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Olfactory Comfort Assurance in Buildings

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1. Introduction

Reducing energy consumption in buildings is one of the main current directions of research in building constructions. An important part of household energy consumption is necessary to achieve, in living spaces, indoor microclimate parameters. Therefore, is particularly important the achievement of structural elements, building equipments and operating modes to allow getting both adequate comfort parameters and energy saving.

The greatest majority of people carry on 80…90% of their lives inside buildings, which must satisfy the objective and subjective requests linked to vital functions of the occupants. That is why the enclosed spaces must insure the possibility for both physical and intellectual work, as well as for some recreation activities, for rest and sleep under most favourable conditions. The achievement of these conditions depends on very many factors that decisively influence the sensation of comfort perceived, the work capacity and man's regeneration capacity. The design of the rooms must take into consideration these conditions and present tendencies to reduce the energy consumption, that are decisively influencing the optimal or admissible values of comfort parameters. Thus the inside microclimate of a building must be the result of a computation of multicriterial optimization, taking into account technical and psychological comfort and the energy saving.

The concept of technical comfort comprises all parameters achieved and controlled with HVAC systems that act upon building occupants senses. This includes thermal, acoustic, olfactory and visual comfort. In accordance with the dissatisfied person percent of the ensured comfort: 10%, 20%, 30%, rooms are classified into three categories: A, B, C.

The perception and appreciation of basic comfort elements to man are influenced by some psychological factors, but at the same time evolution and man psychological equilibrium are closely linked with the environment. So, between psychological and technical comfort is a reciprocal connection. Human psyche depends also by other independent factors like: age, gender, etc., influencing the technical comfort level appreciation. So pleasant sensation may occur as a result of optimum technical and psychological comfort parameters (Fig. 1).

Subjective comfort of persons in a room depends on many factors: temperature, humidity and air circulation; smell and respiration; touch and touching; acoustic factors; sight and colours effect; building vibrations; special factors (solar–gain, ionization); safety factors; economic factors; unpredictable risks.

Because of some technical conditions the common influence of these factors can not be analysed, and the adaptation of the human body to a certain environment is a complex process, this one reacting to the common action of more parameters.
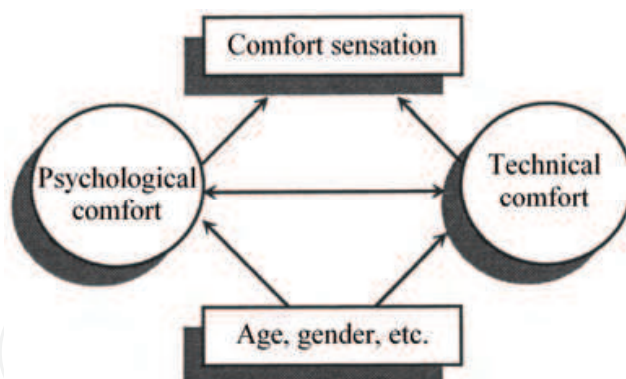
Fig. 1. Comfort sensation

In this chapter an olfactory comfort analysis in buildings is performed starting from a general description of the comfort fundamental components (thermal, olfactory, acoustic and visual comfort). It is developed a computational model for indoor air quality numerical simulation, as well a methodology to determine the outside airflow rate and to verify the indoor air quality in enclosed spaces, according to the European Standard CEN 1752 (1998). Also, it is presented the influence of carbon dioxide on human performance and productivity.

2. Generalities on fundamental components of the comfort

2.1 Thermal comfort

The subjective sensation of thermal comfort is decisively determined by the following parameters (Sârbu & Kalmar, 2002): indoor air temperature (t_i); mean radiant temperature (t_{mr}) of bordering surfaces; relative humidity of air (φ_i); partial water vapours pressure (p_a); air velocity (v_i); thermal resistance of clothing (R_{cl} or R_h), and their influence on the vaporization; heat production of human body and human thermoregulation. The first four are physical parameters, and the other two expresses the capacity of the human body to adapt itself in order to maintain the thermal equilibrium. The main factors that influence the thermal equilibrium of the human body are:

- heat production of human body, which depends on the activity level, age, sex, etc.
- body heat loss, which depends on clothing and on the other parameters mentioned previously.

In general, comfort occurs when body temperatures are held within narrow ranges, skin moisture is low, and the physiological effort of regulation is minimized. Surprisingly, although climates, living conditions, and cultures differ widely throughout the world, the temperature that people choose for comfort under similar conditions of clothing, activity, humidity, and air movement has been found to be very similar (Busch, 1992; Dear et al., 1991; Fanger, 1972).

In order to evaluate the sensation of thermal comfort we use the thermal sensation scale with seven levels (ASHRAE, 2009): +3 (hot); +2 (warm); +1 (slightly warm); 0 (neutral); −1 (slightly cool); −2 (cool); −3 (cold).

Numerical prediction of thermal comfort in a room is performed by using the PMV – PPD model, and testing is achieved at asymmetric thermal radiation, caused by building elements with a temperature much different from the mean radiant temperature. Radiant asymmetry is the difference in radiant temperatures seen by a small flat element looking in

opposite directions. Four calculation methods of radiant temperature asymmetry are available in the technical literature (Frohner et al., 2004).

PMV (predicted mean vote) index has the optimum value equal to zero, but according to the prescriptions ISO Standard 7730 (ISO, 2005) it is considered that the domain of thermal comfort corresponds to values between –0.5 and +0.5. The use of PMV index is recommended only for values between +2 and –2. In the Fig. 2 are represented the values of operative comfort temperature t_c (corresponding to index PMV = 0), correlated to thermal resistance of clothing (R_{cl} and R_h), metabolic rate i_M and metabolic heat production M.

In Table 1 is illustrated the optimal values of operative temperature t_c according to building use, summer and winter, according to European Standard CEN 1752 (CEN, 1998).
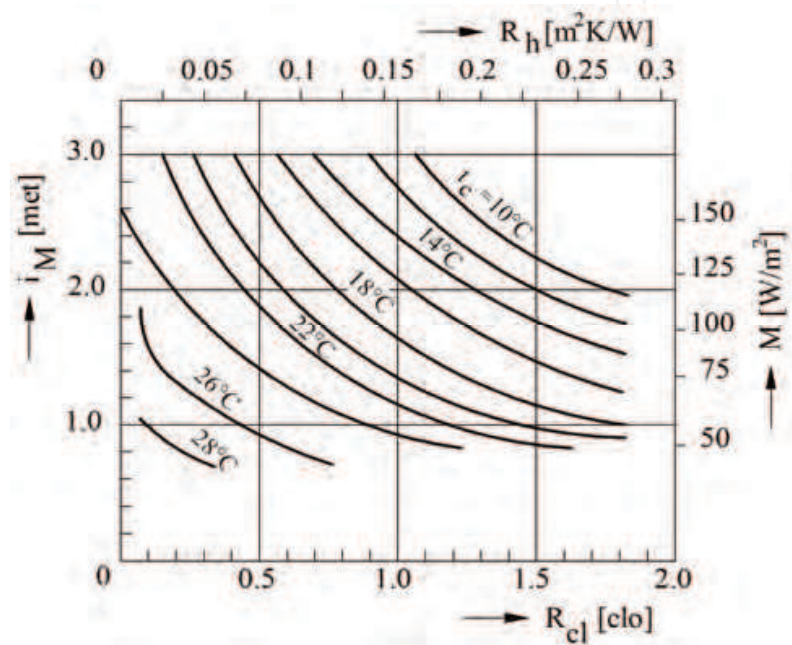

Fig. 2. Operative comfort temperature function of clothing and activity

In recent study (Sârbu & Bancea, 2009) is developed a computational and testing model of thermal comfort in buildings, according to the European Standard CEN 1752. On the bases of this model there was elaborated a computer program, implemented on compatible microsystems IBM-PC.

