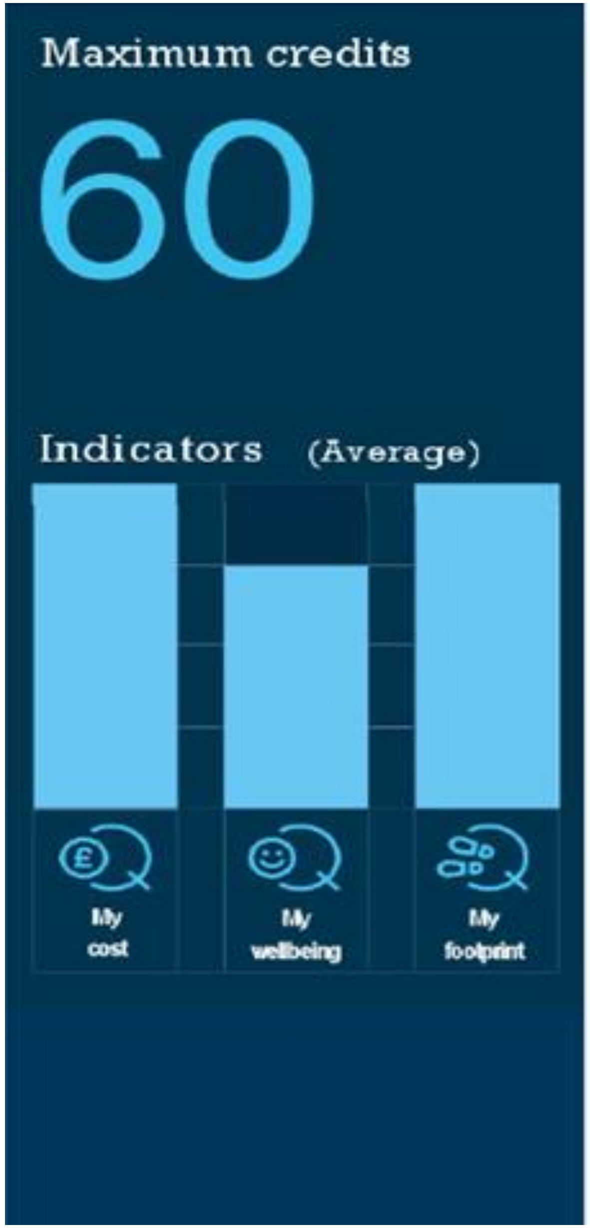
Context

It is widely accepted that the quality of air in the home can affect people's health.

Air quality in the home is a complex combination of pollutants generated inside the home and ones from outside. Personal preferences also have a significant impact on the acceptability of ventilation levels. The design of the ventilation system must therefore be robust, and controllable by the occupants, so that a healthy internal environment can be achieved and maintained.

Increasing levels of building airtightness means that the ventilation system must be capable of providing effective continuous ventilation to all areas of a home, for all levels of likely occupancy and without nuisance to avoid issues of poor air quality, stuffiness and high pollutant levels including VOCs and mould spores.

Energy and cost



Aim

To improve energy performance and reduce costs associated with running the home, and encourage more thorough energy calculations during the design stage.

Benefit

- Reduces energy costs.
- Supports health and wellbeing by keeping homes comfortable and warm.
- Reduces the effect the home has on the environment, by reducing carbon emissions.

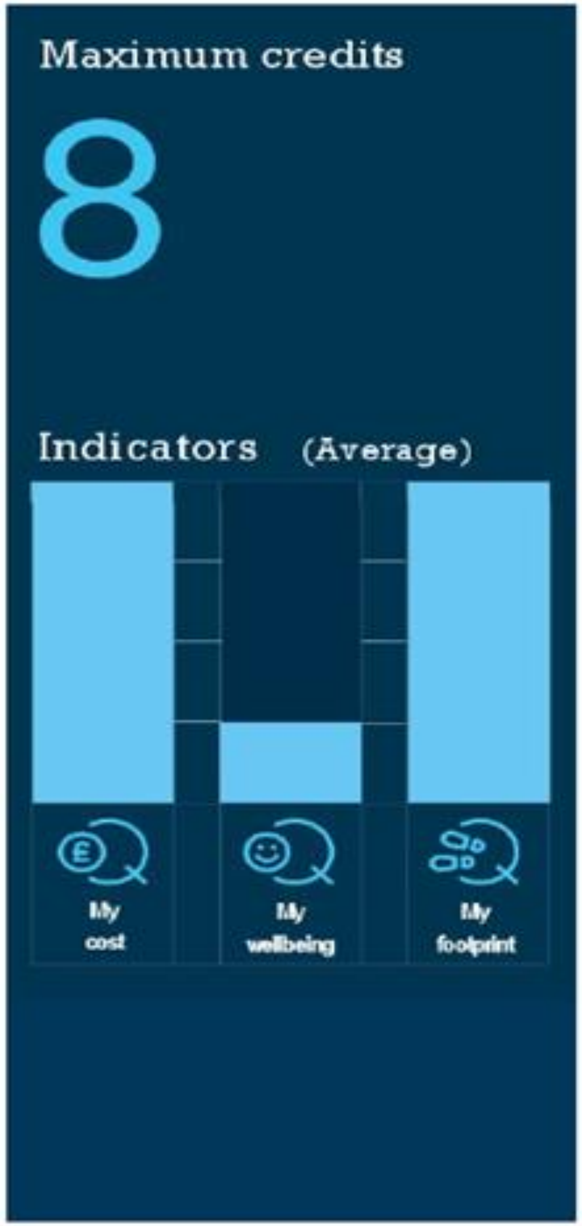
Context

It is well recognised that the energy efficiency of homes has significant impact on human health. It is estimated that in 2013, in England alone, around 2.5 million households were suffering from fuel poverty[95]. Energy use is also a major contributor to global carbon dioxide (CO_2) emissions, with homes contributing a significant proportion of the UK's total carbon emissions (13% of UK greenhouse gas emissions in 2015[96]).

This makes reducing CO_2 emissions and energy costs a key challenge for homes in the UK and an essential part of meeting the Government's target to reduce CO_2 emissions by 80% by 2050[97] (against 1990 levels).

This issue focuses on encouraging energy-efficient design and construction, and making sure that homeowners and tenants are well informed on how to run their home as energy efficiently as possible.

Decentralised Energy



Aim

To maximise the cost and carbon-saving benefits of generating energy from low and zero carbon technologies (LZCTs) by encouraging best practice when selecting, installing and allowing for easy future installation of LZCTs.

Benefit

- Reduces the home's running costs.
- Promotes good-quality installation work to reduce the chance of defects.
- Protects consumers from varying energy costs and incentives by making them less reliant on national grid electricity.
- Helps reduce peak demands on the centralised energy supply network.

Context

There can be significant differences between how well LZCTs perform in practice when compared with their specification, due to inappropriate technologies being specified during the design stage and inconsistent quality of installation [99]. These differences can reduce customer trust and the cost and carbon benefits associated with LZCTs.

Good practice relating to selecting LZCTs, improving on requirements in Building Regulations Part L1 A and carrying out appropriate feasibility studies all help to make the most of the benefits from LZCTs. Schemes recognised by the UK Government and the construction industry include the Microgeneration Certification Scheme (MCS) and the Combined Heat and Power Quality Assurance (CHPQA), which are recognised as valid ways of monitoring the quality of design and installation. In circumstances where it is not appropriate to install LZCTs during the construction phase, it is good practice to make sure they can be easily installed at a later date.

LZCTs are developing quickly, with continuous improvements in performance and reductions in upfront costs. Further innovative solutions are expected that are not specifically acknowledged within this issue. As a result, there is flexibility to acknowledge technologies which are not covered by the schemes mentioned.

Impact on local Air Quality

Aim

To promote the use of heating and hot-water generating appliances which have little or no impact on local air quality.

Benefit

- Reduces the impact on local air quality helping to protect human health.
- Reduces the risk of harmful effects on sensitive ecosystems.

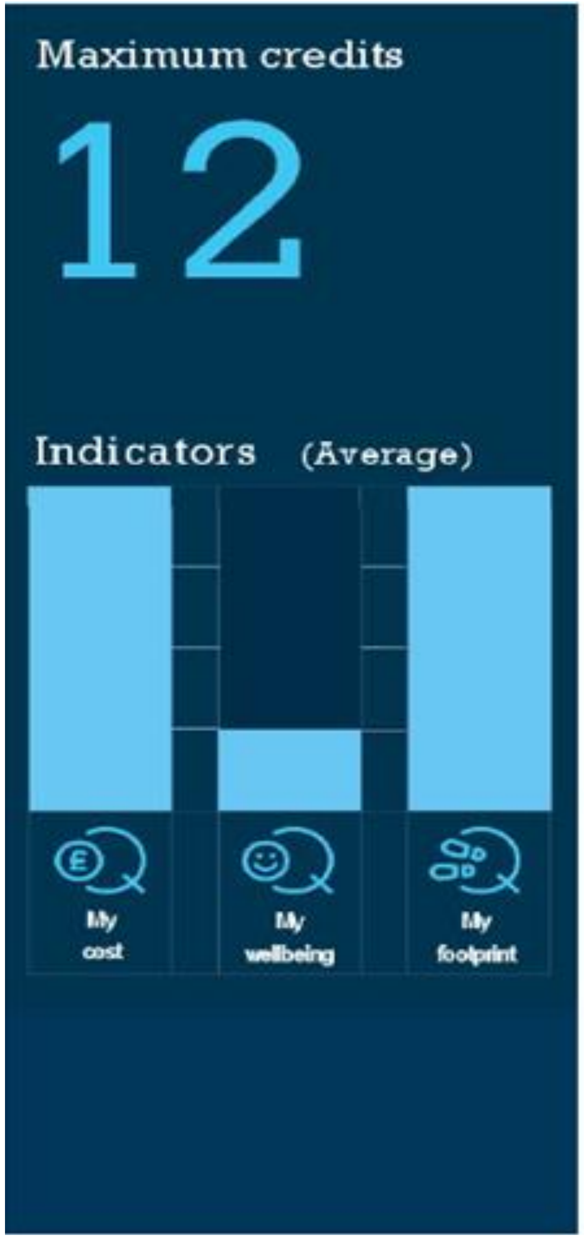
Context

The quality of the air we breathe affects our health and the health of people in our community, particularly the young. There are significant numbers of early deaths and diseases associated with poor air quality. The World Health Organisation estimates that, each year, there are 500,000 early deaths across Europe associated with, or as a result of, poor air quality[101].

Combustion processes in vehicle engines, power generation, homes and industry generate air pollutants, including carbon dioxide (CO_2), nitrous oxides (NO_x), sulphur oxides (SO_x) and small particulates, (particles smaller than 10 and 2.5 microns). These emissions are managed by local authorities through the Local Air Quality Management (LAQM) framework, as part of the Environment Act (1995).

While the main sources of air pollutants are road transport and large combustion plants, homes and the choice of heating and hot water systems do have an impact. NO_x levels vary considerably across the UK, with levels in built-up areas and close to major roads being much higher than in rural areas. This means that emissions from heating systems will have a much greater impact in areas where NO_x emissions are already high.

Life Cycle Costing



Aim

To encourage economic sustainability by recognising and encouraging people to use and share life cycle costing analysis data to reduce maintenance and operational costs and deliver value over the whole life of a home.

Benefit

- Reduces maintenance and operational costs for the homeowner and the occupant.
- Better informs the homeowner and occupant of the running costs of the home.
- Better informs the homeowner of the relationship between cost of buying a home and the cost of running it.
- Reduces the effects of embodied carbon over the whole life of a home by reducing the need for frequent maintenance, repairs, and replacements.

Context

Life cycle cost (LCC) analysis is useful for the occupant because it can provide valuable information on the maintenance and operational costs of the home before and after it is sold. As a result, the occupant will be better informed about the running costs of the home.

This issue presents opportunities for developers, registered social landlords and asset managers to prolong the life of the building. It will also help them to efficiently and economically provide a comfortable, safe and well-maintained environment for tenants and other residents.

User requirements

Nowy Sącz – March 2015

PIERWSZA UMOWA PPP W ADMINISTRACJI RZĄDOWEJ

Informacja prasowa, 5 marca 2015 r.

W formule partnerstwa publiczno-prywatnego powstanie nowa siedziba Sądu Rejonowego w Nowym Sączu. Ministerstwo Infrastruktury i Rozwoju od początku wspierało Sąd Okręgowy w przygotowaniu tej inwestycji.

Umowa pomiędzy Skarbem Państwa reprezentowanym przez Sąd Okręgowy w Nowym Sączu a firmą Warbud - Infrastruktura Sp. z o.o. została podpisana 5 marca 2015 r. Budynek sądu rejonowego ma powstać w systemie DBFOT (Desing-Build-Finance-Operate-Transfer), czyli Zaprojektuj–Zbuduj–Sfinansuj–Zarządzaj-Przekaż. Partner prywatny będzie zobowiązany do zapewnienia finansowania na zaprojektowanie i wybudowanie nowej siedziby sądu, a potem jej utrzymanie i zarządzanie nią. Sąd Okręgowy w Nowym Sączu, jako podmiot publiczny, ma wnieść do inwestycji nieruchomość, na której zostanie wybudowany nowy obiekt. Z analiz przedrealizacyjnych wynika, że wybranie formuły PPP obniży koszt realizacji projektu.

Is it worth it?

- Prestige
- Higher rental cost – a guarantee of quality
- Not necessarily more expensive investment, ecological exploitation
- Comparison?

