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Indoor air quality for sustainability, occupational health and classroom environments through the application of earth plaster

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Topic: 1.3 Studies of traditional techniques and materials.

Abstract

Clearly, the construction sector makes a large scale contribution to environmental degradation and urgently needs to change its principles to focus on environmentally sustainable construction. Earth, as a building material, has a potential cradle to cradle life cycle, thus, achieving a circular economy. This material also displays numerous advantages, namely: economic and ecological and as well as the ease of reuse and recyclability. The earth material also registers a high capacity to absorb and release water vapor, which helps to balance the relative humidity and the internal temperature, promoting not only the comfort of occupants but also the quality of the air in buildings. The materials applied in construction hold great influence over the indoor air quality (IAQ). IAQ ranks as such a crucial issue that it appears in the seventeen 2030 Agenda SDGs. As about 90% of our time is spent inside buildings, whether for leisure or work, it is essential to live in spaces with adequate and healthy interior environments. According to the World Health Organization, good air quality represents a basic requirement for life and is a determining factor for the health and well-being of occupants of indoor spaces. In schools, and due to the complex and diversified activities developed there, in addition to adverse health effects, indoor air quality may also have a direct impact on student concentration and performance. Understanding and studying materials, specifically earth mortars, with the ability to capture pollutants and reduce their concentration while helping to regulate the temperature and relative humidity conditions, and student comfort, is thus extremely important. Hence, with the objective of improving the development of construction strategies, this article details and highlights the beginning of the RESpira project.

Keywords: *earth mortar; indoor air quality; occupational health; environment.*

1. Introduction

The concept of indoor air quality is both quite complex and all-encompassing as it depends on numerous factors, including: temperature, relative humidity, air velocity, concentration of microorganisms and chemical pollutants, suspended air particles, among others (Abreu, 2010). Frequently, indoor air quality problems stem from combinations of the effects of the various pollutants present in those spaces and sometimes present in low concentrations and hence not only due to high concentrations of a single pollutant, which renders the study of indoor air quality (IAQ) even more complex (APA, 2010). The need to eradicate or minimize exposure to indoor pollutants is, for this reason, one of the priorities defined by the World Health Organization (WHO) for protecting public health in developed countries (WHO, 2016).

The WHO estimates that indoor air pollution is responsible for 3.8 million deaths every year (WHO, 2020).

The Environmental Protection Agency (EPA) even suggests that poor indoor air quality can reduce the ability of occupants to perform mental tasks that require concentration, calculation or memorization. According to the EPA, a study carried out in European schools revealed a significant reduction in student concentration following increases in carbon dioxide levels inside the classrooms. Similar results were also obtained among students exposed to high levels of volatile organic compounds (Environmental Protection Agency, 2003) and fine particulate matter, namely PM_{10} and $PM_{2.5}$ (Pulimeno et al., 2020). Even though indoor air quality in schools represents a problem impacting on around 64 million students in Europe alone, it still remains a neglected subject even while gaining greater importance due to the recent COVID-19 pandemic. Ensuring good air quality in schools is, for the reasons presented, a current need that should be high on the list of priorities for buildings managers.

Good indoor air quality can be ensured through the elimination or reduction of indoor pollutant concentrations either through source control (selecting low-emission furniture, materials and equipment) or by upgrading the ventilation (diluting pollutant concentrations). This last set of measures, while quite efficient, nevertheless implies higher energy consumption with a consequent increase in costs and negative environmental impacts (Wargocki, 2007), making it essential to search for more economically and environmentally sustainable solutions.

The UNESCO Chair on Health Education and Sustainable Development and the Italian Society of Environmental Medicine (SI-MA) recently presented a series of recommendations designed to improve IAQ in schools that includes, among other measures, the growing of plants as specific natural filters capable of absorbing some indoor contaminants (Pulimeno et al., 2020).

Earth, as a building material, also represents a material able to help improve indoor air quality. As a construction material, this provides a potential cradle to cradle life cycle in keeping with the circular economy. This material also returns numerous advantages, specifically: economic, ecological, ease of reuse and 100% recyclability. Earth as a material also contains a high capacity to absorb and release water vapour, which assists in balancing the relative humidity and internal temperature, promoting comfort among the building's occupants and overall indoor air quality (Santos et al. al., 2020a,b).

The materials applied in construction have a great influence on air quality. The materials chosen should either improve or at least not negatively affect IAQ. Given we spend about 90% of our time inside buildings (Leech et al., 2002), whether for leisure or work, it is essential we spend this time in spaces with appropriate interior environments.

Based on the assumptions presented, the main objectives of the RESspira project, as presented in this article, focus on monitoring the concentrations of chemical and microbiological pollutants in classrooms, through the application of different types of coatings, namely earth and cementitious mortars. Monitoring the actual concentrations of these pollutants is clearly essential to producing specific protection measures for building occupants. This project will therefore take an important step in trying to answer the following questions: Is it possible to mitigate the levels of pollutants inside classrooms by applying different types of coatings? What kind of passive strategies might be adopted to mitigate the high concentrations of chemical and microbiological pollutants in classrooms?

