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STUDIES ON THE CURRENT CONTEXT OF AIR QUALITY INSIDE EARTHEN BUILDINGS

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Abstract

A global problem that affects almost all areas of life is the environmental pollution, and because people stay indoors about 80-90% of their day, it can say that indoor air pollution is most of concerns. The growing attention paid to the use of natural materials has become a current topic among researchers, due to the increasing need to exploit renewable materials, conserve energy and adopt sustainable production methods to create buildings adapted to modern times. Although, earth might be considered, from a current perspective, an ancient building material, between 30 and 50% of the XXI century population lives in dwellings made of earth. In this respect, our studies focused on exploring the current status of worldwide research on air quality inside earthen buildings, in order to establish the performance indicators related to this field. The findings highlight the need to rethink the way in which indoor spaces are designed and operated given the waste generation, resource depletion and climate change, with increasing numbers of people which want to live in environmentally friendly and healthy buildings.

Key words*: earthen buildings, health effects, indoor air pollution, performance indicators.*

INTRODUCTION

The increasing need to exploit renewable materials, conserve energy and adopt sustainable production methods to create buildings adapted to modern era has led to the increasing importance of using natural materials (Rivera-Gomez et al., 2021). In global terms, current forecasts seem to indicate, that in the next decade, the construction sector will grow continuously at a rapid pace. Although, earth might be considered, from a current perspective, an ancient building material, between 30 and 50% of the XXI century population lives in dwellings made of earth. (Schweiker et al., 2021; Rivera-Gomez et al., 2021). Earthen buildings can be found anywhere on the globe, both in developing countries, it is true most of them, but also in developed countries such as Australia, Brazil, the United States or those of Europe. Because in vernacular buildings can be used climate-adaptive strategies with the possibility of reducing carbon emissions and energy consumption, these have become attractive during the many crises of mankind referring to environmental pollution and energy shortages (He et al., 2023). Earth is a natural building material, intensively used until now and one of the oldest. Thus, the benefits of earth building materials are seeking by a growing number of people from developed countries and societies, people which wants to enjoy of environmentally friendly and healthy buildings. It is clear that the way buildings are designed, constructed and operated needs to be rethought in light of waste generation, climate change and resource depletion (Schweiker et al., 2021).

The subject of many studies is to find solutions to global crisis such as climate change, environmental pollution and energy shortage. There is evidence that vernacular living spaces, by their adapting to the local climate conditions, can become a convenient indoor environment for inhabitants. The key elements in the adjustment of the building's temperature conditions and the occupant's thermal adaptation are the vernacular spaces of the buildings. Analysing the relationships between climate, people and vernacular buildings is a very important topic for understanding and knowing the strategies for sustainable design of

vernacular buildings and for promoting sustainable architecture (Chang et al., 2021). The centuries-long experience of people living in different climates around the world led to the development of vernacular architecture. The environment, the historical background and the culture of the different peoples form the basis for building and design techniques that utilise locally available resources (Chandel et al., 2016).

Clay has several advantages as a building material: It is ecological, economical and can be easily recycled and reused. In addition, clay has good properties for absorbing and releasing water vapour, which has a positive effect on the balance between room temperature and relative humidity, on the air quality of the building and ultimately on the comfort of the occupants (Gomes & Miranda, 2022). A construction technique is rammed earth in which the main components of the earth (gravel, silt, clay and sand), with or without the addition of stabilizers depending on the required strength, are compressed to give it the desired shape, within a set framework (Khadka & Shakya, 2016).

Considering the growing of global population, the request for more resources is increasing every day, causing global warming and all resource exploitation, about 50% of them, being used in the construction industry, one of the least sustainable sectors (Khadka, 2020).

MATERIALS AND METHODS

Given the people spend about 80% of their time indoors (Vijay et al., 2024; Gonzalez-Martin et al., 2021; Karr et al., 2021; Nair et al., 2022; Tsumura et al., 2023; Harb et al., 2018), they being exposed to many different pollutants with high emissions from various sources like furniture, humans and daily activities, construction materials, consumer products, with effects recognized harmful to health (Albertin et al., 2023; Peterson et al., 2023; Petigny et al., 2021; Morin et al., 2019; Arar et al., 2022; Gao et al., 2021; Caron et al., 2016; Santos et al., 2019) our studies focused on exploring the current status of worldwide researches on air quality inside earthen buildings. In order to carry out the proposed aim, a literature review was carried out to afford a better understanding of pollution from indoor spaces, of the main categories of pollution substances, of the dangerous effects of them on people health, and the direct correlation of these with specific indoor environment of the earthen buildings. At the same time, the studies also focused on the establishing of the performance indicators related to this field of great importance for our daily life.

