Field Measurement Studies on Indoor Air Quality

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indoor environmental quality | thermal comfort | indoor air quality

1. Introduction

According to recent studies, people nowadays spend most of their lifetime indoors [1]. Undoubtedly, the Indoor Air Quality (IAQ) is one of the key factors that influence the quality of the indoor environment, as well as the human health [2]. Various health problems have long been known to arise from poor IAQ, with the most severe ones to include lung cancer, carbon monoxide poisoning, pneumonia, asthma, and various allergies [3]. In fact, household air pollution was the main cause for 3.8 million deaths according to the World Health Organization (WHO), which corresponds to 7.7% of the worldwide mortality in 2016 [4]. Note that household fuel combustion is a key contributor for indoor air pollution, especially in developing countries, where the cooking and heating primarily rely on solid fuels including wood, charcoal, and crop waste [5]. The recent lock-downs due to the current COVID-19 pandemic forced most people to work remotely from their homes and has highlighted more than ever before the importance of Indoor Environmental Quality (IEQ) monitoring.

All environmental aspects have a massive impact on the quality of people's lives [6]. Inadequate ventilation and poor IAQ are the key contributors to the Sick Building Syndrome (SBS) [7] which considerably influences the human health and workers productivity. In the United Kingdom and the United States, it is estimated that the State loses roughly 15 billion pounds and 38 billion dollars, respectively, due to reduced productivity of workers and illnesses caused by inadequate supply of fresh air alone [8]. In fact, a workplace with high IEQ obviously improves the workers' health and mood, thereby increasing their productivity and plays a crucial role on the profitability of businesses. Generally, investing on improving IEQ in workplaces is characterized by a short pay back period and generates additional monetary returns thereafter [9]. Studies on the quality of IEQ among students have shown that inadequately set parameters can have a drastic impact on students' cognitive abilities [10]. It should be noted that buildings being rated as "sustainable and green" do not truly guarantee their compliance with the desired IEQ level [11][12][13][14]. Hence, the stringent need to build NZEB (Nearly Zero Energy Buildings) [15][16][17], whose design requires a holistic approach based upon the principles of sustainability, should also focus on ensuring IEQ while designing new buildings, as well as when retrofitting old ones. The need to include IEQ in the building design has also been identified over the last two decades by various green building certification systems, such as the Building

Research Establishment Environmental Assessment Method (BREEAM) from the UK, Green Star from Australia, and Leadership in Energy and Environmental Design (LEED) from the US [18][19][20].

The quality of an indoor space in relation to the health, comfort, well-being, and productivity of occupants forms the IEQ. The concept of IEQ is very broad and depends on many variables such as temperature, relative humidity, air velocity, air flow, occupancy, concentration of pollutants, noise and lighting. These are commonly grouped into four major areas [21] that define the quality of the environment inside a space, namely: (i) Indoor Air Quality (IAQ) [22], (ii) Thermal Comfort [23], (iii) Acoustic Comfort [24][25][26], and (iv) Visual Comfort [27][28], as depicted in **Figure 1**. As shown in the Figure, we additionally propose that (v) Virus Risk, also becomes an essential IEQ pillar. The subject of airborne viruses has been extensively investigated by various research communities in the last two decades. Experimental studies on the presence of virus in air samples are carried out mainly under controlled laboratory conditions. The impact of environmental parameters (e.g., temperature, humidity) on airborne viruses has been also explored, but it still not clear due to the complexities involved. Regarding the estimation of the probability of virus transmission indoors, a number of risk assessment models have been proposed for this purpose. However, only a limited number of IEQ field measurement studies so far have considered the use of real environmental measurements for computing the airborne virus risk.

