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INDOOR ENVIRONMENTAL QUALITY. RISK ASSESSMENT CONCERNING OCCUPANTS COMFORT AND HEALTH

BY

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Abstract. Indoor Environmental Quality has become lately one very important requirement that must be analysed for both new buildings, for buildings that are in the design phase and for existing buildings, on the entire period of exploitation. Users protection against environment hazards is reflected in the need for people to make theres activity in a healthy environment, comfortable and, not least, fun. This study is intended to be an analysis of the main harmful factors affecting indoor environmental quality in public buildings with high occupancy, enumerating the main theoretical concepts that affect the health of building occupants. To create a pleasant indoor environment it must be analysed a number of factors that depend on user requirements, the constructive possibilities, as well as restrictions imposed by technical standards that refer to this chapter.

Key words: Indoor Environmental Quality; public buildings; indoor comfort.

1. Introduction

Technical regulations stipulate certain thresholds that should not be exceeded. Based on these thresholds, wishes users can enroll in a wide more or

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less restricted range, which can be determined by activity, by average age group of those who operate in that environment, and type of interaction with the external environment through the quality of outdoor envelope. All these criteria are the basis of the research on risk assessment relative to indoor environmental quality.

Integrated risk assessment methodology for environmental quality aims to establish clear methods of assessment, verification and validation of models by management matrix effects of misuse of the buildings, identifying factors that influence environmental quality and the possibility of improving their effects on building and its occupants. This goal can be achieved by applying appropriate building solutions since the design and suitability for use in a proper building for the entire period of its existence, ensuring optimal conditions defining the notion of comfort by limiting factors pollutants spaces with crowds of people, through continuous monitoring of indoor environmental quality and by observing the behavior in time of construction elements potentially affected by its degradation, and the impact of building elements on indoor environmental quality degradation.

2. Requirements and Performance Criteria on Indoor Environmental Quality in Public Buildings

Defining requirements and performance criteria is the first step in identifying harmful factors to indoor environmental quality, in order to improve their performance towards the establishing of buildings, sustainable and energy efficient. All of these demands should provide a scientificaly framework to determine constructive solutions and benchmarks performance of the evolution of environmental factors, considering the destination of the building and its user requirements.

User requirements represent all desires and expectations regarding indoor environmental quality, formulated independently of external environmental conditions and building constructive technical solutions.

In public buildings, user requirements are physiological (thermal comfort, acoustic and visual harmful factors protection, observance of hygiene conditions, etc.), psychosocial (in the sense of interpersonal contact and contact with the environment) and efficiency (especially energy efficiency, achieving maximum productivity, the possibility to rest, and so on). Such demands are not quantifiable, but strictly reflect the desires and expectations of building users regarding the indoor space.

Performance requirements are expressed scientifically according to environmental conditions that act on buildings, their response to these factors, the interaction between the indoor environment and the human body in order to meet user requirements.

International Standard Organisation (ISO) wrote a list of 14 performance requirements for civil buildings: stability and durability, fire safety, safety of use, tightness, hygrothermal comfort, atmospheric ambience, acoustic comfort, touch comfort, dynamic anthropological comfort, hygiene, space usage, sustainability, visual comfort and efficiency.

Performance criteria represents the implementation of performance requirements as components of the building or for the whole building, to satisfy the performance requirements by identifying physical measures that refers to the assessment of built space through calculations, experiments and measurements at the site. Indoor environmental quality is influenced and defined by the general notion of comfort (thermal, acoustic and visual), as well as indoor air composition in terms of sources of pollution, the risk of condensation and ventilation rate.

2.1. Indoor Comfort

The concept of comfort represents the state of a building occupant satisfaction is achieved in relation to the environment.

Early research in this area dates from the first century AD, the notion being enunciated by Vitruvius Pollio in the ten famous books about architecture (*De architectura*), a treaty of Greek and Roman architecture dedicated to Emperor Augustus. In his work Vitruvius established performance criteria starting from how to choose the proper site of a city or a building, to compliance criteria of space, lighting, ventilation, acoustics and orientation, solutions to preventing excessive moisture or mutual shading of buildings, and to economic criteria for construction of a building. Considering these criteria enunciated since antiquity, now has been laid the groundwork to scientifically developing criteria of study the environmental effects on buildings and their users.

