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Chapter

Noise Calculation Charts and Indoor Environmental Quality for Evaluating Industrial Indoor Environment and Health

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Abstract

Noise, defined as "a sensation of unwanted intensity of a wave," is perception of a pollutant and a type of environmental stressor. An environmental stressor such as noise may have detrimental effects on various aspects of health. The unwanted intensity of a wave is a propagation of noise due to transmission of waves (viz. physical agents) such as sun, light, sound, heat, electricity, fluid, and fire. The effects of these physical agents on human health as noise-intruding elements in an industrial indoor environment are discussed. Noise characterization is discussed from indoor air quality and health perspective. The noise calculation charts are detailed for interference of noise waves based on a benchmark solution. These charts calculate positive and negative magnitudes of noise based on noise characterization of waves due to power difference of two intensities. The noise interference is calculated from newly devised noise measurement equations and their units. The grades and flag colors are notated to the noise calculation charts. Furthermore, illustrated examples of noise characterization calculations for indoor environment are presented using devised noise measurement equations. Indoor environmental quality and noise instrumentation are discussed. Adverse effects of pollutants on human health are summarized. Ventilation systems for dispersion of pollutants from industrial indoor environment are also elaborated.

Keywords: noise, ventilation, physical agents, noise chart, IEQ, health

1. Introduction

Improved building techniques and concern for energy efficiency have created airtight housing. These buildings also retain and recirculate indoor air-along with any contaminants. At the same time many common chemicals and materials in the home are now being implicated in conditions from chronic respiratory irritation to cancer.

These potentially harmful substances carried in indoor air fall into two groups: particles and gases [1].

Particles are invisible and evade the body's natural filtering mechanisms, carrying toxic substances deep into lung tissue and are absorbed into the body. Dust mites, pet dander, mold spores and pollen are common particles that cause asthma

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in some-but may cause chronic runny noses, watery eyes, headaches, lethargy, or snoring. Many people don't even know they have these allergies; they just endure them.

Gases in indoor air may also present health risks. Of most concern are the volatile organic compounds-or-VOCs-of which over 500 have been identified, and are dispersed from cleaning solutions, carpets, building materials, and many household items.

Lin et al. [2] anticipated that there will be behavioral changes that accompany population growth and aging and examined the relationship between home occupant behavior and indoor air quality. Vlek and Steg [3] discussed *the* necessity of multidisciplinary collaboration and desirable developments in environmental psychology for identifying problems, driving forces in human behavior and environmental sustainability. Stansfeld [4] discussed that in planning and health impact assessment environmental noise should be considered as an independent contributor to health risk. It has a separate and substantial role in ill-health separate to that of air pollution. Dehra [5–28] introduced characterization of physical agents as wanted physical agents and unwanted physical agents. The wanted physical agents are categorized as new field of acoustics [15]. Unwanted physical agents are categorized as noise intruding parameters, which are required to be removed from the environment by proper conditioning and filtering [18].

The aim of this chapter is to present practical understanding of how industrial environments and indoor air quality interact with noise so as to impact health and wellness. Noise, defined as "a sensation of unwanted intensity of a wave," is perception of a pollutant and a type of environmental stressor. An environmental stressor such as noise may have detrimental effects on various aspects of health. The unwanted intensity of a wave is a propagation of noise due to transmission of waves (viz. physical agents) such as sun, light, sound, heat, electricity, fluid and fire. The characterization of these physical agents on human health as noise intruding elements is discussed and also presented in mathematical form.

2. Indoor air quality and health

The following is the list of harmful materials in indoor environment:

Insulation: The jagged edged particles of fiberglass insulation are of even greater concern than asbestos, which can still be found in older homes. Urethane is a further concern.

Pressed wood in furniture and flooring: Manufactured with formaldehyde, which is released as a gas.

Dry cleaning: Source of toxic toluene and PERC.

Dust mites: The excreta and body parts of these organisms are a common allergen, a particular problem in bedrooms.

Lead: Found in older paints and plumbing pipes.

Aerosols in personal care products: A common source of organic gases, some of which are suspected carcinogens.

Gas stoves: Can be a source of combustion by-products.

Cleaning products: Can contain many harmful volatile compounds.

Pesticides: Extremely toxic when released into indoor air.

Fireplace smoke: Open fireplaces can produce ash dust, carcinogenic tars and combustion by-products like carbon monoxide and nitrogen oxides.

Wall coverings: Plasticized wallpapers can emit VOCs; wood paneling is often manufactured with formaldehyde.

Draperies: Treated fabrics can contain formaldehyde. Curtain folds help collect dust.

Tobacco smoke: Contains 43 known carcinogens, many of which are passed to non-smokers, especially in areas with poor air circulation.

Carpets: Outgases formaldehyde, harbors dust, dust mites, animal dander, and other allergens.

Paints and solvents: Sources of many volatile chemicals that are easily vaporized and absorbed by the body.

Pet dander: Animal hair and skin flakes are a common allergen.

Auto exhaust: Such fumes enter the home from the garage or nearby traffic. Carbon monoxide is the primary danger and has a cumulative effect on the nervous system.

Fuels: Storage of gasoline, kerosene, and other fuels can release volatile chemicals into the air.

VOCs and indoor air quality: VOCs are volatile organic compounds. VOCs can be released by human source in indoor environment and can react with the atmosphere to form ground-level ozone, and to a lesser degree, acid rain. Some VOCs, like the fumes from numerous interior products (glues, paints, cabinets, carpets, and pads, furniture, etc.) are toxic, and can cause a range of health problems from occasional headaches to allergic reactions, depending on the concentration and sensitivity of the individual. "Least toxic" products are those which contain levels of VOCs below the permissible levels. In some cases, a "least toxic" product may be preferable to a "non-toxic" product for reasonable performance. For additional assurance, mechanical ventilation with an air-to-air heat exchanger or outdoor duct exposed to solar radiation can be considered (examples of which are provided later) that gives fresh air without wasting heat.

Volatile organic compounds (VOCs) are found in everything from paints and coatings to underarm deodorant and cleaning fluids. VOCs have been found to be a major contributing factor to ozone, a common air pollutant which has been proven to be a public health hazard. While ozone in the upper atmosphere is beneficial, ozone at ground level is quite the opposite. The atmospheric ozone layer helps protect us from the sun's dangerous ultraviolet rays. Ground level ozone, however, is a highly reactive gas which affects the normal function of the lung in many healthy humans. These studies show that breathing air with ozone concentrations above air quality standards aggravates symptoms of people with pulmonary diseases and seems to increase rates of asthma attacks. There is also evidence that prolonged exposure to ozone causes permanent damage to lung tissue and interferes with the functioning of the immune system.

3. Noise characterization

A unified theory for stresses and oscillations is proposed by the author [7]. The following standard measurement equations are derived and adopted from the standard definitions for sources of noise interference as developed by the author [5–15].

Noise of sol: For a pack of solar energy wave, the multiplication of solar power storage and the velocity of light gives solar power intensity I. On taking logarithm of two intensities of solar power, I_1 and I_2, provides intensity difference. It is mathematically expressed as:

$$Sol = \log(I_1)(I_2)^{-1} \tag{1}$$

whereas logarithmic unit ratio for noise of sol is expressed as *Sol*. The oncisol (*oS*) is more convenient for solar power systems. The mathematical expression by the following equality gives an oncisol (*oS*), which is 1/11th unit of a *Sol*:

$$oS = \pm 11 \log(I_1)(I_2)^{-1} \tag{2}$$

Noise of therm: For a pack of heat energy wave, the multiplication of total power storage and the velocity of light gives heat power intensity I. The pack of solar energy wave and heat energy wave (for same intensity I), have same energy areas, therefore their units of noise are same as *Sol*.

Noise of photons: For a pack of light energy beam, the multiplication of total power storage and the velocity of light gives light power intensity I. The pack of solar energy wave and light energy beam (for same intensity I), have same energy areas, therefore their units of noise are same as *Sol*.