2.2 Olfactory comfort

Comfort and indoor air quality (IAQ) depend on many factors, including thermal regulation, control of internal and external sources of pollutants, supply of acceptable air, occupant activities and preferences, and proper operation and maintenance of building systems. Ventilation and infiltration are only part of the acceptable indoor air quality and thermal comfort problem. The condition to achieve human body metabolism in a enclosed space is oxygen (O_2) taking and carbon dioxide (CO_2) releasing. After respiration process air reaches the lungs through upper and lower airways. Upper airways filter the inspired air, while providing to it the proper temperature and humidity. The oxygen is transported from the lungs to tissues through blood that carry back the carbon dioxide. Expired CO_2 flow rate are illustrated in Table 2.

| Room destination | R_{cl} [clo] | | i_M | Pers./ | Room category | t_c [ºC] | |
	Summer	Winter	[met]	/m² floor		Summer	Winter
Small offices	0.5	1.0	1.2	0.10	A	24.5±0.5	22.0±1.0
					B	24.5±1.5	22.0±2.0
					C	24.5±2.5	22.0±3.0
Large offices	0.5	1.0	1.2	0.07	A	24.5±0.5	22.0±1.0
					B	24.5±1.5	22.0±2.0
					C	24.5±2.5	22.0±3.0
Conference rooms	0.5	1.0	1.2	0.50	A	24.5±0.5	22.0±1.0
					B	24.5±1.5	22.0±2.0
					C	24.5±2.5	22.0±3.0
Study rooms	0.5	1.0	1.2	1.50	A	24.5±0.5	22.0±1.0
					B	24.5±1.5	22.0±2.0
					C	24.5±2.5	22.0±3.0
Restaurant rooms	0.5	1.0	1.4	0.70	A	23.5±1.0	20.0±1.0
					B	23.5±2.0	20.0±2.0
					C	23.5±2.5	20.0±2.5
Classrooms	0.5	1.0	1.2	0.50	A	24.5±0.5	22.0±1.0
					B	24.5±1.5	22.0±2.0
					C	24.5±2.5	22.0±3.0
Kindergartens	0.5	1.0	1.4	0.50	A	23.5±1.0	20.0±1.0
					B	23.5±2.0	20.0±2.0
					C	23.5±2.5	20.0±2.5
Deposits	0.5	1.0	1.6	0.15	A	23.0±1.0	19.0±1.5
					B	23.0±2.0	19.0±3.0
					C	23.0±3.0	19.0±4.0

Table 1. Optimum values of operative temperature t_c

Activity	M [W/pers]	Inspired air [m³/h]	Expired CO_2 [l/h]	Consumed O_2 [l/h]
Sedentary	–	0.30	12	14
Intellectual	120	0.375	15	18
Physical very easy	150	0.575	23	27
Physical easy	190	0.75	30	35
Physical hard	>270	>0.75	>30	>35

Table 2. Expired CO_2 flow rate

Air composition in living spaces differs from that of the outside air. Carbon dioxide concentration in outside air is between 300 and 400 ppm, and in living spaces is of about 900 ppm. The maximum admitted limit of CO_2 concentration in the inhaled air is of 1000 ppm (Pettenkofer's number). Table 3 presents the effect of different CO_2 concentrations on human body.

CO$_2$ concentration		Effect
[%]	[ppm]	
3	30000	Deep breathing, strong
4	40000	Head aches, pulse, dizziness, psychic emotions
5	50000	After 0.5…1 hours may cause death
8...10	80000...100000	Sudden death

Table 3. The effect of CO$_2$ concentration on human body

Air quality is prevailingly determined by people's sensations to different odorants. Because is impossible to be measured each of the air contaminants quantitatively and qualitatively (about 8000), Fanger proposed that all these compounds to be measured by one parameter: the odour.

The odours arise in inhabited areas by the release of the human body (ammonia, methan, fatty acids), emanations of the furniture, carpets, paintings and other building materials (formaldehyde), by combustion and heating processes (carbon monoxide, fuel vapour), by exhaust gas poluted air infiltration or air from industrial areas, meal preparation, toilettes areas, mold chemical reactions, mushrooms or any decomposition products. Most of these unpleasant products are made of complex organic substance.

Excitation level in confront of some odours is very low. For example, mercaptan odour is perceived starting from a concentration of 0.00000004 mg/l. The olfactory organ main feature is adaptation. After a while, due to continuous charging, sensation of smell intensity decreases (Fig. 3).

A large number of pollutants come a time in the air with tobacco smoke. This affects the eyes, the nose and it is a risk factor for different diseases. Reduce air pollution by tobacco smoke can not be done only by increasing the air exchange rate. Thus, to annihilate the negative feelings created by smoking one cigarette are requested 100 m^3 of fresh (outside) air.
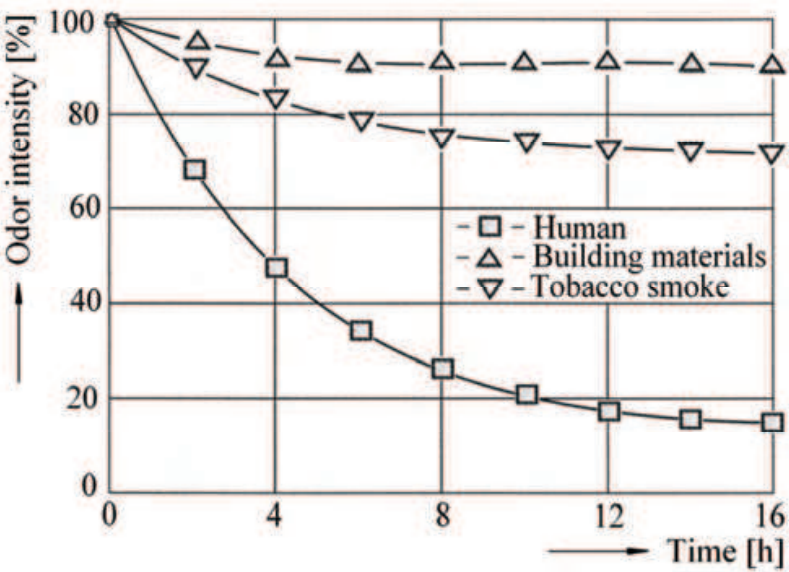