Laboratory exercise 1

Parameters and indices of thermal comfort

DOROTA SKRZYNIOWSKA
RENATA SIKORSKA-BĄCZEK

Optimal thermal comfort

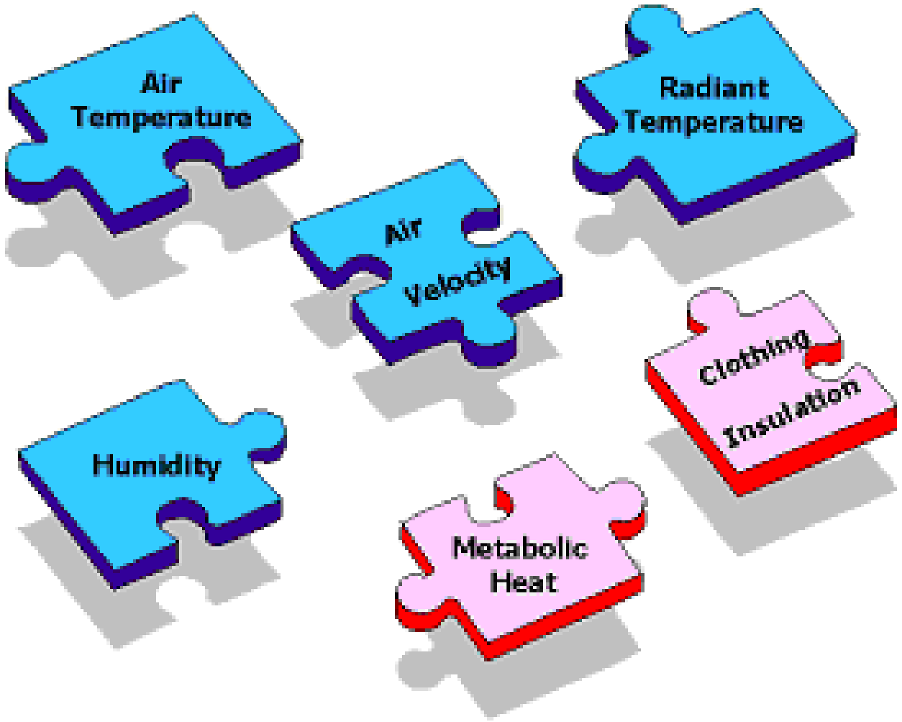
American Society of Heating, Refrigerating and Air Conditioning Engineers

ASHRAE Comfort Standard 55–74:

Thermal comfort is the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation.

Thermal comfort is determined by the room's temperature, relative humidity and air speed.

Environmental parameters



Air temperature

The air temperature (t) is the average temperature of the air surrounding the occupant, with respect to location and time.

Most people will feel comfortable at room temperature, colloquially, this is a range of temperatures around 20 to 22°C (68 to 72°F), but this may vary greatly between individuals and depending on factors such as activity level, clothing, and humidity.

Relative humidity

Relative humidity (RH) is the ratio of the amount of water vapour in the air to the amount of water vapour that the air could hold at the specific temperature and pressure.

The recommended level of indoor humidity is in the range of 30–60% in air conditioned buildings, but new standards such as the adaptive model allow lower and higher humidities, depending on the other factors involved in thermal comfort.

Air speed

It is the average speed of the air (w) to which the body is exposed, with respect to location and time. The recommended level of air speed is $w = 0.1–0.3$ m/s.

Measuring instruments

1. Temperature – thermometer

A thermometer is a device that measures temperature or a temperature gradient.

The types of thermometers:

1.1. Liquid thermometer

A liquid-in-glass thermometer indicates temperature by the distance a liquid contained in a glass bulb has expanded and traveled into a connecting capillary tube.

Mercury or coloured alcohols are usually used. The capillary tube above the liquid usually contains a gas.

Measuring instruments

1.2. Digital thermometer

An instrument that measures the temperature of

something or someone by sensor.

A numerical reading is given on a LCD display, usually to one decimal place, making them more precise than liquid thermometers.

1.3. Gas thermometer

A gas thermometer measures temperature by the variation in volume or pressure of a gas.

Measuring instruments

1.4. Thermocouple

A thermocouple is an electrical device consisting of two dissimilar electrical conductors forming electrical junctions at differing temperatures.

A thermocouple produces a temperature – dependent voltage as a result of the thermoelectric effect, and this voltage can be interpreted to measure temperature.

Thermocouples are a widely used type of temperature sensor.

Measuring instruments

1.5. Temperature transducers

Temperature transducers can detect environmental or surface temperature by means of a thermo-element or a resistor transforming it into an electric signal.

A temperature transducer connected to a control device can control a process.

Measuring instruments

2. Air velocity – **anemometers**

An anemometer is a device used for measuring wind speed, and is also a common weather station instrument. The term is derived from the Greek word *anemos*, which means wind, and is used to describe any wind speed instrument used in meteorology.

The most popular are the vane anemometer. It must have its axis parallel to the direction of the wind and, therefore, horizontal.

Measuring instruments

3. Relative air humidity – psychrometer, hygrometer

A hygrometer is an instrument for determining atmospheric humidity by the reading of two thermometers, the bulb of one being kept moist and ventilated.

Psychrometer refers to a device for determining relative humidity in the atmosphere by the reading and comparing of two thermometers: the dry-bulb and wet-bulb air temperatures that are spun in the air. The psychrometer is one kind of hygrometer.

Measuring instruments

3.1. Assmann psychrometer

3.2. Hair hygrometer

Indices of thermal comfort

Effective temperature

Reflects the combined effect of temperature, air humidity and wind speed on the thermal sensation of a human.
This indicator does not include solar radiation.

The different factors determining thermal comfort – air temperature, humidity and air movements are combined together into a single index.

Indices of thermal comfort

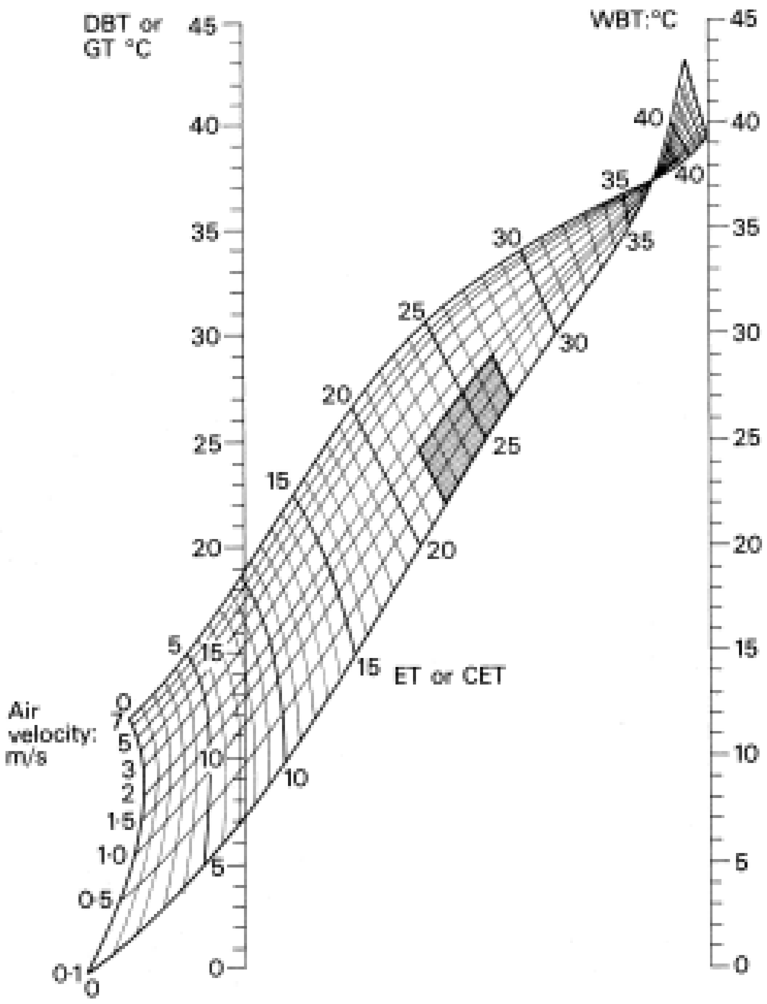


Chart of effective temperature (ET)

Indices of thermal comfort

Kata Thermometer

A device consisting principally of an alcohol thermometer, used to ascertain air cooling power and, indirectly, small wind speeds in circulating air, by measuring the time taken for the temperature of the bulb of alcohol to make a specified drop (100 to 95°F).

The Kata Thermometer is an alcohol thermometer with a large bulb, long stem and a small reservoir. It is graduated only at two points, namely 38 and 35°C.

Indices of thermal comfort

Kata value

$$A = \frac{Q}{\tau}\left[\frac{mJ}{cm^2 \cdot s}\right]$$

Kind of work	Kata $\left[\frac{mJ}{cm^2 \cdot s}\right]$
Leasure time	16.8–21.0
White-collar job	22.2–25.1
Light manual work	25.1–33.5
Hard manual work	50.3–75.5

Indices of thermal comfort

Indices PMV and PPD

European Standard
EN ISO 7730

The PMV/PPD model was developed by P.O. Fanger using heat-balance equations and empirical studies about skin temperature to define comfort.
Standard thermal comfort surveys ask subjects about their thermal sensation on a seven--point scale from cold (–3) to hot (+3).
Fanger's equations are used to calculate the Predicted Mean Vote (PMV) of a large group of subjects for a particular combination of air temperature, mean radiant temperature, relative humidity, air speed, metabolic rate and clothing insulation.

Zero is the ideal value, representing thermal neutrality, and the comfort zone is defined by the combinations of the six parameters for which the PMV is within the recommended limits (–0.5 < PMV < +0.5).
Although predicting the thermal sensation of a population is an important step in determining what conditions are comfortable, it is more useful to consider whether or not people will be satisfied.
Fanger developed another equation to relate the PMV to the Predicted Percentage of Dissatisfied (PPD). This relation was based on studies that surveyed subjects in a chamber where the indoor conditions could be precisely controlled.

Indices of thermal comfort

PMV and PPD

$$PMV = [0{,}303\ \exp(-0{,}036\ M) + 0{,}028] \cdot \{(M-W) - 3{,}05\cdot 10^{-3} \cdot [5773 - 6{,}99\cdot(M-W) - p_a] - 0{,}42\cdot[(M-W) - 58{,}15] - 1{,}7\cdot 10^{-5}\cdot M\cdot(5867 - p_a) - 0{,}0014\cdot M\cdot(34 - t_a) - 3{,}96\cdot 10^{-8}\cdot f_{cl}\cdot[(t_{cl}+273)^4 - (\bar{t}_r+273)^4] - f_{cl}\cdot h_{cl}\cdot(t_{cl} - t_a)\}$$

where:

$$t_{cl} = 35{,}7 - 0{,}028\cdot(M-W) - I_{cl}\cdot\{3{,}96\cdot 10^{-8}\cdot f_{cl}\cdot[(t_{cl}+273)^4 - (\bar{t}_r+273)^4] - f_{cl}\cdot h_{cl}\cdot(t_{cl} - t_a)\}$$

$$h_c = 2{,}38\cdot(t_{cl} - t_a)^{0{,}25} \quad \text{dla} \quad 2{,}38\cdot(t_{cl} - t_a)^{0{,}25} > 12{,}1\cdot\sqrt{v_{ar}}$$

$$h_c = 12{,}1\cdot\sqrt{v_{ar}} \quad \text{dla} \quad 2{,}38\cdot(t_{cl} - t_a)^{0{,}25} > 12{,}1\cdot\sqrt{v_{ar}}$$

$$f_{cl} = 1{,}00 + 1{,}290\cdot I_{cl} \quad \text{dla} \quad I_{cl} \le 0{,}078\ m^2\cdot K/W$$

$$f_{cl} = 1{,}05 + 0{,}645\cdot I_{cl} \quad \text{dla} \quad I_{cl} > 0{,}078\ m^2\cdot K/W$$

Indices of thermal comfort

PMV and PPD

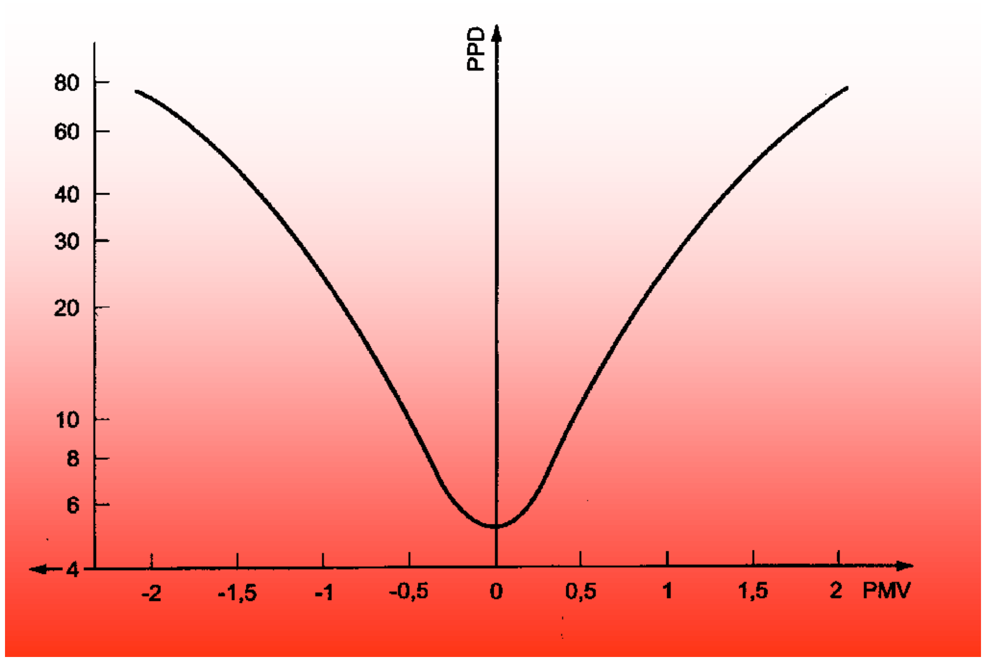
$$PPD = 100 - 95 \cdot \exp(-(0.03353 \cdot PMV^4 + 0.2179 \cdot PMV^2))$$

Category	PPD [%]	PMV
A	< 6	–0.2 < PMV < +0.2
B	< 10	–0.5 < PMV < +0.5
C	< 15	–0.7 < PMV < +0.7