RESULTS AND DISCUSSIONS

Three main classes of pollutants form the basis for the assessment of indoor air quality: volatile organic compounds (VOCs), inorganic compounds (VICs) and particulate matter (PM). VOCs can be classified into different groups based on their properties regarding molecular structure, polarity and boiling point, most of these compounds being in the focus of several international organizations and countries as essential pollutants for their control (US EPA; Gan et al., 2023). A category of pollutants called aerosols, which group VOCs and PM with polycyclic aromatic hydrocarbons (PAHs) and inorganic pollutants, called gaseous pollutants, from this category being carbon oxides (CO, CO_2), sulphur dioxide (SO_2), nitrogen oxides (NOx), and ozone (O_3) (Kumar et al., 2023). There are four categories of PM, considering the dimensions (diameter) of them: < 0.01 μm (ultrafine particles - UFP), between 0.01 μm and 2.5 μm, named fine particles, between 2.5 μm and 10 μm, named coarse and more than 10 μm, so-called large particles (Kumar et al., 2023). It is estimated that, globally, only PM2.5 are the cause of more than 2 million deaths annually (Teiri et al., 2021). PM2.5 can contain various types of chemical substances, such as organic carbon (50%), elemental carbon (3%), sulphates and nitrates (30%), metals (1%), ammonium ions and water (15%) (Kumar et al., 2023). Likewise, PM2.5 could have in the component a new category of coming out pollutants namely environmentally persistent free radicals (EPFR) (Chen et al., 2019). These compounds have high toxicity, increased durability and low reactivity. Another component of PM2.5, black carbon, is produced by the incomplete combustion of various types of fuels, and human exposure to

this chemical can lead to strokes and heart attacks, high blood pressure and lung diseases such as asthma and bronchitis. The description and effects of the pollutants mentioned can be found in Table 1 and their sources in Table 2.

Table 1. Description of main types of pollutants and effects on human health

Type of pollutant	Description	Effects on human health
PM	solid particles and liquid droplets, having different origins sizes, shapes, and chemical compositions, suspended in the air	pulmonary diseases such as bronchitis, asthma, wheezing breath, cardiovascular and neurological problems like high blood pressure, strokes and heart attacks
VOCs	compounds that at room temperature have a low value of boiling point and high vapour pressure, belonging to different classes like alkanes, terpenes, aldehydes (formaldehyde), aromatic compounds, monocyclic like benzene, toluene and xylene or polycyclic, etc.	poor degradability, high volatility and severe toxicity, being able to determine great problems to both humans and environment. Diseases such as nasopharyngeal cancer, lung damage, leukaemia and symptoms related to sick building syndrome can be the results of exposure to formaldehyde on long term
VICs	gases like: sulphur dioxide (SO_2), carbon monoxide (CO), ozone (O_3), carbon dioxide (CO_2), nitrogen oxides (NO and NO_2)	cardiovascular, respiratory, and neurological problems, besides of dizziness, fatigue, sneezing, eye irritation can be the results of long-term exposure at most of volatile inorganic compounds.

Table 2. Summary of air pollutants sources

Pollutant	Outdoor sources		Indoor Sources
	Natural	Anthropogenic	
PM	gaseous emissions, volcanic eruptions, storms, rock debris, forest fires	fuel combustion, steel industry, mining operations, emissions from power plants, glass manufacturing industry, other types of industrial processes – cement manufacturing, etc	heaters, household burners, fireplaces, household activities (ironing, cooking – frying, cleaning), office equipment (photocopiers), paints, plastics, presence animals of company and different activities of occupants
VOCs	forest fires, volcanic eruptions, etc.	using of fossil fuels, refining, exploitation, transportation, storage, etc.	emissions from different types of materials (construction, finishing/ protection, adhesives, paints), furniture, occupants' activities (cooking, cleaning, etc.), household cleaning products
VICs	world's forests, wetlands, and seas.	ventilated kitchens, garages, greenhouses, tobacco smoke, burning of fossil fuels (furnaces, heaters, stoves)	combustion processes in fireplaces, stoves, furnaces, heaters, gas appliances without ventilation