Fig. 3. Time evolution of odour intensity

Along with tobacco smoke in the air reaches carbon monoxide (CO). Maximum carbon monoxide concentration permissible values, given by international prescriptions, are 10

mg/m^3 for housing spaces and 20 mg/m^3 for kitchen and ancillary areas (3 h maximum residence time). Fig. 4 illustrates the variation of CO concentration depending of smoked cigarettes number and fresh air flow–rate introduced into the room. The smoking weighty influences the CO content of expired air, whose values are indicated in Table 4.
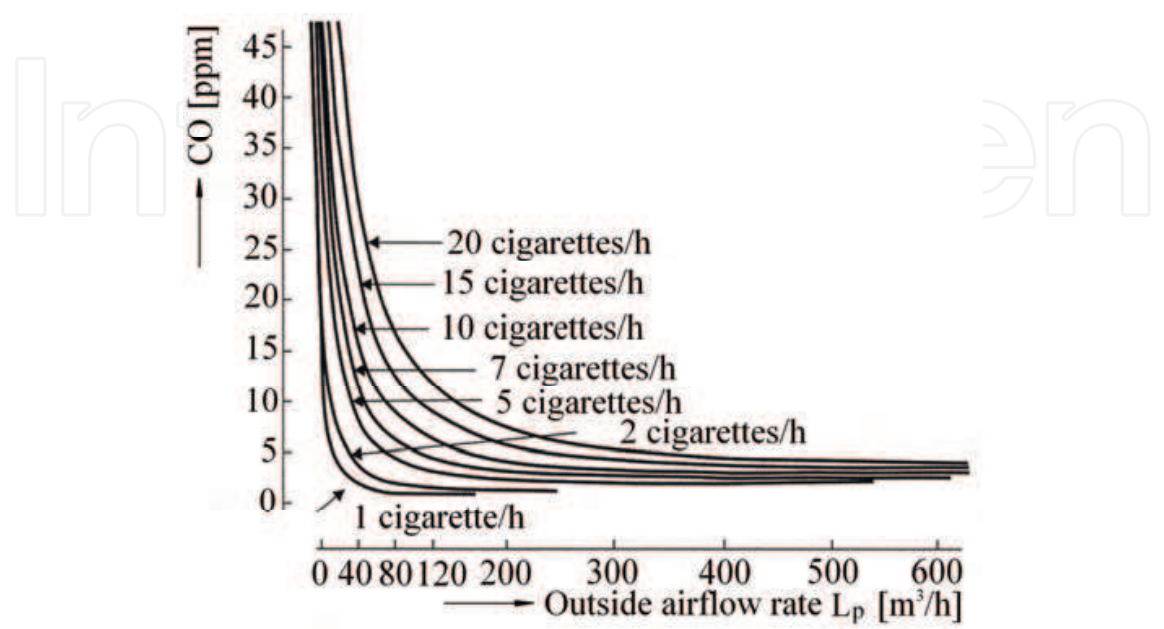

Fig. 4. Variation of CO concentration

Odorant perception depends, on one side, on objective factors: concentration and toxicity of air pollutants (bio–effluents), activity level, outside airflow rate, and on the other hand, on psychological factors with subjective character.

No.	Category	CO concentration [mg/m^3]	
		Male	Female
0	1	2	3
1	Nonsmoker	7.1	5.8
2	Former smoker	7.8	6.5
3	Cigar and pipe smoker	9.6	12.0
4	Tobacco smoker	24.3	21.1

Table 4. Average values of CO concentration in expired air

The relation between perceived odorant intensity and its concentration conforms to a power function (Stevens, 1957):

$$S=kC^{\beta} \tag{1}$$

where: S is odorant intensity (magnitude); C – odorant concentration, in ppm; β – exponent of psychophysical function; k – constant characteristic of material.

In the olfactory realm: $\beta < 1.0$. Accordingly, a given percentage change in odorant concentration causes a smaller percentage change in perceived odour intensity.

Sometimes IAQ scientists cannot successfully resolve complaints about air in offices, schools, and other nonindustrial environments. Customarily, complaints are atributed to elevated pollutant concentrations; frequently, however, such high concentrations are not found, yet complaints persist.

Assuming that the inability to find a difference between air pollutant levels in buildings with registered complaints and those without complaints is due to inadequacies of pre-vailing measurement techniques, Fanger and other changed the focus from chemical ana-lysis to sensory analysis (Fanger, 1987, 1988; Fanger et al., 1988). Fanger quantified air pollution sources by comparing them with a well–known source: a sedentary person in thermal comfort. A new unit, the *olf*, was defined as the emission rate of air pollutants (bio–effluents) from a standard person. A *decipol* (*dp*) is one olf ventilated at a rate of 10 l/s of unpolluted air.

The percentage of persons dissatisfied (PPD) with air polluted by human bio–effluent (1 olf) can be calculated from the equations (Fanger et al., 1988):

$$PPD = 395 \exp\left(-3.66 L_p^{0.36}\right) \quad \text{for } L_p \geq 0.332 \, \text{l/s} \tag{2}$$

$$PPD = 100 \quad \text{for } L_p < 0.332 \, \text{l/s} \tag{3}$$

where: L_p is the outside air flow–rate, in l/s.

The curve (Fig. 5) generated by equations (2) and (3) is based on experiments involving more than 1000 European subjects (Fanger & Berg–Munch, 1983). Experiments with American (Cain et al., 1983) and Japanese (Iwashita et al., 1990) subjects show very similar results.
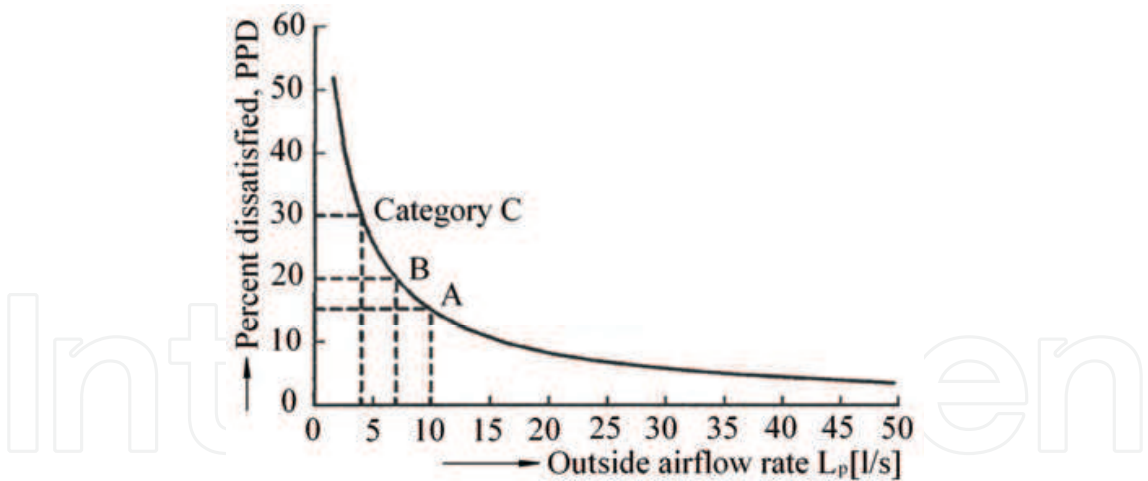

Fig. 5. PPD as a function of ventilation rate per standard person (i.e., per olf)

The idea behind the olf is to express both human and nonhuman sensory sources in a single unit: *equivalent standard persons* (i.e., in olfs). A room should therefore be ventilated to handle the total sensory load from persons and building. Table 5 shows the sensory loads from different pollution sources used in CEN.