Sources: http://www.PMV_PPD,

http://comfort.cbe.berkeley.edu/

Thermal sensation scale and predicted percentage of dissatisfaction



-3	-2	-1	0	1	2	3
cold	cool	slightly cool	neutral	slightly warm	warm	hot

Indices of thermal comfort

Calculation of PMV and PPD

M (W/m^2), Metabolic energy production (58 to 232 W/m^2)

W (W/m^2), Rate of mechanical work, (normally 0)

Ta (C), Ambient air temperature (10–30)

Tr (C), Mean radiant temperature (often close to ambient air temperature)

v (m/s), Relative air velocity (0.1 to 1 m/s)

rh (%), Relative humidity

Icl (clo), basic clothing insulation (1 clo = 0.155 W/m^2K)

Indices of thermal comfort

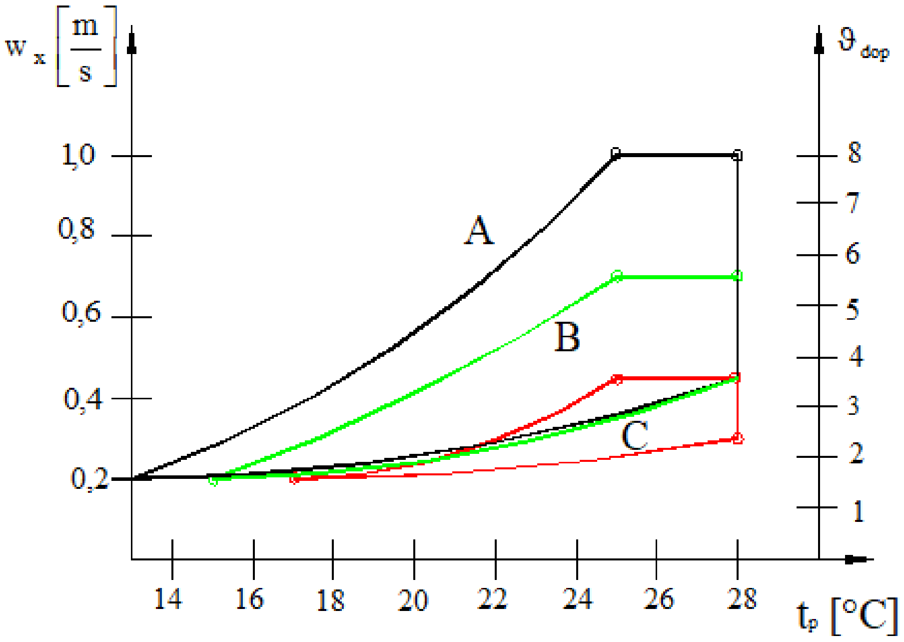
Rydberg's criterion

The basic limitation is speed of air in the work area, which should not exceed 0.2 m/s. Permissible speed in the human residence zone results from the place of work (office, industrial, etc.), accepted internal conditions in the room, and air temperature supply. Generally, it is assumed that the temperature difference between supply air and air in human residence zone should not exceed 1 K.

An element that combines speed and the air temperature is cooling capacity of the air stream (criterion Rydberg) described by the formula:

Indices of thermal comfort

$$\upsilon_x = \Delta t_x + 8w_x$$



υ_x	–	effective draft temperature [-],
Δt_x	–	difference between ambient air temperature in the human residence zone and air temperature at a distance of x from the grill, [K],
w_x	–	velocity of air at a distance of x [m/s],

Measure of temperature, air humidity and air velocity

No.	Instruments	Displays
1		
2		
3		

Laboratory exercise 2

Air velocity and filters

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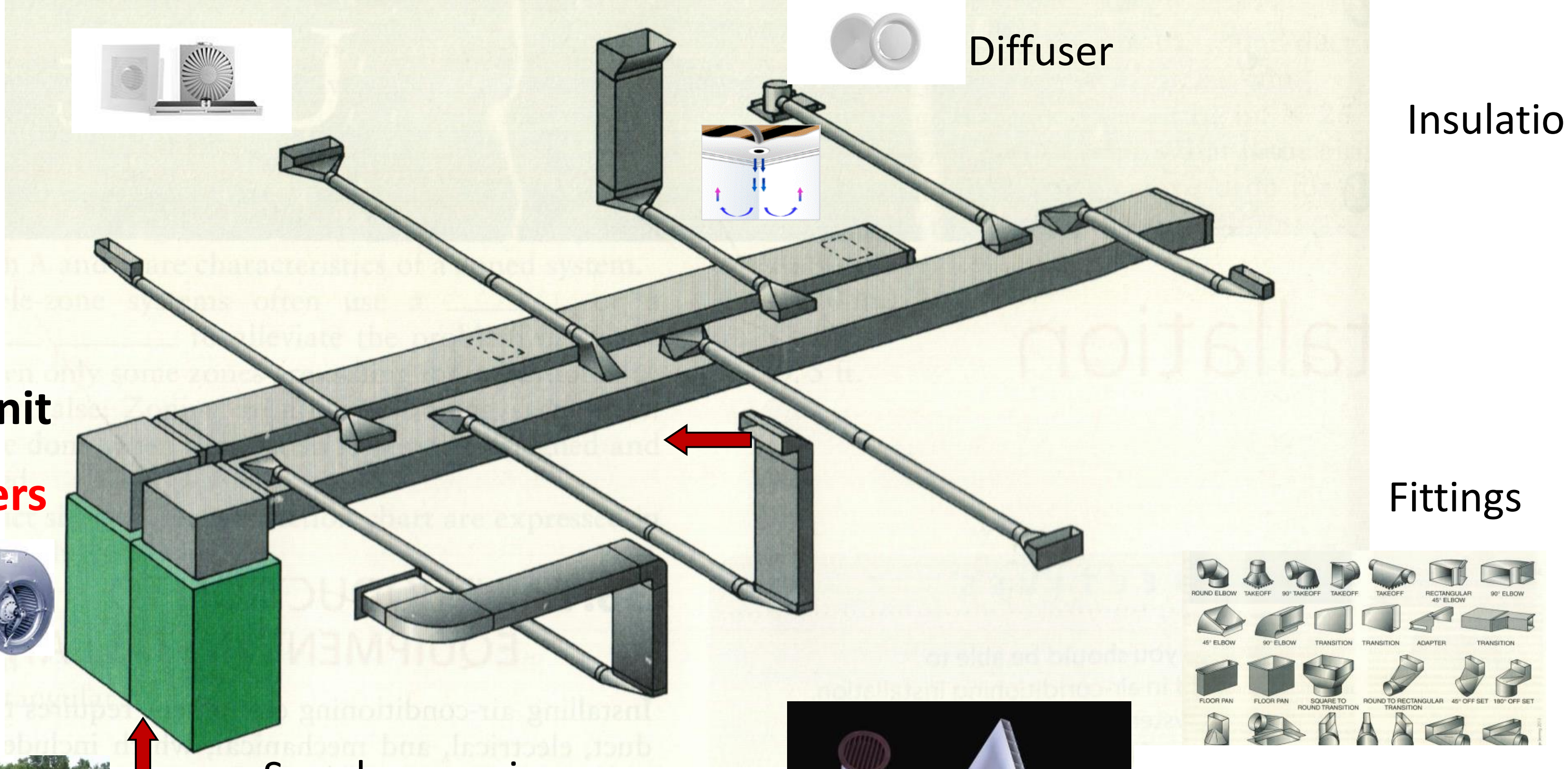
Ductwork, duct accessories – part of ventilation system

Air terminals (grilles)

Diffuser

Insulation



AHU – air handling unit

Fan **Filters**

Rooftop

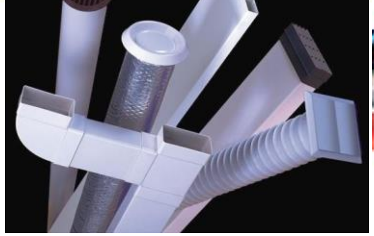
Intake

Supply – nawiew

Exhaust – wywiew

Fittings

Ducts

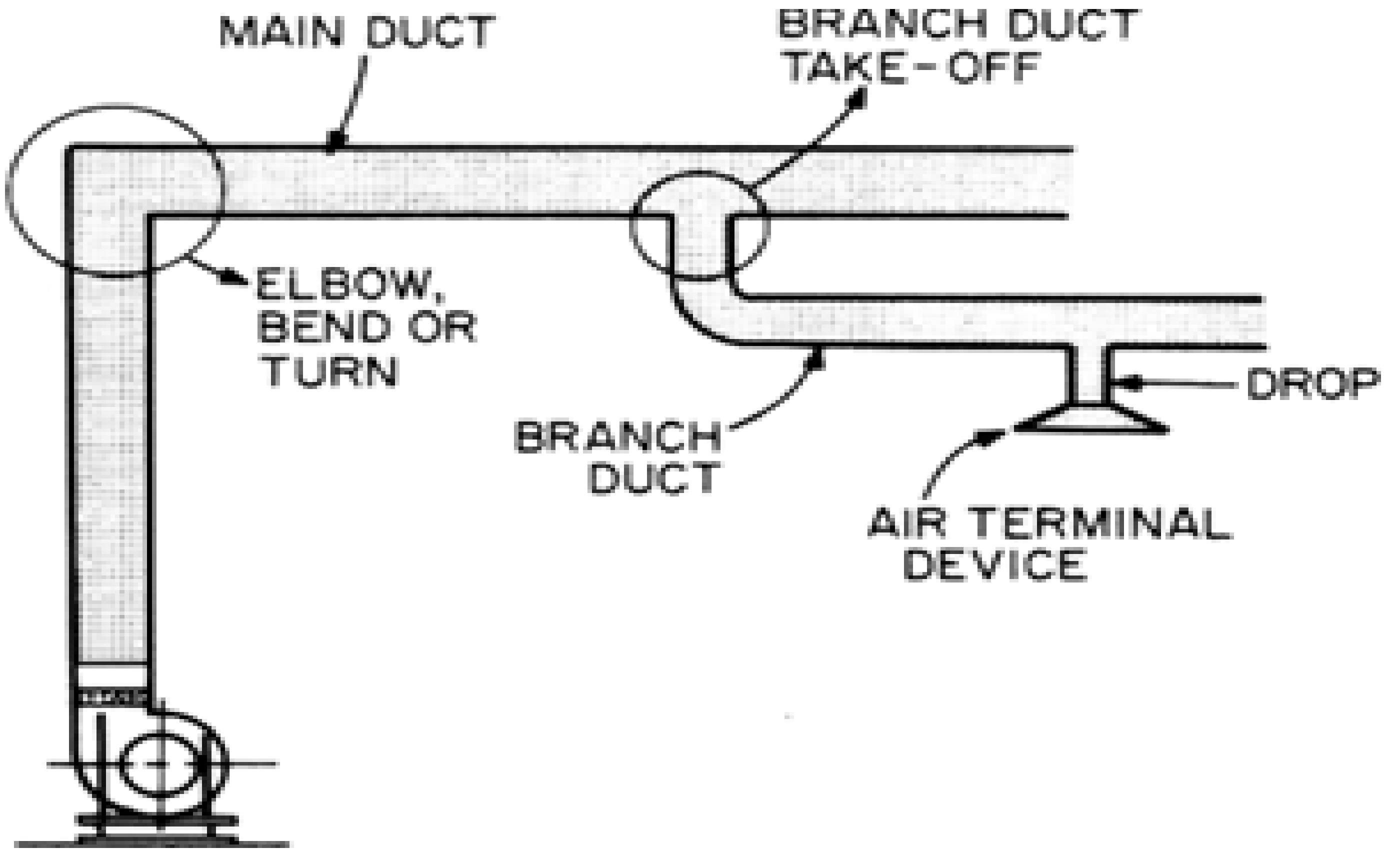


Ductwork – materials

Ducts can be fabricated from a range of materials:

1. Galvanised mild steel
2. Aluminium
3. Polyurethane and phenolic foam panels
4. Fibreglass

Air ducts



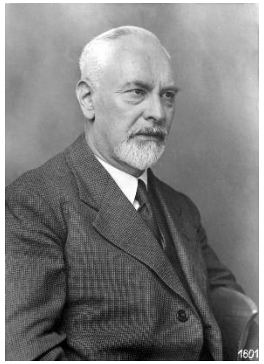
Source: https://branch+duct

Air flow velocity in ducts

Type of Duct	Comfort Systems		Industrial Systems		High Speed Systems	
	m/s	ftm	m/s	ftm	m/s	ftm
Main ducts	4 - 7	780 - 1380	8 - 12	1575 - 2360	10 - 18	1670 - 3540
Main branch ducts	3 - 5	590 - 985	5 - 8	985 - 1575	6 - 12	1180 - 2360
Branch ducts	1 - 3	200 - 590	3 - 5	590 - 985	5 - 8	985 - 1575

Pitot tube (Prandtl tube)

Henri Pitot 1695–1771
French hydraulic engineer



Ludwig Prandtl 1875–1953
German engineer

Flow measurement device used to measure fluid flow velocity

The basic Pitot tube consists of a tube pointing directly into the fluid flow. As this tube contains fluid, a pressure can be measured.