Interior comfort is made up of several components, studying the interaction between them, and how they affect the building and people. Therefore, interior comfort components are

a) Thermal comfort relative to temperature, humidity, air velocity.

b) Acoustic comfort: noise from outside, inside, vibrations, and so on.

c) Visual comfort and lighting quality: vision, lighting, indicator of brightness, reflection, and more.

d) The quality of indoor air pollution, odor, fresh air supply, and more.

A. *Thermal comfort* is one of the most important components of interior comfort, based on a number of criteria and levels of performance established over time in order to obtain the users of the building to a state of satisfaction with the environment (definition on ASHRAE – American Society of Heating, Refrigeration and Air-Conditioning Engineers). Interior comfort also depends

on the physical, psychological and sociological profile of each individual and is directly influenced by indoor and surface delimiters of the room temperature, humidity, air velocity and the air conditioning operation.

Indoor air temperature depends on the type of rooms, a comfortable level for public buildings such as hospitals, nurseries, kindergartens being of 18°…22°C, and for theaters, cinemas, schools, clubs, social and administrative buildings being of 16°…20°C.

Vertical temperature difference measured 0.1 m from the floor and to the head (1.80 m and 1.10 m standing for a sitting position) must not exceed 3.0°C ($\Delta T \leq$ 3.0°C).

Perimeter surface temperature also affects indoor comfort due to radiation heat exchange between the human body and surfaces of walls, floor and ceiling.

It is considered that to achieve an acceptable level of floor surface thermal comfort if the minimum temperature ($T_{p,\min}$) is of +18°C and the maximum ($T_{p,\max}$) is of +26°C. Also the moving average air speed must not exceed 0.15 m/s, and indoor air humidity must be situated between 30% and 70%.

Temperature difference between the inside surfaces of the closing elements and room air must not exceed the values indicated in Table 1.

Table 1

The destination of building	$\Delta T_{i\,\max}$, [°C]		
	Walls	Ceilings	Floors
Hospitals, clinics, nurseries, kindergartens, schools, colleges	4.0	3.0	2.0
Social and cultural buildings	4.5	3.5	2.5
Social buildings with high moisture regime	6.0	4.5	3.0

For determining how temperature affects the surrounding areas as comfort the average radiant temperature is calculated according to the relation

$$T_{rm} = \frac{\sum_j T_j A_j}{\sum_j A_j}, \tag{1}$$

where: T_{rm} is the average radiant temperature, [ºC]; T_j – surrounding surface temperature, j, [ºC]; A_j – area of the surrounding surface, j, [m^2].

Depending on the average radiant temperature (T_{rm}), can be calculated the resulting temperature of rooms representing the arithmetic average between indoor air temperature, T_i, and medium radiant temperature, T_{rm}

$$T_r = \frac{T_i + T_{rm}}{2}, \tag{2}$$

where: T_r is the resulting temperature, [ºC]; T_i – indoor air temperature, [ºC]; T_{rm} – the average radiant temperature, [ºC].

Indoor ambient temperature should be inversely proportional to temperature of the perimetral elements.

Another possibility for assessing mathematical calculation of thermal comfort is assumed by the *global thermal indicator* (*B*) proposed by Van Zuilen:

$$B = C + 0.25(T_i + T_{rm}) + 0.1X - 0.1(37.8 - T_i)\sqrt{v}\ , \tag{3}$$

where: *B* is the overall heat indicator; *C* – constant equal to 9.2 (winter) and 10.6 (summer); T_i – indoor air temperature, [ºC]; T_{rm} – the average radiant temperature, [ºC]; *X* – water content in indoor air, [g vapour/kg dry air]; *v* – the movement's speed of air, [m/s].

Depending on the the result, if the value of overall heat index is less than –1 or greater than 1, the feeling of discomfort is too cold or too hot, respectively. For values between –1 and 1, is considered a comfortable environment. The indoor thermal comfort is also influenced by humidity and air movement speed.

The recent approaches of the comfort parameters introduced new assessment that analyses all the features of indoor environment and the human components that carry out activity in the environment. Have been introduced indicators such as *Predicted Mean Vote* (PMV) and *Predicted Percentage of Dissatisfied* (PPD).