The sensory load on the air in a space can be determined from Fig. 5 by measuring the outside air flow–rate and determining the percent dissatisfied, using an untrained panel with a minimum of 20 impartial persons (Gunnarsen & Fanger, 1992). The required outside air flow–rate depends on the desired percentage of occupant satisfaction.

No.	Source	Sensory load
0	1	2
1	Sedentary person (1… 1.5 met)	1 olf
2	Person exercising low level (3 met)	4 olf
3	Person exercising medium level (3 met)	10 olf
4	Children, kindergarten (3… 6 yrs)	1.2 olf
5	Children, school (4… 16 yrs)	1.3 olf
6	Low–polluting building	0.1 olf/m^2
7	Non–low–polluting building	0.2 olf/m^2

Table 5. Sensory pollution load from different pollution sources

Various factors make odor control an important consideration in ventilation engineering:
- contemporary construction methods result in buildings that allow less air infiltration through the building envelope;
- indoor sources of odours associated with modern building materials, furnishings, and office equipment have increased;
- outdoor air is often polluted;
- energy costs encourage lower ventilation rates at a time when requirements for a relatively odour–free environment are greater than ever.

Outdoor air requirement for acceptable indoor air quality have long been debated. Historically, the major considerations have included the amount of outdoor air required to control moisture, carbon dioxide and tobacco smoke generated by occupants. These considerations have led to prescriptions of a minimum rate of outdoor air supply per occupant.

Tables 6 and 7 present the minimum rate of outside airflow per occupant for different activities, according to European Standard CEN 1752, that also takes into consideration the smokers in ventilated rooms.

No.	Activity	Outside airflow rate [m^3/(h·pers)]
0	1	2
1	Intellectual	30
2	Physical very easy	30
3	Physical easy	40
4	Physical hard	50

Table 6. Minimum rate of outside airflow

Room category	Outside airflow rate [m^3/(h·pers)]			
	Without smokers	20% smokers	40% smokers	100% smokers
0	1	2	3	4
A	36.0	72.0	108.0	108.0
B	25.2	50.4	75.6	75.6
C	14.4	28.8	43.2	43.2

Table 7. Minimum rate of outside airflow for rooms with smokers

The perceived olfactory sensation depends not only on the pollutant source but also to a great extend, on the dilution degree with outside air. The olfactory pollution degree of a room is given by:

$$C_i = C_p + \frac{10G}{L_p} \qquad (4)$$

where: C_i is the indoor air quality, in dp; C_p – outdoor air quality, in dp; G – contaminants concentration of room air.

2.3 Acoustic comfort

Another key element contributing to the overall comfort in an enclosed space is acoustic comfort. Should be made the difference between the notions of *sound* and *noise*. Thus, the notion of sound has several definitions, depending on the purpose of interpretation.

If sound is considered a physical phenomenon, then it represents the elementary vibration of elastic matter which spreads as wave in transport medium.

The concept of sound can have the sense of external excitement of creatures auditory organ, which leads to different reactions from them. Perceptible sound field to human is illustrated in Fig. 6.
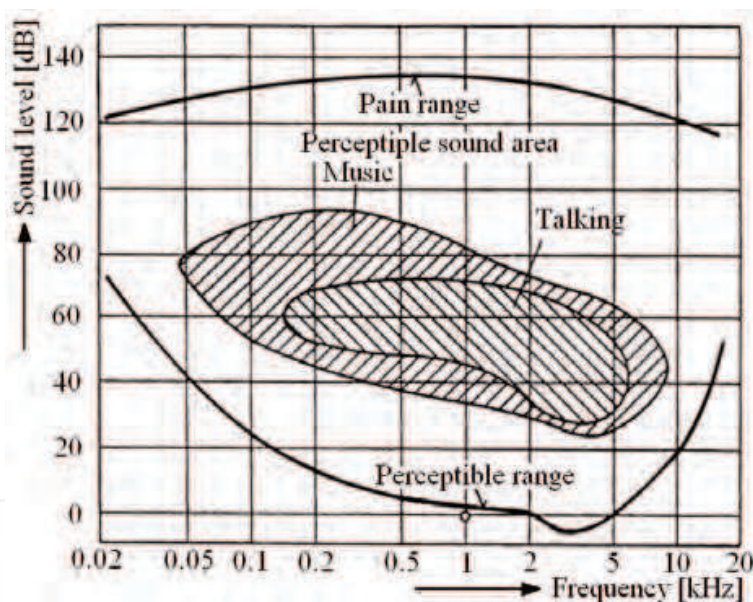

Fig. 6. Range of human audibility with normal hearing

The third sense of the sound concept is aesthetic and understanding effect. From this point of view the sound has a coded form information content, that the brain decodes it and the correct perception of sound crucial influence the human comfort.

The main element of relationship between people is the speaking and any event that disturbs the understanding it creates uncertainty and with this the discomfort. So there are sound effects, negatively perceived by human, called noises and they are indistinguishable by sound after the first two definitions. The difference between them is made by human through the given interpretation.

From researches performed in medical science it is known that the noises act on the autonomic nervous system. Nervous system reflex response is strangling noises capillaries.

Increased blood flow resistance does not involve the increase of heart beatings. This leads to a decrease blood flow rate that determines the amount reduction of oxygen transported to cells. Reduced amount of oxygen is manifested by various symptoms such as headaches, migraines, decreased concentration, blurred vision etc.

The negative effect of the arterial system bottleneck is felt especially during sleep when the body functions are reduced to a minimum. If in this state the body is subjected to the effect of noise, then reduce the amount of oxygen that feeds the cells causes lengthening the period of regeneration. It was shown that frequent sleep disturbances lead to nervousness, loss of efficiency, fatigue and nervous system degeneration. Also, intellectual activity done in terms of high noise level the yield is particularly low.

Acceptable interior equivalent noise level, according to prescriptions of the European Standard CEN 1752, is shown in Table 9.

Room destination	Cate-gory	Noise level [dB (A)]	Room destination	Cate-gory	Noise level [dB (A)]
0	1	2	3	4	5
Small offices	A	30	Restaurant rooms	A	35
	B	35		B	45
	C	40		C	55
Large offices	A	35	Classrooms	A	30
	B	40		B	35
	C	45		C	40
Conference rooms	A	30	Kindergaertens	A	30
	B	35		B	40
	C	40		C	45
Study rooms	A	30	Deposits	A	40
	B	33		B	45
	C	35		C	50

Table 9. Acceptable interior noise level, according to CEN 1752

2.4 Visual comfort

Human life is closely connected with the visual environment, because the information is collected at a rate of 90% within sight, and activity is also linked to vision in most cases.

The visual comfort is conscious state, which occurs due to physiological and psychological actions, expressing satisfaction with the environment.

Visual environment in an enclosed space appears if it is illuminated and has two compo-nents:
-    the room delimited by opaque or transparent surfaces (passive component);
-    the light that makes the room visible (active component).

Human perceives only the light reached in the eyes. Thus, are seen only the surfaces that send light in the observer`s eye. Usually those are opaque surfaces (walls, floors, furniture etc.). The surfaces that allow natural light (windows, skylights etc.) have a particular impor-tance because:
-    glazed and opaque surfaces do not create the same visual environment;
-    usually the visual environment does not coincide with built interior space.

