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Ventilation rate determination method for residential buildings according to TVOC emissions from building materials

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A B S T R A C T

People spend most of their time indoors in residential buildings; thus, maintaining good indoor air quality (IAQ) is essential. It is necessary to provide a suitable ventilation rate in these spaces (low-density occupation) taking into account that materials (finishes and furnishing) are one of the main sources of indoor pollution. For that purpose, this research, based on both the National Research Council (NRC) database and a specific case study, followed a method that consisted of the identification of indoor pollution sources, evaluation of the emission factor and characterization of the IAQ. It is intended to show the influence of materials (quantity, type and age), loading ratio and pollution concentration threshold in the calculation of a ventilation rate which guarantees a good IAQ. This study also reflects the need to bring together an overall pollution concentration threshold of TVOC, below which a safe level of exposure to indoor pollution is recognized.

1. Introduction

Today, in developed countries, most time is spent indoors [1] and, depending on each person, presence at home ranges from 60% to 90% of the day, and 30% of that time is spent sleeping [2]. Taking these data into account, indoor residential environments have a direct influence on human health; consequently, having a good indoor air quality (IAQ) in those spaces appears to be essential. Thus, reaching high concentrations of volatile organic compounds (VOCs), which cause risks for the occupant health, can be avoided. One of the main causes which trigger high indoor pollution in dwellings is the VOC-emission materials, such as wet materials in new buildings and a mixture of wet materials and furnishings in old buildings [3–5]. Examples of materials with high VOC-emission rates are paints and coatings, adhesives, carpeting, etc. It should be noted that indoor residential environments also have high concentrations of aldehydes and terpene hydrocarbons due to the use of wood and its derivatives [6].

Emission source control (by limiting the use of high VOC-emission materials), along with dilution control (through ventilation processes), are the most effective strategies to control the IAQ [4,7]. The purposes of those control methods are both to prevent indoor pollution and to establish proper ventilation rates in order to deal with uncontrolled emission sources [8,9]. During the process of finishes selection, at the design stage of the residential building, both construction and use stages are affected, not only in terms of IAQ, but also in terms of energy efficiency and economic cost. Therefore, an exhaustive analysis has to be developed, especially during the design stage, with the purpose of saving energy and resources, in such a way that the lower the materials VOC-emissions, the more the energy efficiency achieved [7], since the need for ventilation will be reduced.

VOCs play an important role in the IAQ evaluation process. They adversely affect both occupant comfort [10] and health [11–14] and they reduce productivity [15,16]. VOCs exposure effects in non-industrial indoor spaces vary from sensory irritation, at low and medium exposure levels, to toxic effects at high exposure levels [17]. Formaldehyde (HCHO) is especially important as it is known to be the highest indoor airborne irritant, causing eye, nose and throat irritation (at concentrations higher than 0.1 mg m^{-3}) [18,19] and may possibly even cause asthma attacks at high concentrations

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[18]; additionally, it is classified as carcinogenic by several scientific studies and organizations [20–22]. Most of the health hazards related to VOCs emissions occur during the first months of occupation or after refurbishing the building [23], since the highest VOC indoor concentrations are usually found on new or renovated buildings.

Previous studies [24–26] provide total VOCs concentration data by using the concept of total volatile organic compounds (TVOC). This parameter is used to perform a simpler and faster interpretation than the analysis of a high amount of VOCs which is usually detected in indoor spaces [27]. The concentration of any pollutant in an interior space results from the balance between the net emission in that space and what is removed or added by ventilation. Therefore, if the TVOC level is high, it indicates that there are significant sources of contamination or that the local ventilation is inadequate. Thus, it is important to take measurements of TVOC concentration, since they represent an indication of contamination load in the indoor environment and of the sustainability of the ventilation rate supplied [28]. It should be noted that the TVOC concentration value does not contain all the VOCs present in indoor air since there are organic pollutants that are not included, such as low molecular weight aldehydes, like HCHO, because the identification method differs from that for the rest of the VOCs. Consequently, in order to characterize the IAQ and to determine an appropriate ventilation rate, it is essential to consider the concentration of TVOC and HCHO.