PMV global indicator is based on the principle which considers that the state of comfort is achieved when the body temperature is maintained constant so that the sum of the amount of heat produced by the body as a result of metabolic processes and the amount of heat received from the environment to be approximately equal to the amount of body heat from the environment.

This difference in temperature from the absolute value is the *residual heat*

$$\Delta Q = Q_{\text{internal}} + Q_{\text{received}} - Q_{\text{yielded}} \neq 0. \tag{4}$$

To calculate PMV is applied the relationship proposed by P.O. Fanger

$$\text{PMV} = \left(0.303\text{e}^{-0.036M} + 0.028\right)\Delta Q\ , \tag{5}$$

where: PMV is the predicted mean vote; *M* – energetic metabolism, [W/m^2]; ΔQ – wasted heat, [ºC].

PPD represents the average number of people dissatisfied with the general conditions in an inner space. Considering this variable, the estimated average option is calculated as

$$\mathrm{PPD} = 100 - 95\mathrm{e}^{-\left(0.03353\mathrm{PMV}^4 + 0.2179\mathrm{PMV}^2\right)}. \quad (6)$$

Recent research has developed the concept of *adaptive comfort*, concept studying how the human body adapts to indoor environmental conditions, considering the acceptable limits for each individual. User reactions to environmental factors are influenced by the physical state of each individual, the activity performed, or the way it is dressed.On this approach is based the principle that, if there is a change that causes discomfort to indoor environment, man reacts in order to restore comfort. This is done on the basis of statistical data on the combination of temperature, humidity, air quality and its velocity analysed in order to identify the best choice for comfort.

B. *The acoustic comfort* is achieved in situations where noise levels caused by human activities is suitable for relaxation, health and human communication. Noise is messy overlapping of sounds with different frequencies and intensities, acoustic phenomenon that produces a hearing sensation considered annoying or unpleasant (Table 2). Unit of measure intensity of sound is the decibel (dB). The upper limit is 80 dB sound. Sounds of 130 dB create a sensation of pain, and of 150 dB are intolerable.

Table 2

Psycho-physiological disorders	Noise level, [dB (A)]
Threshold of hearing	0
Quiet area	20…30
Inconvenience to the rest and physiological effects	40…50
Intellectual working capacity decrease	50…60
Decreased routine work capacity	60…70
Failure sleep and intellectual work	70…80
Unable to work, psychophysiological disorders	80…90, >90

Noise acts on the nervous system and can cause rapid heart rate and breathing, increased blood pressure, inhibition of peristalsis and gastric secretion, disturbances in thyroid gland release hormones and adrenal glands. Also, acoustic discomfort can cause fatigue, headaches, insomnia, irritability, changes in behavior and attitude, neurosis, psihastenie, hypertension, gastritis and gastric and duodenal ulcers, colitis, diabetes, hyperthyroidism.

The effects of noise are classified as follows:

a) Physiological effects as tiredness.

b) Pathological effects: hearing loss, deafness, hearing injuries.

Classification of sound sources is made according to the following criteria:

a) Depending on *location*, noise may come from internal sources or external sources.

b) Depending on the *direction* of radiation may come from sources unidirectional (or directional), which occurs after radiation preferential direction determined by the directionality factor (*Q*) or untargeted sources (or omnidirectional), in which radiation occurs uniformly in all directions.

c) Depending on *the mode of production* of noise can be sources of noise producing mechanical principles (by collision or friction), the action aerodynamics (air passing through holes), by electromagnetic action (noise consists of a given frequency sound grid (50 Hz) and its harmonics), or thermal action (low frequency noise (below 100 Hz) when some facility has inadequate circulation).

d) Depending on the *time of emission* the noise can be produced by continuous or intermittent sources.

C. *Visual comfort* is ensured by a suitable light activity, without possibility of blindness contrasts pronounced or in a continuous mode with adjusted colour temperature lighting. He is reached as far as the quantitative and qualitative aspects of light indoor environment provide the necessary functional and aesthetical determined by activity.

