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87

Health risk assessment by CRPS and the numerical model for toluene in residential buildings

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ABSTRACT

Purpose: Indoor air quality in residential buildings needs to be evaluated over the long term. In previous research, there has been an attempt to perform the health risk assessment of pollutants by using numerical models as a method of long-term evaluation. However, the numerical model of this precedent study has limitations that do not reflect the actual concentration distribution. Therefore, this study introduces the CRPS index, constructs a numerical model that can reflect the concentration distribution, and then presents a more accurate health risk assessment method using it. At this time, the pollutants are toluene, which is a typical material released from building materials. **Method:** CRPS index was applied to existing numerical model to reflect concentration distribution. This was used to calculate concentrations at adult breathing area and to use them for exposure assessment in a health risk assessment. After that, we entered adult data and conducted a health risk assessment of toluene. **Results:** The non-carcinogenic risk of toluene was calculated to be 0.0060. This is 5% smaller than the existing numerical model, meaning that it is more accurate to predict the pollutant risks. This value is also lower than the US EPA reference value of 1. Therefore, under the conditions of this study, long-term exposure of adults to toluene has no impact on health.

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KEYWORD

건강위해성평가
CRPS
수치모델
톨루엔
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1. Introduction

Modern people are getting more and more time to live indoors, and there is a problem of indoor air quality due to lack of ventilation made by the closure of buildings and expansion of chemical use [1] [2]. According to the National Statistical Office's Life Time Survey (2014), Koreans are living in housing for about 50% of the 24 hours [3]. Therefore, indoor air quality problem is especially important.

Representative materials that cause indoor air quality problems in homes include formaldehyde (HCHO) and volatile organic compounds (VOCs) from building materials and living pollutants [4]. This causes problems such as Sick Building Syndrome (SBS), Multiple Chemical Syndrome (MCS), which cause various diseases such as headache, dizziness, nausea, drowsiness and atopic dermatitis and seriously threatens the health of the occupants [5]. In Korea, the concentration of pollutants in the house is compared with the indoor air quality recommendation standard of the new housing complex of "Multi-use facilities indoor air quality management law" and it is regulated below the standard.

However, even low concentrations of contaminants that do not exceed the recommended standards may present long-term exposure hazards [6]. In particular, vulnerable groups such as elderly people and children are vulnerable to low-level long-term exposures because they have a high longevity time in the house and weak immunity [7] [8]. Therefore, it is necessary not only to regulate the indoor air quality in the house to be below the recommended standard but also to evaluate it in the long term and to establish preventive measures.

One of the methods to evaluate the indoor air quality over the long term is the health risk assessment [9]. Health risk assessment is an easy way to assess the possible effects on the human body that can be caused by prolonged chemical exposure. In previous research, there have been attempts to construct an appropriate numerical model to calculate indoor pollutant concentration and to perform health risk assessment using it. Young-Hee Kim(2006) used toluene emission model of indoor finishing materials by actual measurement and evaluated the health risk of toluene in new housing [10]. In addition, Da-Young Kim(2016) constructed a numerical model using the release rate function of toluene and benzene and indoor living source scenarios, and assessed the health risks of toluene and benzene in the apartment complex [11].

However, the concentration calculated from the numerical model of the preceding study has a limit of the complete mixed

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concentration without considering the concentration distribution of the indoor pollutants. In practice, the results may be overestimated or underestimated when performing a health risk assessment using the calculated concentrations because the concentrations of pollutants vary depending on the indoor location.

The purpose of this study is to construct a numerical model considering the concentration distribution of indoor pollutants and to suggest a health risk assessment method using them.

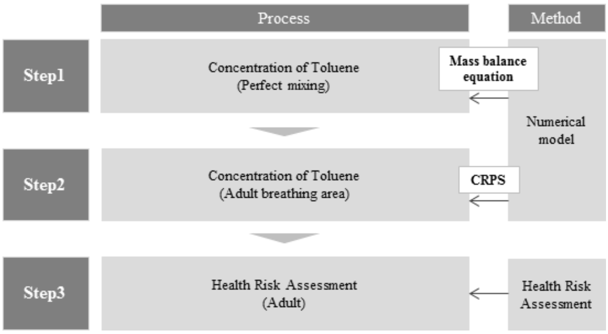


Fig. 1. Process and method of the study

To accomplish the purpose of this study, we used a numerical model that considers indoor pollutant concentration distribution and a health risk assessment method. The numerical model does not exist independently of the health risk assessment, and the concentration calculated using the numerical model is used in the exposure assessment phase, which is a step in the health risk assessment. The specific procedure for carrying out this study is as follows.