A significant relationship between excessive exposure to concentrations of indoor air pollutants and the appearance of symptoms that make up the so-called Building-Related symptoms (BRS) or Building-Related Illnesses (BRIs) has identified by previous studies (Chamseddine et al., 2019; Zoran et al., 2020; Shaw et al., 2020; Brown et al., 2021; Suzuki et al., 2021; Gomes and Miranda, 2022; Gan et al., 2023). The two differ because, in the case of SBS, there is not the possibility of the associating the exposure inside the building with symptoms described by the occupants (Gomes and Miranda, 2022), and the etiology of these symptoms are not known. The range of SBS symptoms varies from red eyes, headache, fatigue, concentration difficulties, dry skin and respiratory irritation (Arar et al., 2022). But researchers agree that the cardiovascular and respiratory illnesses are the most dangerous effects of pollution on humans (Brown et al., 2021; Zoran et al., 2020; Shaw et al., 2020; Arar et al., 2022). The admissible limits of some indoor air pollutants concentrations are presented in Table 3 (Kumar et al., 2023; WHO, 2021).

Table 3. Threshold levels of different indoor air pollutants

Pollutant	Exposure time	Limit value	Measure unit
PM2.5	Annual	5	$\mu g/m^3$
	24 h	25	$\mu g/m^3$
NO_2	Annual	10	$\mu g/m^3$
CO_2	24 h	1000	ppm
	-	1600	mg/m^3
SO_2	Average of 24 h	40	$\mu g/m^3$

From the study of the existing specialized literature in the sciencedirect.com and springerlink.com databases, few studies were found in the field of air quality inside earthen buildings, most of them referring to parameters of thermal comfort, namely temperature and relative humidity (Costa-Carrapiço et al., 2023; He at al., 2023; Chang et al., 2021). Only one study contains data on CO, CO_2 and TCOV pollutant concentration values (Costa-Carrapiço et al., 2023). Only three articles were found related to materials that have an earth composition, namely two ongoing projects on earth plaster (Gomes and Miranda, 2022; Santos et al., 2019), of which one will monitor the emissions of CO, CO_2 and PMx, and the other study (Darling et al., 2012) looked at the possibility of increasing of inside air quality by studying the ability of a clay plaster to lower ozone concentrations, as well as to lower the concentrations of secondary reaction products. Some details about these studies are presented in Table 4.

Table 4. Details regarding studies carried out in the indoor spaces of some constructions made of earth and on materials that have earth in their composition

Author's/Location/ Material	Study publication year	Monitored parameters/monitoring periods
Studies in indoor spaces of earthen buildings		
Costa-Carrapiço et al., 2023/ Alentejo, Portugalia	2023	air quality (CO, CO_2, VOCs), surface temperature, relative humidity, indoor and outdoor air temperature, black body temperature, air velocity, light level, sound level/summer, winter
He at al., 2023/ Turpan, China	2023	wind speed, relative humidity, indoor air temperature, outdoor air temperature, solar radiation intensity /summer, winter
Chang et al., 2021/ Turpan, China	2021	air speed, relative humidity, air temperature, radiation temperature /summer, winter
Studies on materials containing earth		
Gomes & Miranda, 2022/Earth plaster	2022 (ongoing study)	air temperature, relative humidity, CO, CO_2, PMx (PM2.5 and PM10)/spring, summer, winter
Santos et al., 2019/Earth plaster	2022 (ongoing study)	air temperature, relative humidity
Darling et al., 2012/ Clay plaster	2012	ozone, six aliphatic aldehydes (C5-C10) and two aromatic aldehydes (benzaldehyde and methyl-benzaldehyde)

