

## **A DISCUSSION ON INDOOR AIR POLLUTION EXPOSURE PROCESS AND RESULTANT PROBLEMS**

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### **ABSTRACT**

The production and usage processes of buildings correspond to a highly complex interrelation among many experts of professionals and users in which the space is produced according to certain approaches to become one of the essential factors to affect the users' life. In this context, indoor air and its pollution are in the most critical aspects of spaces with a very high potential to create a wide range of comfort, many health and related economic problems. In order to structure a better cause and effect relation between spaces and users in the context of enhanced indoor air quality, among other aspects particularly the exposure phenomenon: process between encountering indoor air pollution and the formation of problems should be investigated in regard to underlying mechanisms. Existence of harmful substances with diverse properties for a definite period of time causes indoor air pollution and certain parts or the entire indoor environment of a building can constitute an exposure environment as the pollution meets with building users. This process can occur via respiration, olfaction or contact to skin and eyes where pollutants, their metabolites or reaction products compose biomarkers. The number of biomarkers, determined as dose, is directly related with the occurrence of a vast number of health / comfort conditions ranging from odour intolerance, headache or irritation to respiratory infections, heart diseases and cancers. Although there are many different approaches for classification of these outcomes, the problems are categorized under three groups in this research: cancers, non-cancerous diseases and sick building syndrome. It is believed that the study is beneficial to present an alternative qualitative point of view different from the common quantitative tendencies in the field of indoor air quality studies and the resultant classification can be useful for a more practical and accurate assessment process which is appreciated to be vital to sustain existing building stock and transform the problematic spaces in better and healthy living environments by raising

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awareness for particularly important but mostly ignored or misplaced problem groups.

**Keywords:** Indoor air pollution, Exposure process, Health problems, Systems thinking, Evaluation process

## 1. INTRODUCTION

The production and usage processes of buildings correspond to a highly complex interrelation among many professionals and users creating a vicious and prevalent circle of interactivity during which a living space is produced impulsively mostly in line with certain popularized approaches to turn out to be one of essential factors affecting its users' life adversely on many levels. In this context, pollution of indoor air is one of the most critical aspects of spaces with a very high potential to create a wide range of comfort, many health (Balanlı & Öztürk, 1995) and related economic problems (Commissions of the European Communities [CEC], 1991). Each year in the world, nearly 4 million people lose their lives due to indoor air pollution correlated illnesses such as pneumonia, stroke, ischemic heart disease and lung cancer (World Health Organization [WHO], 2018). A design process overlooking its possible consequences or a usage period negligent to necessary assessment activities are within significant indifference to feed this vitiation and elevate an essential requirement for a different thinking system to break the circle. In order to establish a potent cause – effect relation between indoor spaces and their users to serve not only for the assessment but also to unveil important design principles consequently, producing an accurate decision about the qualitative and quantitative properties of indoor air pollution in terms of human health by using a practical method constitutes one of the primal necessities (Darçin, 2014). Stated deficiency of knowledge systematization about exposure to indoor air pollution (Darçin & Balanlı, 2018a) is among the missing essential inputs to construct and operate this method effectively.

The aim of this research is to examine the progress mechanism of exposure between encountering indoor air pollution and the formation of problems and through interpretation of scientific information to procreate a new categorization for its possible results. The scope of the research, limited with the stated aim, is believed to present an alternative frame to common quantitative tendency in the field of indoor air quality studies and categorical systematization as the outcome of this research can be useful for a more practical assessment process.

## 2. INDOOR AIR POLLUTION

Disparity in the contents of air or existence of harmful materials in indoor environment (Vural, 2004) for a definite period of time at certain concentration

levels towards affecting the health adversely creates indoor air pollution. Many substances with diverse properties – more than 60 thousand different types and two million mixtures (Ferro & Hildemann, 2007) – are considered as indoor air pollutants. It can be observed that specific classifications have been structured according to physical (National Research Council [NRC], 1991), chemical properties, sources, effects or origins (Vural, 2004) in scientific literature. Most common pollutants are given under groups according to their physical properties in Table 1.