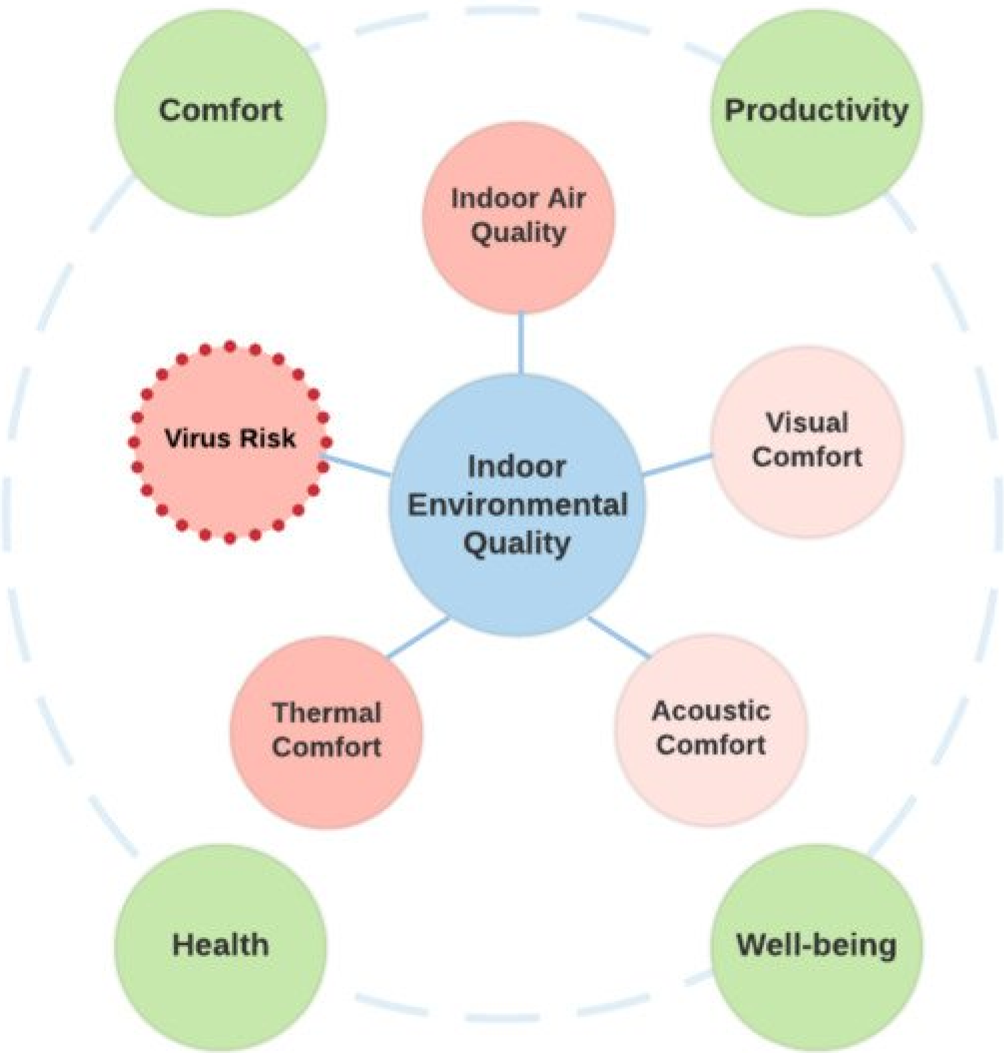

Figure 1. Typical influencing factors of the IEQ.

IEQ evaluation depends on numerous factors that can be subdivided into four categories: external conditions (temperature, air pollution, noise, sun and natural lighting, green environment), building (enclosure, construction material, furniture), building services (HVAC systems, lighting) and human activities (HVAC use, cleaning, use of paints, varnishes, and glues) [29]. The assessment of IEQ is mainly performed by two approaches, Post-Occupancy Evaluations (POE) and field measurements [9]. In the case of POE, a subjective assessment of the IEQ is performed based on data collected using occupants' questionnaires. In the latter case, an objective assessment of IEQ is performed using data collected by instruments (i.e., sensing devices, portable loggers or passive samplers). Data acquired by both field measurements and occupants' questionnaires can contribute towards a more accurate and comprehensive analysis of the indoor environment as perceived by the occupants. To achieve a complete and reliable characterization of thermal comfort and IAQ levels in the built environments and related energy needs, several challenging issues must be addressed with regard to properly designing measurement campaigns (not only from technical and operational perspectives, but also by managing psychological and physiological issues) and effectively elaborating huge amounts of field data.