Sources: https://www.ptottube, https://www.pressure measurement

Bernoulli's equation states

$p_{total} = p_{static} + p_{dynamic}$
$p_{dynamic} = p_{total} - p_{static}$

$$p_{dynamic} = \frac{\rho v^2}{2} \text{ [Pa]}$$

where:
v – air flow velocity, [m/s]
P – air density in temperature 20°C, $\rho = 1.2$ kg/m^3

Solving that equation for air flow velocity gives:

$$v = \sqrt[2]{\frac{2(p_{total} - p_{static})}{\rho}} = \sqrt[2]{\frac{2\, p_{dynamic}}{\rho}} \approx 1.3\sqrt[2]{p_{dynamic}} \text{ [m/s]}$$

Volumetric flow of air flowing through the duct is estimated from equation

$$V = v_a\ F \text{ [m}^3\text{/s],[m}^3\text{/h]}$$

where:
v_a – average air velocity, [m/s]
F – duct surface, [m^2]

Tasks to be carried out

1. Measurement of dynamic pressure of air in duct using Pitot (Prandtl) tube
2. Calculation of air flow velocity
3. Creation of air flow velocity profile in duct (for different fan rotational velocities)
4. Calculation of volumetric flow of air flowing through the duct

European standards and Polish standards

1. PN-EN 15242:2007 – English version: Ventilation for buildings – Calculation methods for the determination of air flow rates in buildings – including infiltration
2. PN-EN 16798-7:2017-07 – English version: Energy performance of buildings – Ventilation for buildings – Part 7: Calculation methods for the determination of air flow rates in buildings – including infiltration (Modules M5-5)

Air velocity in duct

L.p.	Distance from duct wall X	Dynamic pressure in duct	Dynamic pressure in duct	Air velocity in duct
	cm	[mbar]	[Pa]	[m/s]
1	0			
2	5			
3	10			
4	15			
5	20			
6	25			
7	30			
8	35			

The function of air filters

An air filter is usually made of a spun fibreglass material or cloth enclosed in a cardboard frame. Its basic function is to clean the air that circulates through HVAC system. Filters trap and hold many types of particulates and contaminants that could affect health and comfort, including:

- Dust and dirt,
- Pollen,
- Mould and mould spores,
- Fibres and lint,
- Metal, plaster or wood particles,
- Hair and animal fur,
- Bacteria and microorganisms.

When should a dirty filter be replaced?

Dirty filters:

- can damage heating and cooling equipment,
- can reduce the airflow inside the HVAC system, which can cause air-handling fans to work harder and wear out quicker,
- cannot remove particulates and contaminants effectively, which allows these materials back into the indoor air,
- can cause contaminants to accumulate in a HVAC system's ductwork,
- can cause HVAC equipment to work harder, increasing energy usage and unnecessarily driving up monthly energy bills.

When should a dirty filter be replaced?

High pressure drop on a filter – the best moment to replace a dirty filter

$$p_{dynamic} = \frac{\rho v^2}{2} \quad [\text{Pa}]$$

where:

$p_{dynamic}$ – dynamic pressure, [Pa]

v – air flow velocity, [m/s]

P – air density in temperature 20°C, ρ = 1.2 kg/m^3

When should a dirty filter be replaced?

High pressure drop on a filter – the best moment to replace a dirty filter.

Solving that equation for air flow velocity gives:

$$v = = \sqrt[2]{\frac{2\,p_{dynamic}}{\rho}} \approx 1.3\sqrt[2]{p_{dynamic}}\ [\text{m/s}]$$

Volumetric flow of air flowing through the duct is estimated from equation:

$$V = v_a\ \ F\ [\text{m}^3/\text{s}],\ [\text{m}^3/\text{h}]\ (3)$$

where:

v – air velocity, [m/s]

F – duct Surface, [m^2]

Source: http://www.filters

Measurements of the pressure drop: clean filter

Fan speed	Pressure drop at filter	Dynamic pressure in duct	Air velocity in duct	Air flow in duct	Air flow in duct
%	[Pa]	[Pa]	[m/s]	[m^3/s]	[m^3/h]
100					
90					
80					
70					
60					
50					
40					
30					
20					
10					

Measurements of the pressure drop: dirty filter

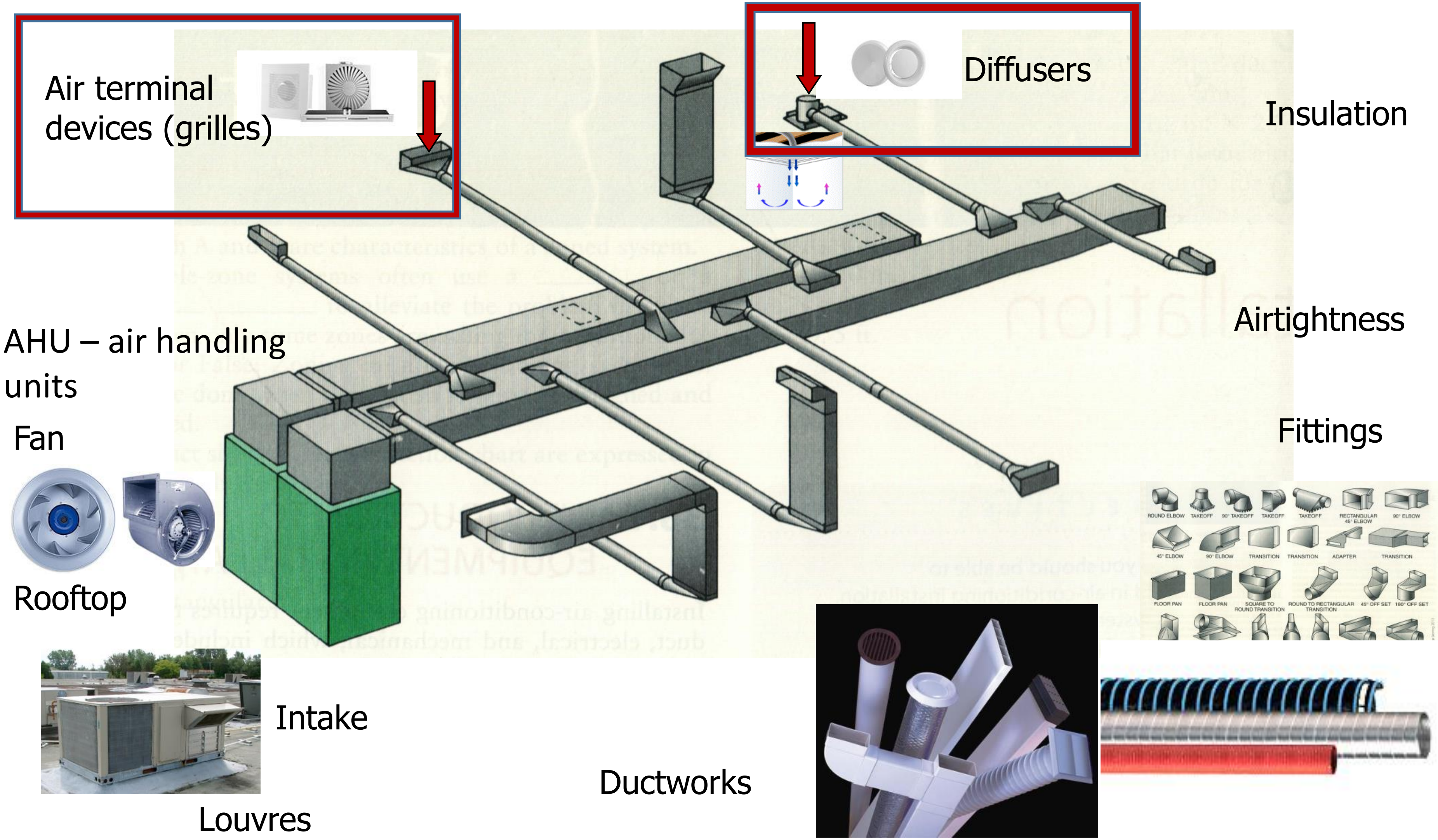
Fan speed	Pressure drop at filter	Dynamic pressure in duct	Dynamic pressure in duct	Air velocity in duct	Air flow in duct	Air flow in duct
%	[Pa]	[mbar]	[mbar]	[m/s]	[m^3/s]	[m^3/h]
100						
90						
80						
70						
60						
50						
40						
30						
20						
10						

Laboratory exercise 3

Distribution of air and grilles

DOROTA SKRZYNIOWSKA
RENATA SIKORSKA-BĄCZEK

Air grilles and diffusers – parts of ventilation system



Air grilles and diffusers

Air terminal devices for the ventilation of buildings and spaces in terms of supply cold or warm air to rooms:

- **grille** – a special device used in supplying and extracting air vertically without any kind of deflection,
- **diffuser** – a device used to direct the air at different angles by profiled blades when the air is leaving the unit and going into the space.

Materials

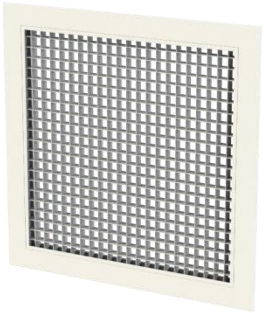
Air terminals are made of following materials:

- aluminum
- mild steel
- stainless steel
- plastic

Location

These devices are usually mounted in the floors, walls, doors, ceiling and in ducts. Some of these devices are specially designed for horizontal and vertical mounting. Floor devices are robust enough to withstand the pressure from foot traffic.

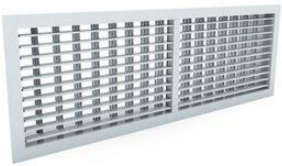
Type of grilles – examples



Egg crate – These devices are considered to be the cheapest and the simplest equipment of their category. The plenum box is visible above the equipment and can be seen from the room below. If the purpose is to remove air by an extracting ventilation system, then there is no need of the device to have profiled blades to direct the air, and an egg grate device can be used.

Bar type – This device's blades are shaped as a bar as opposed to a narrow blade. The bar is mostly of T shape which reduces the see--through factor.

- Some linear bar devices come with angled or adjustable blades.



Transfer type – These devices are commonly used in the walls and doors for ventilation and also stop the fire and smoke from spreading if in any case these occur. Sometimes transfer devices come with an intumescent fire damper to act as insulation if fire erupts.

Type of grilles – examples

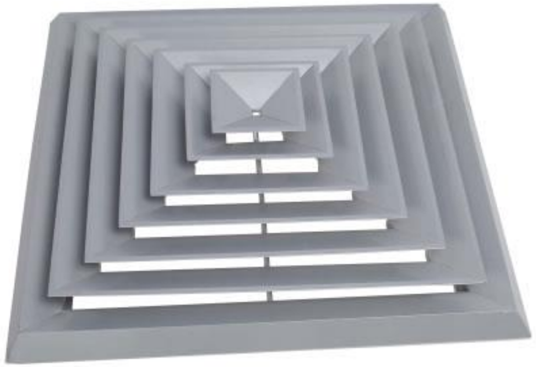
Linear Bar Grille
Polymer Plenum Box
Linear bar grilles have a single row of horizontal blades

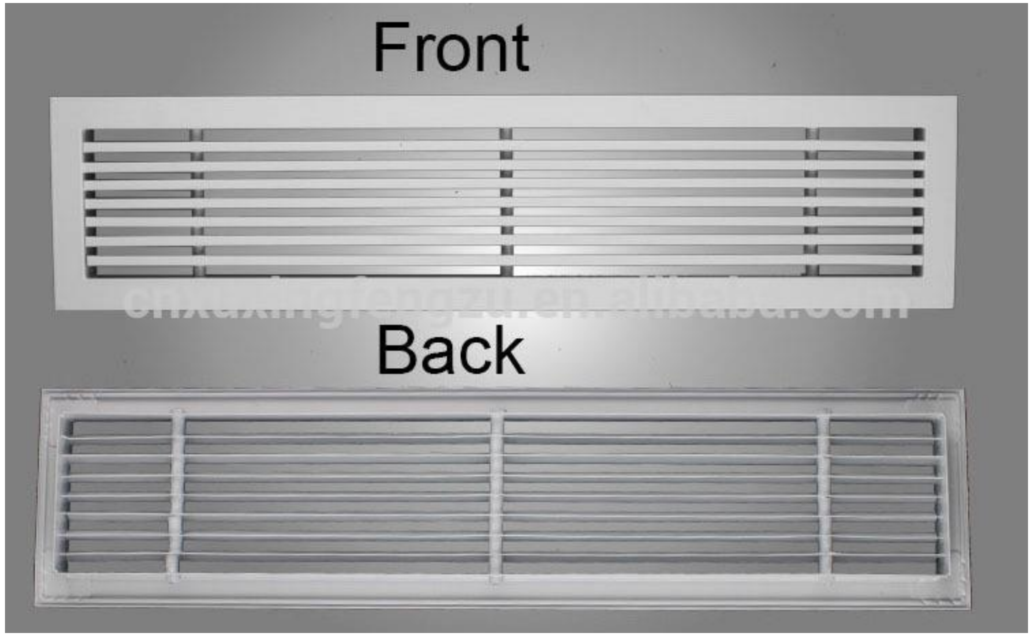
Louver bladed device – They supply air at the ceiling level and can be round and square in shape. Curved blades are capable of deflecting air in more than two directions (depending on the place at where it is located).

Straight bladed – Straight bladed devices are normally cheaper than Louvre Bladed devices and some of their types come with adjustable blades.

Linear slot device – Linear slot devices are installed not only for distributing, but also for aesthetic purposes. They can be used for both the purposes of supplying or returning air. Blanking plates create dummy slots to create a continuous linear effect.