**Table 1. Indoor Air Pollutant Groups (Darçın & Balanlı, 2018b)**

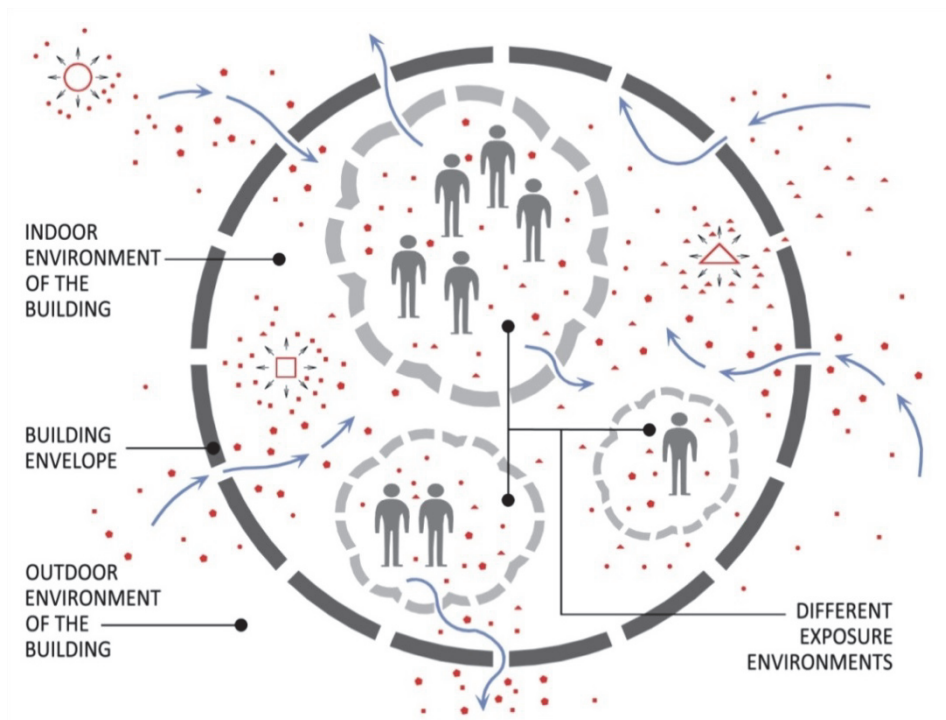
<b>gas / vapor</b>	carbon monoxide, carbon dioxide, nitrogen monoxide, nitrogen dioxide, sulfur dioxide, radon, ozone, mercury, volatile organic compounds, ...	
<b>particulate matter</b>	fibers	asbestos, plant fibers, stone wool, glass wool, ...
	metals	lead, ...
	biological pollutants	viruses, bacteria, mold, pollens, arthropods, skin residues, ...
<b>some pollutant groups</b>	different types of smoke, pesticides, ...	

Pollutants can be emitted from various sources in the form of objects (i.e. building products, living entities, etc.) or activities (i.e. cooking, vacuuming, etc.). Location of sources and emission properties such as direction, rate, duration and frequency are the primal factors that cause air pollution which can occur in indoor environment through emissions directly from indoor sources or due to transportation from outdoor environment via air movements, humans or pets (Darçın & Balanlı, 2015). The quantity of pollutants emitted from a source in unit time (Koontz, Evans & Wilkes, 1998), unit activity or unit area (CEC, 1992) determines the rate of emission which may be long or short, continuous or intermittent (Kephelopoulos, Kositinen & Kotzias, 2006), may repeat frequently with short breaks or rarely with long intervals (Koontz, Evans & Wilkes, 1998). Pollutants can be emitted towards one or more directions (Patrick, 1999).

Because almost always many pollutants are present in a group forming a mixture in indoor air, there is a definite possibility for physical or chemical interactivities amongst different types (Weschler & Shields, 1997). Physical activity is determined with aggregation of different pollutants to form clusters in indoor air (Kephelopoulos, Kositinen & Kotzias, 2006) and chemical reactions are specified as oxidation or photochemical reactions (Jantunen, 2000) in which the concentration levels of pollutants change or new types emerge and reach to a certain amount.

The other essential group of determinants comprises the aspects of closed spaces as volume (Repache, 2007), geometric features (Chen & Glicksman, 2001), interior organization (Spengler, Chen & Dilwali), movement of air (Demokritou, 2001) and certain interactions between pollutants and indoor surfaces (Kephelopoulou, Kositinen & Kotzias, 2006) due to affecting both the qualitative and quantitative properties of pollutants, users and their co-presence.