First, a numerical model is constructed using the mass balance equation used in the previous research, and the change in the pollutant concentration in the target space is calculated over a 24-hour period. That is, the transient state analysis is performed. At this time, the subject space is set as a living room of a common apartment house. The contaminants are also limited to toluene, one of the volatile organic compounds. Toluene is a typical contaminant released from architectural finishes and living pollutants [12].

Second, the perfect mixing concentration of toluene calculated is converted into the concentration at a specific point in the room in consideration of the concentration distribution. The CRPS index is used for this purpose. Contribution Ratio of Pollutant Sources (CRPS) is an index suggested by Kim (2007). Using CRPS, the concentration of pollutant concentration can be calculated at any point in the room [13]. On the other hand, the room specific point is located at the center of the room and is the breathing height of the adult. It is then used in health risk assessments targeting adults.

Finally, a health risk assessment of toluene is conducted on adults using concentrations calculated at specific sites.

The method and the specific procedure of this study are expressed in <Figure 1>.

2. Theoretical Background

2.1. Health Risk Assessment

Health risk assessment is the process of qualitatively or quantitatively estimating lifelong human impacts that may be caused by chemicals. Health risk assessment consists of four steps: hazard identification, exposure assessment, dose-response assessment, and risk characterization [9].

(1) Hazard Identification

Hazard identification is the step of identifying the chemical causing a deleterious effect on the body when a chemical is exposed to. Toxicity and carcinogenicity of substances are confirmed based on various evidence data such as epidemiological data, toxicity data, and experimental data. Although the method varies from country to country, this study referred to the United States Environmental Protection Agency (EPA) data [14] [15].

(2) Dose-Response Assessment

The dose-response assessment step is a quantitative assessment of how risky a risk-identified substance has. This approach is divided into non-carcinogens and carcinogens. According to US EPA's Integrated Risk Information System (IRIS) data, toluene is classified as a non-carcinogenic toxin in this study. For toluene, a non-carcinogenic toxin, the risk is determined based on the Reference Concentration (RfC).

(3) Exposure Assessment

Exposure assessment is an assessment of how much the human body is exposed to indoor air pollutants. This is expressed as Lifetime Average Daily Dose (LADD), which is the amount of contaminants exposed per day per kg of body weight, and is calculated by the following Equation 1.

$$LADD = \frac{C \times IR \times EF \times ED}{BW \times AT \times 24} \quad (1)$$

LADD(㎍/kg/day)	:	Lifetime Average Daily Dose
C(㎍/㎥)	:	Contaminant concentration
IR(㎥/day)	:	Inhalation Rate
EF(hr/day)	:	Exposure Frequency
ED(day)	:	Exposure Duration
BW(kg)	:	Body Weight
AT(day)	:	Average Time

(4) Risk Characterization

Risk Characterization is the final step in a health risk assessment. For non-carcinogenic toxicants, Hazardous Quotient

(HQ) is determined using the ratio of the intake-exposure reference value calculated in the dose-response evaluation to the exposure value of the whole human body calculated from the exposure assessment. It is then compared with the US EPA standard values. According to the US EPA guidelines, a non-carcinogenic risk exceeding 1 may lead to potential human toxicity effects [15]. Non-carcinogenic risk is calculated by Equation 2.

$$HQ = \frac{LADD}{RfC \times IR/BW} \qquad (2)$$

HQ(-)	:	Non-carcinogenic hazard
RfC($\mu g/m^3$)	:	Reference Concentration

This study is conducted by using the numerical model and CRPS in the existing health risk assessment procedure. The health risk assessment procedure using CRPS and numerical model is shown in <Figure 2>. In this study, the stage of utilizing the CRPS and the numerical model is the 3-step exposure assessment stage. Using the CRPS and the numerical model, the contaminant concentration (C) at a specific point is calculated and accumulated for the Exposure Duration (ED) in the same manner as the previous study [10] [11]. After that, using the average daily Inhalation rate (IR), average daily living time (Exposure Frequency, EF), body weight (BW), average time (AT), calculate the Lifetime Average Daily Dose(LADD). Finally, the risk of non-carcinogenicity of toluene is determined using the Lifetime Average Daily Dose(LADD) calculated at the risk characterization stage.

