Building and Environment 95 (2016) 133–144

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Methodology for assessing human health impacts due to pollutants emitted from building materials

Hyo Seon Park, Changyoon Ji, Taehoon Hong*

Department of Architectural Engineering, Yonsei University, 50 Yonsei-ro, Seodaemun-gu, Seoul, 120-749, Republic of Korea

ARTICLE INFO

Article history:
Received 26 May 2015
Received in revised form
31 August 2015
Accepted 2 September 2015
Available online 9 September 2015

Keywords:
Human health impacts
Pollutants
Life cycle assessment
Intake fraction
Emission model
Building materials

ABSTRACT

Pollutants, which are emitted from building materials during the 'use phase', may have significant adverse impacts on human health. This study proposes a methodology for assessing the impacts on human health due to pollutants emitted from building materials during the 'use phase'. The proposed methodology estimates the amounts of pollutants emitted from building materials by applying the emission factors measured by chamber tests to the emission models. Then, the human health impacts are derived by multiplying the intake fraction and human health effect factors by the amount of pollutants emitted from building materials. In case study, the human carcinogenic potential (HCP) (6.74E-05 $case_{can}$) calculated by the proposed methodology was almost identical to the HCP (6.80E-05 $case_{can}$) calculated by the health risk assessment. It turns out that the proposed methodology is capable of producing reasonable results. The proposed methodology can be expected to assess the human health impacts of buildings more accurately in LCA. In addition, the proposed methodology will be useful to improving the indoor environment of buildings because it can predict the impacts on human health during the building design phase.

1. Introduction

Various pollutants such as formaldehyde, which are emitted from building materials during the 'use phase' [1], can negatively affect human health (e.g., cancer) [2–4]. In particular, since the indoor concentrations of pollutants are significantly higher than outdoor concentrations [5,6] and people spend more and more time indoors during their whole lives [7–9], indoor pollutants may more negatively affect human health than outdoor pollutants [10–13]. Thus, various efforts have been made to reduce the health impacts due to indoor pollutants [14–16]. For example, in South Korea, the *Indoor Air Quality Control in Public-use Facilities, etc. Act* specifies that the concentration of formaldehyde in a new apartment house should be below 210 μg/m^3 [15].

Generally, the health risk assessment has been used to assess the human health impacts due to indoor pollutants emitted from building materials [17–23]. However, since the health risk assessment assesses the impacts on human health based on the indoor concentration of pollutants measured, it cannot predict the human health impacts of buildings at the building design phase. Life cycle assessment (LCA) has been used to assess the environmental impacts of buildings including the human health impacts by considering the building life cycle [24–27]. In addition, LCA can predict the human health impacts of buildings based on the information obtained from the design phase. However, it did not consider pollutants emitted from building materials. The human health impacts due to indoor pollutants emitted from building materials may be much more significant than those due to outdoor pollutants emitted from the material manufacturing. Thus, the pollutants emitted from building materials should be included in the system boundary of LCA. Although several LCA studies considered pollutants emitted from building materials, they did not propose a methodology considering both the inventory analysis (i.e., calculating the amount of pollutants emitted from building materials) and impact assessment (i.e., calculating the human health impacts due to the pollutants) [28,29].

Therefore, this study aims to propose a methodology assessing the potential impacts on human health due to pollutants emitted from building materials during the 'use phase', which is able to be integrated into LCA. To this end, this study is carried out as follows: (i) reviewing the health risk assessment and human health impact assessment in LCA; (ii) proposing the methodology for assessing

* Corresponding author.
E-mail addresses: hspark@yonsei.ac.kr (H.S. Park), changyoon@yonsei.ac.kr (C. Ji), hong7@yonsei.ac.kr (T. Hong).

http://dx.doi.org/10.1016/j.buildenv.2015.09.001
0360-1323/

human health impacts due to pollutants emitted from building materials during the use phase; (iii) conducting a case study to validate the proposed methodology and demonstrate the necessity of the methodology.