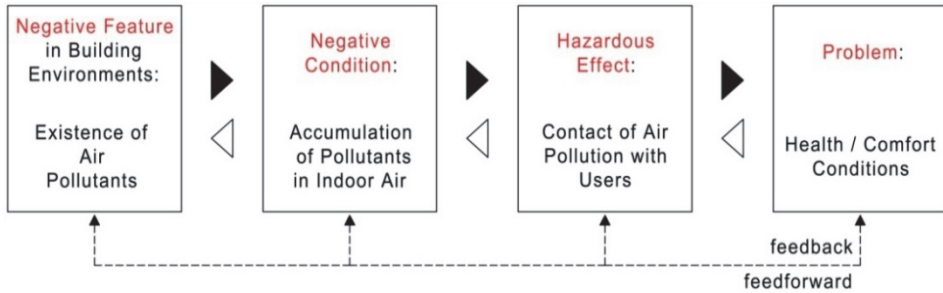
Certain parts or an entire closed space or building itself can constitute an environment of exposure as different types of pollutants at certain concentration levels meet with building users for a significant period of time (Figure 1).



**Figure 1. Exposure Environments in a Building**

### 3. EXPOSURE TO INDOOR AIR POLLUTION

The occurrence of problems through exposure to indoor air pollution can be determined by following an examination and relations model (Figure 2) in which the existence of a negative feature at the indoor or outdoor environments may cause a negative condition to trigger a hazardous effect and ultimately reveal a certain probability for a problem (Balanlı, 2011).

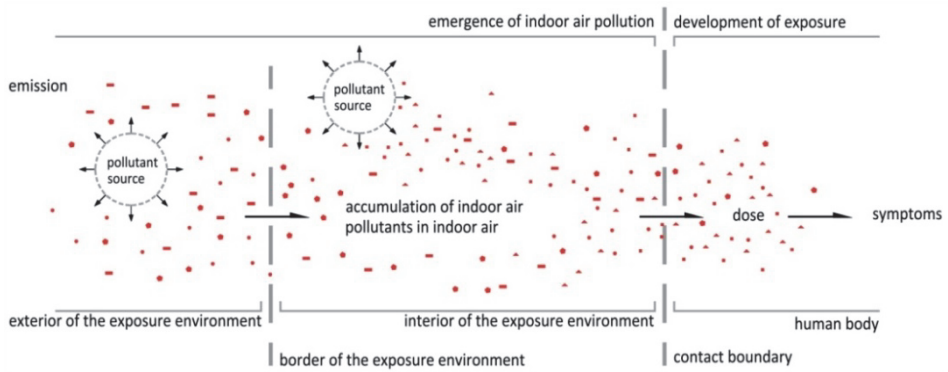


**Figure 2. Indoor Spaces – Health Relationship**  
(adapted from Balanlı & Öztürk, 2004)

Based on the scientific definition (Zartarian, Ott & Duan, 2007), exposure occur as the pollutants, which can be considered as agents, reach to and touch building users - here represent the targets - on a contact boundary to create a change (Environmental Protection Agency [EPA], 1992). Contact boundary forms a hypothetical membrane on which the agent touches and / or passes through into the internal structure of the target (EPA, 2012). For indoor air pollutants, this process can occur via respiration, olfaction or contact to skin and eye surfaces where the inner surfaces of the respiratory system and outer surfaces of the body can be regarded as the contact boundary (EPA, 1992).