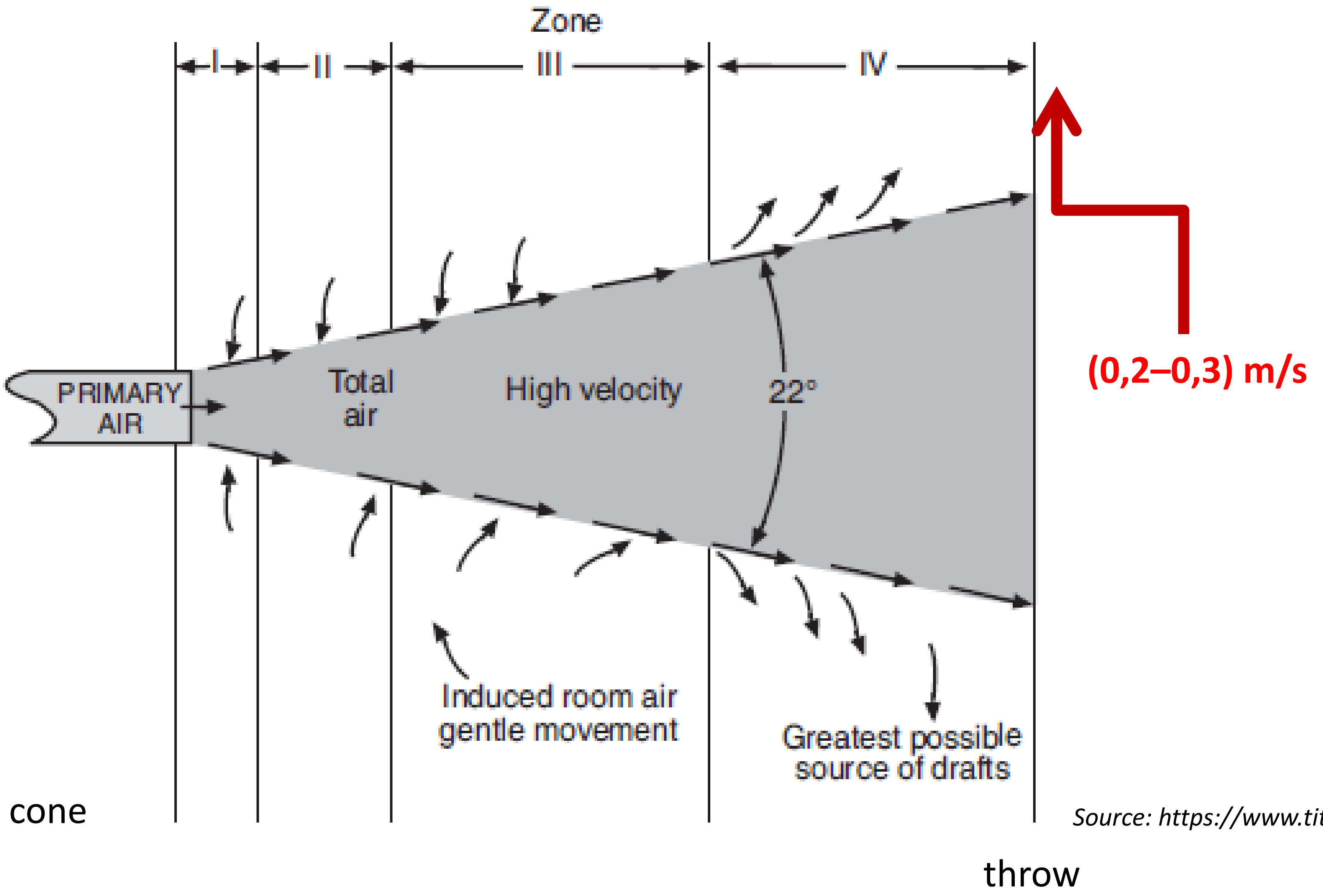
Type of grilles – examples





Air distribution – expansion of primary air jet

Schematic free flowing – model of ideal isothermal air jet



Source: https://www.titus-hvac.com

Flow velocity

Flow velocity is an important factor when controlling air conditioning systems or ventilation systems and in many other systems.

Measurements can be made in open space, as well as inside the ventilation, air-conditioning and exhaust systems, and wherever the medium is being tested.

Flow rate/volume flow means the quantity of air that flows through a certain area (section) within one second.

Instruments used to measure velocity – anemometer

Fan

Measuring rod

- An **anemometer** is a device used for measuring air stream velocity.

Instruments used to measure air volume – balometer

- Air velocity
- Air volume
- Air pressure

the types of instrumentation that can be used for the measurement and verification of various airflow parameters

A balometer is a device used for measuring the volume of air coming out of grilles and diffusers in HVAC systems. The name **balometer** has become synonymous with "airflow capture hood" today.

Source: https://www.balometer use

Instruments used to measure distance – vernier caliper

A vernier caliper – is a device used to measure the distance between two opposite sides of an object.

The tips of the caliper are adjusted to fit across the points to be measured and then the caliper is then removed and the distance read by measuring between the tips with a measuring tool, such as a ruler or distance scale.

Air stream

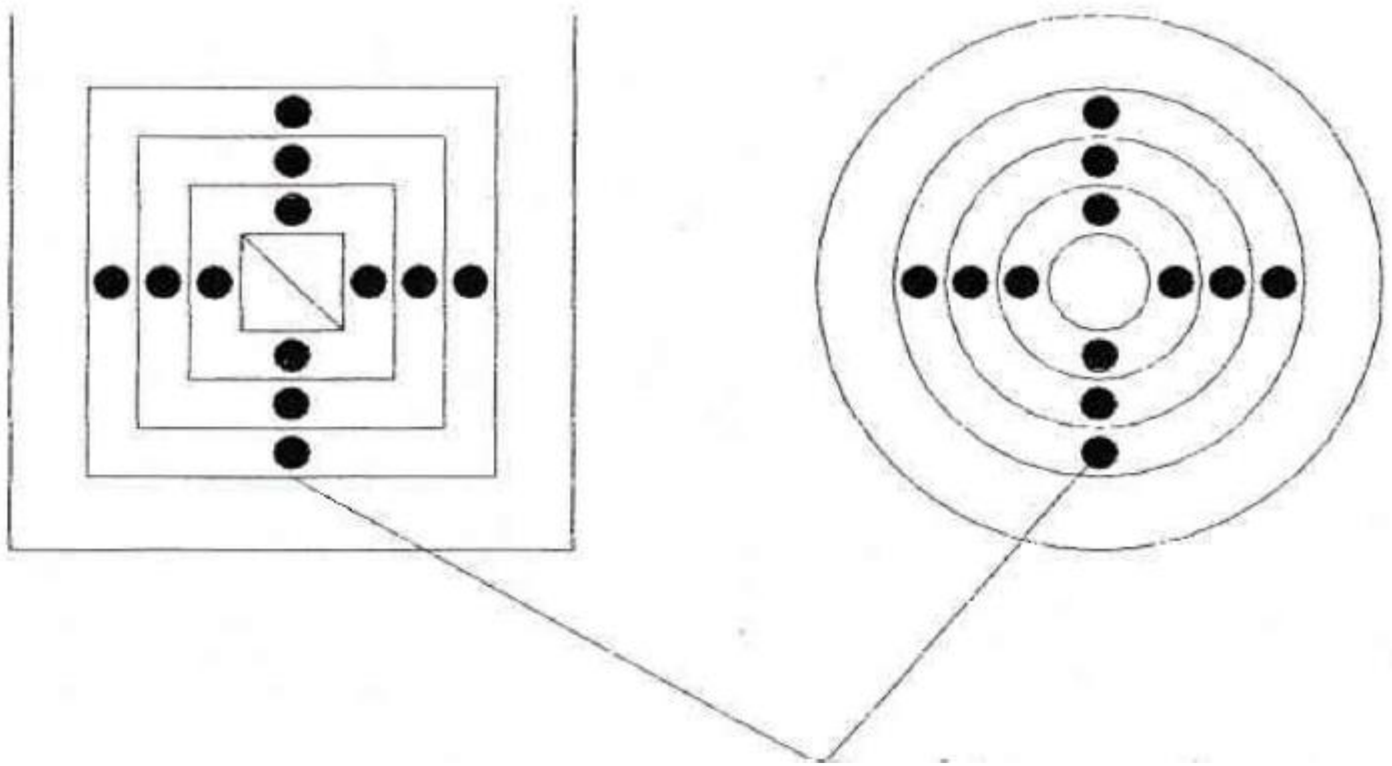
Air stream is calculated by measuring the velocity of air passing through a grill by using an anemometer or a balometer, and multiplying the velocity by the effective area of the grill.

Effective area vs. free area

What are *effective area* and *free area* as they apply to grilles, registers and diffusers? What are the differences between these two areas and how are they used in our industry?

Effective area, given the abbreviation A_k, is the area of the register, grille, or diffuser in square meter that is utilized by the air flowing through it.

Where to measure?



Air flow calculations

No.	Measuring velocity of air from grill		
	Rotational speed of fan		
	50%	70%	100%
1			
2			
3			
4			

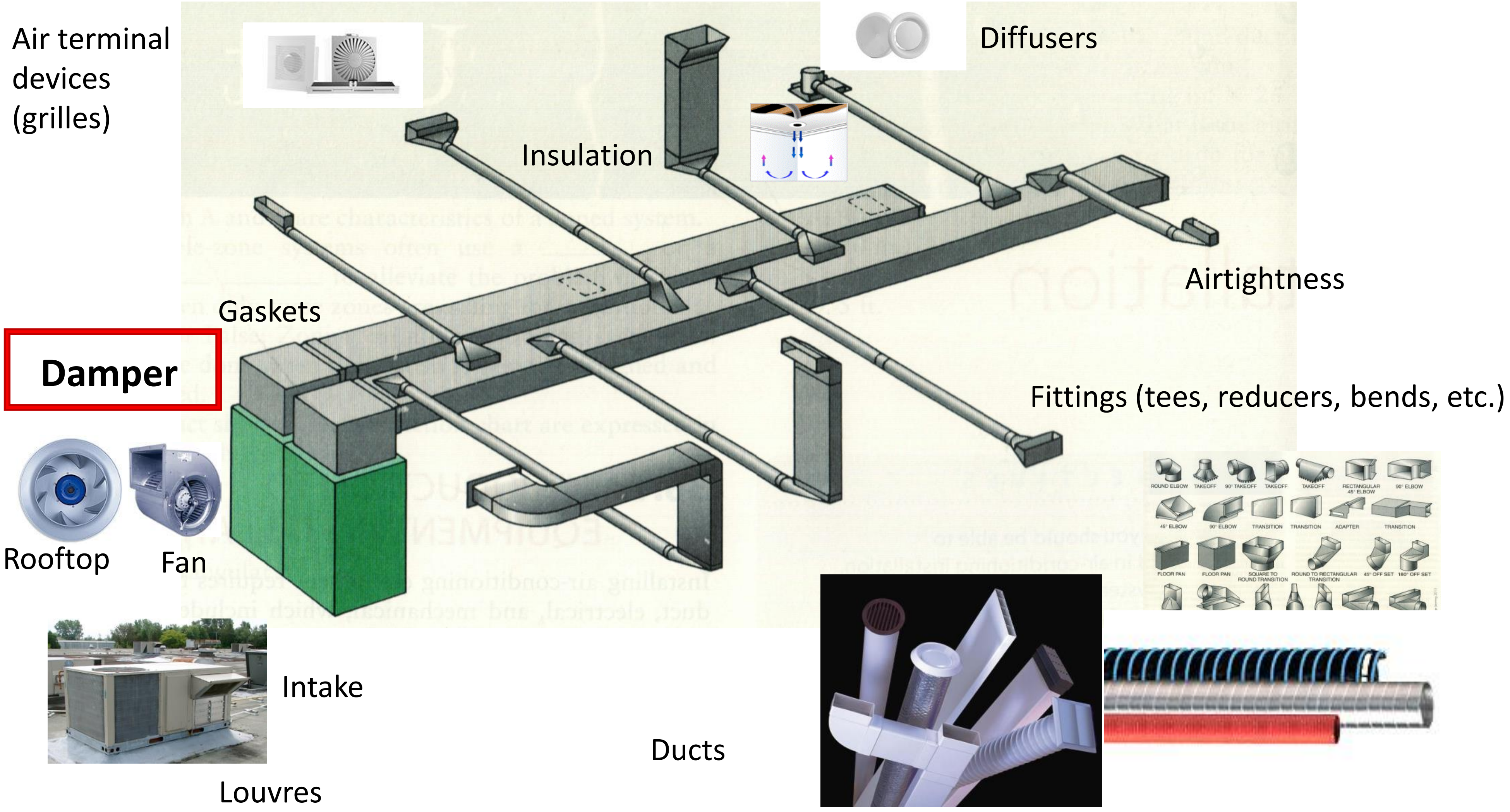
	Effective area A_k = … [m^2]	
No.	Air flow based on anemometer measuring [m^3/h]	Air flow from balometer [m^3/h]

Laboratory exercise 4

Damper – airtightness

DOROTA SKRZYNIOWSKA
RENATA SIKORSKA-BĄCZEK

Damper



Air terminal devices (grilles)
Diffusers
Insulation
Airtightness
Gaskets
Damper
Fittings (tees, reducers, bends, etc.)
Rooftop
Fan
Intake
Ducts
Louvres

Damper

Damper – a mechanical device like a valve or plate that stops or controls the flow of air inside a duct, chimney, Variable Air Volume (VAV) box, air handler, or other air handling equipment.