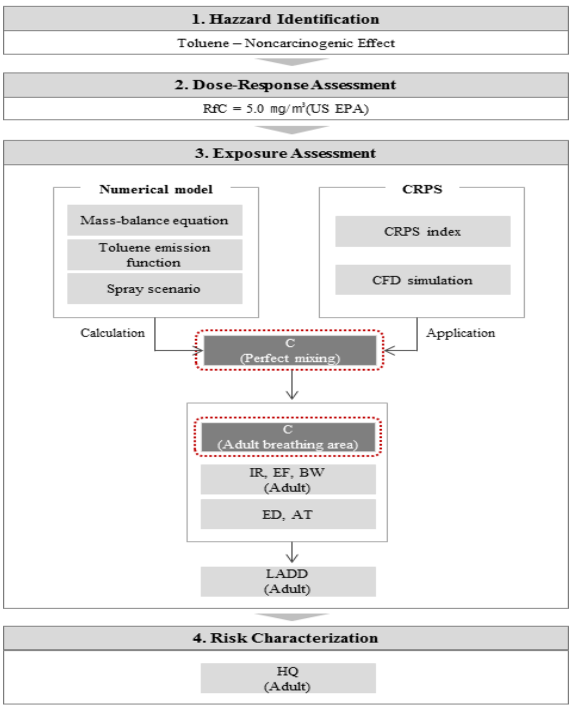


Fig. 2. Process of health risk assessment by CRPS and the numerical model

2.2. Mass Balance Equation

The mass balance equation is often used to describe indoor air quality as a useful expression of the relationship between indoor pollutant concentrations and related variables [16]. The mass balance equation assume a room as an unit space and the perfect mixing concentration of the indoor pollutant is calculated by using the volume, the ventilation rate, the pollutant incidence rate, and the initial concentration

$$\frac{V}{Q} \cdot \frac{dC}{dt} = C_0 - C_i + \frac{M}{Q} \qquad (3)$$

V(m^3)	:	Volume
Q(m^3/s)	:	Ventilation Rate
C($\mu g/m^3$)	:	Contaminant concentration
C_0($\mu g/m^3$)	:	Initial Contaminant concentration
C_i($\mu g/m^3$)	:	Indoor Contaminant concentration
M($\mu g/s$)	:	Contaminant concentration incidence rate

In this study, mass balance equations were used to calculate the perfect mixing concentration of toluene over time.

2.3. CRPS

In this study, the CRPS index was used to convert the perfect mixing concentration to an arbitrary point concentration considering the concentration distribution. CRPS is an indicator proposed by Kim (2005) to evaluate the contribution of the pollutant source to the concentration of arbitrary sites, and is expressed as Equation 4 [13]. CRPS can be obtained experimentally, but it is computed mainly through CFD (Computational Fluid Dynamics) simulation of the target space.

$$CRPS(x,n) = C_w(x,n)/|C_{w,n}| \qquad (4)$$

$C_w(x,n)$	=	Contaminant Concentration in pollutant source n measured at x ($\mu g/m^3$)
$C_{w,n}$	=	Indoor perfect mixing concentration when pollutant source n occurs independently ($\mu g/m^3$)

According to the definition of CRPS, if the pollutant source n at point x has a large CRPS, it can be said that the pollutant source n greatly affects the contaminant change at the point x. Using this, Eun-Jeong Lee(2007) analyzed the effect of the contaminant s emitted from the finishing materials on the living room center of the apartment house, and predicted the indoor pollution concentration according to the contaminant intensity of the finishing material and the ventilation amount [17]. In addition, Seong-Hyeon Park(2013) quantitatively assessed how much contaminants emitted from various building materials in the room affect the humOn the other hand, unlike the attempt to evaluate the contribution rate of the pollutant source using the original definition of CRPS, there has been an attempt to calculate the concentration of the contaminant at a certain point considering the concentration distribution using the CRPS and the perfect mixing concentration. Him-Chan Kim(2015) carried out an analysis considering the concentration distribution of 18 points in the room using the perfect mixing concentration of toluene released from sofas and CRPS [19]. In addition, Ha-neul Choi(2017) analyzed the concentrations of toluene in the central of bed room and adult breathing heights by applying CRPS to the total concentration of toluene released from the spray [20]. In this study, CRPS was applied to the perfect mixing concentration and used to calculate the concentration of contaminants at random sites considering the concentration distribution.