In function on the room destination there are requirements for visual environmental characteristics which can be divided as follows:
- the informations about certain parts of the space have to be accurate;
- the visible space must not create discomfort (visual disturbance).

Accurate vision means also the right colors perception. They are regarded as suitable if they coincide with the colors seen in natural light, hence the need for natural lighting.

For artificial lighting the source light quality can be differentiated from the point of view of body natural colors reveling. So if the bodies color lighted with artificial source corresponds to their natural color when color rendering is perfect, otherwise the color rendering is more or less good.

The visual comfort sensation represents the concordance between lighting and the quality of light, caracterised by light color or its temperature. The color pleasant effect refers to the fact that a less lighting ambient presents visual comfort if is the result of a rich warm color and an lighted ambient presents visual comfort if is the result of cold light. In terms of color rendition, the visual comfort can be analyzed in base of Kruithoff charts, that presents the variation of lighting E with light temperature T (Fig. 7).
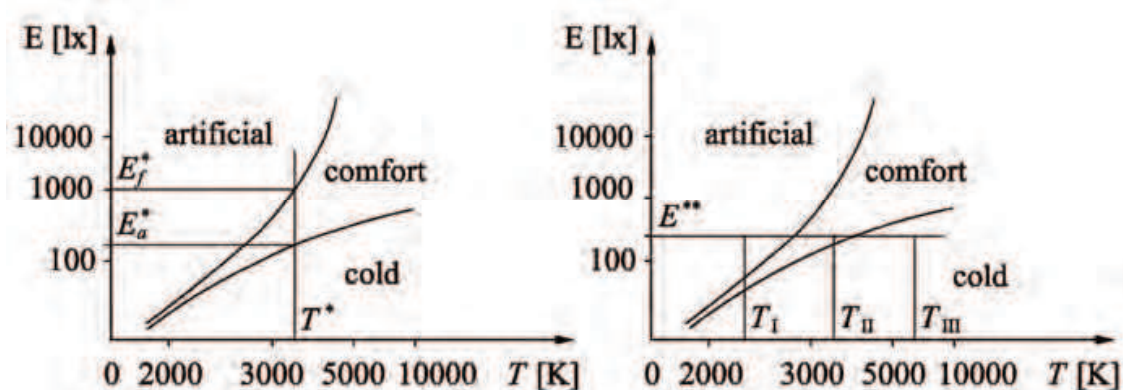

Fig. 7. Relation between lighting level, lighting temperature and visual comfort

So, a light source with temperature T^* can create different observer sensations depending of lighting value:
- for $E < E_a^*$, the lighting is perceived as cold;
- for $E_a^* < E < E_f^*$ are satisfied the visual comfort conditions;
- for $E > E_f^*$, the lighting is perceived as artificial (disturbing).

For a given value of lighting E^{**}, created subjective visual sensation depends by light temperature: artificial lighting at T_I, visual comfort at T_{II} and cold lighting at T_{III}.

2.5 Sick building syndrome

Concern about the health effects associated with indoor air dates back several hundred years, and has increased dramatically in recent decades. This attention was partially the result of increased reporting by building occupants of complaints about poor health associated with exposure to indoor air. Since then, two types of diseases associated with exposure to indoor air have been identified: *sick building syndrome* (SBS) and *building related illness* (BRI).

The people with their activity in buildings with large glazed exterior surfaces, equiped with complex building climatisation systems (commercial areas, office buildings, etc.) are affected of SBS. Sick building syndrome describes a number of adverse health symptoms related to

occupancy in a „sick" building, including mucosal irritation, fatigue, headache, and, occasionally, lower respiratory symptoms and nausea. There is no windespread agreement on an operational definition of SBS. Some authors define it as acute discomfort (e.g., eye, nose, or throat irritation; sore throat; headache; fatigue; skin irritation; mild neurotoxic symptoms; nausea; building odours) that persists for more than two weeks at frequencies significantly greater than 20%.

In Figs. 8 and 9 are presented the main symptoms of the "sick" building for their occupants and also the consequences of these ones. The most common causes of the SBS are thermal comfort and inadequate air quality.
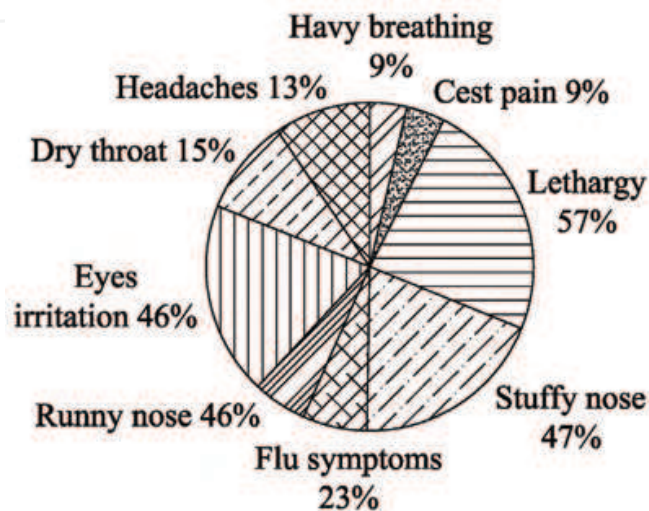

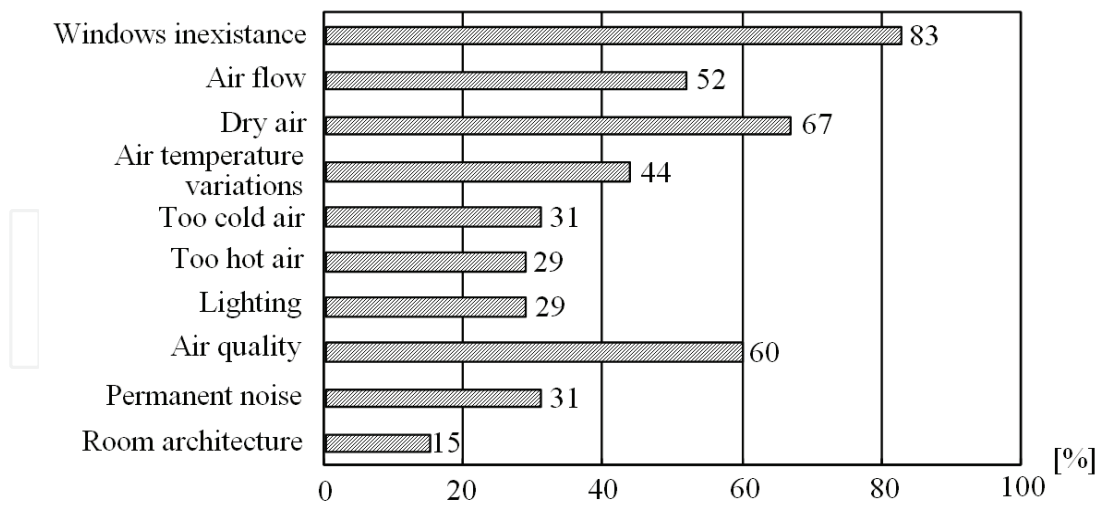Fig. 8. The "sick" building symptoms distribution

Fig. 9. Causes of sick building syndrome

The increased prelevance of health complaints among office workers is typical of sick building syndrome (Burge et al., 1987). Widespread occurrence of these symptoms has prompted the World Healt Organization to classify SBS into several categories (Morey et al., 1986):
-    sensory irritation in the eyes, nose, or throat;
-    skin irritation;

- neurotoxic symptoms;
- odor and taste complaints.