Regulating damper

Zone damper

Source: https://www.zone damper

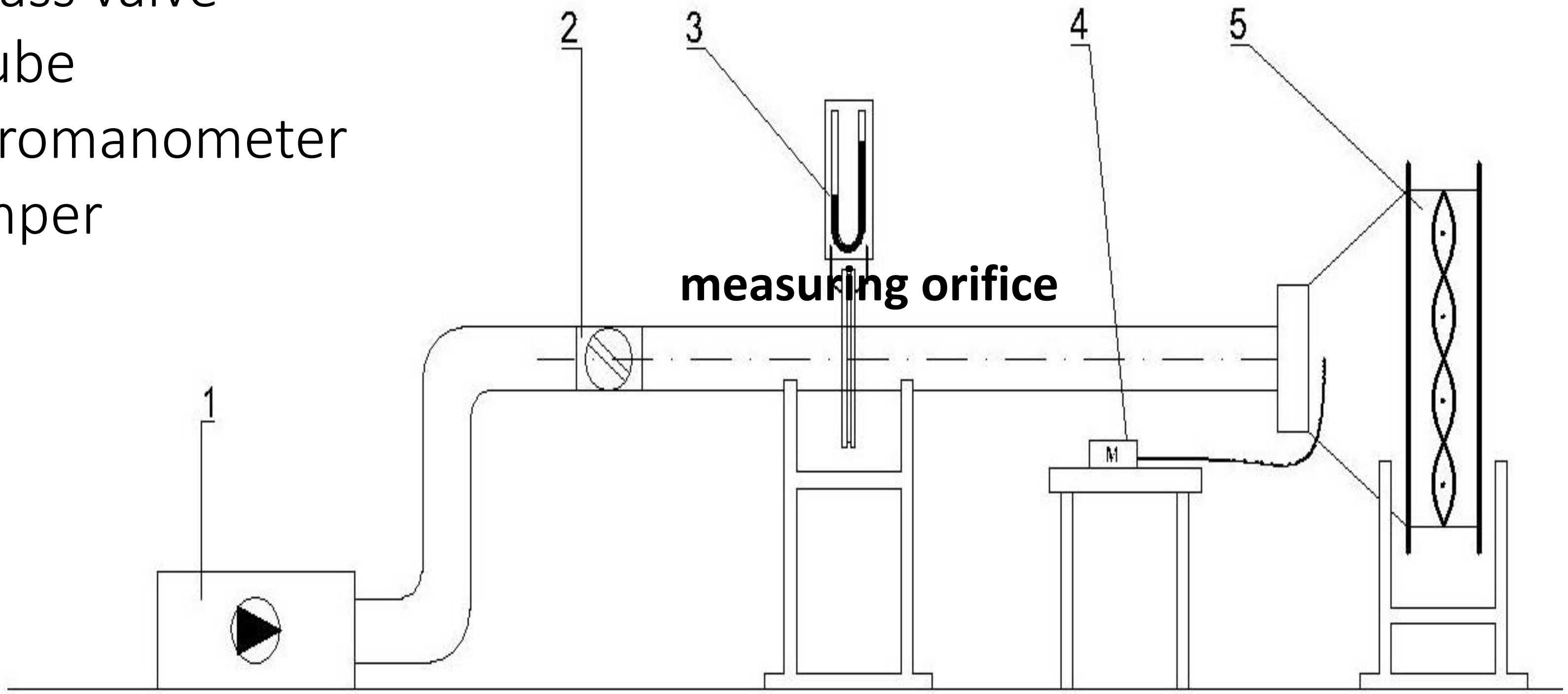
Regulating damper

Airfoil control damper (blade)

Source: http://dampers/

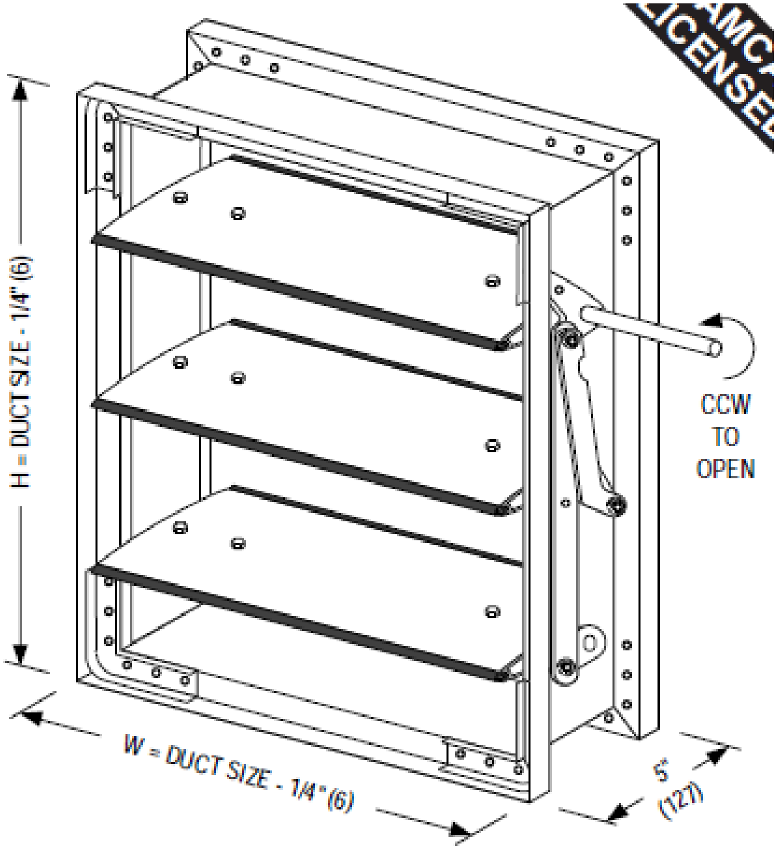
Damper – airtightness

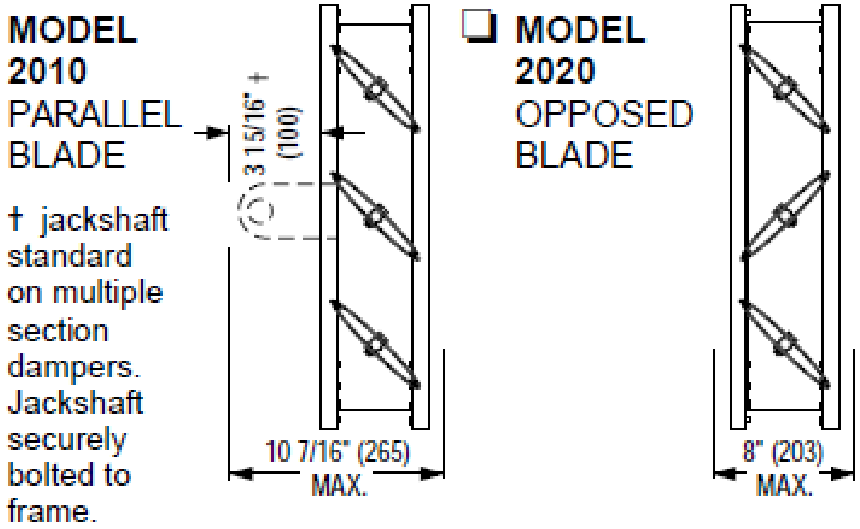
1 – fan
2 – bypass valve
3 – U tube
4 – micromanometer
5 – damper

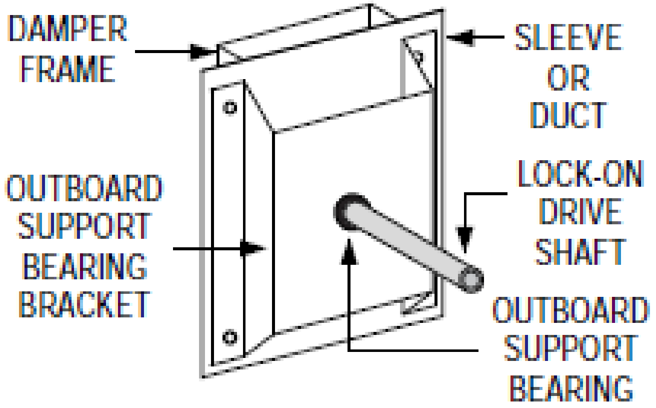


Test bed (laboratory set up)

Damper – airtightness







Source: https://nailorproduct/catalog/NailorCatalog

Calculating Leakage Air Flow Rate through a Closed Damper

$q_v = q_m/\rho$ – volume flow rate [m^3/s]

$q_m = \frac{C}{\sqrt{1-\beta^4}} * \varepsilon\pi * \frac{D_k^2}{4} * \sqrt{2\Delta p\rho}$: mass flow rate [kg/s],

$\varepsilon = 1 - 0.295\frac{\Delta p}{p_i} = 1 - 0.295\Delta p * 10^{-5}$: expansion number

$$p_1 = p_{otoczenia} - p_{1pom} \cong 10^5\ [\text{Pa}]$$

$$\rho \cong 1.2\left[\frac{\text{kg}}{\text{m}^3}\right]$$

Calculating Leakage Air Flow Rate through a Closed Damper

$c = 0{,}6151$: flow rate

$D_k = 0{,}015$ [m]: diameter of venturi (reducers)

$D = 0{,}052$ [m]: diameter of duct

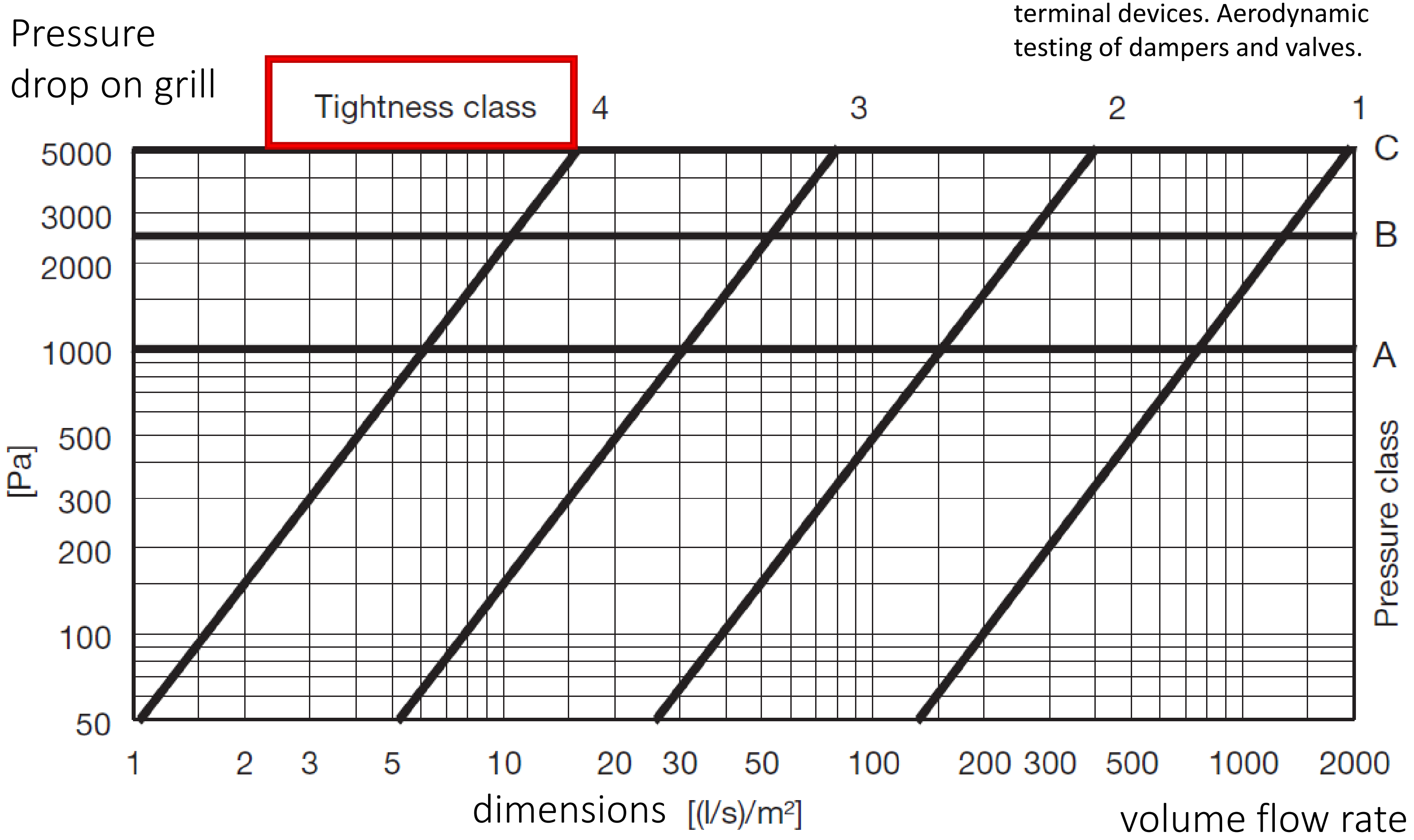
$\beta = \frac{D_k}{D}$: necking of venturi

Δp: differential pressure [Pa]

$\rho_{alk} = 1000 \left[\frac{\text{kg}}{\text{m}^3}\right]$: density of water

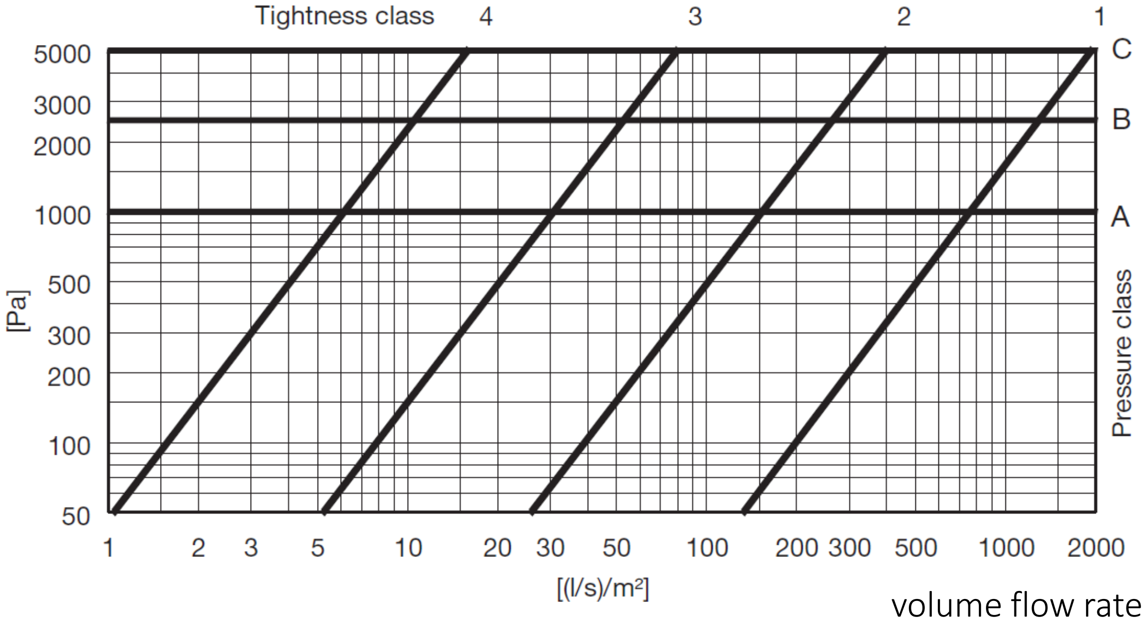
Classification by leakage class

BS EN 1751:1999
Ventilation for buildings. Air terminal devices. Aerodynamic testing of dampers and valves.