2. School buildings *vs* indoor air quality *vs* earth mortars

School buildings have particularities that distinguish them from other types of buildings and that significantly influence their indoor air quality, such as (US EPA, 2021):

- concentration of occupants: in schools, occupants are closer, with a greater concentration of occupation by area;
- investment in maintenance: funds available for preventive maintenance are generally low, with investment in new systems and equipment still lower;
- various sources of indoor pollutants: due both to the diversity of activities taking place and the wide variety of sources of pollutants, such as: laboratory products and equipment, workshop equipment, leisure and sports spaces;
- large amounts of heating and ventilation equipment and often with complex systems.
- variety of spaces: in addition to classrooms and offices, schools generally contain other types of spaces, with different maintenance and intervention requirements, including: laboratories, amphitheatres, cafeterias, gyms and diversified green spaces.
- adapted and temporary facilities: spaces are often adapted for other purposes or are facilities installed for temporary occupations.

According to the EPA, ineffective action when facing indoor air quality problems in schools can also indirectly lead to: increased absenteeism; reduced levels of comfort and performance among students and teachers; jeopardise the functioning and efficiency of systems and equipment; increase the probability of the departure and/or transfer of students and teachers; and produce negative publicity for the establishment impacting on the community's trust.

In Portugal, the monitoring of indoor air quality, pursuant to Decree-Law no. 79/2006 of 4 April, became mandatory for certain types of buildings, including school buildings, with the establishing of maximum values for the concentration of certain pollutants that the respective law states were selected according to guidance values issued by the World Health Organization (WHO) and national and international standards handed down by the International Organization for Standardization (ISO) and the Committee Européen de Normalization (CEN).

Currently, and in accordance with this development in the prevailing legal framework, the provisions on indoor air quality are regulated by specific legislation that determines the need to monitor the following physical-chemical pollutants and microbiological parameters: particulate matter (fraction PM_{10} and $PM_{2.5}$), volatile organic compounds (VOC), carbon monoxide (CO), formaldehyde (CH_2O), carbon dioxide (CO_2), radon, bacteria and fungi.

2.1. Indoor air quality *vs* health effects

Poor indoor air quality has direct effects on the health of occupants with the appearance of a set of symptoms potentially directly associated with the time spent inside buildings and described in the literature as Sick Building Syndrome (SBS) or Building-Related Illnesses (BRIs). SBS differs from the BRIs as there is no ethology knowledge on the symptoms described in the case of SBS and it is therefore not possible to associate the symptoms described by occupants with their particular exposure inside the building. However, in the case of the BRIs the causes of the pathologies developed are perfectly known (Jones, 1999).

Although apparently minor, Jones (1999) maintains the symptoms associated with SBS may have significant impacts on the economy and public health as they contribute to increased absenteeism and reduced employee productivity. Furthermore, in the case of schools, students and teachers register decreased levels of concentration and performance.

The likelihood an individual will become ill or develop symptoms due to exposure to certain indoor pollutants depends on a variety of factors, such as individual susceptibility, the concentration levels of the pollutant, their physical and mental health state at the time of exposure, and the duration and frequency of exposure. Each pollutant, depending on its characteristics and the concentrations present in indoor air, can have noxious impacts on occupant health.

Jacobson et al. (2019) analyze the direct risks CO_2 poses to human health with acute or even chronic exposure potentially causing psychological and physical effects; ranging from depressive behaviors, drowsiness to bone demineralization and physiological stress. High levels of CO_2 can be found in densely populated indoor environments such as sports halls, hospital waiting rooms as well as classrooms. An acceptable CO_2 value is normally 400 ppm for indoor environments even though this value may potentially reach between 600 and 800 ppm with and this increase primarily due to human respiration (Hays et al., 1995). These values can easily rise to 1000 ppm or more (Wu et al., 2021), resulting in symptoms such as loss of concentration, states of drowsiness, headaches, among others. Thus, we may clearly perceive the importance of reducing CO_2 levels in interior spaces to drive increases in the IAQ for building occupants. As mentioned, and due to the complex and diversified activities carried out, in addition to the adverse effects on health, indoor air quality in schools may also directly impact on the concentration and performance of their occupants.