Some investigations have sought to correlate SBS symptoms with reduced neurological and pysiological performance. In controlled studies, SBS symptoms can reduce performance in susceptible individuals (Molhave et al., 1986).

Research performed on the basis of questionnaires on a sample of 4000 people (43.1 % men and 56.9% women) with their activity in a Frankfurt administrative building revealed the following discomfort factors (Bánhidi & Kajtár, 2000): indoor climate (65.4%); noises (32.7%); noncorresponding lighting (25.5%); tobacco smoke (24.7%); small work space (23.9%); overtime work hours (12.8%); stress caused by chief (9.7%); competition (7.1%).

3. Indoor air quality simulation model

3.1 General equation for the time evolution of a contaminant concentration

Consider a single zone compartment, where there is a source of pollution that has gas exchanges with the outside air, and where an air purifier may be used. Admitting the possibility of deposition and absorption of the pollutant on the walls and other surfaces, the temporal evolution of the concentration of a pollutant is modeled by the following differential equation (Gameiro da Silva, 2009):

$$\frac{dc}{d\tau} = \frac{P}{V} + nc_p - nc - v_d \frac{S}{c} - \frac{L_p}{V} c \varepsilon_p \qquad (5)$$

in which: c is the instantaneous average contaminant concentration, in mg/m^3; P – pollutant generation inside the compartment, in mg/h; V – room volume, in m^3; n – air exchange rate, in h^{-1}, i.e., the fresh air flowrate divided by the room volume; c_p – concentration of the contaminant in outside air, in mg/m^3; v_d – deposition rate of pollutant, in mg/(h·m^2); S – surface of deposition, in m^2; L_p – flow rate through the air purifier, in m^3/h; ε_p – efficiency of the air purifier.

The effects of absorption or deposition of the pollutant inside the compartment and the removal of filtering through the air purifier system may be considered in a simplified form, reducing the intensity of the sources of their value to them. Thus, for purposes or simplification, their terms in the equation may be despised, coming:

$$\frac{dc}{d\tau} = \frac{P}{V} + nc_p - nc(\tau) \qquad (6)$$

That, integrated for a situation where V, P, c_p, L_p remain constant, since an initial time instant $\tau = 0$, where the initial concentration $c_0 = c_p$, till a generic time instant τ, will come:

$$c(\tau) = c_{eq} + \left(c_0 - c_{eq}\right) \cdot e^{-n} \qquad (7)$$

in which c_{eq} is the equilibrium concentration.

3.2 Equilibrium concentration

The equilibrium concentration c_{eq}, in the equation (7), is the value that occurs when it ceases the variation in concentration. Thus, it is obtained equalizing the first member of equation (6) to zero, which gives:

$$c_{eq} = c_p + \frac{P}{Vn} \qquad (8)$$

that as $n = L_p/V$, comes:

$$c_{eq} = c_p + \frac{P}{L_p} \qquad (9)$$

The equations are solved numerically. The outputs of the simulation are instantaneous concentration of the pollutant and the graphical results of the time–evolution of the pollutant concentration.

3.3 Metabolic CO_2 computation

The expressions to calculate the volumes of oxygen (O_2) and carbon dioxide (CO_2) in the human respiration process are given (Emmerich & Persily, 2001), as a function of the metabolic rate and the corpulence of the studied person. The volume of consumed O_2 is given by:

$$V_{O2} = \frac{0.00276 A_D M}{0.23r + 0.77} \frac{1}{S} \qquad (10)$$

where:

$$A_D = 0.202 \, m^{0.425} h^{0.725} \qquad (11)$$

in which: A_D is the nude body surface area (DuBois & DuBois, 1916), in m²; M – metabolic rate, in met (1 met = 58.15 W/m²); r – ratio between the volume of released CO_2 and the consumed volume of O_2.; m – mass of human body, in kg; h – height of human body, in m.
The ratio r usually takes the value of 0.83, but that may vary till 1, for a person with a very high metabolic rate (more than 5 met).
Once the volume of O_2 has been calculated, the volume of released CO_2, for normal metabolic rate cases is computed from:

$$V_{CO2} = 0.83 \times V_{O2} \qquad (12)$$

In recent study (Gameiro da Silva, 2009) is presented a software tool for indoor air quality simulation. Typical values of pollutants usually checked in IAQ audits and released by one cigaratte burning are given in Table 10, which summarizes information collected in (Charles et al., 2008; REHVA, 2004).

Type	Pollutant	Unit [mg]
0	1	2
Particle	Particles suspended in air	18
Chemical	Carbon dioxide (CO_2)	160…550
	Carbon monoxide (CO)	60
	Formaldehyde (HCHO)	0.4
	Total volatile organic compunds (VOC)	3.6

Table 10. Typical emission from a smoked cigarette

4. Computation of outside air flow–rate and indoor air quality control

4.1 Mathematical model

Computation of outside air flow–rate in a room can be performed function of:
- number of occupants, keeping CO_2 concentration under the maximum admitted level, according to Romanian Norms (I 5, 1998);
- number of occupants and room surface, according to German Norms (DIN 1946, 1994);
- indoor air quality, according to European Standard CEN 1752, described below.

Ventilation efficiency ε_v is a criterion for energy and fan performances. This is used to evaluate a ventilation system and is defined by following expression:

$$\varepsilon_v = \frac{c_i - c_p}{c_{zl} - c_p} \qquad (13)$$

where: c_i is the contaminants concentration in the exhausted air; c_p – contaminants concentration the supply outside air; c_{zl} – contaminants concentration in the working area.

The value of ε_v depends on the entrance place and the exhaust way of outside air, and on the difference between the outside air temperature t_e and indoor air temperature t_i (Table 11).

The outside air flow–rate L_p, in l/s, can be computed function of IAQ from equation:

$$L_p = 10 \frac{G}{\left(C_i - C_p\right)\varepsilon_v} \qquad (14)$$

where:

$$G = G_{oc} + G_{ob} \qquad (15)$$

in which: G is the contaminants concentration of room air, in olf; C_i – indoor air quality, in dp (Table 12); C_p – outside air quality, in dp (Table 13); G_{oc} – contaminants quantity from the occupants (Table 14); G_{ob} – contaminants quantity from room objects (building elements, furniture, carpets, etc.) having the values in Table 15.

