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Influence of Humidity on Environmental Sustainability, Air Quality and Occupant Health

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***Abstract*—**Nowadays, sustainable development issues have a key role in the planning of the man-made environment. Ensuring this development means limiting the impact of human activity on nature. It is essential to secure healthy places and good living conditions. For these reasons, indoor air quality and building materials play a fundamental role in sustainable architectural projects. These factors significantly affect human health: they can radically change the quality of the internal environment and energy consumption. The use of natural materials such as earth has many beneficial aspects in comfort and indoor air quality. As well as advantages in the environmental impact of the construction, they ensure a low energy consumption. Since they are already present in nature, their production and use do not require a high-energy consumption. Furthermore, they have a high thermo-hygrometric capacity, being able to absorb moisture, contributing positively to indoor conditions. Indoor air quality is closely related to relative humidity. For these reasons, it can be affirmed that the use of earth materials guarantees a sustainable development and at the same time improves the health of the building users. This paper summarizes several researches that demonstrate the importance of indoor air quality for human health and how it strictly depends on the building materials used. Eco-efficient plasters are also considered: earth and ash mortar. The bibliography consulted has the objective of supporting future experimental and laboratory analyzes. It is necessary to carry on with research by the use of simulations and testing to confirm the hygrothermal properties of eco-efficient plasters and therefore their ability to improve indoor air quality.

***Keywords*—**Hygroscopicity, hygrothermal comfort, mortar, plaster.

I. Introduction

THE factors that influence indoor environment play a key role in the ensuring of sustainable architecture development. The aim is to not only to limit the impact of human activity on nature, but also to guarantee healthy places construction. For this reason, it is important to know how to control the quality of built environments.

People spend most of their day indoor: several studies report high percentages of time spent inside buildings [1]-[3]. Considering this fact, it is possible to affirm that ensuring good outdoor air quality is important, but it is fundamental to focus on the indoor one too. Both of them have a big influence on environmental impact and human health.

For further investigation of the indoor air quality (IAQ), it is necessary to know in depth the factors that affect it. Pollutants can be produced by biological and non-biological sources and can have different consequences. First, outdoor air pollution can entail easily IAQ by natural ventilation and infiltration. Occupancy and human activities also play an important role: pollutants can be produced both by the activities and by the materials used in them.

Researches carried on in the past years demonstrate that also constructive techniques and building materials have a considerable influence on IAQ. These can act as pollutants sources or as air cleaning agents. They can also change indoor temperature and humidity, two fundamental properties for internal comfort and IAQ control. These properties of building materials have been demonstrated by some of the researches described below like [3]-[5] that analyze the relationship between materials and IAQ. Deeping these studies permits to determinate the factors that affect human health. Depending on the type of pollutant, more or less serious organism reactions may occur. Symptoms resulting from unhealthy IAQ are also analyzed.

The paper lists poor IAQ causes and the effects on human health. Beyond this, important studies about building materials proprieties are also reported: their role in changing the quality of IAQ is considered [6]-[8]. Plasters are mainly considered, as materials that are directly in contact with the internal air. Some experiment about buffering moisture capacity, pollutant absorption-desorption and the ability to guarantee healthy internal environment are described. Eco-efficient natural materials are mainly considered because they can both improve internal conditions and ensure a lower environmental impact. Being already present in nature, they do not require a high-energy consumption for their production. Furthermore, they can affect IAQ in a passive way, guaranteeing a lower energy demand to achieve internal comfort.

The aim of this article is to show the importance of IAQ and benefits of using eco-efficient plasters. Information about causes and effects of a poor internal air conditions and influence of building materials is collected. The objective is to demonstrate that, among the various advantages that derive from the use of natural materials, there is also the improvement of human health.

II. Air Pollution and Human Health

Developing a good architectural project means being able to respect natural environment and human needs. For this reason, knowing boundary conditions and understanding people's need are fundamental. By analyzing current lifestyle of population, it has been estimated that people spend 90% of their life indoors, in private and public buildings [1]. To guarantee a good quality of internal environment, it is important to understand causes that affect it. After studying

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these, it is possible to give solutions to improve the IAQ and to build more healthy spaces.

A. Types of Air Pollutants

There are several types of air pollutants and they can be divided into produced by non-biological and biological sources, as Jones describes [9]. In his work, he analyzes pollutions sources, giving a detailed description of them. Non-biological source contaminations are mainly produced by human activities and building materials. The best known are asbestos, carbon dioxide, carbon monoxide, formaldehyde, nitrogen dioxide, radon, particulate respirable particles and volatile organic compounds (VOCs) (chemical compounds contains at least one carbon and hydrogen atom). Biological sources are animals, fungi and bacteria that can also be in indoor environment. Unhealthy internal conditions may encourage their development. All types of pollutants can be more or less dangerous, depending on the amount and the exposure period. Principal air pollutions, divided considering non-biological and biological sources, are reported in Tables I and II.