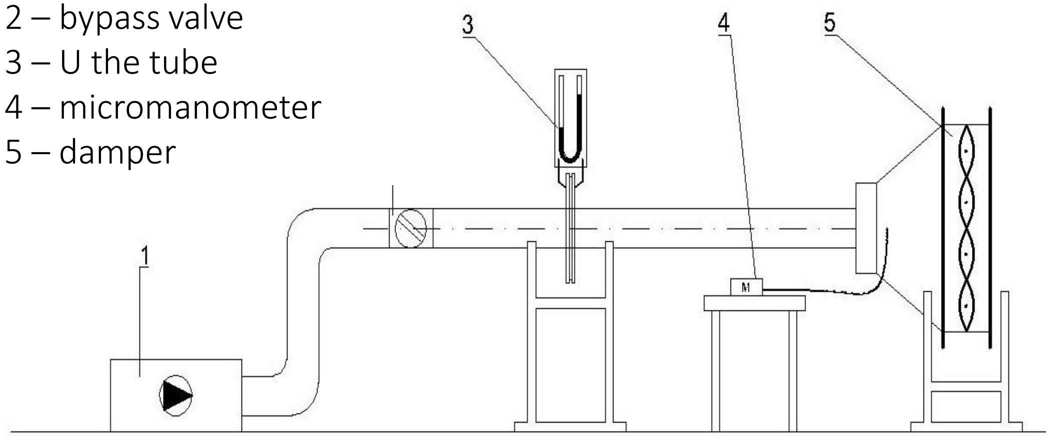
Classification by leakage class

Pressure
drop on grill



volume flow rate

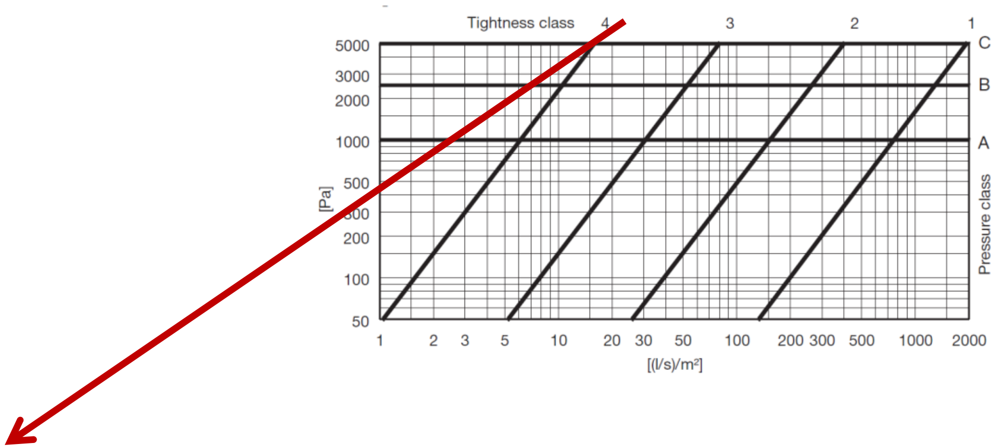
1 – fan
2 – bypass valve
3 – U the tube
4 – micromanometer
5 – damper



Measurement and calculation results

Pressure in the ductwork (Δp imposed on the damper)	U-the tube		Differential pressure gauge		Voltmeter		Δp	Expansion number	mass flow rate	volumetric flow rate
	h	$\Delta p = \rho g h$	Δp	Δp	ΔU	Δp	$\Delta p_{śr}$	ε	q_m	q_V
Unit →	[m]	[Pa]	[mBa]	[Pa]	[V]	[Pa]	[Pa]	[-]	[kg/s]	[m^3/s]
50										
100										
200										
500										
1000										

Damper – class of airtightness



The tested damper is of ... class of airtightness.

Laboratory exercise 5

Heat recovery

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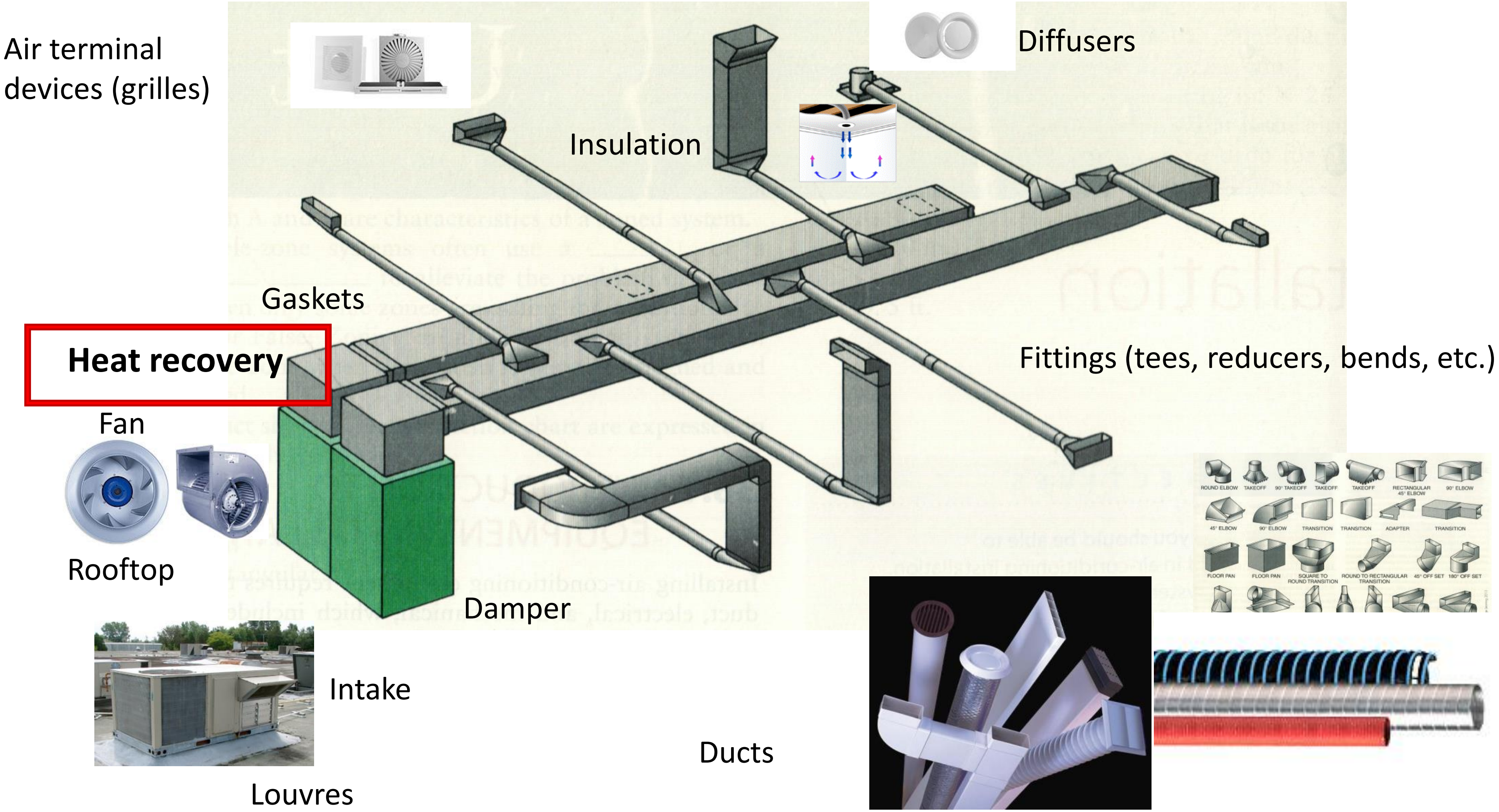
Heat recovery



Heat recovery

Heat recovery systems

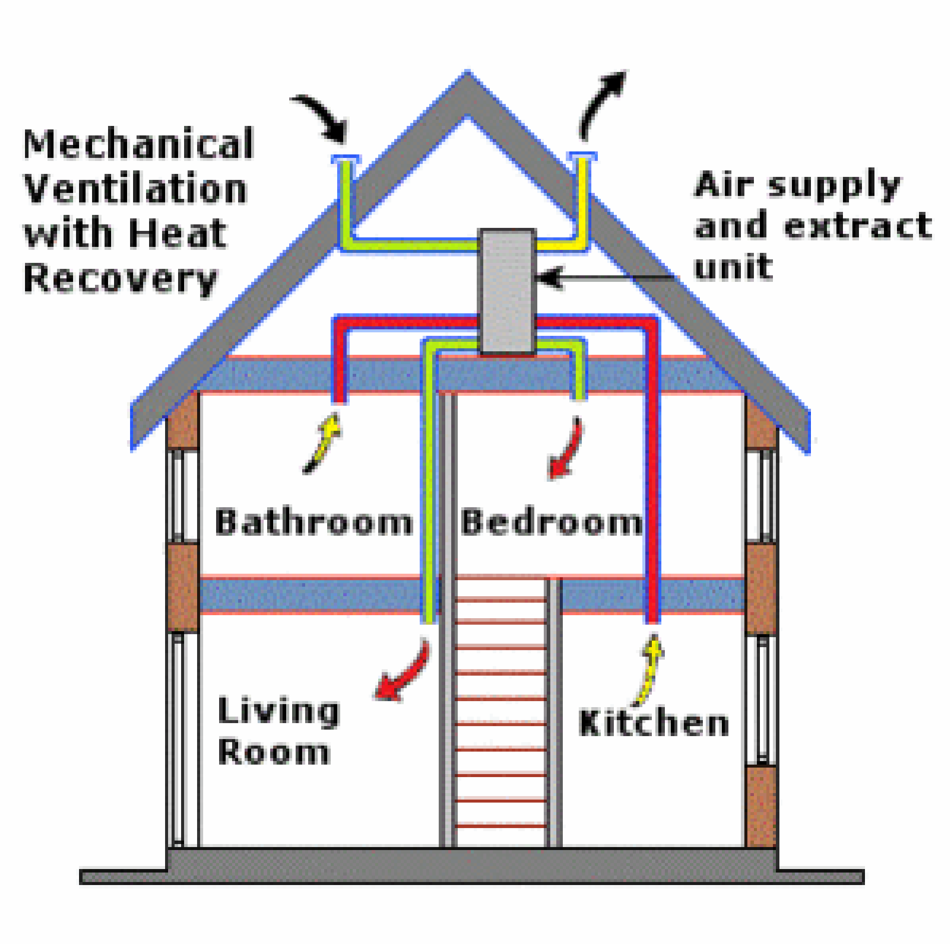
are designed to use the heat in the air being extracted from the building to heat fresh air being drawn into the building.

Heat recovery systems-benefits

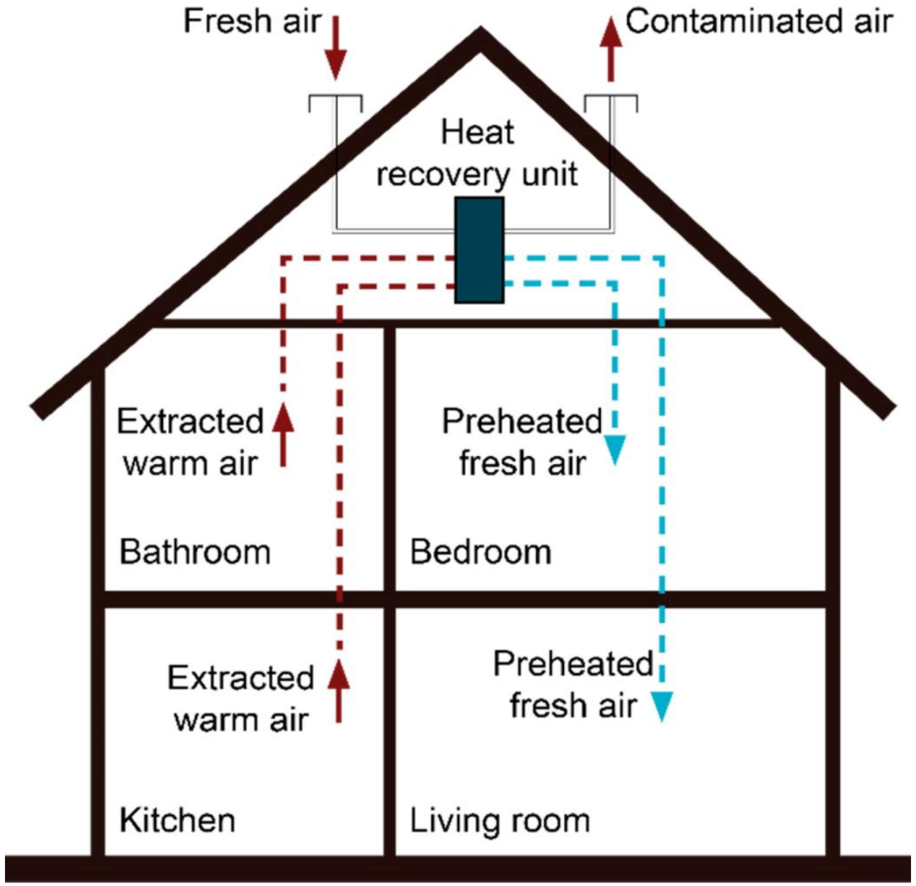
Benefits:

- cost savings,
- reduces heat loss from uncontrolled ventilation.