2. Building Type

Figure 2 illustrates statistics on the type of built environment for the 41 selected field measurement studies. From the plot, it becomes evident that the majority of field studies were conducted in Educational facilities with a percentage of approximately 49%, followed by Offices and Residences, both with 14.5%, Care centers with 7.5%, while the remaining 14.5% were either conducted in a combination of the aforementioned built environments, or in other types of buildings. It is worth pointing out, that educational facilities are characterized by high levels of occupancy, the young age of occupants, the long duration and the weekly consistency of activities from the same occupants; characteristics which render them ideal environments for such controlled field studies. It is evident however, that a very limited number of field measurement studies exist for other types of indoor environments, such as gyms, hospitals, shopping malls and train stations. Such environments are also of high interest since they exhibit a high number of occupants daily both in terms of staff and visitors with various types of activities and could significantly contribute to the understanding of the impact of poor IEQ.

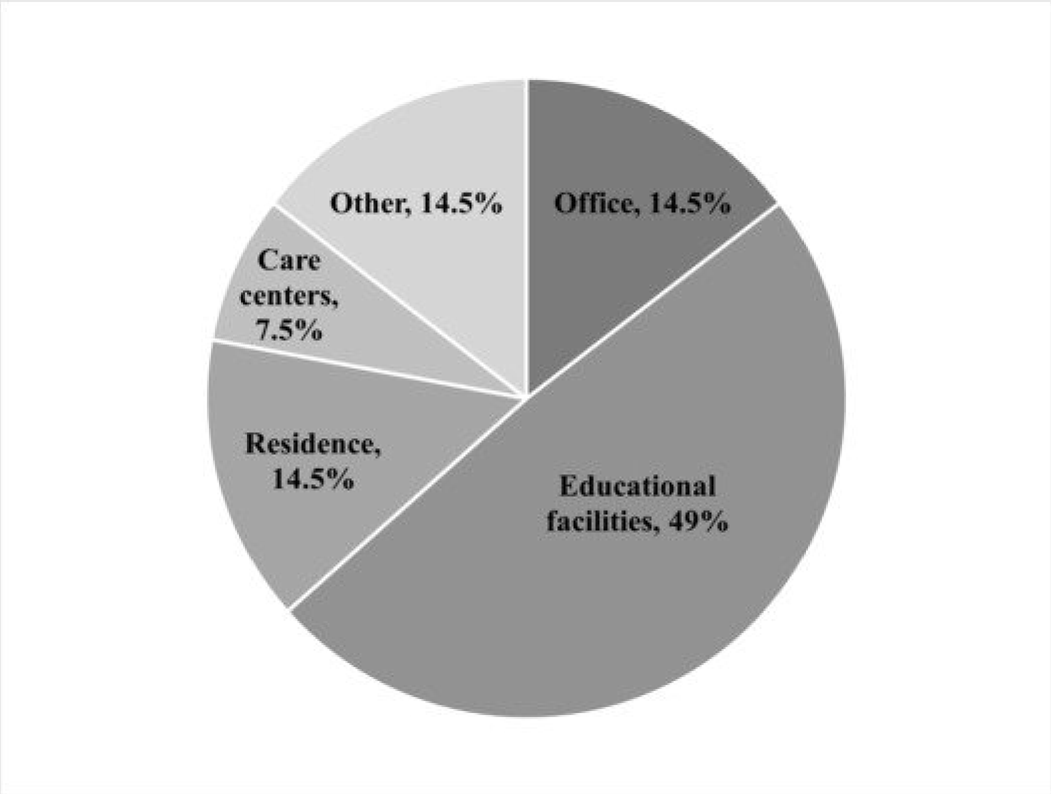

Figure 2. Building type statistics for the selected field measurement studies.