TABLE I
NON-BIOLOGICAL SOURCES OF AIR POLLUTANTS, ADAPTED FROM [9]

Pollutant	Sources
Acetaldehyde	Environmental tobacco smoke, a product of wood or kerosene combustion, carpets, floorings (non rubber based and cork), paints, varnishes (VOC)
Acrolein	From the heating of oils and fats containing glycerol (during cooking), wood combustion, and tobacco smoke, biodiesels (VOC)
Ammonia	Household cleaners, environmental tobacco smoke, fuels, refrigeration units (considered a VOC by some environment agencies)
Carbon dioxide (CO_2)	A product of combustion and respiration. It is not a pollutant, in the concentrations found in most buildings, but is an indicator of bio effluents and combustion
Carbon monoxide (CO)	A product of incomplete combustion
Carbon tetrachloride	Building materials, pesticides, cleaning products (VOC)
Crotonaldehyde	Wood smoke, tobacco smoke, forest fires, and motor vehicle emissions, outdoor air (VOC)
1,1-Dichloroethene	Incense smoke (VOC)
1,4-Dichlorobenzene	Pesticides, dry cleaning solvents, aerosol propellants, degreasing agents, paint strippers, household fumigants (VOC)
Formaldehyde	Adhesive resins, insulators, paints, wood products, gypsum products, plastics, household products, carpets, acoustic ceiling panels, and combustion (vehicle exhausts) (VOC)
Nitrogen dioxide	A product of combustion
Nitrosamines	Some cosmetics, pesticides, rubber products, tobacco smoke
Ozone	Electrostatic appliances (photocopiers) operating at high voltage, outdoor air
Polycyclic aromatic hydrocarbons	A product of incomplete combustion (indoor second-hand tobacco smoke, cooking, and outdoor air)
Radon-222	From soil, rocks and building materials, and ground water
Styrene	Plastic materials such as synthetic carpets, tobacco smoking, synthetic rubbers (VOC)
Sulfur dioxide	A product of combustion of fuels containing sulfur, particularly coals
Asbestos	Long thin silicate mineral fibers formerly used as an insulator and fire retardant
Biological debris	Metabolic products and cell fragments
Chromium	A heavy metal. Food, soil, ground water, waste sides, industrial emissions. Airborne from soil erosion
Man-made mineral fibers	Insulators, carpets and furnishings
Particulate matter	A product of combustion (cooking, candles, open fires, tobacco, boilers). Organic aerosol formation, aerosol product use, hair drying, pyrolytic oven cleaning, and washing machines. The resuspension of particles by vacuuming, sweeping, and dusting. Often classified by their diameter, such as PM10, PM2.5, and PM1, where the subscript indicates the diameter in micro-meters (mm)

TABLE II
NON-BIOLOGICAL SOURCES OF AIR POLLUTANTS, ADAPTED FROM [2] AND [9]

Pollutant	Sources
Allergens	House dust, domestic animals, insects
Bacteria	-
Fungal spores	Soil, plants, foodstuffs, internal surfaces
Micro-animals	Microscopic living organisms, such as dust and spider mites (people, animals, plants, air conditioning systems)
Molds	Damaged construction materials. Found in high humidity and damp buildings
Pollen	The male reproductive cells of seed-producing plants (outdoor air, trees, grass, weeds, plants)
Spores	Released by plants, algae, fungi, and protozoa when reproducing asexually
Virus	-

B. Effect on Human Health

Polluted IAQ can cause effects on human health, which can also have serious consequences. The symptoms are generally divided into building related illness (BRI) and sick building syndrome (SBS). In the first one, they are easy recognized, but causes could not be certain. SBS is the discomfort reaction that occupants perceive because of an unhealthy environment. This distinction is shown in Table III [2].

TABLE III
BRI AND SBS SYMPTOMS, DEVELOP FROM [2]

BRI	Airborne infectious diseases
	Hypersensitivity diseases
	Toxic reactions
SBS	Upper respiratory and mucosal
	Lower respiratory
	Neuro-physiological
	Skin irritation

Health effects mainly affect the respiratory tracts, causing

disturbances in breathing or olfactory discomfort. A poor air quality can also provoke burning eyes, headaches, nausea, concentration disorder, drowsiness, psychological stress. Allergic reactions can also be developed.