Noise of electrons: For a pack of electricity wave, the multiplication of total electrical storage and the velocity of light gives electrical power intensity I. The pack of solar energy wave and electricity wave (for same intensity I), have same energy areas, therefore their units of noise are same as *Sol*.

Noise of scattering: For a pack of fluid energy wave, the multiplication of total power storage and the velocity of fluid gives fluid power intensity I. On taking logarithm of two intensities of fluid power, I_1 and I_2, provides intensity difference. It is mathematically expressed as:

$$Sip = \log(I_1)(I_2)^{-1} \tag{3}$$

whereas, logarithmic unit ratio for noise of scattering is *Sip*. The oncisip (*oS*) is more convenient for fluid power systems.

The mathematical expression by the following equality gives an oncisip (*oS*), which is 1/11th unit of a *Sip*:

$$oS = \pm 11 \log(I_1)(I_2)^{-1} \tag{4}$$

For energy area determination for a fluid wave, the water with a specific gravity of 1.0 is the standard fluid considered with power of $\pm 1\ \mathrm{Wm}^{-2}$ for a reference intensity I_2.

Noise of scattering and lightning: For a pack of fire wave, the intensity, I, of fire flash with power of light is the multiplication of total power storage and the velocity of light. Whereas for a pack of fire wave, the intensity, I, of fire flash with power of fluid, is the multiplication of total power storage capacity and velocity of fluid.

- For a noise due to fire flash, the collective effect of scattering and lightning is obtained by superimposition principle.
- For same intensity I, the pack of solar energy wave and a fire flash with light power have same energy areas; therefore, their units of noise are same as *Sol*. The therm power may also be included in fire flash with power of light.
- For same intensity I, the pack of fluid energy wave and a fire flash with fluid power have same energy areas; therefore, their units of noise are same as *Sip*.

In determining the areas of energy for the case of fluids other than water, a multiplication factor in specific gravity has to be evaluated.

Noise of elasticity: For a pack of sound energy wave, the product of total power storage and the velocity of sound gives sound power intensity I. On taking logarithm of two intensities of sound power, I_1 and I_2, provides intensity difference. It is mathematically expressed as:

$$Bel = \log (I_1)(I_2)^{-1} \tag{5}$$

whereas, logarithmic unit ratio for noise of elasticity is Bel. The oncibel (oB) is more convenient for sound power systems. The mathematical expression by the following equality gives an oncibel (oB), which is 1/11th unit of a Bel:

$$oB = \pm 11 \log (I_1)(I_2)^{-1} \tag{6}$$

There are following elaborative points on choosing an *onci* as 1/11th unit of noise [15]:

i. Reference value used for I_2 is $-1\ \text{Wm}^{-2}$ on positive scale of noise and $1\ \text{Wm}^{-2}$ on negative scale of noise. In a power cycle, all types of wave form one positive power cycle and one negative power cycle [9]. Positive scale of noise has 10 positive units and 1 negative unit. Whereas, negative scale of noise has 1 positive unit and 10 negative units;

ii. Each unit of sol, sip, and bel is divided into 11 parts; 1 part is 1/11th unit of noise.

iii. The base of logarithm used in noise measurement equations is 11.

iv. Reference value of I_2 is $-1\ \text{Wm}^{-2}$ with I_1 on positive scale of noise and should be taken with negative noise measurement expression (see Eqs. (2), (4) and (6)); therefore, it gives positive values of noise.

v. Reference value of I_2 is $1\ \text{Wm}^{-2}$ with I_1 on negative scale of noise and should be taken with positive noise measurement expression (see Eqs. (2), (4) and (6)); therefore, it gives negative values of noise.

3.1 Estimating changes in noise power and noise pressure levels

In some cases, it is difficult to measure intensity of a power source; therefore pressure p can be measured. The relationship between pressure and intensity is given by:

$$I = \frac{p^2 rms}{\rho c} \tag{7}$$

where, p = root mean-square (rms) pressure, N/m^2, ρ = density of wave medium, kg/m^3, c = speed of wave, m/s.

Equations (2), (4), (6) are re-written in the form:

$$\text{Intensity difference } \Delta I = \pm 22 \log \frac{p}{po} \tag{8}$$

The addition of two equal pressures results in an increase of:
$22 \log 112 = 6.4$ onci sol (oS) and addition of two equal powers result in an increase of 3.2 onci sol. When two equal pressure levels are added, we are adding in effect two equal power levels, therefore:

$$Lp1 + Lp2 = 11 \log_{11} \left(\frac{p}{pref}\right)^2 + 3.2oS \quad (9)$$

Similarly, it can be shown that when N identical noise sources are added,

$$Lp(total) = Lp1 + 11 \log_{11} N \quad (10)$$

$11 \log N$ is plotted as a function of N in **Figure 1**.

Table 1 shows how to add two unequal noise levels and **Figure 2** presents **Table 1** graphically.

Table 2 has also notated grades and flag colors under limiting conditions [15]. **Figure 3** has presented a double-sided hexagonal slide rule with seven edges for noise measurement representing seven sources of noise. Reference value used for I_2 is -1 Wm^{-2} on positive scale of noise and 1 Wm^{-2} on negative scale of noise. Positive scale of noise has 10 positive units and 1 negative unit, whereas negative scale of noise has 1 positive unit and 10 negative units. Each unit of sol, sip and bel is divided into 11 parts, 1 part is 1/11th unit of noise. The base of logarithm used in noise measurement equations is 11.

The results of noise filtering using various noise measurement equations for an outdoor duct exposed to solar radiation are tabulated in **Tables 3–7**. **Table 8** has presented noise calculation charts based on intensity and pressure differences so as to calculate onci sol, onci sip and onci bel.

3.2 Thermal environment

Temperature of the ambient air has a great influence on the occupant's physical state and his work efficiency. Air conditioning can prevent excessive cold and heat because high temperature in combination with high degree of humidity cause

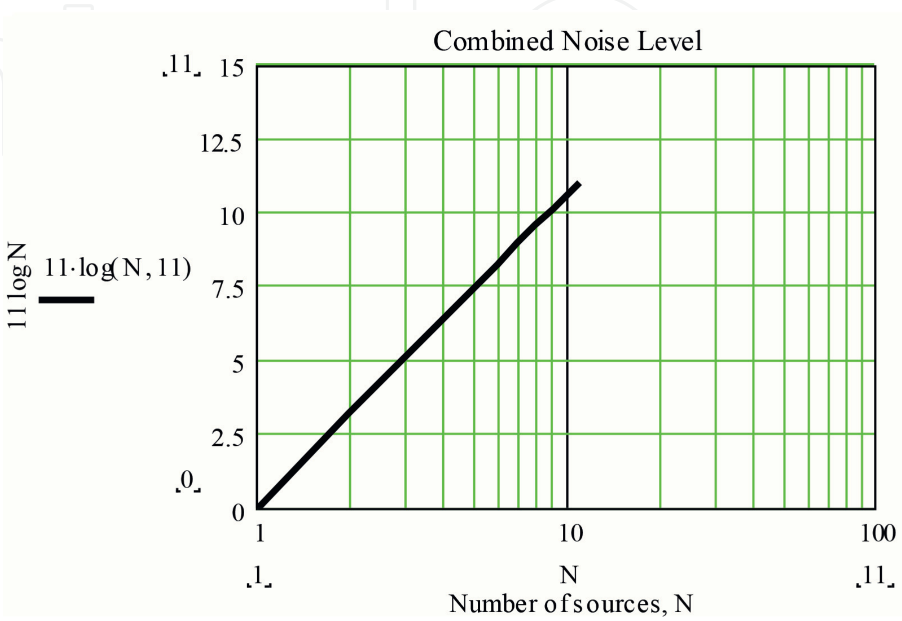

Figure 1.
Predicting the combined noise level of identical sources.