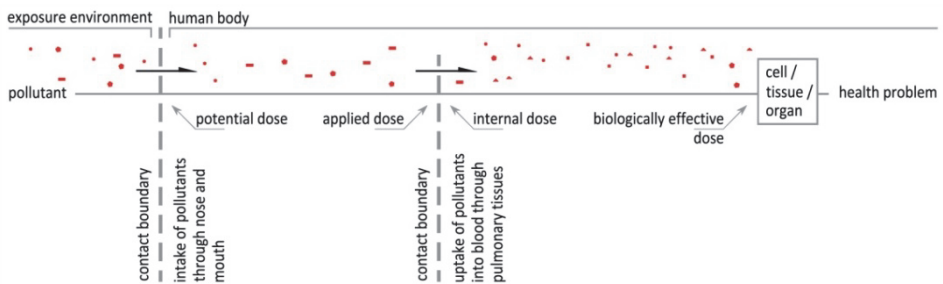
### 3.1. Biomarkers and Dose

Although exposure can start with pollutants to only touch to the skin, eyes, olfactory receptors or inner surfaces of the respiratory system (Darçın, 2014), in most cases, it happens as they pass these borders into blood and are transported to other body systems (Mølhave, 1998). Pollutants, their metabolites or new substances produced by interactivity between pollutants and various body parts compose biomarkers (Wallace, 2007) which can be found inside tissues, cells or fluids throughout the body (Anderson & Patrick, 1999). The number of biomarkers, determined as dose, is directly related with the occurrence of symptoms of health / comfort problems (Duan, Dobbs & Ott, 1990), this approach of examining exposure at interface of human body – indoor environment (Georgopoulos & Lioy, 1994), is depicted in Figure 3. Yet it is not possible to state neither every exposure results in dose nor development of dose always causes a health problem (NRC, 1991).

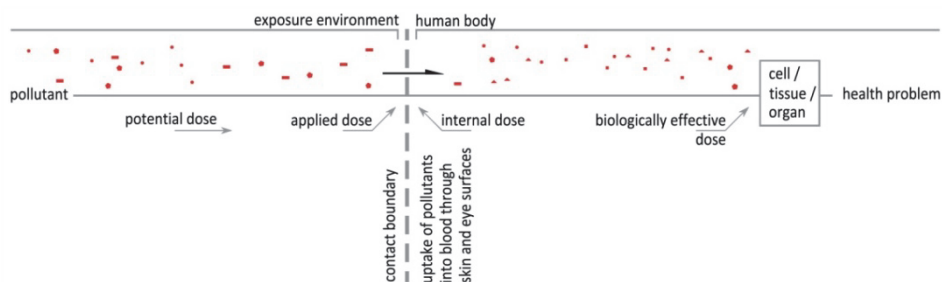


**Figure 3. Process of Dose and Relations (adapted from Darçin, 2014)**

Types and concentration level of pollutants in the vicinity of building users, duration of exposure, respiratory and dermal absorption rates are the factors to determine the level of dose. According to Zartarian, Ott and Duan (2007), the quantity of biomarkers can be described as intake dose if pollutants permeate the contact boundary without a resistance (i.e. permeation of pollutants into respiratory system through nostrils or mouth), whereas this level is specified as uptake dose when the pollutants penetrate the boundary overcoming a certain resistance (i.e. transfer of pollutants into blood through tissues of alveoli) (Figures 4 and 5). Absorption, distribution, metabolization and elimination of a substance in a biological system are associated with its pharmacokinetic, development of a health problem as the result of interaction between them is related to its pharmacodynamic properties (NRC, 1991).



**Figure 4. Intake Dose in Exposure via Respiration (adapted from Darçin, 2014)**



**Figure 5. Uptake Dose in Exposure via Dermal Contact (adapted from Darçın, 2014)**

### 3.2. Resultant Problems of Exposure

The route, duration, frequency of exposure, susceptibility and biological properties related to respiratory system, skin and eyes of building user along with the qualitative and quantitative properties of indoor air pollutants (Darçın & Balanlı, 2018a) are the basic determinants of problems which are examined under various classifications (Table 2) in scientific literature.

**Table 2. Classification of Health / Comfort Problems (adapted from Darçın, 2014)**

institute	criteria	classification	
NRC (1991)	duration and genre	acute:	acute respiratory infections, transient deficits in lung function, allergenic reactions, etc.
		nuisance:	noxious odors; eye, nose, throat irritation, coughing, etc.
		chronic:	chronic obstructive lung disease, cancer, heart disease, etc.
EPA (2020)	duration	immediate:	irritation of the eyes, nose, throat, headaches, dizziness, fatigue, etc.
		long-term:	respiratory diseases, heart diseases, cancer, etc.
Kephalopoulos, Kositinen & Kotzias (2006) (European Commission)	severity	severe	cancer, acute and chronic pulmonary diseases, upper airways inflammatory diseases, allergic diseases, ocular and mucosal reactions, infectious diseases and respiratory infections, intoxications,
		less severe	discomfort, odor perception, sensorial irritation and annoyance, SBS
WHO, 2018	-	pneumonia, chronic obstructive pulmonary disease, stroke, ischaemic heart disease, lung cancer, impaired immune response, reduced oxygen carrying capacity of the blood, low birth weight, tuberculosis, cataract, nasopharyngeal and laryngeal cancers, etc.	
Liccione (1999)	-	acute and chronic respiratory effects, neurological toxicity, lung cancer, eye and throat irritation, reproductive effects, developmental toxicity, odor	