System type	t_e-t_i [°C]	ε_v
0	1	2
up–up	<0	0.9…1.0
	0…2	0.9
	2…5	0.8
	>5	0.4…0.7
up–down	<–5	0.9
	–5…0	0.9…1.0
	>0	1.0
down–up	<0	1.2…1.4
	0…2	0.7…0.9
	>2	0.2…0.7

Table 11. Ventilation efficiency, ε_v

Room category	C_i [dp]	Percent dissatisfied [%]
A	1.0	15
B	1.4	20
C	2.5	30

Table 12. Indoor air quality, C_i

No.	Air source	C, [dp]
1	Mountain, sea	0.05
2	Locality, fresh air	0.1
3	Locality, mean air	0.2
4	Locality, polluted air	0.5

Table 13. Outside air quality, C_p

No.	Contaminants source	G_{oc} [olf/pers]
0	1	2
1	Adults resting, if the percentage of smokers is: 0 % 20 % 40 % 100 %	 1 2 3 6
2	Adults, if metabolic rate is: reduced (3 met) medium (6 met) high (10 met)	 4 10 20
3	Children: children under school age (2.7 met) pupils (1…1.2 met)	 1.2 1.3

Table 14. Contaminants quantity from the occupants, G_{oc}

The outside air flow–rate L_p, in m³/h, can be computed and function of hygienic sanitary conditions follow as:

$$L_p = \frac{P}{\left(c_{i\,max} - c_{p\,max}\right)\varepsilon_v} \tag{16}$$

where: P is the power of the indoor pollutant source, in mg/h; $c_{i\,max}$ – maximum admitted concentration of the most critical contaminant of room air, in mg/m³; $c_{p\,max}$ – maximum admitted concentration of the most critical contaminant of outside air, in mg/m³.

No.	Building destination	G_{ob} [olf/m²]
0	1	2
1	Offices	0.02…0.95
2	Schools	0.12…0.54
3	Kindergarten	0.20…0.74
4	Meeting rooms	0.13…1.32
5	Houses	0.05…0.10

Table 15. Contaminants quantity from room objects, G_{ob}

To determine the time evolution of the contaminants concentration c_i in indoor air two hypotheses are assumed:

- constant pollution in time, where the balance equation within an infinitesimal time interval dτ is:

$$L_p c_p \, d\tau + P \, d\tau - L_p c_i \, d\tau = V \, dc_i \qquad (17)$$

where V is the room volume.

Integrating the equation (17), with the initial condition $c_i = c_p$, for $\tau = 0$, we obtain:

$$c_i = c_p + \frac{P}{L_p}\left(1 - e^{-n\tau}\right) \qquad (18)$$

where n is the air exchange rate.

- instantaneous pollution at moment $\tau = 0$; consequently, the contaminant initial concentration is given by the equation:

$$c_o = \frac{P}{V} \qquad (19)$$

The balance equation for an infinitesimal time interval dτ is:

$$L_p c_p d\tau - L_p c_i d\tau = V dc_i \qquad (20)$$

Integrating equation (20) with the initial condition $c_i = c_o$, for $\tau = 0$, is obtained following expression:

$$c_i = c_p - c_o e^{-n\tau} \qquad (21)$$

4.2 Computer program COMFORT 2.0

The computer program COMFORT 2.0 allows to determine the outside air flow–rate and air exchange rate for the ventilation of a room and the variation in time of contaminants concentration of room air both on the basis of the mathematical model described above and on some national norms (I5, DIN 1946), as well as to analyse the influence of different parameters on these characteristics.

- The inputs data are: geometrical characteristics of the room, in m; number of occupants; activity type; room category; outside air quality, in dp; ventilation system type; ventilation efficiency; smokers existence in room.
- The results of program are the following: outside air flow–rate; air exchange rate; polluting substances of indoor air; time variation of CO_2 concentration from room air.

4.3 Numerical application

It is considered an A category room with geometrical dimensions 10×10×2.7 m, where there are 11 persons having an intellectual activity, and smoking is forbidden. Production rate of CO_2 for the occupants is of 15 l/(h·pers) and CO_2 concentration in outdoor air has the value of 350 ppm. The floor finishing is made of parquet floor or PVC.

A comparative study for computation of outside air flow–rate and indoor air quality control according to the European Standard CEN 1752 and national norm I5 and DIN 1946 is performed using the computer program COMFORT 2.0.

The values obtained for the outside air flow–rate and the air exchange rate are reported in Table 16. In Fig. 10 is represented the variation of outside air flow–rate function of the indoor and outdoor air quality. The Fig. 11 shows the time variation of CO_2 concentration in room air.

Computational norm	Method	L_p [m³/h]	n [h⁻¹]
0	1	2	3
CEN 1752	Air quality – parquet floor	2306	8.54
CEN 1752	Air quality – PVC floor	8494	31.46
I5	Number of occupants	330	1.22
DIN 1946	Surface of the room	600	2.22
DIN 1946	Number of occupants	660	2.44

Table 13. Outside air flow–rate L_p and air exchange rate, n

From Table 13 it is to be seen that the outside air flow–rate computed according to norm I5 has the smallest value, leading to the highest values of CO_2 concentration of room air. This CO_2 concentration determines a state of strong tiredness and head aches for the occupants.
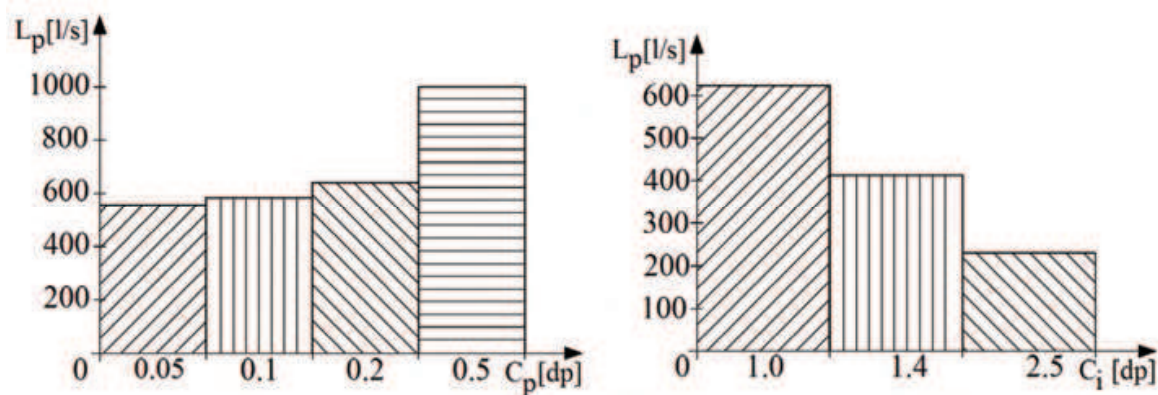

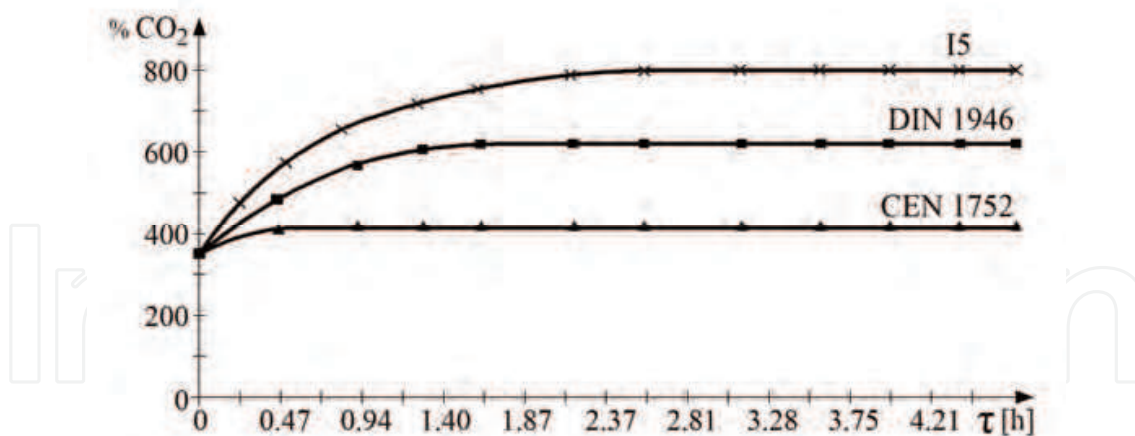Fig. 10. Variation of outside air flow–rate function of outdoor and indoor air quality

Fig. 11. Time variation of CO_2 concentration

5. Influence of carbon dioxide on human performance and productivity

Interdisciplinary efforts in the last decade of many researches converge to the necesity to find and develop the "resources" for achieving optimal environment conditions.