Difference between two levels, oncisol, oncisip, oncibel	Add to the higher level, oncisol, oncisip, oncibel
0	3.18
1	1.86
2	1.319
3	1.024
4	0.836
5	0.708
6	0.612
7	0.54
8	0.484
9	0.437
10	0.399
11 or more	0

Table 1.
Addition of unequal noise levels.

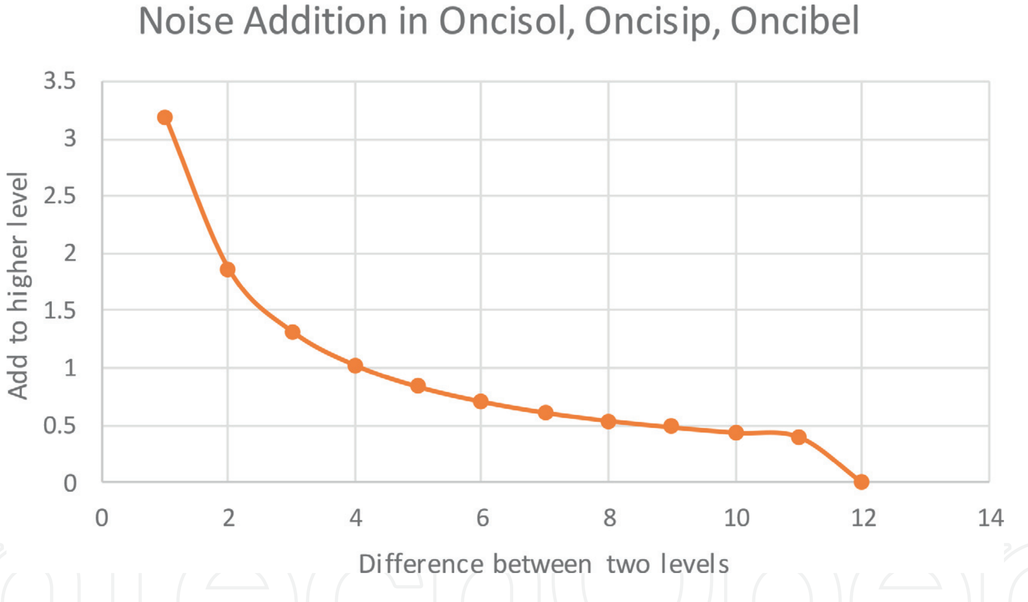

Figure 2.
Noise addition.

premature fatigue, overheating and excessive sweating. Interestingly, air temperature appears to increase 1–2°C and even more with every subsequent meter above the floor level and may reach 40–50°C near the ceiling. Low temperatures are likely to cause local or general cooling of the human body and lead to catarrhal and other respiratory disorders. Humidity is an important environmental characteristic which determines the optimum safe temperature in the work zone, other being the physical effect that the work may demand. The air remains humidified, no matter how dry it feels, by water vapors it invariably contains. The concept of air humidity differentiates: maximum humidity which is the uppermost quantity of moisture that may be held in the air at a given temperature; absolute humidity, that is the actual quantity of moisture held in the air at a given temperature; and relative humidity, defined as the percentage ratio of the absolute humidity to the maximum humidity at a given temperature. The hygienic and sanitary standards refer always

Grades	Noise grades and flag colors under limiting conditions		
	Noise of sol	Noise of scattering	Noise of elasticity
$G_2{}^a = \pm U$	Sol	Sip	Bel
$G_1 = G_2 = U$	No positive solar energy	No positive fluid energy	No positive sound energy
Base color for $G_1 = G_2$			
$G_1 = U$ $+ \rightarrow 0\ Wm^{-2}$	Decreasing solar energy	Decreasing fluid energy	Decreasing sound energy
Base color for G_2			
$G_1 = +ve$	Increasing solar energy	Increasing fluid energy	Increasing sound energy
Base color for G_2			
$G_1 = -U\ Wm^{-2}$	Negative solar energy	Negative fluid energy	Negative sound energy
	Darkness	Low pressure	Inaudible range
Base color for G_2			
$G_1 = -ve$	Darkness increasing, distance from point source of light increasing	Low pressure increasing, vacuum approaching	Inaudible range increasing, vacuum approaching
Base color for G_2			
$G_1 = -U$ $+ \rightarrow 0\ Wm^{-2}$	Negative solar energy	Negative fluid energy	Negative sound energy
	Decreasing darkness	Decreasing low pressure	Decreasing inaudible range
Base color for G_2			

[a]*Reference value of $G_2 = \pm U$ signifies the limiting condition with areas of noise interference approaching to zero.*

Table 2.
Noise grades and flag colors under limiting conditions.

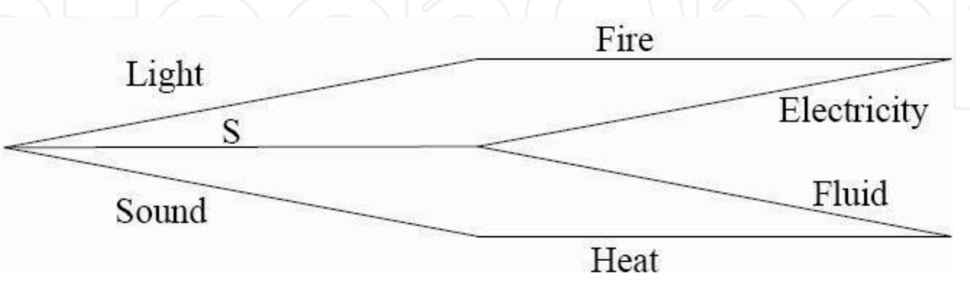

Figure 3.
A double sided hexagonal scales of noise with seven edges (S denotes sun).

to relative humidity as a factor conducive to the safe working environment. Excess humidity may result from various processes that produce water vapors into the working atmosphere. It is generally accepted that the optimum relative humidity is 40–60%. Excessive saturation of the air with water vapor prevents vaporization of moisture from the skin and the lungs which causes much discomfort and reduces work efficiency. Vaporization of excess moisture that results from hyperhidrosis plays an important part in heat transfer from the human body. Vaporization or

Property	Value	Property	Value
Solar irradiation	650 Wm^{-2}	Width of air gap	0.025 m
Ambient heat transfer coefficient	13.5 Wm^{-2} K^{-1}	Thermal conductivity of air	0.02624 Wm^{-1} K^{-1}
Ambient air temperature	−5°C	Specific heat of air (cp)	1000 J kg^{-1} K^{-1}
Building space temperature	20°C	Density of air	1.1174 kg m^{-3}
Height of duct	3.0 m	Kinematic viscosity of air	15.69 × 10^{-6} m^2 s^{-1}
Width of duct	1.0 m	Prandtl number of air	0.708
Thickness of outer wall of duct	0.0025 m	Air velocity for obtaining mass flow rate	0.75 m s^{-1}
Absorbance of outer wall with flat black paint	0.95	Stefan Boltzmann constant for surface of duct walls	5.67 × 10–8 Wm^{-2} K^{-4}
Thermal conductivity of aluminum alloy for HVAC duct	137 Wm^{-1} K^{-1}	Emissivity of back surface of duct walls	0.95
RSI value	1.0 m^2 K W^{-1}	Number of nodes in *x*-direction	$Nx = 3$
Thickness	0.04 m	Number of nodes in *y*-direction	$Ny = 10$, $\Delta y = 0.3$ m

Table 3.
Properties of physical domain.

Solar irradiation (Wm^{-2})	Air temperature difference (ΔT) °C	Noise of sol oS (oncisol)
450	15.50	28
550	18.90	28.93
650	22.40	29.7
750	25.90	30.36
850	29.40	30.91

Table 4.
Temperature difference and noise of sol with solar irradiation (air velocity: 0.75 ms^{-1}).