In general, CFD simulations are used to obtain concentration distributions of indoor contaminants. However, CFD simulations are often used to analyze a single point in time(steady state) because of the long time required for interpretation, and are limited to long-term evaluations that require multiple interpretations over time. On the other hand, as described above, the concentration distribution of indoor contaminants can be easily calculated by using CRPS. Theoretically, the CRPS has the same value regardless of the concentration of the contaminants in the air, unless the airflow pattern of the indoor space is changed [13]. Therefore, given the perfect mixing concentration of the contaminants over time, it is possible to calculate the contaminants concentration considering the concentration distribution at a high speed by simple calculation by multiplying CRPS calculated once. The feasibility of high-speed calculation of contaminants concentrations using CRPS has already been proven [21].

In this study, the indoor toluene concentration considering the concentration distribution is calculated at high speed over 24 hours by using CRPS. This is significant because it reduce the errors that may occur when using the perfect mixing concentration in a long-term evaluation by calculating the room concentration distribution without using multiple computationally expensive CFD simulations.

3. Analysis Conditions

3.1. Target Analysis Area

The study area was set as the living room (area: 41.85㎡), which has the largest living time among residents in a general apartment house with a private area of 104㎡ <Figure 3>The target space is a new apartment complex, which is a space 30 days after the construction of wallpaper, ceiling, and flooring materials. Therefore, it is assumed that low concentrations of toluene are emitted in a relatively stable state rather than a high concentration at the beginning of the occupancy in wallpaper, ceiling paper and flooring materials. It is also assumed that toluene is released periodically from a spray that is a life-pollutants source. It is assumed that there are no other sources of pollutants such as furniture. In addition, the target space is ventilated 0.5 times per hour according to the ventilation equipment standard of new apartment house.

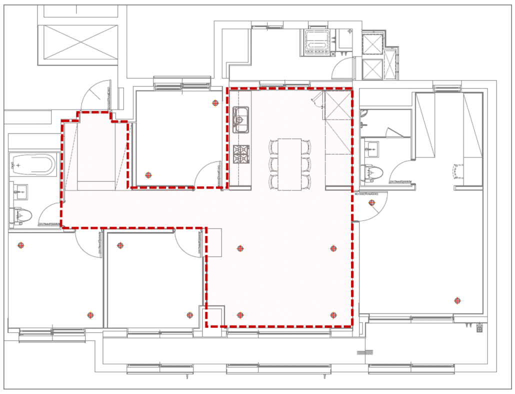


Fig. 3. Floor plan of the residential building

3.2. Toluene Emission Condition

As can be seen from Equation 3, in order to calculate the perfect mixing concentration over time using the mass balance equations, the amount of toluene generated in each of the pollutants with time is needed. However, studies on the emission equation for the pollutant source over time are still insufficient. Da-Young Kim(2016) applied the approximated function using emission data of wallpaper and floor material to the numerical model with reference to previous studies [11]. In this study, we also set the toluene release rate function for each source in the same way. This is summarized in Table 1. In this case, the variable x means the number of days (days), and v means the release rate (㎍/㎡/hr).

On the other hand, the emission of life pollutants in houses is various, such as spraying, cleaning, dry cleaning, and furniture replacement [22]. However, since all variables can not be taken into consideration in reality, this study considers only the spraying behavior. Unlike the finishing materials, toluene in the spray does not continue to be released over time. Therefore, there is a need for scenarios in which the use of spray and the amount of emission are regularized over time. In this study, we refer to the scenario of the previous study [23]. Table 2 shows the spray usage scenarios. The scenario shows spray use during the day from 5 am to 11 pm. There are five kinds of products, and they reflect the amount of toluene emission depending on the product. The spray injection time was set to 1 second per product regardless of the product.