Several studies deal with defining the effects that bad air quality can have on human health. For example Jacobson et al. [10] focus their researches on the effects of CO_2. They consider both acute and chronic exposure that can cause physical and psychological effects. The first one can produce inflammation; elevate interleukin production that provokes vascular damage in muscle, brain and distal colon tissue, headache, reduction of cognitive performance, decline in decision-making performance, somnolence and depressive behaviors linked to interleukin production. A chronic exposure can provoke deoxygenation of hemoglobin, causing damage within red blood cells, bone demineralization, kidney calcification (effects evaluated on guinea pigs), chronic, low-grade respiratory acidosis, behavioral changes, physiological stress, hedonic feeding behaviors, oxidative stress and endothelial dysfunction.

Krejcirikova et al. [4] report that pollutant exposure can provoke sensory nuisance, fatigue, eye irritation, itchiness, nose and throat irritation, nausea, headaches, dizziness, skin irritation, rashes, asthma, reproductive impairment, disruption of the endocrine system, cancer, impaired child development, birth defects, and immune system suppression.

Almeida-Silva et al. [11] study the effect of airborne nanoparticles. They can produce harmful health effects depositing into the respiratory track, entering into the bloodstream and into end organs, provoking oxidative stress and cancer. Jones [9] describes effect of pollutants from biological sources. They can cause allergies, respiratory diseases, asthma rhinitis, humidifier fever, extrinsic allergic alveolitis and atopic dermatitis. Also da Silva et al. [3] list the effects of poor IAQ, considering mainly VOCs, produced by human activities, furniture, outdoor pollution and building materials.

Human health effects related to different air pollutants are described in Table IV.

TABLE IV
HUMAN HEALTH EFFECTS RELATED TO DIFFERENT AIR POLLUTANTS, CONSIDERED FROM [6]

Sources	Health effects
Pollutant: CO (Carbon monoxide)	
Combustion processes (heating, stoves, fireplaces), exhaust gases from vehicles. Tobacco smoke	Carboxyl Hemoglobinuria (hinders oxygen absorption) Headaches, nausea, dizziness, Effects on nervous and cardiovascular systems
Pollutant: CO_2 (Carbon dioxide)	
Occupants (sweat, respiration, stomach and intestine). Tobacco smoke	Effects on nervous and cardiovascular systems Headaches, eye and throat irritation, dizziness, asthma
Pollutant: HCHO (Formaldehyde)	
Disinfectants, pesticides Wood preservers, construction materials, insulation foams, furniture, textiles, adhesives, paints, glues, solvents, resins. Tobacco smoke	Eye, throat and skin irritation, Respiratory problems, Dizziness, Headaches
Pollutant: VOC	
Paint, solvents, adhesives, resins and varnishes, construction materials, agglomerated cork, furniture, cleaning products, disinfectants, deodorants, fragrances, insecticides, pesticides, fungicides, tobacco smoke, proximity to gas filling stations	Smells Allergy symptoms, Headaches, nausea, dizziness, Leukemia, Lung and skin cancer, Throat and nose dryness, eye irritation
Pollutant: O_3 (Ozone)	
Photocopy machines, LASER printers, Cleaning activities, Photochemical reactions, Water disinfectant	Respiratory problems, allergic reactions, asthma, eye irritation, headaches Lung edema for prolonged or repeated exposure Mouth and throat dryness, cough
Pollutant: PM_{10} (Particulate)	
Combustion processes, tobacco smoke, Occupants, AVAC systems, Paper	Respiratory problems, cough, sneezes, Eye irritation, asthma, allergies, Dryness of skin and nose
Pollutant: Bacteria, Fungi and Legionella	
AVAC systems, construction materials, textiles (carpets), pollens, wet construction areas, occupants (bacteria), hair, and insect droppings, still waters (Legionella and fungi)	Allergies – rhinitis, sinus, asthma Infections – tuberculosis, pneumonia, cryptococcosis Irritation – eyes, nose, throat and skin (fungi) Headache, fever, Legionary diseases and Pontiac fever - Legionella
Pollutant: Radon	
Construction materials, soil from granitic regions	Increases risk of lung cancer
Pollutant: C_6H_6 (Benzene)	
Wood derived products, Tobacco smoke	Cancer
Pollutant: NO_2 (Nitrogen dioxide)	
Combustion processes	Respiratory problems, chronic bronchitis, irritation of eyes, throat, cough and dizziness
Pollutant: Naphthalene	
Tobacco smoke, Naphthalene	Eye irritation, Respiratory irritation

III. IAQ CONTROL

Considering causes and sources of indoor air pollutants, it is possible to determine how they can be controlled and decreased. It is important to manage knowingly the internal

condition, both in the project phase and during building life.