Air velocity (ms^{-1})	Fluid power (Wm^{-2})	Air temperature difference (ΔT) °C	Noise of scattering *oS* (oncisip)
1.35	47.62	15.28	17.72
1.05	37.0	18.22	16.50
0.75	26.45	22.40	15.02
0.45	15.87	28.15	12.65
0.15	05.29	29.80	07.64

Table 5.
Temperature difference and noise of scattering with air velocity (S = 650 Wm^{-2}).

evaporative heat transfer brings relief and prevents unnecessary fatigue and discomfort. Likewise, a decreased level of humidity, e.g., up to 20% also brings much discomfort to the occupant: he feels very dry in the upper respiratory tract and the mucosal membranes. Movement of the air about the work zone is an important factor of a comfortable working environment. It will be noted that the human body

(ΔT) °C	Mass flow rate (kg s^{-1})	Thermal power (Wm^{-2})	Noise of therm *oS* (oncisol)	(ΔT) °C	Mass flow rate (kg s^{-1})	Thermal power (Wm^{-2})	Noise of therm *oS* (oncisol)
15.50	0.01376	71.09	19.5602	15.28	0.0231	117.65	21.868
18.90	0.01275	80.325	20.119	18.22	0.0171	103.85	21.296
22.40	0.0120	89.6	20.614	22.40	0.0120	89.6	20.614
25.90	0.0115	99.2833	21.043	28.15	8.1×10^{-3}	76.0	19.866
29.40	0.0111	108.78	21.505	29.80	6.2×10^{-3}	61.59	18.898

Table 6.
Mass flow rate and noise of therm with (ΔT) *°C.*

Air velocity (ms^{-1})	Fluid power (Wm^{-2})	Noise of scattering *oS* (oncisip)	Sound pressure (Nm^{-2})	Sound power intensity (Wm^{-2})	Noise of elasticity *oB* (oncibel)
1.35	47.62	17.72	557.5	752.7	30.36
1.05	37.0	16.50	433.65	455.33	28.05
0.75	26.45	15.02	309.75	232.31	24.97
0.45	15.87	12.65	185.85	83.63	20.24
0.15	05.29	07.64	61.94	09.29	10.12

Table 7.
Noise of elasticity with air particle velocity (impedance $Z_o = 413$ *N s* m^{-3} *at 20°C).*

feels slight movements of the air at flow velocities about 0.15 m/s, and at temperatures up to 36°C the effect of movement is refreshing, while at 40°C and higher, it is suppressing. It is commonly believed that the optimum comfortable temperature in the indoor environment in a temperate climate is 20°C. It will be however more correct to say that the optimum safe temperature depends on a number of factors including relative humidity, physical effort, air movement, etc. All the environmental factors are closely interrelated.

3.3 Noise instrumentation for sensing physical agents of indoor environment

Noise instrumentation can be classified as per type of physical agent (light, sound, heat, fluid, electricity, fire and sun) in indoor environment for which monitoring is required. To ensure proper environmental control, the climatic parameters within an enclosure should be periodically checked and measured. Various kinds of measuring instruments can be used for this purpose.

Thermometers, placed on the walls or columns 1.5 m high above floor level and not closure than 1 m to the heating device, are used to measure the air temperature. Careful temperature control is necessary. In such cases, thermographs are used for continuous recording of the air temperature in the workroom. Psychrometers or wet and dry hydrometers, are devices used to determine the relative humidity of the air by the difference in the readings of a pair of similar thermometers mounted side by side. The one is dry bulb, and the other has its bulb wrapped in a damp wick dipping into distilled water. The rate of evaporation of water from the wick and the consequent cooling of the wet bulb is dependent on the relative humidity of the air which can be obtained by using a psychrometric table, or a nomogram from readings of the two thermometers. Use is also made of stationary aspiration

a	b	Intensity ratio (11^a)	Pressure ratio (11^b)	←oSol→ ← oSip → ← oBel→	Pressure ratio $(1/11)^b$	Intensity ratio $(1/11)^a$
0	0	1	1	0	1	1
1/11	1/22	1.244	1.115	±01	0.897	0.804
2/11	2/22	1.546	1.244	±02	0.804	0.647
4/11	4/22	2.392	1.546	±04	0.647	0.418
6/11	6/22	3.699	1.923	±06	0.520	0.270
8/11	8/22	5.720	2.392	±08	0.418	0.175
10/11	10/22	8.845	2.974	±10	0.336	0.113
12/11	12/22	13.679	3.699	±12	0.270	0.073
14/11	14/22	21.155	4.599	±14	0.217	0.047
16/11	16/22	32.715	5.720	±16	0.175	0.031
18/11	18/22	50.594	7.113	±18	0.141	0.020
20/11	20/22	78.242	8.845	±20	0.113	0.013
22/11	22/22	121.000	11.000	±22	0.091	8.264×10^{-3}
24/11	24/22	187.124	13.679	±24	0.073	5.344×10^{-3}
26/11	26/22	289.383	17.011	±26	0.059	3.456×10^{-3}
28/11	28/22	447.525	21.155	±28	0.047	2.235×10^{-3}
30/11	30/22	692.089	26.308	±30	0.038	1.445×10^{-3}
32/11	32/22	1070	32.715	±32	0.031	9.343×10^{-4}
34/11	34/22	1655	40.684	±34	0.025	6.042×10^{-4}
36/11	36/22	2560	50.594	±36	0.020	3.907×10^{-4}
38/11	38/22	3959	62.917	±38	0.016	2.526×10^{-4}
40/11	40/22	6122	78.242	±40	0.013	1.633×10^{-4}
42/11	42/22	9467	97.300	±42	0.010	1.056×10^{-4}
44/11	44/22	14,640	121.0	±44	8.264×10^{-3}	6.830×10^{-5}
46/11	46/22	22,640	150.47	±46	6.646×10^{-3}	4.417×10^{-5}
48/11	48/22	35,020	187.12	±48	5.344×10^{-3}	2.856×10^{-5}

a	b	Intensity ratio (11^a)	Pressure ratio (11^b)	←oSol→ ← oSip → ← oBel→	Pressure ratio $(1/11)^b$	Intensity ratio $(1/11)^a$
50/11	50/22	54,150	232.70	±50	4.297×10^{-3}	1.847×10^{-5}
66/11	66/22	1.772×10^{6}	1331	±66	7.513×10^{-4}	5.645×10^{-7}
77/11	77/22	1.949×10^{7}	4414	±77	2.265×10^{-4}	5.132×10^{-8}
88/11	88/22	2.144×10^{8}	14,640	±88	6.830×10^{-5}	4.665×10^{-9}
99/11	99/22	2.358×10^{9}	48,560	±99	2.059×10^{-5}	4.241×10^{-10}
110/11	110/22	2.594×10^{10}	161,100	±110	6.209×10^{-6}	3.855×10^{-11}

Example: to find oSol corresponding to a pressure ratio of 363
Ratio of 363 = 11 × 33
In oSol = +22 + 32 oSol
= +54 oSol

Table 8.
Noise calculation chart estimating onci sol, onci sip, and onci bel.

psychrometers which are equipped with a fan to draw the air through the device and increase the accuracy of measurement.

Hydrographs are used for continuous recording of air humidity where the humidity requirements are most stringent. Anemometers are instruments for measuring the velocity of the air. The common types are revolving-vane and revolving-cup anemometers. A common anemometer of the vane type consists of eight vanes fixed on a bulb at 45° to the air stream and pivoted so as to be capable of rotation in a vertical plane. The speed of rotation is indicated on a dial calibrated to read air velocity from 0.3 to 5 m/s. The cup anemometer differs from the vane type anemometer in that it consists of four semi-spherical cups carried on the ends of four radial arms pivoted soas to be capable of rotation in a horizontal plane. The speed of rotation is indicated on a dial graduated to give velocities of air stream from 1 to 20m/s. Airstream velocities under 0.3 m/s are measured by means of a micro-anemometer or electrical-thermal anemometer. Pressure tubes are used to measure both pressure (total and static) and velocity of the air in air ducts. The dynamic (velocity) pressure is determined as the difference between the total and the static pressures. The air velocity in air ducts can be measured with a pressure head device (which is combination of a static and pitot tube connected to the opposite sides of a differential pressure U-gage to give a visual reading corresponding to the speed of an air current).