The study by Costa-Carrapiço and colleagues (2023) analysed a sample of sixty-nine vernacular dwellings in Alentejo, Portugal and sought to evaluate the performance of their inside environment, indoor air quality being evaluated based on the concentrations of CO, CO_2 and VOCs, by the collecting of data on long period of time (summer and winter). In the case studies, the obtained results confirmed that the main sources of indoor air pollution are the emissions from heating and cooking. The minimum values of average concentrations for CO, CO_2 and VOCs (0.1-0.2 ppm) were obtained in living rooms heated electrically, during no cooking periods of time. VOCs concentrations are 10 ppm near the stove, during cooking activities, but in the living room, this is only 2 ppm. A period of exposure till 15 h results from leaving, in the cold season, the heat working all day, something that more than half of the occupants of the buildings do. Moreover, the health of building occupants can be affected by extended periods with wood heating, this being source of some VOCs like aldehydes (formaldehyde) or aromatic compounds, mono- and polycyclic,

and fine or ultrafine particles. The mentioned chemical substances are harmful in a very small quantities and can have as result serious respiratory problems, by affecting lung's function, even and cancer. Regarding materials that contain earth, Darling et al. (2012) conducted a study to evaluate a clay plaster as a Passive Removal Materials (PRMs) of pollutants to improve air quality by controlling their concentration. This was done by monitoring during the tests of the perceived air quality (PAQ) and quantifying the ozone levels, six aliphatic aldehydes (C5-C10) and two aromatic aldehydes, in two experimental enclosures, which contained eight combinations of an emitting and reactive and pollution source (new textile carpet type floor covering on polyurethane foam support), clay plaster for walls, applied to plasterboard, with and without ozone presence. A commercially available plaster was used for this study, consisting of a proprietary clay mixture (fire clay, kaolin, montmorillonite - an aluminium-rich clay mineral from the group of smectites) and broken marble (size of aggregate: 5-1000 μm). The conclusions of the mentioned study (Darling et al., 2012) can be summarized as follows: clay wall plasters can improve PAQ, especially in the presence of ozone or ozone and textile carpet; perceived air quality was most acceptable and aldehyde concentrations were lowest when only clay plaster or both clay plaster and carpet were present in the ozone-free experimental chambers; addition of clay plaster to the least acceptable PAQ condition (carpet-ozone) considerably decreased both ozone and aldehyde concentrations and significantly improved PAQ.

Obtaining information about existing documents, normative (regulations) or recommendations (guidelines) regarding the quality of the indoor environment (IEQ - Indoor Environmental Quality) is useful for decision-makers who prepare such documents, as well as for scientists and practitioners operating in different countries (ieqguidelines.org).

In 2018, a members group of International Society of Indoor Air Quality and Climate - ISIAQ discussed the challenges related to the compilation of international guidelines. Challenges include language barriers, varying degrees of quality, and questions about comparing guidelines with many key differences, including health effects, climate, and common building types. To help overcome these challenges, a Scientific and Technical Committee (STC34) was officially launched in September 2020, part of ISIAQ, with three main objectives, namely: congregating and organizing continuously of the information about the global guidelines; realizing of database, functional and open, able to spread information contained in guidelines; updating of guidelines in force and making recommendations. The committee has created an open IEQ guideline database (ieqguidelines.org). This database is organized in fields, including: pollutant name; performance indicators in the form of limit values; average time interval; document category (guideline or regulation); issuing authority (agency, ministry, department of a ministry, etc.); type of effect on human health (acute, chronic, etc.); the type of indoor environment to which it applies (public buildings, schools, homes, etc.). Figures 1-3 show examples of the worldwide performance indicators for some of indoor pollutants, namely TVOC, HCHO and O_3.

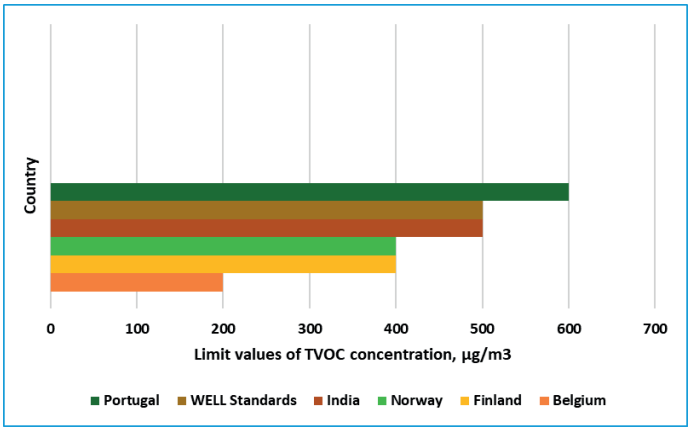

Figure 1. Examples of admissible values of TVOC concentration in different countries