Table 1. Toluene emission function

Sources	Function
Wall	$y = 39.504x^{-0.306}$
Ceiling	$y = 39.504x^{-0.306}$
Floor	$y = 0.5332x^{-0.397}$

Table 2. Spray scenario

Time	Product	Spraying behavior (times)	Emission rate(㎍/times)
5:00	air freshener	1	0.137
10:00	air freshener	1	0.137
11:10	hairspray	1	0.188
11:30	air freshener	1	0.137
18:30	air freshener	1	0.137
22:00	spray mosquitocide	2	0.447
22:20	fabric deodorant	3	0.171
23:00	insecticide spray	2	0.602

3.3. CFD Analysis Condition

To calculate the CRPS, a CFD simulation of the target space must be performed. <Figure 4> shows the result of modeling the target space for CFD simulation. Two circular outlets and inlets of air are located on the ceiling with a diameter of 100 mm. The concentration analysis point (adult breathing area) was the center of the room and the height was set as the breathing height of the adult, 1.3 m from the floor.

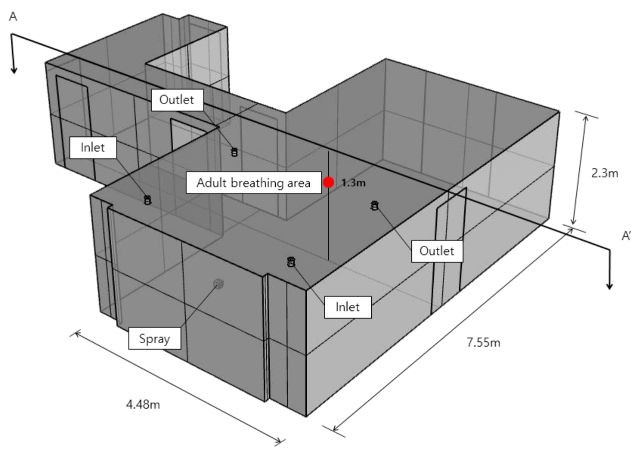
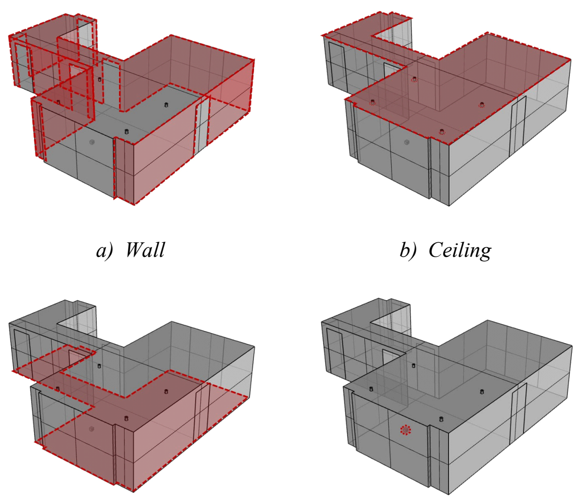


Fig. 4. CFD simulation model

On the other hand, based on the toluene release function and the spray scenario of the finishing material, four pollutants such as wall, ceiling, floor, and spray were classified and modeled. In the modeling process, windows and doors were not included as pollutants. The pollutant toluene was set to have the same air flow and behavior.

The boundary conditions of the CFD simulation are summarized in Table 3. The program uses the commercial program Star-CCM+, and the turbulence model uses Realizable k-ε which is widely used for the pollutant diffusion analysis.