Although there are many weaknesses and divergents in the knowledge of environment effects on productivity and health activities, one thing is universally recognized, namely the obligativity of keeping the comfort parameters: temperature, humidity, sound level, indoor air quality, air velocity, etc. That is why VAC specialists must convince that positive effects of air–conditioning are much larger and important than negative ones.

Temperature influence is decisive both in terms of comfort and productivity. Another cause that causes discomfort associated with interior temperatures beyond the comfort limit is the dioxide carbon concentration. Manifestation of this discomfort is characteristic to densely populated rooms: theatrical and meeting rooms, public buildings (bank lobbies, counter rooms etc.), and especially to rooms from education buildings. Classrooms are usually densely populated and the length of stay is at least four hours.

It is considered that air is contaminated when the content of carbon dioxide ranges between 0.1 and 0.15%, which corresponds for a concentration of 1000 ppm and 1500 ppm. Becomes harmful to the body starting from a concentration of 2.5%. Normal air contents corbon dioxide in ranges of 0.032% and 0.035%, reaching 0.04% in urban centers.

Measurements of carbon dioxide concentration in a natural ventilated classroom through leaks had shown that in 10…15 minutes the concentration reaches values over 1000 ppm, and after 45 minutes values to 2500 ppm.

The sedentary human body approximatively releases 15 l/h of carbon dioxide. For not exceeding the maximum concentration it is has to be assured a fresh airflow rate L_p for each person:

$$L_p = \frac{Q}{c_{i\max} - c_{p\max}} = \frac{15000}{1500 - 400} = 12.5 \, \text{m}^3/(\text{h} \cdot \text{pers}) \tag{22}$$

in which: Q is the CO_2 emission of human body, in cm³/h; $c_{i\max}$ – maximum admitted CO_2 concentration for indoor air, in ppm; $c_{p\max}$ – maximum admitted CO_2 concentration for outside (fresh) air, in ppm.

This airflow rate can not be assured with a natural ventilation through leaks. For rooms with these destinations, the simple windows opening (intense natural ventilation) can not satisfy, because in winter time only in break time will partly solve the reduction of carbon dioxide. In summer time, even if the windows can be opened, comes out the growth temperature and noise intesity inconvenience.

In Fig. 12 is represented in a nomogram the outside air flow–rate depending by maximum admitted CO_2 concentration.
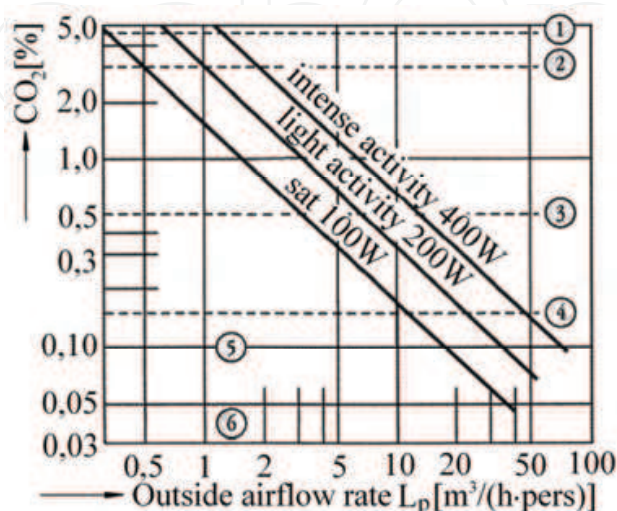
1-expired air; 2-underground rooms; 3-industrie maximum concentration;
4-offices maximum concentration; 5- Pettenkofer's number; 6-outdoor air

Fig. 12. Outside airflow rate depending by admitted CO_2 concentration

Taking into account the overlapping of contaminant, an insanitary environment, correlated with a high temperature reduces even more the human productivity.

Even if only in these two aspects (temperature and CO_2 concentration) the VAC specialists have the duty to convince over the need to assure these two parameters by using air–conditioning systems.

6. Conclusions

Computer model developed offer the possibility of detailed analyses on olfactory comfort in enclosed spaces, being of a real use for the design and research activity and in the environmental studies.

Results show that the microclimate in rooms influence not only the comfort but also the health of the occupants, and preserving the comfort parameters at the optimal values is the mission of the engineer for designing and operating of HVAC systems.

The indoor environment is influenced by the way the equipments are designed, produced and operated. That is why it is necessary to decide upon the equipments that are able to give the proper microclimate conditions, permanently observing the elimination of all secondary effects (professional illnesses) that have negative influences upon human health. It is possible at the design stage of HVAC systems and buildings to take into account most of the comfort criteria.

In addressing the relationship between building energy efficiency and IAQ, one needs to consider more than just outdoor air ventilation rates as the sole link between these critical

goals. One challenge is the use of ventilation for IAQ control under conditions of poor outdoor air quality. While increased ventilation can help reduce occupant symptoms (Seppänen & Fisk, 1999), that relationship assumes that the outdoor air is clean. Ventilating with polluted outdoor air will degrade IAQ, at least in terms of contaminants that are not generated indoors.

High performance buildings should provide better IAQ conditions than exist in current buildings, and many strategies will not conflict with energy efficiency. As more experience and information is generated, the goal of truly high performance, sustainable and healthy buildings will be more fully realized in practice.

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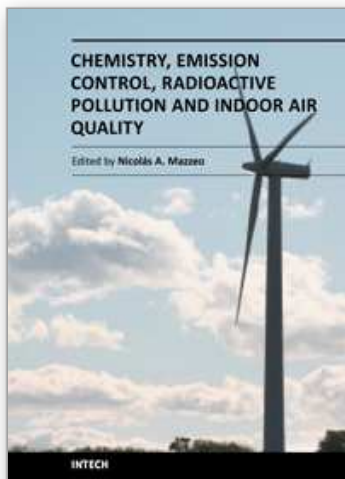
Chemistry, Emission Control, Radioactive Pollution and Indoor Air Quality

Edited by Dr. Nicolas Mazzeo

The atmosphere may be our most precious resource. Accordingly, the balance between its use and protection is a high priority for our civilization. While many of us would consider air pollution to be an issue that the modern world has resolved to a greater extent, it still appears to have considerable influence on the global environment. In many countries with ambitious economic growth targets the acceptable levels of air pollution have been transgressed. Serious respiratory disease related problems have been identified with both indoor and outdoor pollution throughout the world. The 25 chapters of this book deal with several air pollution issues grouped into the following sections: a) air pollution chemistry; b) air pollutant emission control; c) radioactive pollution and d) indoor air quality.

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