2.2. Earth Mortars

Current consumption of the earth's resources has led to levels of development in Western society that are now deemed unsustainable. Perceived environmental disturbances clearly indicate that, unless urgent measures are taken, humans will encounter considerable difficulties in adapting to their global habitat. The construction sector alone contributes on a large scale to environmental degradation. In 2018, the building and construction sector accounted for 39% of carbon dioxide (CO_2) emissions from processes and energy, and 36% from end-use energy; of these, 11% resulted from products such as cement, steel and glass, and from the manufacture of building materials (IEA and UNEP, 2019). Cement manufacturing is known to be a very CO_2 intensive process and responsible for about 60% of total emissions worldwide (GCCA, 2020). By weight, cement is the second most consumed substance in the world, trailing behind only water. One building material with very different properties to cement is earth as a construction material. Earth as a construction material (Fig. 1) displays numerous advantages, in particular: economic, as local material, without the need for transport or calcination, easy to extract and transform, and with low processing costs. Earth is simultaneously ecological, hence, with low energy consumption associated with its manufacture and, in many cases, its transport (since the material is obtained from construction work site), thus reducing the carbon footprint and the corresponding CO_2 emissions due to low embodied energy. The ease of reuse and recyclability represents another major environmental advantage in allowing for 100% reuse (Gomes et al., 2018). This material also returns thermal comfort as another contribution due to its low thermal conductivity, which stems from high levels of thermal inertia due to significant wall thickness. Last but not least, this contributes to interior comfort in keeping with clay's ability to regulate the relative humidity of the interior environment as a hygroscopic material - that is, fostering the regulation of the relative humidity in such environments and thereby promoting occupant comfort in buildings and indoor air quality (Santos et al., 2020a,b).

Fig. 1. Naturarte, rural tourism built with the earth technique, located in São Luís, Portugal.

3. RESpira Project

The RESpira project (Regulation of Indoor Air Quality Through the Use of Eco-Efficient Mortars) will focus on monitoring the concentrations of chemical and microbiological pollutants in classrooms, through the application of different types of coatings, namely earth and cementitious mortars. To achieve the project's objectives, earth (two different earth types will be used) and cement mortars will first be applied in classrooms

(Fig. 2). For the results to be as comparable as possible, the mortars will be applied in rooms with the same type of usage, number of occupants, temperature and relative humidity.

After applying the coatings, surveys will be carried out among students who attend the pilot classrooms to monitor and quantify the benefits, the feelings of comfort and their ability to concentrate due to the application of the different coatings (sustainable vs. common coatings). It is preferable to carry out these surveys in the winter, spring and summer seasons.

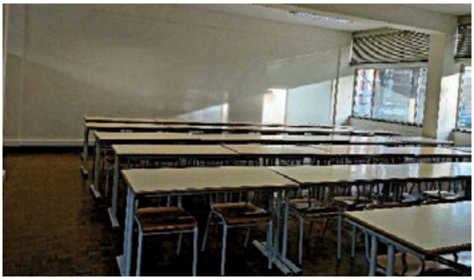

Fig. 2. Classroom to be plastered with earth mortars.

This research will contribute directly to ascertain whether or not improvements in indoor air quality are confirmed following the application of earth coatings in comparison with the current types. It is important to refer here that earth plasters are presented as eco-efficient and healthy in keeping with several of the UN Sustainable Development Goals (SDGs). Furthermore, this study emerges as unprecedented given the conditions are real (as opposed to simulations).

In the same three seasons (winter, spring and summer), air and surface samples will be collected for microbiological research (fungi and bacteria) using selective culture media and with the mortars also subject to microbiological analysis (Viegas et al. 2019). Simultaneously, evaluations of the chemical and physical parameters (T, HR, CO, CO_2, PMx) will be carried out by direct reading equipment (Fig. 3). In addition, electrostatic precipitators will be placed for one month in the pilot and "common" rooms, which will subsequently be analyzed chemically and microbiologically (Viegas et al. 2021).

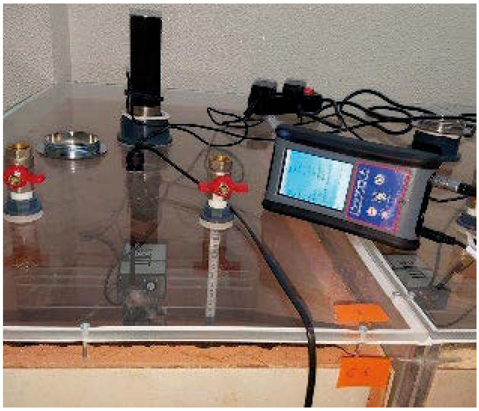

Fig. 3. Equipment for measuring pollutants.

4. Conclusions

There is currently sufficient scientific evidence relating complaints and environmental discomfort felt by the occupants of buildings to the construction materials applied inside these buildings. Hygienic and human-toxicological aspects are now beginning to be studied in built environments in order to guarantee not only the existence of pleasant and comfortable environments but also, and especially, healthy indoor surroundings.

Indoor air quality is very important both for the comfort and the health of building inhabitants as poor indoor air quality can have a high impact on health, low comfort levels and poor cognitive performance among the building's occupants. We would here stress how the levels of pollution inside buildings are often higher than those verified on the exterior. Understanding the determinants of health constitutes a fundamental issue for society, whether in classrooms or in other environments with high population densities, in order to nurture better health conditions. Another important factor is prevention as good IAQ boosts the health of the occupants inhabiting such buildings, not only improving health throughout life but also cutting the cost burden on national health services due to the reduction in Sick Building Syndrome related problems. The RESpira project thus aims to help answer some of the questions presented in order to achieve improvements in the indoor air quality of schools.

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