Indication tube is used for measuring contents of air contaminants (largely toxic vapors and gases, such as, CO, SO_2, nitrogen oxides, ethanol, etc.). A common type is hermetically sealed glass tube about 4–7 mm wide and 100 mm long containing a filler (crushed silica-gel, glass, or porcelain crumps) treated with solutions of variable reagents. It also has chemical absorbents to bind unsuitable analysis, a measured quantity of air is brought into intimate contact with the contents of the open tube for a certain time interval, and the concentrations of the controllable impurity can be read on a scale by length or rate of change in color of the filler material that has completed reaction.

Purity of the air can also be measured by air or gas analyzers of certain design. Direct techniques of gas analysis-spectrometry, electrical-chemical, and optical methods, permit the analysis of the air to be performed continuously and automatically. The sampling method implies that samples of air are analyzed in a laboratory by trained specialists. Although the process is lengthy and costly it provides accurate measurements necessary for the adequate air control.

Dust contents in the air of indoor environment are determined by passing a measured quantity of air through filters during a particular time interval and calculating the mass of dust thus collected. There exist also several other proximate methods of quick determination of the character of dust and size of dust particles.

3.4 Checking human noise behavior

Noise behavior is checked by identifying a source and a sink of noise, i.e., a person making noise in the environment and a person affected by such noise in the environment. Behavior of human beings is controlled by the central nervous system. Neurology is the study of nervous system. The behavior of human beings is studied in psychology. Psychophysics is a study in which physical stimuli are perceived by human beings. Psychophysiology is the field of study of the interaction between environmental stimuli and physiological functions of the body. The study of abnormal behavior is dealt by a psychiatrist. Abnormal human noise behavior interferes in proper functioning and wellness of the individual and society.

In order to monitor noise and human noise behavior in indoor environment, these noise characterization techniques mentioned in previous sections can be used. For example, a monitoring of an improved built environment for sensing integrated noise parameters would not only result in energy conservation, economical affordability but also result in generating less noise pollution of indoor pollutants mentioned earlier. Sensors and transducers for measurement, monitoring and control of noises (light, sound, heat, fluid, electricity, fire and sun) can be electromagnetic, thermoelectric and piezoelectric, etc. With integrated environmental control, these environmental parameters can be characterized and checked for comfort and wellness and controlled through various environmental monitoring sensors. The effect of these human behavioral parameters is characterized on a logarithmic noise scale.

Biomedical instrumentation for measurement and monitoring of human noise behavior from human systems of indoor environment require real time informatics capabilities. Sensing and actuating capabilities as well as measurement systems for noise can be "in vivo" and "in vitro." The signals can be classified as bio-electric, bio-sound sample, bio-mechanical, bio-chemical, bio-magnetic, bio-optic and bio-impedance depending upon origin of "stresses and oscillations" in a noise system.

Use of biological sensors: all living organisms contain biological sensors with functions similar to those of the electro and mechanical sensors. Most of these are specialized cells that are sensitive to: light, motion, temperature, magnetic fields, gravity, humidity, vibration, pressure, electrical fields, sound and other physical aspects of the external environment and also physical aspects of the internal environment such as stretch motion of the organism and position of appendages (proprioception) an enormous array of environmental molecules including toxins, nutrients and pheromones and many aspects of the internal metabolic milieu, such as, glucose level, oxygen level or osmolality, an equally varied range of internal signal molecules such as hormones, neurotransmitters and cytokines and even the differences between proteins of the organism itself and the environment or alien creatures. The human senses are examples of specialized neuronal sensors.

3.4.1 Psychophysiological measurements

With proper psychophysiological measurements it is possible to detect source and sink of noise, i.e., a person making noise in the environment and a person affected by such noise in the environment. One of the ways to study noise behavior is to measure electrical signals of the brain and nervous system. The voltages recorded in EEG are the result of many processes that occur in the brain. It is very difficult to obtain signals related to particular function. Autonomic nervous system controls many body functions like blood pressure, heart rate, perspiration and salivation. The autonomic nervous system cannot be controlled, but will be influenced by external stimuli and emotions of a person. On recording these body functions one can get insight into emotional changes that cannot be measured directly but can be estimated from these recordings. One of the practical applications of this principle is the polygraph. It is a device for recording several body functions simultaneously that may show changes when interrogation causes anxiety in the person. It is the recording of pulse, blood pressure, respiratory rate, sweating (skin resistance), EEG, heart rate, plethysmographs, temperature, EEG, EMG and EOG simultaneously through multiple channels. A polygraph is otherwise called a lie detector as it is sometimes used to detect if a person is lying. The principle behind this is that the fright causes sweating which may reduce skin resistance response, increase heart rate and increase blood pressure. The judicial system has not yet accepted the polygraph as a foolproof system.

Testing motor responses: Response of the skeletal muscles or simply motor responses are under voluntary control. But it requires learning phase for the proper functioning with coordination of adjacent muscles. Many devices are available in the literature and in the market to measure motor responses and to study the influence of factors like fatigue, stress and/or for drugs taken. The devices used to test are simple as follows: manual dexterity test instrument consists of small objects to be assembled by the patient. The time required to assemble the objects is the measure of motor response. Another instrument, called steadiness testers consist of a metal stylus, has to be moved through narrow channels of different shapes, without touching the adjacent walls. For every contact of stylus with wall increment a counter. The counter reading is a measure of motor response. The third method of measuring motor response is that a light spot moves with adjustable speed and adjustable shape pattern (circular/rectangular/star shaped). The patient has to track the spot with a photosensitive probe. An indicator and timer measure the percentage of duration on which the patient is on target during a certain test interval. Similarly, the performance of certain muscles or muscle groups can be monitored and measures with the help of dynamometers which measure the force exerted by the patient.

Sensory measurements: Human sensors provide information inputs required by the person to orient him-self in the desired manner. There are many methods and instruments available to measure the performance of the sense organs. No sophisticated equipment is required for some of these sensory measurements. Ability of sensing of temperature can be measured by having different objects at different temperatures or water baths at different temperatures. Touch perception can be measured by stimulating the skin with bristles of horse hair. Complex devices are required to measure optical perception. For example, ability of a person to view a spot with respect to variable brightness and size of the spot as well as background brightness. A special device to study visual perception is "tachistoscope." In this case, two objects are shown alternatively with adjustable time interval. This can be achieved by illuminating the objects one at a time or by mechanical shutters. The ability of the person to recognize the objects and time duration for switching between the objects are measure of perception of eyes.

Experimental analysis of the behavior: Numerical data is required to describe and analyze behavior accurately. Especially for a mathematical analysis numerical data is required. Many basic behavioral experiments are conducted with animals like rats, pigeons and monkey as subjects. These basic behavioral experiments are conducted in skinner boxes (soundproof enclosure) in which animals are isolated from the external environment. Behavior expressed by a subject to interact with and to modify the environment is called instrumental or operant behavior. Instrument behavior that is positively reinforced tends to occur more frequently in future, whereas behavior that is negatively reinforced decreases in frequency. In the case of animal experimental study, positive reinforcement is usually done in the form of food given to animals. Negative reinforcement is in the form of harmless, but painful electric shocks through the floor of the cage. On selecting suitable reinforcement, the behavior of the animal can be studied. In this case, the skimmer box should be equipped with response bar and stimulus light. A response of the animal for a given stimuli will give pressure on the response bar. The pressure on the bar will be sensed electronically and can be stored or can be plotted on a recorder. The results obtained on animal experiments can be extrapolated on human behavior. Some of the human behaviors can be explained as having been reinforced by the social environment.