2. Existing methodologies for assessing human health impacts due to pollutants

2.1. Health risk assessment

Health risk assessments have often used to evaluate the adverse effects of indoor pollutants on human health. Health risk assessment includes four steps: hazard identification, dose–response assessment, exposure assessment, and risk characterization [30]. The hazard identification examines whether a substance has the potential to negatively affect human health. During the dose–response assessment, the relationship between exposure to pollutants and effects is examined. Generally, the information on the hazard identification and dose–response assessment steps has been obtained from the existing database [17–23,31,32]. For example, the integrated risk information system (IRIS) has been developed by the Environmental Protection Agency (EPA) to provide consistent information on chemical substances for use in risk assessments [33,34]. The persistent organic pollutants (POPs) toolkit has been created as part of the World Bank Regional Capacity Building Program for Health Risk Management of Persistent Organic Pollutants in South East Asia Project [35]. These databases contain information such as the unit risk, slope factors, and reference concentration (*RfC*) [34,35]. Unit risk is an excess cancer risk (ECR) which can be estimated when a healthy adult is continually exposed to air contaminated by a unit concentration (1 μg/m^3) of a pollutant. Slope factor is the probability of incurring cancer per unit exposure level (mg/kg·day). *RfC* can be defined as an exposure reference level that does not cause toxic effects after a lifetime of exposure to the pollutant [21,22,36,37]. The exposure assessment estimates the lifetime average daily doses (LADD) by considering parameters such as the indoor concentration of pollutants, inhalation rate, exposure duration, exposure frequency, and the body weight and lifetime of occupants, as shown in Equation (1) [19–21]. Here, the indoor concentration of pollutants, which is measured by methods such as the gas chromatograph [15], is used. The risk characterization step presents the risk to human health by integrating the results of the preceding steps. For instance, the cancer risk, which is represented as the ECR, is calculated by multiplying the LADD by the slope factor of the pollutant, as shown in Equation (2). The non-cancer risk, which is represented as the hazard quotient (HQ), is calculated by applying the *RfC* to LADD. As *RfC* is established based on the average body weight (70 kg) and daily inhalation rate (20 m^3/day) of an average adult in the United States, 70 kg of the body weight and 20 m^3/day of the daily inhalation rate are applied, as shown in Equation (3) [19–22].

$$LADD = \frac{C \times IR \times Ed \times EXF}{BW \times LT \times 24} \tag{1}$$

$$ECR = LADD \times Slope \quad factor \tag{2}$$

$$HQ = \frac{LADD}{RfC \times 20(m^3/day) \div 70(kg)} \tag{3}$$

where, *LADD* is the lifetime average daily doses (mg/kg·day); *C* is the indoor concentration of pollutants (mg/m^3); *IR* is the inhalation rate (m^3/day); *Ed* is the exposure duration (year); *EXF* is the exposure frequency (h/day); *BW* is the body weight (kg); *LT* is the lifetime (year); 24 is the hours in a day (h/day); *ECR* is the excess cancer risk; *HQ* is the hazard quotient; RfC is the reference concentration (mg/m^3), 20 is the average daily inhalation rate of an average adult in the United States (m^3/day); and 70 is the average body weight of an average adult in the United States (kg).

2.2. Human health impact assessment in life cycle assessment

Various life cycle impact assessment (LCIA) methodologies such as CalTox have been developed to assess human health impacts [38–44]. These LCIA methodologies consider exposure and dose–response assessments. However, LCA methods using these LCIA methodologies differ from health risk assessments in terms of the assessment process.

In the health risk assessment, the LADD is calculated by directly considering parameters such as the indoor concentration of pollutants, inhalation rate of occupants, exposure duration, exposure frequency, and the body weight and lifetime of occupants. The potential impacts on human health are calculated by applying the slope factor to the LADD [17–20].

The health risk assessment assesses the adverse health impacts based on the indoor concentration of pollutants measured during the building use phase [30], while the LCA methods assess the human health impacts based on the amount of pollutants which is calculated by the life cycle inventory analysis [28,29]. Life cycle inventory analysis, which is the first step of four LCA basic steps, quantifies the amount of substances emitted from the life cycle of products or services [45]. In LCA, the amount of inhaled and ingested pollutants is then calculated by applying the intake fraction to the amount of pollutants calculated by the life cycle inventory analysis. The intake fraction, which represents the ratio of the amount of emitted pollutants to the amount of inhaled and ingested pollutants, is calculated by considering parameters such as the average inhalation rate, exposure duration, population, wind speed, temperature, and space volume in advance [46]. Finally, by multiplying the amount of inhaled and ingested pollutants by the human health effect factors (*HEFs*) of the pollutants, the human health impact is calculated. The HEFs, which signify the health impact caused by one unit of the inhaled or ingested pollutants, is derived based on the data such as slope factor [41]. As the intake fraction reflects the average values instead of actual values of the parameters such as inhalation rate and exposure duration, the human health impact calculated by LCA is the predicted value in contrast with the result of the health risk assessment.

In addition, the existing LCA methods did not consider the human health impacts due to pollutants emitted from building materials during the use phase, although they have considered the human health impacts due to pollutants emitted from the manufacturing process of building materials. Therefore, this study develops a methodology to assess the human health impacts due to the pollutants emitted from building materials and integrated into the LCA.

3. Materials and methods

As shown in Fig. 1, the methodology for assessing human health impacts due to pollutants emitted from building materials during the use phase consists of three steps: (i) estimating the amount of pollutants emitted from building materials, (ii) calculating the amount of inhaled and ingested pollutants, (iii) assessing the human health impacts due to the inhaled and ingested pollutants.