Interior lighting can be natural or artificial. Natural light is a constant light source as distribution and range, improving health and also having positive effects on concentration. Windows provide visual communication with outer space. Thus, a study performed by Markus on 400 observers from several office buildings, show that 88% of them prefer a panoramic view of a landscape or city and only 12% are satisfied with the view of the sky or neighboring buildings. Perspectives to the open spaces produce positive responses, reducing stress, anxiety, increasing attention and improving the mood. Natural light has a beneficial aspect of the body, physiologically and psychologically.

According to Dr. Ott (Ott Biolight Systems, Inc. 1997), the body uses light as a nutrient for metabolic processes, stimulating the biological functions and neuro-sensory. On a cloudy day or in poor lighting conditions, inability to perceive colours of light can affect mood and energy level. Users of natural light in office buildings recorded a relative improvement of health, reduce stress and absenteeism, increase productivity, mental performance and desire to work, workplace satisfaction, commitment and motivation. The sun is the primary source of vitamin D, increased the intake of vitamin D and stimulating calcium metabolism.

3. Risk Assessment on Occupant Health and Comfort Relative to Indoor Environmental Quality

Indoor environmental quality affects both human health, and sustainable buildings.

The human body is influenced by environmental action on the nervous system, immune system and endocrine system, causing disorders or accentuating existing diseases, such as

1. Diseases/disorders induced by external factors that affect the nervous system and the endocrine system, but can also affect immune status such as

a) related to the human senses (smell, noise, heat, cold, etc.);

b) systemic effects (tiredness, poor concentration, etc.);

c) psychological effects (depression, anxiety, etc.).

2. Diseases / disorders that are caused by external harmful effects and affects the immune system and the endocrine system, but can also affect the nervous system status, such as

a) irritation, allergic effects and hyper-reactive (*e.g.* mucous membrane of the respiratory tract and skin, asthma, skin rashes caused by allergic reactions to certain pollutants, sunburn, hearing loss, vision deterioration caused by light too bright, etc.);

b) infectious diseases;

c) disease chronic toxic effects that increase or occur gradually (cancer).

3. Psychological or mental effects that are difficult to identify, but may cause a range of different diseases and disorders, mostly indirectly related to environmental factors, but which are affected by psycho-social factors and personal.

3.1. General Elements on Risk Assessment and Risk Management

Specialized literature concerning the concept of *risk* is very different, leading to the hypothesis that they are different approaches for the same facts, according to the applicability domain and the factors affecting risk.

To get a unitary view over the risk, it is necessary to identify rigorous common elements behind all these definitions, it being uncertainty about the possibility of certain events and losses resulting from these events. The term of doubt is present in all definitions of risk, because validation will result in permanent being by the existence of two distinct possible outcomes. It is considered that an event is not affected by risk, if known with certainty, that no matter the circumstances, there will be a loss. Regardless of the study, the uncertainty can not be eliminated, being defined even as a risk factor.

Risk represents both a numeric value (possibility of unwanted event, hazard, size consequences of its occurrence or the product of two elements), and

an attitude of scientific evaluation, prevention events or reduce their consequences. Risk is defined as an element always appears uncertain but possible events in the technical, human, social, political, reflecting variations in the distribution of possible outcomes, the probability of subjective and objective values, with possible damaging and irreversible effects.

Risk management is defined as an uncertain event management in order to achieve success, all having distinct methods and means by which risk is managed to achieve the objectives described in the technical events, social, human and political analysed, with uncertainty as the major factors risk. Risk management uses three basic components: risk assessment, response planning and monitoring risk factors and risk control. The risk management process is applied systematic to policies management, procedures and practices of communication, establishing the context, identifying, analysing, evaluating, treating, monitoring and reviewing existing or potential risks.

Integrated concept of "healthy building" - "occupant health" can exist only in terms of achieving a healthy and comfortable indoor environment for its occupants. Indoor environmental quality represents a determining factor in terms of the health of the occupants of a building being determined by the composition of air (pollutant chemical, physical, biological or otherwise) and comfort (acoustic, thermal, visual).

3.2. Risk Assessment Depending on Indoor Environmental Quality

Indoor environmental assessment methods are mathematical methods for determining the conditions under which environmental factors are influencing its quality depending on measurable components.