Biofeedback instrumentation: Feedback signal is used to control a process. The output of a system is measured and compared with reference signal, based on the difference; necessary action is taken to bring the output of the system very close to reference value. These types of systems are called feedback systems. If this concept is applied to biological processes within body, it is called biological feedback or biofeedback. Many physiological processes have been evaluated for possible control through biofeedback methods. The physiological processes that can be controlled by biofeedback methods are EEG, EMG, heart rate and blood pressure. It has also been observed that the alpha wave is more prevalent when a person is mediating or being with closed eyes. Heart rate and blood pressure can be controlled to a certain degree by biofeedback methods. Biofeedback instrumentation includes a transducer and amplifier to measure the variable to be controlled. The magnitude of the measured variable is converted into suitable visual or audio signals, and then is presented to the person as feedback. Biofeedback has been defined as the purest form of self-control. The success of biofeedback depends on how the data is interpreted and also depends on the training of the person.

3.5 Indoor air quality and noise

With the increased interest in indoor air quality and the need to monitor potentially dangerous gases, gas concentration measurements have become increasing more prevalent in building DDC system design. Many gas measuring devices are currently available for use in HVAC applications [29].

There are many types of gas measuring devices available for use with DDC systems. Currently, the three most common gases measured in HVAC applications are carbon monoxide, carbon dioxide, and refrigerant gases. These gas measuring devices can be modified for measuring noise of scattering (oncisip) based on concentration and fluid power of these gases. Some examples illustrating noise of scattering (oncisip) are mentioned in previous sections.

Carbon monoxide: Carbon monoxide is a poisonous gas that is most commonly generated as the byproduct of the incomplete combustion of carbon based fuels. Carbon monoxide is generated by all fuel burning equipment including internal combustion engines. Carbon monoxide detectors are used to operate ventilation equipment to prevent carbon monoxide levels from becoming unsafe. They are also used to warn facility owners and occupants of unsafe levels in garages, loading docks, tunnels and other areas where vehicles are operated. Solid state sensing technology is most commonly used. Simple or multiple sensing point versions are available that can provide contact closures at one or more set levels and/or analog signals that are proportion to carbon monoxide concentration.

Carbon dioxide: Carbon dioxide is a non-toxic gas produced by the respiration of living organisms, by the complete combustion of carbon, and by photosynthesis in green plants. Carbon dioxide exists in the air in the amount of 320–350 ppm. Carbon dioxide concentration inside buildings has been related to general ventilation adequacy and is commonly monitored by DDC control systems as a measure of indoor air quality and ventilation adequacy. It is also measured by building DDC systems and used to control outdoor air fans and dampers to keep concentration below set levels. The most commonly used sensing technology is Non-Dispersive-Infra-Red (NDIR). This is based on the principle that carbon dioxide gas absorbs infrared radiation at the 4.2 μm wavelength. Attenuation of an infrared source can be related to the gas concentration in air in the range of 0–5000 ppm with a general accuracy of plus or minus 150 or 50 ppm over narrower ranges.

Refrigerant gas: Refrigerant gas detectors have been in widespread use since safety codes for mechanical refrigeration required their use in the operation of emergency ventilation systems to evacuate hazardous concentrations of refrigerant gas in machinery rooms and other applicable enclosed areas. Detectors broadly sensitive to families of CFC and HCFC gases commonly used, as refrigerants are available. Gas specific detectors are also available to detect individual refrigerant gases including CFC, HFC, HCFC and ammonia specific to the equipment in use. The most commonly used are infrared (IR), photo-acoustic, and solid state sensing technologies. Single or multiple sensing point versions are available that can provide contact closures at one or more set levels and/or analog signals that are proportional to refrigerant concentration.

4. Effects on human health

It has been proved beyond doubt that polluted air is highly detrimental to human health and is a contributory factor in deaths from diseases, such as lung cancer [1]. Bad air quality is mostly associated with respiratory diseases ranging from common cold to lung cancer. Both gaseous and particulate pollutants cause severe damage to the respiratory system leading to emphysema, bronchitis and asthma. Polluted air irritates the eyes and some pollutants like lead tend to accumulate in the body, at times to dangerous levels. Deaths from lung cancer are on the increase and the prime causative agent is suspected to be polluted air. It may be noted that the rate of lung cancer is twice in large cities in comparison to rural areas. An important point to mention here is that children are more susceptible to polluted air than grown-ups. The prominent gaseous pollutants are carbon monoxide, sulfur dioxide, oxides of nitrogen, hydrogen sulfide and certain acids, aldehydes and hydrocarbons. The particulate pollutants include dust, silicious matter and asbestos.

Carbon monoxide is an asphyxiant gas which when inhaled reacts with the hemoglobin in blood to reduce the oxygen-carrying capacity of blood. Persons already suffering from diseases like anemia are more prone to get affected because carbon monoxide may lead to serious injuries to vital organs. Sulfur dioxide is the most serious and widespread air pollutant. It has been reported that lower levels of concentration of sulfur dioxide cause temporary spasm of the smooth muscles of the bronchia. Higher concentration induces increased mucus production. The cilia which protect the respiratory system get affected by sulfur dioxide causing cough, shortness of breath and spasm of the larynx. It may also cause acute irritation of the eye membranes resulting in tears and redness.

Oxides of nitrogen are pulmonary irritants and excess concentrations of which may lead to pulmonary hemorrhage. Hydrogen sulfide is well known for its characteristic rotten-egg odor. Hydrocarbons emitted from automobile exhaust reportedly cause lung cancer. Lead, which is discharged into the air via the automobile exhaust, is a cumulative poison that may cause brain damage in children. It interferes with the development and maturation of red blood cells. An interesting point to note is that the amount of lead in blood is higher in smokers than in non-smokers.

Among the particulate pollutants asbestos needs a special mention. The use of asbestos needs a special mention. The use of asbestos has increased several folds during 1970s–1990s. Used primarily as roofing material for buildings, and for insulating brake and clutch linings in automobiles, asbestos content in the air has also increased. Accumulation of asbestos can lead to the dreaded disease, asbestosis—a severe scarring of the lungs.

Another dreaded disease caused by polluted air (containing dust particles) is silicosis. Silicosis is the most common dust-related disease. It results from inhaling quartz dust or particles of other silica-containing rocks. Workers in mines, and industries like that of pottery, ceramics, granite carving and sand basting, run a risk of contracting this disease which in early stages shows no subjective symptoms but gradually leads to cough and shortness of breath. Silicosis is often combines with tuberculosis. The disease is gradually progressive and death occurs due to heart failure or pulmonary tuberculosis. Other serious dust diseases include block-lung disease (from inhaling coal dust), berylliosis (from beryllium dust), and byssinosis (cotton dust).

A summary of pollutants and their effects on human health is given in **Table 9** for ready reference.

5. Ventilation systems

The dispersion of pollutants from working and production areas depends very much on the proper choice of a ventilation system [30]. Ventilation systems require careful designing. This applies particularly to exhaust ventilation which, if badly designed, can be worse than no ventilation at all. Exhaust hoods or slots should be so located that no part of the fumes or dusts being removed can enter the worker's breathing zone. At the same time, ventilation should ensure that other conditions (equipment, structural elements of buildings, etc.) satisfy the requirements of the manufacturing process. Ventilation in industrial buildings and other auxiliary facilities is mandatory. Ventilation is the process of replacement of vitiated air by fresh air. Depending on how the air currents are induced, ventilation can be natural or drought and mechanical. A combination of the two types is known as the compound or hybrid ventilation.

Mechanical ventilation, depending on the direction of induced currents, can be exhaust, forced (plenum), and plenum-exhaust. By scope of action, distinction must be made between the general or dilution ventilation and local ventilation. Proper choice of ventilation system is essential for ensuring continuous supplies of good quality air into the working areas. Exhaust ventilation, for example, is one means of removing dusts, vapors and corrosive gases. Determining proper places of their possible releases and providing such hazardous spots with exhaust inlets and return points is very essential. It should however be noted that the provision of exhaust ventilation only is a limited measure and should be considered as supplementary to the general ventilation by dilution.