Heat recovery

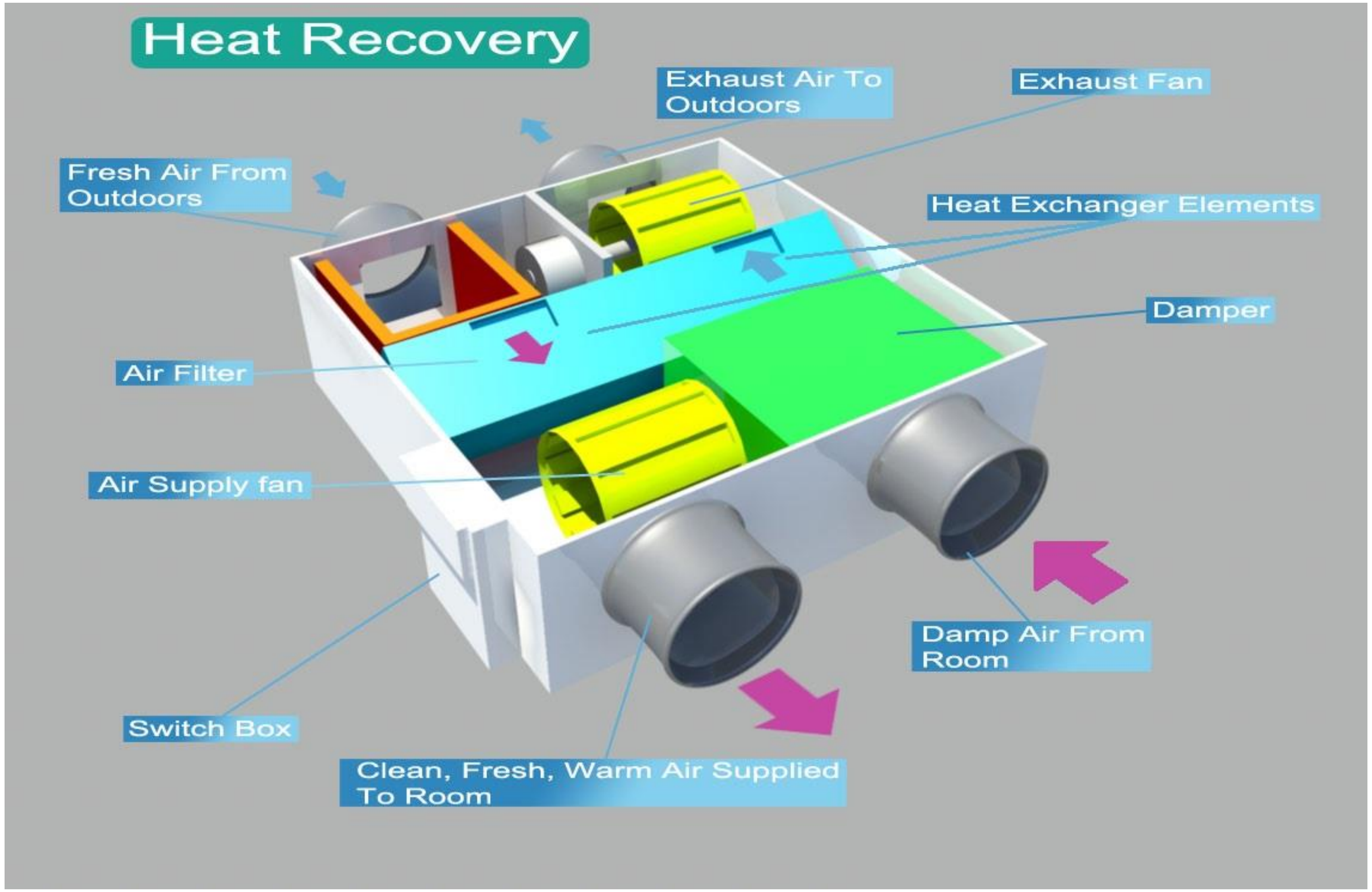


Source: https://heat-recovery



Source: https://www.mdpi.com

How do heat recovery systems work?



Source: https://www.renewableenergy

Heat exchanger – process

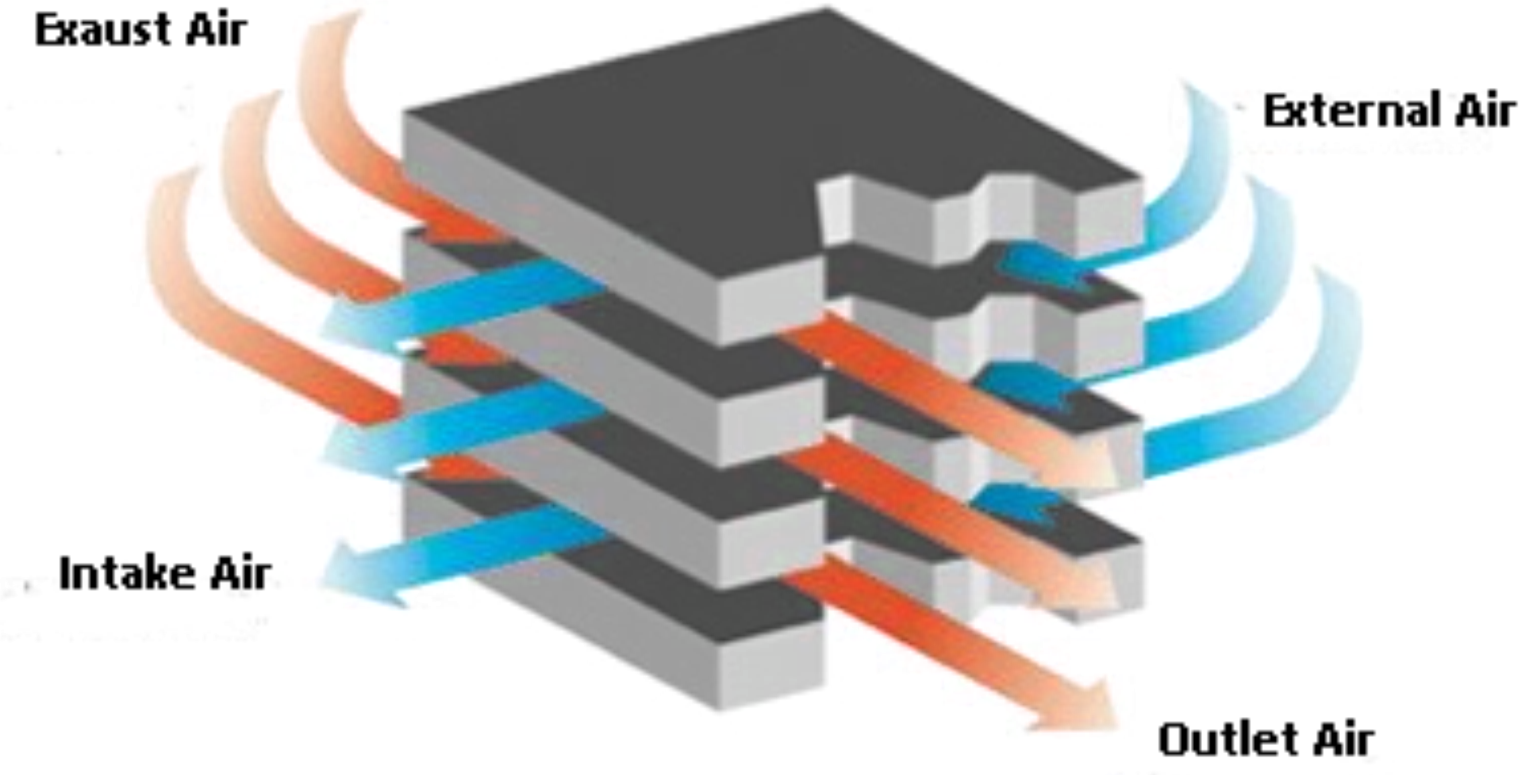
A **heat exchanger** is a device used to transfer the heat between two or more fluids.

Heat exchangers are used in both cooling and heating processes.

Fresh air is brought into the heat exchanger, passes through the heat exchanger and picks up the heat recovered from the exhaust air.

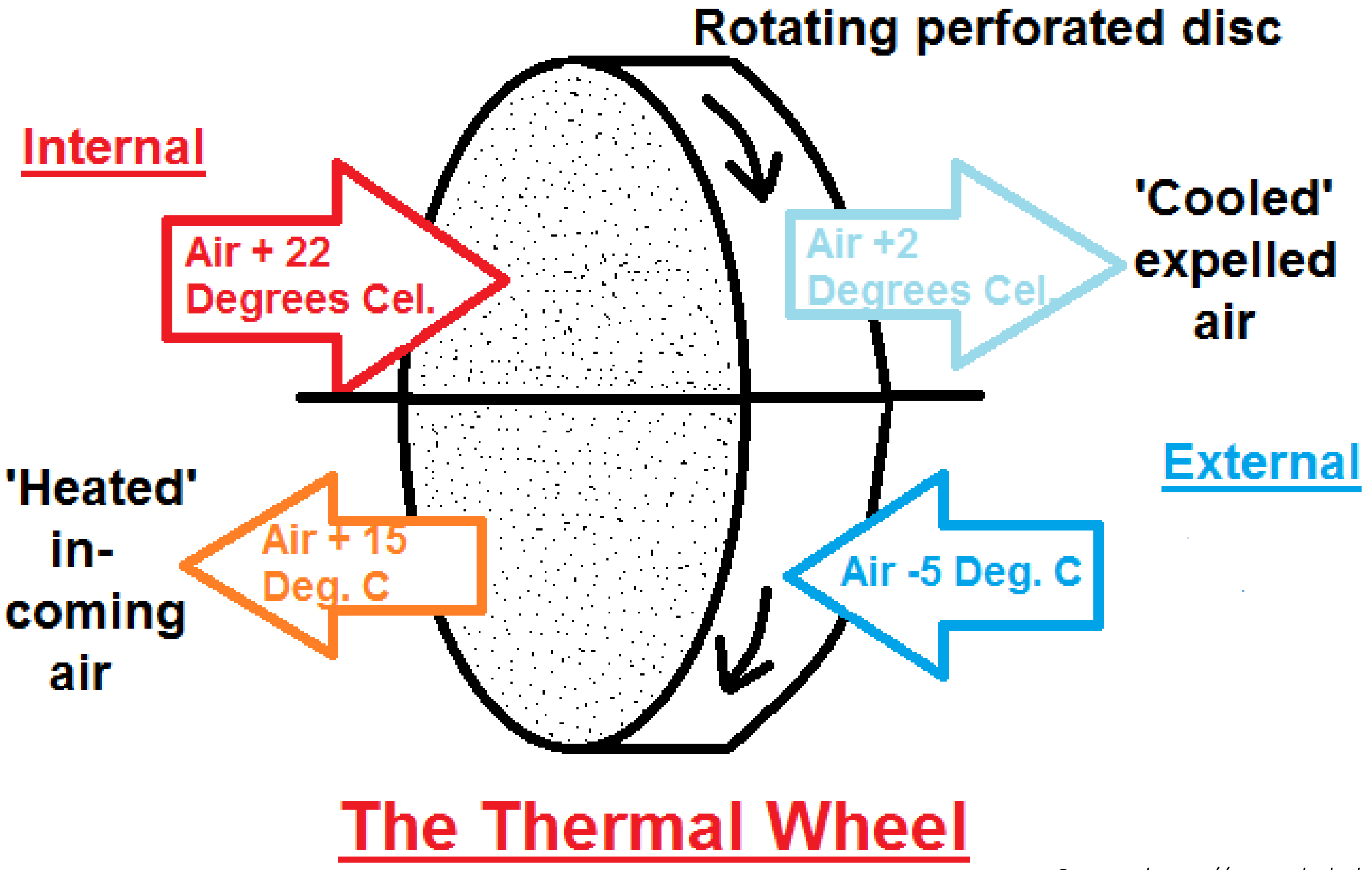
The warmed fresh air is then ducted to all of the habitable rooms within the building.

Plate heat recuperator technology – heat exchanger



Source: https://heat-recovery-systems

The thermal wheel – rotary heat echanger



Source: https://www.thehelpfulengineer

Heat flow, heat transfer

Sensible heat (on account of difference in temperature)

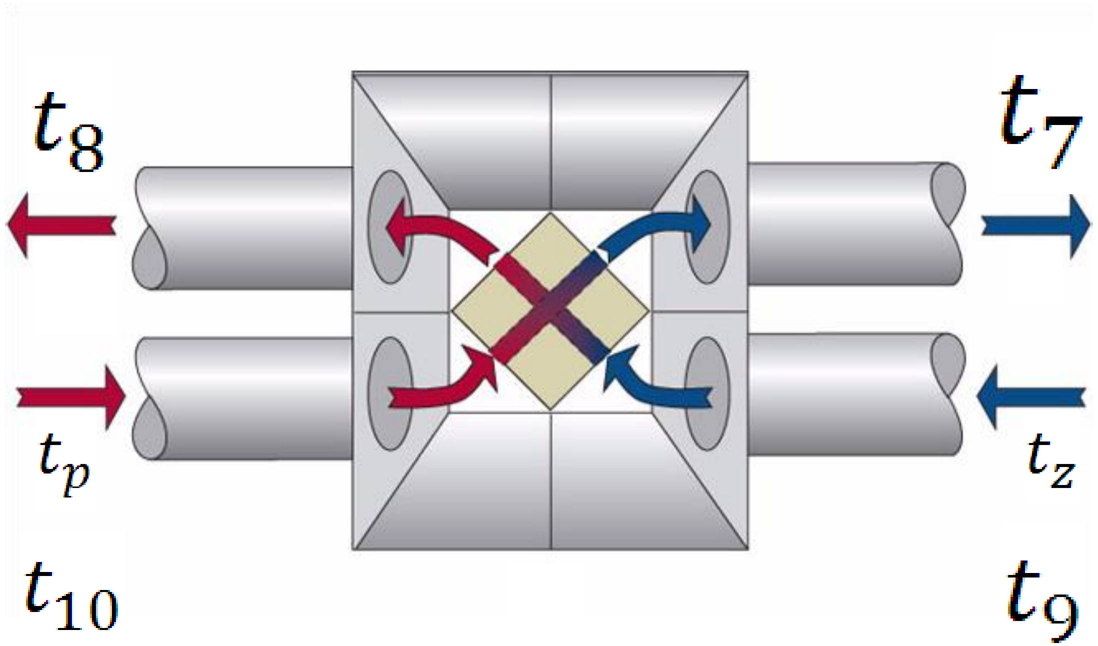
Latent heat (moisture recovery)

Heat and moisture exchange:

Heat recovery – when intake air and outlet air are separated by a solid wall to prevent mixing or when they may be in direct contact.

Regeneration – when intake air and outlet air flow one after the other.

Efficiency of heat recovery
Sensible heat



$$\eta = \frac{t_8 - t_9}{t_{10} - t_9}$$

Temperature of air taken into room T_8 [°C]	Temperature of air before heat exchanger T_9 [°C]	Temperature in room T_{10} [°C]	Efficiency of heat recovery η [-]

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