a) Wall *b) Ceiling*

c) Floor *d) Spray*

Fig. 5. Contaminant sources of the CFD simulation model

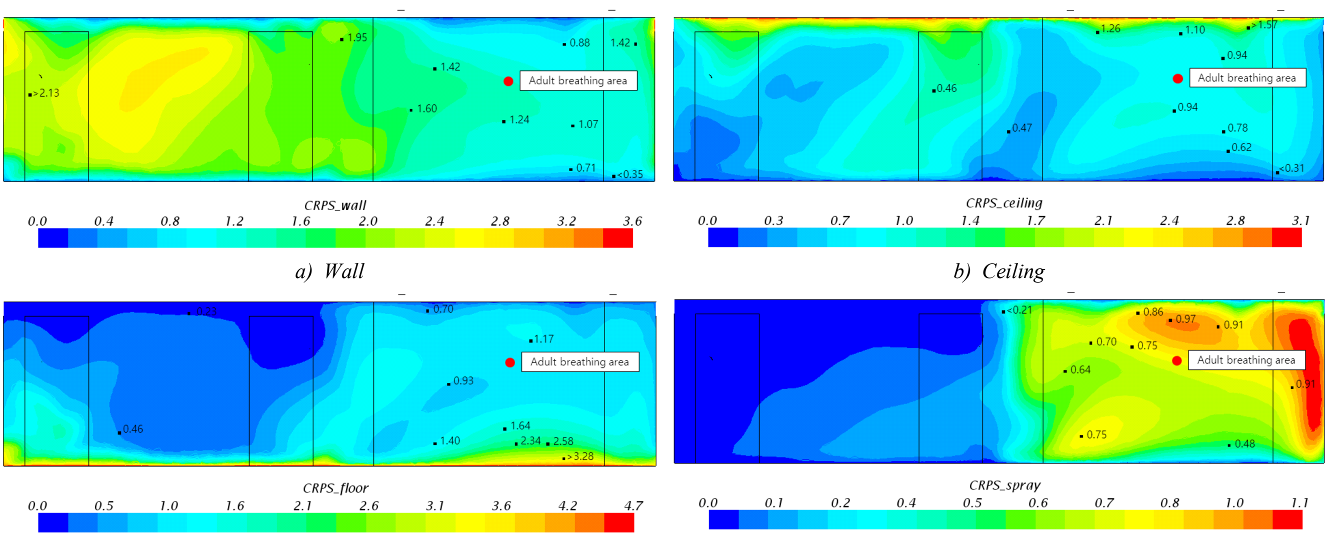
Table 3. CFD simulation boundary condition

	Condition
Tool	Star CCM+ 9.02
Turbulence Model	Realizable k-ε
Mesh Properties	Polyhedral Mesh, Prism Layer
Toluene	Passive scalar
Turbulence intensity	0.01
Turbulent viscosity ratio	10
Wall Function	E=9.0, Kappa=0.42
Mesh Results	160,109cells
Ventilation rate	48.47㎥/hr
Inlet(each)	Area: 0.00785㎡, Velocity: 0.8576m/s
Outlet(each)	Area: 0.00785㎡, Velocity: -0.8576m/s

4. Analysis Results

4.1. Concentration Analysis using Mass Balance Equation

A numerical model was constructed using the toluene emission function for the target space, and a total of 86,400 concentration data were calculated by analyzing 24 hours in units of 10 seconds through the mass balance equations. The calculated concentration data is the perfect mixing concentration without considering the indoor distribution and the change is shown in <Figure 6>.The concentration of toluene by the finishing materials such as wallpaper, ceiling paper and flooring in the total concentration has an average value of 31.08 ㎍ / ㎥.The concentration decreased with



a) Wall b) Ceiling

c) Floor d) Spray

Fig. 7. CRPS distribution of pollutant sources by the CFD simulation

time, but the decrease was about 1%, indicating almost constant concentration. On the other hand, when spraying, the concentration varies from a minimum of 10.13 μg / ㎥ to a maximum of 158.1 μg / ㎥ depending on the scenario. This is up to 5.1 times the concentration of toluene released from the finish at the same time. This shows that the concentrations of contaminants that occur periodically in living pollution sources are considerable. Considering the characteristics of the finishing material with which the emission of pollutants decreases with time, it is expected that the rate of contribution of living pollution sources to the indoor pollutant concentration will increase as time passes after completion of building.