3. Measured Parameters

Figure 3 illustrates the percentage of the studies considering each measured parameter. It is evident that the most common parameters measured in the considered field studies are T and CO_2 with 75.6% and 73.2% of the field studies, respectively, followed by RH with 70.7% of the field studies, PM with 56.1% and VOC with 41.5%. On the other hand, the least common parameters are Rn which is considered in just 4.9% of the field studies, SO_2 with 7.3% of the field studies, O_3 with 9.8%, HCHO with 12.2%; while RT, N, and NO_2 were considered in 17.1%, 14.6% and 17.1% of the field studies, respectively. Interestingly, one of the most harmful gases, i.e., radon (Rn), is at the same time the least studied parameter throughout the presented studies. However, one of the largest studies presented in [30] that considers 319 classrooms from 115 schools in Europe has already identified that Rn levels were above recommended in the majority of the field sites. One could thus argue that Rn monitoring and the understanding of its impact in our daily lives is still an under-investigated problem.

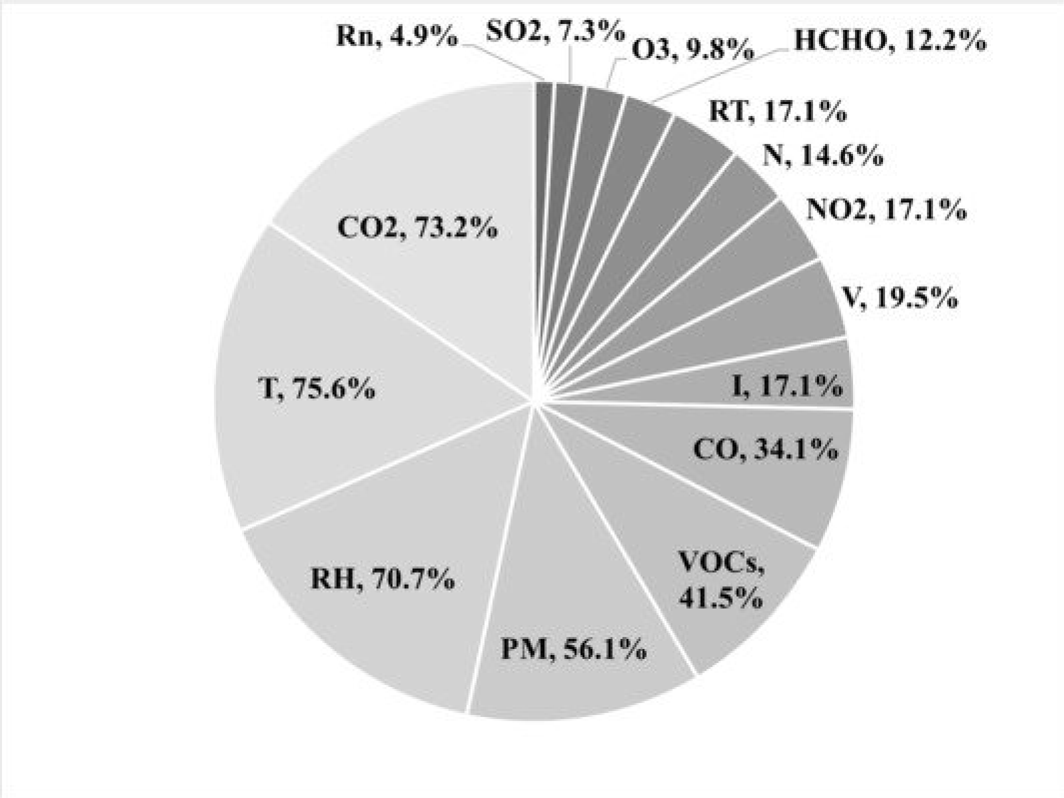

Figure 3. Measured parameter statistics for the selected field measurement studies.

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