A. Ventilation

Outdoor pollutants produced by vehicular traffic and industrial activities can affect internal environment through infiltration and natural or mechanical ventilation system, as Cincinelli and Martellini affirm [1]. Building strategies to increased air tightness and the insulation can both improve internal condition and decrease IAQ. Reduction of ventilation can determinate an accumulation of pollutants.

Projecting a good air changes system is the first step to ensure good internal conditions. It is important to provide the necessary ventilation to avoid harmful substances' indoor accumulation by an efficient system. This must not allow the infiltration of air pollutions by cleaning entering air. Ventilation is one of the most important parameters that can change internal comfort and energy use.

B. Temperature and Humidity

In addition to ventilation system, internal conditions are also significant to control IAQ. It is important to consider that not only chemical properties but also physical ones, like temperature and humidity, can influence IAQ. They are normally considering important only for thermal sensation, but they can also have an important role in the internal environment as Fang et al. [12] say. As they reported ''temperature, in fact, is one of the most important factors in air quality and unless it is controlled the quality will suffer badly, no matter what the outdoor air supply, particularly when the air is overheated''.

Temperature and humidity can change odor intensity and air quality. Several studies are carried on to understand how internal moisture load can affect IAQ. Fang et al. [12] demonstrate how this two physical properties affect the perception of odor and air quality, also considering the influence of pollution levels. They carry on their studies by using climate chambers. After defining internal condition, 30 subjects evaluate odor and acceptability of the air. This experiment allows making important consideration about relationship between temperature, humidity and air quality. Giosuè et al. [13] report that level of relative humidity (RH) causes negative effect on the comfort. They affirm that the optimal one is about 50%. A RH level lower than 25% can cause discomfort and drying of the mucous membrane and skin; a high level may favor biological growth.

C. Building Materials

To IAQ control, building materials also have a significant role, as previously anticipated. Their chemical proprieties can cause harmful or beneficial effect. Building materials can emit noxious substances to human health, acting as pollution sources. It may be caused by their chemical properties, use or deterioration and it may be more or less harmful to organism. Some materials can also favor the development of biological pollution sources. On the other side, some building materials can act as "air filters". Several studies demonstrate their buffering moisture capacity, and their absorption of CO_2, VOCs and harmful substances. By assimilating RH and pollutions, they can affect significantly IAQ and disease the insane environment conditions. The sorption phenomenon is studied by da Silva et al. [3]. They consider 15 different natural materials (insulation, coating and wood panels) and, by using environmental chambers, they analyze absorb and re-emit of VOCs and formaldehyde. They affirm that absorption/ desorption characteristics are related to the material microstructure and polarity of the VOCs; emissions depend on the chemical composition of building materials and the production process. The experiment demonstrates that wood-based panels have the highest emission of formaldehyde; sheep wools have the lowest. As these materials can change the emission of VOCs, they can affect IAQ in a passive way. For these reasons, in an architectural project, it is important to choose carefully building materials used and know their properties.

IV. Eco-Efficient Plasters

Among the several studies carried on to improve IAQ control, many of them concerned the development of new eco-materials and components. The aim is to guarantee both healthier and more energy-efficient buildings through humidity control and the passive techniques to remove airborne chemical pollutants [3].

A. Plasters and Internal Conditions

The IAQ is also related to building materials, as previously described. They can affect indoor conditions from different points of view. For example, an isolating material can change internal temperature, time required to achieve comfort conditions, air rate and energy consumption. A structural material can modify the construction system and therefore all the structure's function. Transparent materials affect both internal temperature and the visual comfort.

Among the building materials, plasters are extremely important in air quality because they are always in contact with it. They can significantly influence internal condition by their chemical properties. They can change concentration of air pollution and humidity by their sorption and re-sorption capacity.

Several studies, analyzes, laboratory tests and experiments are carried on to deepen the knowledge concerning their proprieties [3]-[5]. Nowadays non-conventional building materials are also considered to guarantee a sustainable architecture development.

B. Eco-Efficient Material Proprieties

Eco-efficient plaster materials are taken into account because they can both improve IAQ and reduce energy consumption. Since they are already present in nature, their production does not require a high-energy consumption.