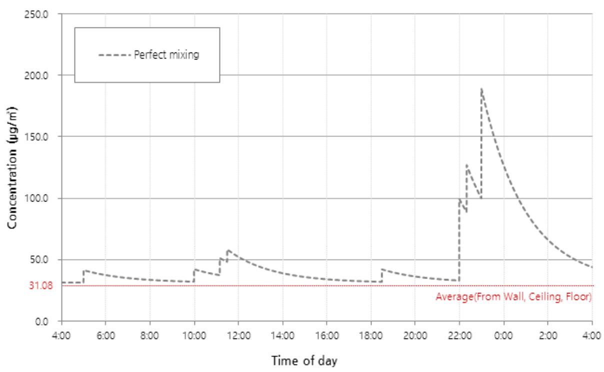


Fig. 6. Indoor perfect mixing concentration of toluene

4.2. Concentration Conversion using CRPS

4.2.1 CRPS calculation using CFD

The CRPS can be calculated by the ratio of the concentration of the arbitrary point and the exhaust concentration (perfect mixing concentration) calculated by the CFD simulation. <Figure 7> shows the result of analyzing the distribution of CRPS over pollutants sources in the cross-section AA '. In the case of the wall, the value near the wall was 2.13 or more, and the value of 1-2 was spread evenly across the section AA '. On the other hand, in the case of ceiling and floor, the CRPS gradually decreased with distance from each pollutant, and almost 0 on the opposite side of each pollutant. In the case of spraying, the CRPS is not as large as 1.08, but the variation varies greatly with distance. Out of a certain distance from the spray, the CRPS is less than 0.21, which means that the spray has little effect.

Table 4. CRPS calculation results of pollutant sources at the adult breathing area

Point	Sources	CRPS
Adult breathing area	Wall	1.19
	Ceiling	0.87
	Floor	1.05
	Spray	0.78

The results of the CRPS for the breathing area among the CRPS distributions according to the pollutant sources are shown in Table 4. This shows how much of the four pollutant sources contribute to breathing area concentration. The contributing factors for each pollutant were wall (1.19), bottom (1.05), ceiling (0.87) and spray (0.78). Thus, changes in the amount of pollutants released from the walls have the greatest effect on changes in respiratory density and spray has the least effect. In other words, if the total concentration of toluene in each source is the same, the percentage of toluene released from the wall is the largest in toluene composition measured in adult breathing area, and the fraction of toluene released from spray is the smallest.

4.2.2 Conversion to concentration at adult breathing area

According to Equation 4, the toluene concentration in the breathing area can be calculated by multiplying the perfect mixing concentration of toluene calculated by the mass balance equations and the CRPS of each source. The results of calculating the toluene concentration change over the 24-hour period are shown in <Figure 8>. For comparison with the perfect mixing concentration, the results of Fig. 6 were also described. The overall breathing area concentration is similar to the perfect mixing concentration. Specifically, the source of pollutants forming the indoor toluene concentration can be classified into two kinds of finishes and spray. The abrupt changes in the concentration in eight time zones at 5:00, 10:00, 11:10, 11:30, 18:30, 22:00, 22:20 and 23:00 are the result of spraying and except this, the concentration at the time zone is the concentration due to the finishing material.

The average concentration of toluene by the finishing material is 33.14㎍/㎥ which is approximately 7% greater than the perfect mixing concentration with a value of 31.08㎍/㎥.

On the other hand, the toluene concentration due to the spray has a value of at least 7.91㎍/㎥to a maximum of 123.32㎍/㎥. This is about 21% less than the perfect mixing concentration at 22 o'clock, which is the highest concentration. Therefore, it is known that the normal concentration of the breathing area is the concentration due to the toluene release of the finishing material, which is slightly larger than the perfect mixing concentration, and that the breathing area concentration at spraying is significantly smaller than the complete mixture concentration.

Table 5 shows the results obtained by integrating the concentration of the above graph over a 24hour period. The concentration sum of the breathing area (C × ED) is 48.45㎍·day/㎥ which is about 5% smaller than the sum of the perfect mixing concentrations.

Table 5. Sum of concentration of toluene over 24hours

	Adult breathing area	Perfect mixing
C × ED (μg · day / ㎥)	48.45	50.72

4.3. Health Risk Assessment

4.3.1 Health risk assessment conditions

Using the numerical model and the breathing area concentration calculated by CRPS, the health risk assessment was performed on adults. At this time, the adult is defined as an imaginary object having the average respiration rate, weight, etc. of the adult male and female over 18 years old. First, in the second step of the fourth step of the health risk assessment, the non carcinogenic inhalation exposure value of toluene was set at 5,000 ㎍/㎥. This is based on the value of US EPA [11].㎍/㎥. The multiplying of the concentration of pollutants in the indoor air and the exposure period used in the third stage exposure assessment was the sum of the concentrations in Table 5. In addition, daily average respiration rate, average body weight, and average indoor residence time of Jang (2014) were referenced by the National Institute of Environmental Research [24] [25]. The average life span was set to the same value as the exposure period according to the non-carcinogenicity calculation standard [9].