Despite these many different and easily diversifiable classes, in certain risk assessment approaches and regulations, problems are grouped under two main categories: cancers and non-cancerous diseases. As a collection of related more than 100 diseases, cancer is caused by uncontrollably dividing cells which can spread through the body to other organs / tissues (National Cancer Institute [NCI], 2015). Non-cancerous diseases are reviewed under building related illnesses which are identified with diagnosable signs and symptoms directly attributable to specific air pollutants (EPA, 1994). The fundamental reason for this categorization is the theories of carcinogenesis according to which it is not possible to determine a safe level of concentration for carcinogenic pollutants, exposure to even lesser amounts can cause cancers (CEC, 1992).

It is believed that examining some symptoms of building users under a third category is required and can be beneficial at this juncture. Classified as sick building syndrome (SBS), these problems are determined according to time and frequency of their occurrence (Kephelopoulos, Kositinen & Kotzias, 2006) which are observed to be temporally related to the presence of the user in indoor environment. Symptoms mostly occur after a short period the user enters a building (Spellman, 2009) and disappear soon after they exit (National Safety Council [NSC], 2009). Although it is not certainly validated, mostly accepted cause of SBS is the mixture of many indoor air pollutants at low concentration levels in indoor air (Bernstein, et al., 2008). Mainly headache; eye, nose or throat irritation, dry cough, dry or itchy skin, dizziness and nausea, difficulty in concentrating, fatigue and sensitivity of odors are regarded as the basic symptoms (EPA, 1991). However, cacosmia due to odors of indoor air pollutants (Balanlı & Darçin, 2012) and other negative features related to other properties of indoor environment such as visual, auditory, tactile, dimensional and spatial should also be acknowledged under this category (Vural & Balanlı, 2011).

#### **4. FINDINGS AND CONCLUSION**

Existence and accumulation of harmful substances in indoor air create a high probability for exposure. In regard to the relationship of building with its users, many factors define and affect the results through various interactions between its multi-scale nested systems. Numerous sources in indoor and outdoor environments, constant transportation through the permeable building envelope, possible interactivities and properties of closed spaces determine the emergence of indoor air pollution by affecting physical, chemical and biological properties and concentration levels of pollutants. Development of this negative condition can trigger a hazardous effect whenever pollution meets with users and creates



an exposure environment as an interwoven sub-system of building with ever-changing boundaries.

Adverse effects are highly correlated with progress and properties of exposure. As the pollutants touch to the outer surfaces of the body or pass through the contact boundary and create a certain dose in various locations throughout the body, many problems, varying from odour intolerance, headache or irritation to respiratory infections, heart diseases and cancers, can occur.

Resolving and preventing indoor air pollution exposure require an efficient assessment process in which an accurate decision must be made about the encountered situation in terms of health. The primary procedure for this evaluation is to compare the resultant dose of biomarkers or the concentration levels in the breathing zone of the user to a threshold regarded as harmless to human health. It can be acknowledged that this method has been constructed over the hypothesis in which conceptually the relationship between the dose and possibility of comfort / health problems allows to determine of a limit value where the problem cannot be encountered. However, for some pollutants – especially the types specified as carcinogens – it is impossible to define such limit; if there is dose, there is a risk. Accordingly, specifying the possible results of indoor air pollution based on properties of pollutants, users and exposure becomes an essential step during the assessment process.

Health and comfort conditions have been examined under various groupings, nevertheless in order to avoid inconsistencies between accepted definitions and categorization and more importantly to conclude the assessment process with a substantive decision, a three-section classification: cancers, non-cancerous diseases and sick building syndrome symptoms, is constructed. It is believed that, with this system, a practical evaluation can be managed for evaluation of indoor air pollution in existing buildings during which determined pollutants can be grouped according to their possible health effects and risk can be calculated for each three group.

With improved future researches on detailed dose-response relationship for different pollutant types, the assessment activities can be more feasible which should be regarded as a vital necessity in order to sustain existing building stock and transform the problematic spaces in better and healthy living environments.

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