Several studies, reported below, concerning different type of unconventional materials, are carried on. Analyzing them can be useful to understand how research may be developed, even if they illustrate behavior of different materials. For example Krejcirikova et al. [4] carry on a research about emissions from cement-based and cement-ash-based mortar

slabs, singly and together with linoleum and carpet. In ash mortar, fly ash used partially replaces cement. For this reason, this study supports researches about alternative constructions solution to reduce cement production. The experiment carried out with climatic chambers is described. Sensory perceptions are analyzed and chemical measurements are deepened. The research demonstrates that IAQ changes by modifying the type of plaster considered. This experiment shows also how future laboratory tests could be carried on.

Considering the possibility of using eco-efficient plasters, studying earth is interesting. This material has several benefits: it is natural, non-toxic, ecological, non-polluting, with low embodied energy and economic (especially if it is used at the construction site). Construction techniques that use earth plasters can be very effective for IAQ and humidity control.

Liuzzi and Stefanizzi [7] consider the capacity of earth materials to improve the internal conditions. They analyze their features by WUFI+ simulations, a software used to study buffering capacity. They examine clay plaster, describe how simulations are carried on and report significant the results. They show that these materials can affect internal humidity, and therefore IAQ, temperature and energy consumption. The simulations are realized both without and with HVAC system, to study also the relation between building materials properties and mechanic ventilation system.

McGregor et al. [8] present an important review about buffering capacity of earth building materials. They consider that a passive control of RH levels can be more effective than a control through ventilation. Experimental works about moisture buffering capacity of material are described. They consider the dynamic adsorption or earth blocks, rammed earth and earth plasters. They explain that earth plasters have a lower absorption capacity than earth blocks, yet have higher moisture buffering value than existing result on rammed earth. Values of buffering moisture capacity are reported. The research demonstrates that earth building materials can control RH and improve IAQ. Also Lima et al. [5] describe earth plaster property. They consider 16 earth mortar formulations, evaluating hygroscopic characterization and behavior when in contact with liquid water. Vapor permeability, low-pressure water absorption, capillary water absorption and drying test are considered. The results report different behaviors depending on the grain size and the presence of natural fibers. Earth-building material combined with other natural ones could have a better absorption capacity, affecting IAQ in a passive way.

V. Discussion and Future Research

Throughout the researches carried on to this paper, it is possible to make some useful considerations that can support also future studies. First, it is important to take into consideration that IAQ depends on several factors. A more detailed research is required to better understand causes, effects and solutions to develop internal environment conditions. Moreover building materials' adverse effects are not described in detail in this paper. This is not one of the aims of this work, but this argument requires a more in-depth analysis. Knowing materials' proprieties is extremely important and by the study of them, it is possible to realize more healthy architectural projects. Finally, it is essential to consider that only some experiments and studies concerning natural materials are reported. They are significant for the research method and the topics covered. To deep these studies it may be useful examining more, also considering conventional and natural materials unions.

As anticipated, this paper wants to be a support for future researches concerning earth plasters. It would be useful to carry out further laboratory tests to evaluate the reactions that these materials have on IAQ. It would be interesting to observe sorption and re-sorption of humidity and pollutants, considering internal and external environment. Analyzing how properties can change due to poor IAQ exposure is also an interesting theme.

Simulations should accompany the laboratory tests. This could allow making a priori and a posteriori considerations to understand better these topics.

VI. Conclusion

Researches considered in this paper allow reaching important conclusion.

First, it is possible to affirm that IAQ is extremely important for human health. This can affect it even more than outside air, since people pass most of their time inside. There are several health effects depending on the type of pollutant. Cause-effects studies are fundamental to guaranteeing healthier constructions.

Considering the sources of air pollution, it is possible to understand the factors that can modify the IAQ. Ventilation control is not the only way to improve internal conditions. Temperature and humidity also play a fundamental role and therefor the building materials must be considered. Their chemical properties can significantly influence the indoor environments.

Several natural materials can guarantee a better IAQ control; by using them, it is possible to ensure the sustainable architecture development. They can both reduce energy consumption and increase health conditions and internal comfort.

Researches and experiments already carried out can be a starting point for the future ones. They demonstrate the buffering capacity of these natural materials and the possibility to control internal humidity in a passive way.

Earth plasters can be a great solution as they have many benefits. Clay is already present in nature, it requires low energy consumption, is a non-toxic material and it is available in large quantities. It has a good absorption moisture capacity and it is possible to make compounds with earth and other natural materials.

Future research can start from this knowledge to guarantee the development and diffusion of more eco-efficient materials. This can help the development of a sustainable and healthy architecture.

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