Table 6 summarizes the values required for health risk assessment. In addition, a risk assessment based on the perfect mixing concentration was also carried out so as to be comparable.

Table 6. Health risk assessment condition

Factors	Adult breathing area	Perfect mixing
C × ED((μg/㎥)*day)	48.45	50.72
Inhalation Rate(㎥/day)	14.25	
Body weight(kg)	62.8	
Exposure Frequency(hr/day)	15.1	
Average Time(day)	1	
RfC(μg/㎥)	5,000(Toluene)	

4.3.2 Health risk assessment results

Based on the above conditions, the results of calculating the lifetime whole human body exposure and non-carcinogenic risk were as shown in Table 7. The calculation result of life time human body dose was 6.91㎍/kg/day. The non-carcinogenic risk was calculated to be 0.0060 in comparison with the non-carcinoma inhalation exposure reference value. According to the US EPA's Health Risk Guideline, if the non-carcinogenic hazard exceeds 1, the non-carcinogenic toxin is considered to be harmful to health. However, as a result of the analysis of this study, the risk of non - carcinogenicity of toluene was less than 1 standard. Therefore, it can be seen that, even in the above analysis conditions, even when exposed to the indoor toluene concentration, there is no harmful effect on the adult. On the other hand, when the health risk was evaluated based on the perfect mixing concentration, the human body dose was 77.24㎍/kg/day and the non-carcinogenic risk was 0.0064. Therefore, it can be seen that performing a health risk assessment based on breathing area concentration produces a result about 5% smaller than the result based on the perfect mixing concentration.

Table 7. Results of health risk assessment

	Adult breathing area	Perfect mixing	EPA Health Risk Guideline
LADD (μg/kg/day)	6.91	7.24	
HQ (-)	0.0060	0.0064	1

5. Results

In this study, a numerical model considering the concentration distribution of indoor pollutants was constructed by using CRPS and the method of evaluating toluene health risk for adults in the complex apartment was suggested. In particular, attempts to assess health risk using CRPS are different from those of the previous studies in that the concentration of pollutants is calculated more accurately. It can be used for long-term evaluation, and it has potential for various analyzes in the future.

The results of this study are summarized as follows.

First, it was found that the effect of spray on indoor toluene concentration was more significant than that of finishing material. In the case of toluene released from the finishing material, the constant concentration is continuously released, and the sum of the daily concentration accounts for 68% of the total. On the other hand, toluene emitted from the spray accounts for 32% of the total, even though it is analyzed according to the scenario of spraying eight times a day. This means that the emission concentration of the finishing material decreases with time, while the emission of the living pollutant source occurs periodically, which means that the influence of the life pollution source can not be ignored in the long-term evaluation. In this study, only the spray of various pollutants was considered, but it is considered necessary to consider other pollutants in order to evaluate more accurately in the future.

Second, when the concentration of breathing area was compared with that of the perfect mixing concentration, the concentration by the finishing material was similar to that of the perfect mixing concentration, and the concentration by spraying was 21% lower than that of the perfect mixing concentration because the spray CRPS (0.78) for the breathing area is significantly smaller than the finishing material. The reason for the low CRPS of the spray is that the size of the pollution source is small, the injection position is distant from the breathing area, and the exhaust hall is located between the spray and the breathing area to prevent diffusion. When the total concentration of the finishing material and the spray is examined, the sum of the daily concentration of the breathing area is smaller than the sum of the daily concentration of the perfect mixing concentration and is about 5%. This is significant because it can obtain about 5% more accurate results than the previous research method

Finally, a health risk assessment in an adult breathing area showed that the risk of non-carcinogenicity of toluene was less than 1.

This study has limitations such as that toluene release rate of the finishing materials such as wallpaper, ceiling paper and flooring are expressed as an arbitrary approximate function and the fact that only the spray of the various life pollution sources is limited and analyzed. Therefore future research will need to complement the scenarios for various pollutant sources such as cleaning, dry cleaning, furniture replacement, and analysis of pollutant release rates of finishing material over time

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