Therefore, by applying mathematical formulas can determine *the degree of satisfaction of a demanding performance* and *the weight of demanding performance*.

Satisfaction level of performance demanding represents the way that satisfy any requirement of performance, *i*, in relationship between the designed and standardized criteria

$$p_i = \frac{\text{performance level achieved (according to project)}}{\text{required performance level}}. \tag{7}$$

If $p_i = 1$, it is considered that the requirement *i* is respected. If $p_i < 1$, the performance requirement is not assured, and if $p_i > 1$ requirement is exceeded favourable.

Each demanding performance is conventionally attributed to a coefficient, α_i, subunitary that determines its importance, considering that the sum of these coefficients must be equal to 1

$$\sum_i \alpha_i = 1. \tag{8}$$

Finally, building performance is appreciated by grade (N) assigned by relationship

$$N = \sum_i \alpha_i p_i. \tag{9}$$

Methods for monitoring indoor environmental quality are within the following three categories:

a) Methods of disposal of sources.

b) Methods of dilution with less contaminated air ventilation.

c) Cleaning extraction methods by filtration.

The main ways to maintain a level of comfort acceptable are the following:

1. Eliminate biological agents, toxic or hazardous substances, the bioaerosols, asbestos, smoke-free.

2. The use of less hazardous materials, furniture or building materials with low emissions, water based paints. Storage possible materials and emissions in naturally ventilated rooms specially equipped.

3. Proper ventilation spaces, especially those with clusters of people or where hazardous substances are stored.

4. Providing since the design phase of some systems to protect building users for each component of interior comfort.

5. Maintaining a high level of cleanliness, use of cleaning materials without air emissions, and cleaning and decontamination facilities, especially HVAC.

6. General maintenance and renovation of their spaces before installation in construction elements of mold or micro-organisms. Training of staff responsible for maintenance and cleaning in terms of proper use of the spaces.

4. Conclusions

Indoor Environmental Quality control is difficult, considering that in the air can be over 900 different chemicals, particles and biological materials with potentially harmful effects.

The risk assessment of environmental pollution indoor public buildings must be made responsibly since the time of design. Buildings may have pollutants whose weight varies depending on their activity. Including them in acceptable range is a goal that must be achieved for maintaining a healthy environment and a friendly use work space.

REFERENCES

Bluyssen P.M., *The Indoor Environment Handbook. How to Make Buildings Healthy and Comfortable.* Earthscan in the UK and USA in association with the International Institute for Environment and Development, London, UK, 2009.

Burroughs H.E., Hansen S.J., *Managing Indoor Air Quality*. Fifth Ed., The Fairmont Press, Inc., Lilburn, USA, 2011.

Edwards L., Torcellini P., *A Literature Review of the Effects of Natural Light on Building Occupants.* National Renew. Ener. Labor., Golden, USA, 2002.

Vitruvius Pollio, *The Ten Books on Architecture.* Morris Hicky Morgan. Cambridge: Harvard Univ. Press. London: Humphrey Milford, UK, 1914.

CALITATEA MEDIULUI INTERIOR. EVALUAREA RISCURILOR PRIVIND CONFORTUL ŞI SĂNĂTATEA OCUPANȚILOR CLĂDIRILOR

(Rezumat)

Calitatea mediului interior a devenit în ultima vreme o exigență foarte importantă care trebuie analizată atât pentru clădirile noi, aflate în faza de proiectare, cât şi pentru clădirile existente, pe întreaga perioadă de exploatare a acestora. Protecția utilizatorilor unei clădiri împotriva factorilor dăunători ai mediului se reflectă în necesitatea oamenilor de a-şi desfăşura activitatea într-un mediu sănătos, confortabil şi, nu în ultimul rând, plăcut.

Se efectuează o analiză a principalilor factori dăunători ce afectează calitatea mediului interior în clădirile publice cu grad ridicat de ocupare, enunțând principalele noțiuni teoretice care stau la baza evaluării riscurilor privind sănătatea ocupanților clădirilor.

Pentru a crea un mediu interior agreabil trebuie analizați o serie de factori care depind atât de cerințele utilizatorilor, de posibilitățile constructive, cât şi de restricțiile impuse de normele tehnice ce fac referire la acest capitol.