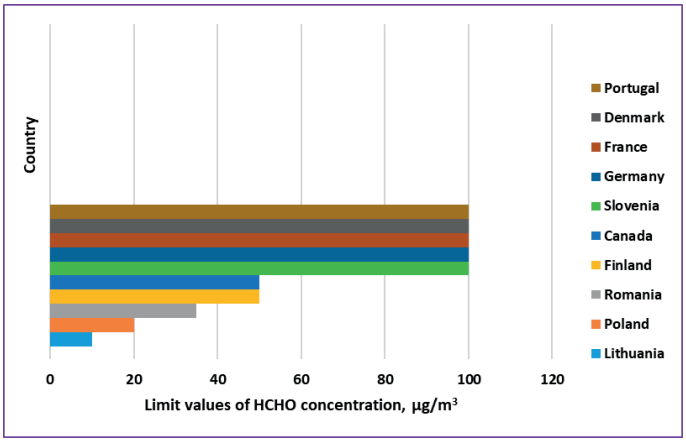

Figure 2. Limit levels of HCHO concentrations, nationally and internationally

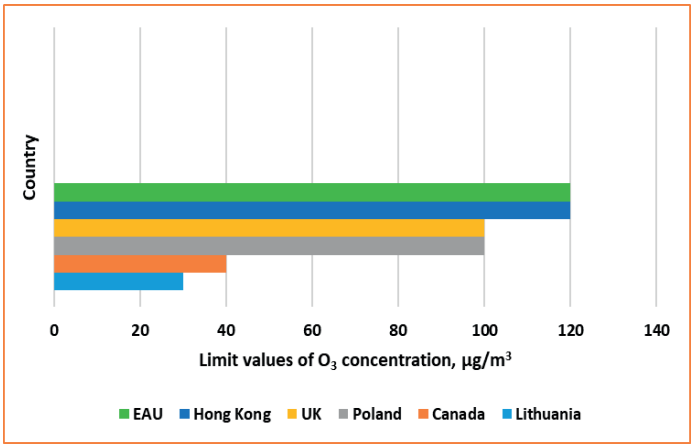

Figure 3. Limit values of O_3 concentrations, internationally

CONCLUSIONS

The conclusions of the bibliographic study carried out to know the current context regarding the air quality inside earthen buildings are:

✓ earth, as a construction material, has several advantages (economic, ecological, easy of reuse and recycling), between 30 and 50% of the world's population living nowadays in dwellings made of earth;

✓ indoor air, where people spend 80 to 90% of their time, contains multiple sources of pollutant emissions, as well as many types of pollutants, leading to ecosystem damage and causing a range of adverse health effects even in the lower detectable concentrations;

✓ air quality of indoor spaces is evaluated mainly having as base the concentration levels of three main categories of pollutants, namely volatile compounds, organic (VOCs) and inorganic (VICs), and particulate matter (PM);

✓ exposure on short or long-term to indoor pollutant concentrations leads to the appearance of symptoms which are part of the categories named sick building syndrome (BRS) or building-related illnesses (BRIs), among which are listed: headaches, fatigue, drowsiness, nausea, irritation of respiratory tract and eyes, dizziness, irritability, nervousness, the most common diseases mentioned being respiratory, cardiovascular, neurological, allergic, etc.;

✓ from the study of the specialized literature existing in the international databases, few studies were found in the field of air quality inside earthen buildings, most of them referring to parameters of thermal comfort, namely temperature and relative humidity. Only one study contains data on CO, CO_2 and TCOV pollutant concentrations, and only three articles were found on earth-based materials, one of which looked at the ability of a clay plaster to improve the quality of indoor air, directly by decreasing reduction the level of ozone, and indirectly by decreasing the levels of secondary products of chemical reactions;

✓ existing documents, normative (regulations) or recommendations (guidelines) regarding the environment quality from inside buildings, have recently been grouped into the ieqguidelines.org database, which contains sixteen types of information, including the name of the pollutant, performance indicators in the form of admissible limit values, issuing authority and country, etc.

Considering the mentioned conclusions, it is necessary to continue the research with the exploration of the performances of the buildings made of earth and the materials that have earth in their composition, from the point of view of fulfilling the indicators regarding indoor air quality.

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