Natural ventilation, unless induced artificially, occurs through un-tight closures of doors, windows and various other openings by effect of temperature and

No.	Pollutants	Origin of pollutants	Effects
1.	Sulfur dioxide	Industries, especially where coal and oil are fired.	Irritation to eyes and respiratory system, increased mucus production, cough and shortness of breath.
2.	Carbon monoxide	Principal contributors are automobile exhausts and industries.	Reduction in oxygen carrying capacity of blood.
3.	Oxides of nitrogen	Automobile exhausts.	Pulmonary irritant, affecting lung functioning.
4.	Hydrocarbons	Automobile exhausts.	Lung cancer.
5.	Chlorine	Chloralkali industry.	Mucosal irritation.
6.	Ammonia	In the fertilizer industry and poultry farming.	Mucosal irritation.
7.	Hydrogen sulfide	Manufacture of coke, viscose rayon, distillation of tar and petroleum.	Illness and excessive inhalation leads to death.
8.	Acids and aldehydes	Chemical industries.	Eyes, nose, and throat irritation.
9.	Suspended particulate matter (SPM)	Industries; automobile exhausts.	Respiratory diseases.
10.	Dust	Industries and automobile exhaust.	Silicosis.
11.	Asbestos	Roofing, brake linings.	Asbestosis; is carcinogenic to workers.
12.	Lead	Automobile exhausts.	Cumulative poison; affects central nervous system.
13.	Beryllium	Aerospace industry; manufacture of household appliances.	Fatal lung disease; heart and lung toxicity.
14.	Manganese	Mining operations.	Damages nerves and reproductive system.
15.	Benzene	Automobile exhausts and manufacture of chemicals.	Leukemia; chromosomal damage.
16.	Pesticides	Manufacture of pesticides.	Leads to death if inhaled in excess; causes depression.

Table 9.
Major air pollutants and their effects on human health.

difference of densities of the indoor and outdoor air, velocity and direction of wind. **Figure 4** shows schematically the distribution of air pressure and the difference in the elevation of the inlet and outlet openings provided for natural ventilation.

The various types of natural ventilation are the airing and aeration. Airing is achieved by periodic opening of air wings in the windows. It is essential that airing will induce no changes in the temperature of air nor be conductive to the formation of mists, condensation of water vapors on the wall, floor or exposed glass surfaces. Aeration is the induced natural ventilation that serves the purpose of general dilution ventilation for interior space to maintain the necessary air quality within the specified limits. Aeration is effective only if the mechanical control mechanisms for frequent shutting and opening of the window wings are well designed and dependable. In the work areas where air changes cannot be effected too often, use is made of exhaust ducts or shafts the uppermost portion of which is led above the roof

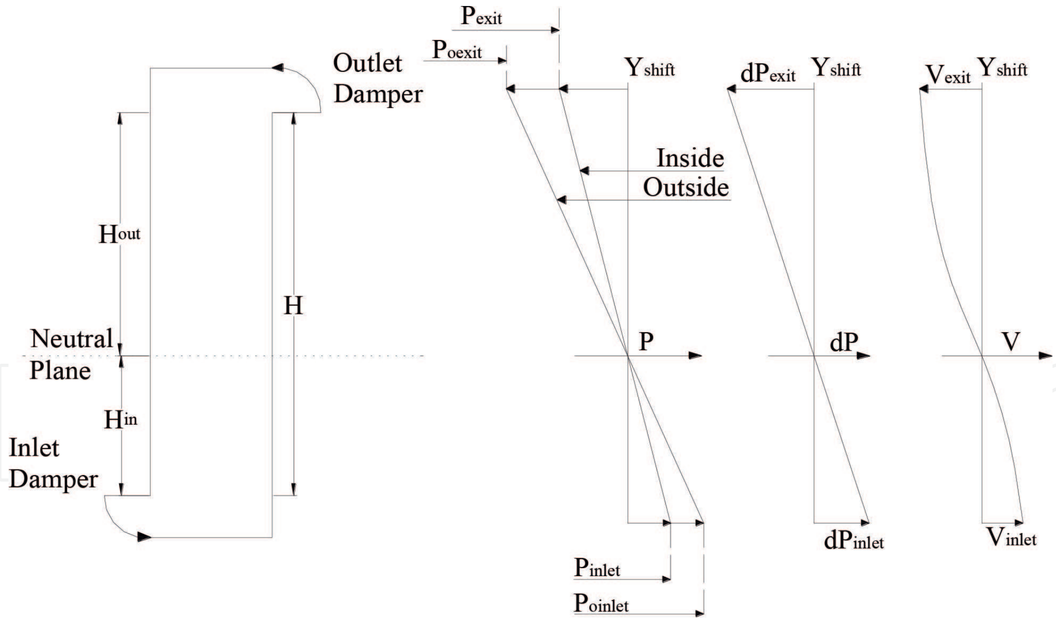

Figure 4.
Air motion pattern in natural ventilation.

ridge. To increase efficiency of air exchange the exhaust air ducts are crowned with diffuser attachments or deflectors.

Deflectors increase the draft of the indoor warm air due to wind force. There exist a large number of deflector types of various designs. The deflector is a branch pipe that flares at the top to form a diffuser which is capped with a baffle secured to the branch pipe upper portion. Both the diffuser and baffle are housed in a cylindrical shell which through arms is fixed to the diffusor so that certain space separates them. The deflector is installed over the top of an exhaust duct or shaft to catch wind. By wind action, air currents flowing about the shell outer surface build up a vacuum in the diffuser thereby increasing the exhaust flow from the enclosure.

Mechanical ventilation can be of different types, namely the forced (plenum), exhaust, and plenum exhaust ventilation. Forced ventilation is a system whose function is to force fresh air through ventilation ducts to work spaces with excess heat and minor concentrations of pollutants in the air. The removal of foul air through ventilation shafts is not only due to heat load and wind force but also due to the effect of overpressure created by forced ventilation. Fresh air is distributed between various zones of working spaces through a network of air ducts passing to various work places where it emerges from various inlet grills and other outlets. Exhaust ventilation can be used in enclosures free of releases into the air of harmful substances, also in work zones where few air changes are sufficient, in auxiliary type structures, service rooms and warehouses. In such cases, fresh air is supplied by natural ventilation through air vents and windows, through voids in the walls and floors, also through un-tight closures at doors, windows and from adjacent rooms. Plenum-exhaust ventilation is necessary in all work spaces where there are demands for an exceptionally dependable air exchange. When using this type of ventilation it is desirable to build up a little overpressure within work spaces where air contains negligible amounts of airborne contaminants to prevent the spread of vitiated air from the adjacent zones where the harmful contaminants may be quite significant. Fresh air outlets should be made so as to face the working zones. Hybrid or compound ventilation, the combination of mechanical and natural ventilations, can be resorted to where mechanical ventilation may unobjectionably be supplemented with natural ventilation for delivering or exhausting the air. Local ventilation may be of the exhaust and the plenum type. Local exhaust ventilation is intended for the removal of specific indoor air contaminants directly from where they form or release to prevent their spread throughout the environment of the working area, or to minimize harmful releases into the air in work zones. The advantages of local ventilation lies in that it prevents pollution of the entire air space within a working enclosure and exhausts minimum air volumes containing concerned amounts of dangerous impurities.

Air-conditioning serves to maintain a desired environment (air temperature, humidity, purity and velocity) within working zones regardless of the outdoor climatic conditions. Industries use air-conditioning in laboratories where work is measurable in high degree of accuracy and in departments whose output is high-precision instruments and devices. Air-conditioning provides for cleaning, heating or cooling, humidifying or drying of the air before admission to the work zone. Normally, air-conditioning systems use return air except for some production processes where recirculation of air is not allowed for health reasons. All processes of air-conditioning are controlled automatically. Self-contained, general purpose air conditioners are designed to control room temperature from +18 to +20°C, to within ±1°C. Other types of air-conditioners control humidity from 30 to 70%, to within ±5%. The choice for the use of return air is governed by reasons of saving energy. In summer the air conditioner requires too much cold water for air cooling, and in winter, hot water for air heating.