The objective of this study is to propose a preliminary method for determining the appropriate ventilation rates in residential buildings in Spain based on the emissions from building materials, finishes and furnishings. The application of the method is done by evaluating a case study consisting of a single bedroom and by taking into account different materials (only finishes, and finishes together with furnishings); by considering several configurations of the space (volume variation); and by using different regulations for IAQ (modification of the allowable TVOC concentration limit). This method is based on the guidelines of ASHRAE [29] and it is applicable in interior spaces where finishes and furnishings are important sources of pollution, such as indoor residential environments where there is a low-density occupation. It is intended to show the influence of the materials, the loading ratio (relation between the surface of the emission source and the volume of the room) and the maximum allowable concentration in the calculation of an appropriate ventilation rate.

2. Methodology

To determine the appropriate ventilation rate, the following steps were performed [30]: (a) identify the concentration emission sources, (b) evaluate the emission factor of these sources (together with the pollution concentration produced as a function of time) and (c) determine the IAQ. In this study, a typical room was considered and several emission sources were introduced using the database included in the IA-Quest software [31] (developed from the CMEIAQ project [32]). This is an IAQ simulation software developed in Canada by the National Research Council (NRC) to evaluate the impact of VOC emissions from building materials, finishes and furnishings on both IAQ and occupant health.

2.1. Emission sources identification

A standard single bedroom was studied, where the geometric dimensions and emission sources were defined in order to establish both the loading ratio and the emission factor of the sources and to determine an appropriate ventilation rate. The room is defined in Fig. 1, which shows the geometry of the room and the furnishings it

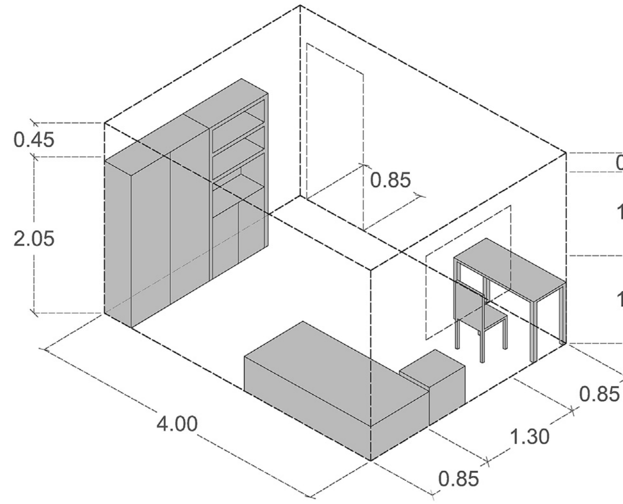

Fig. 1. Standard room dimensions.

contains. Table 1 shows the surfaces and volumes of the various elements, together with the names and IDs of the materials used, as defined by the NRC database. The selection criterion followed in this study is based on choosing from the NRC database the typical materials used in residential buildings in Spain that are representative within their category.

In this investigation, the method used to determine the ventilation rate was based on the sum of the different air exchange rates required by each material. Additionally, the sink effect of materials, or the absorption of VOCs by wall and other surfaces indoors, is usually taken into account when evaluating IAQ, since VOCs are temporarily lost and reduced from the indoor environment; however, this effect was not considered, since a room with a good air mixture was assumed and adsorbents such as wallpaper or adhesives were not included.

2.1.1. The age of materials as a parameter influencing the emission factor

Most of the health hazards associated with VOC emissions occur during the first few months of building use or after remodeling, as the highest concentrations of VOCs are found in new or renovated buildings. Therefore, as shown by several investigations that have evaluated the influence of the age of the building on the levels of indoor VOCs concentration [33–38], it is important to take into account the age of the materials to characterize VOC emissions in residential indoor environments [23]. For this reason, 4 different periods of study were considered to establish the corresponding ventilation rate: 3 months, 6 months, 1 year and 2 years. These four periods were defined considering previous research developed by Ye et al. (2016) [30] that established two years as the period of time when VOC emissions are reduced to their minimum intensity.

2.2. Ventilation rate determination

2.2.1. Theoretical quantification of the emission rate

Two terms are commonly used to describe the emission rate, as described in the ASTM D5116-10 Standard [39], from indoor materials: the emission factor (EF) and the emission rate (ER). ER is the emitted mass of pollution (mg) per unit of time (h) and it can be applied to sources with emission area as well as to sources without emission area, while EF is shown as mass/surface/time. Both concepts are related as shown in equation (1), where ER is the emission