Ventilation equipment includes ventilation shafts, air ducts, ventilating fans, air cleaners and heaters. Intake (plenum) shafts provide supplies of atmospheric air. The concentrations of pollutants in fresh outdoor air supplies measured at air outlet points should not exceed 30% of their maximum safe concentrations. Air shafts can be separate structures or lean-to extensions. Plenum shaft intakes are normally grilled with louver-type shutters to protect them from atmospheric precipitation. The choice of a proper size for plenum openings and shaft sections relies on the air velocity which for openings ranges from 4 to 12 m/s, for ducts from 2 to 6 m/s. Air ducts located inside the building are intended to convey air to working zones or remove vitiated air from workrooms at points specified by the design of the ventilation system. The choice of construction materials for air ducts is made depending largely on the medium they are supposed to convey with due regard to the fire-prevention requirements. Air ducts can be round or rectangular in shape. Choice of the proper size or diameter of the air duct depends on the efficiency of the selected fan and rests on the assumption that the air velocity is high enough to prevent dust load. To minimize the air drag, the inner surfaces of air ducts are made smooth, and the branching, bends and transitions easy. Flange-type coupling ensures a tight connection and a joint that is easy and fast to assemble. The delivery of the air and its distribution at workspaces is affected by way of air outlets of various design, which are normally grilled branch pipes communicating with a common air duct.

Humidifiers are devices for maintaining desired humidity conditions of the air supplied to working zones. During the warm period they can also serve for cooling the air. Air heater is a device for conditioning the air to a desired temperature before admission to industrial buildings during the cold period. Fan is a device for delivering or exhausting large volumes of air or gas through a ventilation system with a low pressure increase. By manner of action, distinction is made between centrifugal and axial fans. The impeller consisting of a number of interconnected paddles or blades is an essential part of a fan of any type. Centrifugal fan has an impeller of a paddle-wheel form, a spiral jacket, a shaft, a pulley and bearings. The air enters axially at the center of impeller and is discharged radially by centrifugal force into the spiral jacket where it gets partially compressed. It is also called paddle-wheel or radial fan. Axial fan consists of an impeller or rotor carrying several blades of airscrew from working in a cylindrical casing, sometime provided with fixed blades. It is also called propeller fan. The air enters axially at the center of the impeller and is discharged centrally along its axis of rotation. The direction of the air discharge can thus be easily altered by changing the direction of the impeller rotation. Axial fans are usually driven by a direct coupled motor, but may be geared up or down through a belt transmission by choosing suitable pulleys. Axial fans are usually used for conveying large volumes of air against small counter pressures when friction or pressure loss in the ventilation system is not more than 0.1–0.25 kPa. Normally the choice for a fan depends on the value of total pressure loss which for low pressure systems is 1 kPa; medium pressure systems, more than 1–3 kPa; and high pressure systems, more than 3–12 kPa. Fans also bear numbers which, in decimeters, indicate the impeller diameter. The choice for a suitable fan can be made using fan performance curve usually given in ventilation equipment catalogs. Fan characteristics can be individual and universal. The individual characteristics show the efficiency (m^3/h) on the abscissae versus pressure (Pa) on the ordinate. Because the efficiency and the pressure produced by a fan depend on the speed of impeller (rpm) and friction loss of the air ducts the fan characteristic is constructed for various speeds and can be used against the various pressure loss values of the air duct. Usually, the same fan operating at a given speed discharges different air volumes, depending on the friction loss of the air duct network to which it is connected. When looking for a fan of a suitable efficiency, take the abscissae point of the necessary air discharge and find the necessary speed (rpm) and efficiency of the fan by constructing a vertical line till it intercepts the curve in a point across the ordinate. Power consumption (kW) of fans can be obtained from the expression:

$$N = \frac{VxP_f}{3600x102x\eta_f x\eta t} \tag{11}$$

where V is the volume flow rate, m^3/h; P_f is the air duct friction loss, Pa; η_f is the efficiency of fan; and η_t is the efficiency of transmission, which for direct-coupled motor is 1; and for V-belt transmission, 0.9–0.96.

5.1 Air cleaning equipment

One of the basic principles of ventilation of a building with pollutants is the cleaning of both plenum and exhaust air, if the last is heavily dust-laden. To clean the plenum air which normally has little dust, use is made of dry porous, wet porous and electrical filters. The exhaust dust laden air should be cleaned before it is exhausted to atmosphere. The process is affected by means of dust collectors or catchers in which dust separation is achieved by gravity force, centrifugal force, or by bag filters. If the cleaned air contains not more than 1–2, 40–50 , and more than 50 mg/m^3 of dust particles, cleaning is regarded as fine, medium-coarse, and coarse, respectively. There are many types of air cleaning equipment.

De-dusting chamber is an apparatus by means of which suspended dust can be precipitated; the process is generally affected by means of an exhaust fan. The dust-laden air through air ducts enters a chamber with a section several times that of the air duct in which the air loses its speed and dust separates from the air by pull of gravity. Only, coarse dust settles in dust collectors of this type which constitute the first stage cleaning for initially large content of airborne dust.

Cyclone is a type of a conical dust extractor in which dust is separated from the cyclonically rotating dust-laden air by centrifugal force. Airborne dust particles are forced against the walls of the dust separator, lose speed and settle down in the conical lower portion of the collector from which the collected dust is periodically removed. Cleaned air is exhausted to atmosphere through the upper pipe.

Bag filter is a widespread device for cleaning of the air. It is an apparatus for separating air from fine dust and constituting essentially of a canvas cloth through which dust-laden air is forced or driven by pressure of suction leaving dust particles on the outside of the canvas. It is equipped with a shaker device to regularly clean the canvas. To improve the removal of dust from the canvas filter, the shaker may be assisted by back-flushing, i.e., blowing clean air through the canvas from the inside. Baghouse filters produce a high degree cleaning (99%) when catching dust particles sized from 0.3 to 4 μm. Their disadvantages include large dimensions need for frequent removal of the collected dust and filter cleaning for, as the cloth resistance of the filter increases, its capacity lowers.

To clean the plenum air from fine dust, ventilation systems employ air cleaners with paper filters. The filtering medium is pure cellulose made in the form of very thin layers of crimp paper and packed into stacks of a definite thickness. Filter paper for quantitative purposes is treated with acids to remove all or most inorganic substances. The disadvantages of paper filters are relatively high resistance to airstream and frequent need for changing the filter paper stacks. Besides, paper filters are impracticable for high concentrations of dust as their resistance to the air passes increases, and this demands for immediate replacement as it reaches 120–150 Pa. The efficiency for fine dust separation is 92–95%.

Electrical precipitators are dust collectors in which the process of dust separation is affected by an electrical precipitation plant using a unidirectional electric field in which airborne dust particles are attracted to, and collected on, the positive electrode from which dust is shaken off into a dust bunker. These are also called electrostatic precipitators whose separation efficiency for fine dust is 95–99%.

The choice of a filter or dust arrester is based largely on the required degree of cleaning, content of dust in the dust-laden air, nature of dust and size of dust particles, efficiency and pressure of the ventilating unit, resistance and capacity of the dust separator. The physical properties of dust are also important. Thus, inertia-type de-dusters and baghouse filters are ineffective for sticky moist or fibrous kind of dust. Dust collectors, cyclones or electrical precipitators are usually ineffective for dusts in which the vast majority of particles are less than 10 μm in size. Content of dust suspended in the air is also important for choosing an air cleaner of a suitable type and capacity.

6. Conclusion

Pollutants of industrial indoor environment, along with importance of indoor air quality and health are elaborated in detail. The noise calculation charts are provided for interference of noise waves based on a benchmark solution. The grades and flag colors are notated to the noise calculation charts. Noise characterization calculations for indoor environment are presented using devised noise measurement equations. Indoor air quality and noise instrumentation based on source of noise are correlated and discussed. Effects of pollutants on human health are summarized. Human noise behavior along with psychophysiological measurements is briefly discussed. Ventilation systems along with air cleaning equipment for industrial indoor environment are discussed in detail.

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