VOC Emission from Building Materials in Residential Buildings with Radiant Floor Heating Systems

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ABSTRACT

The emission rates of volatile organic compounds (VOC) from building materials and the resulting indoor concentrations are influenced by temperature. Radiant floor heating systems are widely used in most residential buildings in Korea, and VOC emissions from flooring materials increase as the floor temperature rises. In this study, a numerical model is presented to evaluate the VOC emissions from building materials at different temperatures depending on the heating conditions. A coupled model is developed to simulate the temperature variation of building materials and VOC emissions in the floor heated space, which combines the building heat transfer model for materials and indoor air temperature with the mass transfer model for VOC emissions and indoor VOC concentrations. The model was validated by a mock-up test, and it was then used to examine the emission characteristics from flooring materials under different heating conditions. The results show that emissions of VOC from flooring materials tend to increase as the floor temperature rises during the heating condition.

Keywords: Volatile organic compounds; Building material; Building thermal model; Emission model; Floor heating.

INTRODUCTION

In recent years, there has been a growing public concern over sick housing syndrome resulting from the poor indoor air quality of new houses. Indoor air pollution in a new building is mainly caused by hazardous chemical compounds such as formaldehyde and volatile organic compounds (VOC). Most building materials and household products contain organic chemicals, and VOC emissions are considered to be the main cause of indoor air pollution.

The VOC emission rates from building materials and resulting indoor air concentrations are influenced by environmental factors, such as temperature, humidity, air change rate and surface air velocity (Haghighat and Bellis, 1998; Wolkoff, 1998; Alevantis, 1996; Fang et al., 1999). In particular, increased temperature may accelerate chemical reactions within the material, leading to additional VOC emissions. Therefore, temperature has a major impact on VOC emissions from building materials and products (Van der wal et al., 1997). There is a wide range of outdoor temperature variation throughout the year, and it can cause the temperature change in building materials. In addition, floor heating systems which use hot water in embedded tubes are widely used in residential buildings. As thermal energy is directly transferred to floor materials, flooring materials will be heated to higher temperatures during floor heating in the winter. During the construction period, VOC emissions from flooring materials are restrained due to low outdoor temperatures, but then may increase significantly when the floor heating system is activated after occupancy occurs. It is known that even so-called low-VOC emitting materials emit greater amounts of VOC when their temperatures are kept high because material emission rates are typically measured in controlled environmental chambers at a normal temperature of 23°C or 25°C (ASTM, 1997; ISO, 2006). Previous research has shown that VOC and formaldehyde concentrations in unoccupied new houses were relatively lower than recommended levels (Choei et al., 2005). After occupancy, the concentrations were higher in the winter than in the summer (Chun et al., 2005). Kim et al. (2005) has investigated the effect of various temperatures on formaldehyde emission from flooring materials by the desiccator method, and also shown that flooring materials at high temperature had less formaldehyde emission rates than flooring materials at low temperature after four weeks. Zhang et al. (2007) showed that temperature has significant effect on the VOC emission parameters of dry building materials by experimental and theoretical analysis.

Therefore, it is important to analyze the influence of
environmental factors on VOC emissions because accurate emission and indoor air quality prediction can lead to more appropriate control strategies. This requires an integrated or coupled model that can simultaneously take into account various factors in the simulation process (Yan et al., 2008).

The purpose of this research is to develop a coupled thermal and VOC emission model that can yield the effect of temperature variation on VOC emissions from building materials and to predict the VOC emission rates from building materials and indoor concentrations in residential buildings with radiant floor heating systems.

**COUPLED THERMAL AND VOC EMISSION MODEL DEVELOPMENT**

In order to analyze VOC emissions and indoor concentrations within the context of material temperature variation, mass transfer model is coupled with a building heat transfer model. The model consists of two main parts, the room thermal model and the VOC emission model. Both are based on the finite difference method for the calculation of one-dimensional unsteady-state heat transfer and VOC diffusion, evaporation, and convection.

**Room Thermal Model**

Based on building heat transfer theories, the room thermal model was set up to calculate building material temperatures and indoor air temperatures. To analyze the temperature distribution in materials and indoor air caused by floor heating, the thermal model incorporates the theories about heat transfer in a floor heating panel, the walls, and throughout the room. The heat transfer in a floor heating panel was analyzed by the fin efficiency theory and effectiveness-NTU (number of transfer unit) method for the unit section perpendicular to the pipe as shown in the following Eqs. (1) and (2) (Udagawa, 1986).

$$q_{\text{panel}} = e_{\text{PNL}} \cdot M_{\text{flow}} \cdot C_{\text{pw}} (T_{\text{water}} - T_{\text{m}})$$  \hspace{1cm} (1)

$$e_{\text{PNL}} = \frac{e_{\text{px}}}{1 + (e_{\text{px}} M_{\text{flow}} C_{\text{pw}} / A_t C_f) (1 / \eta_p) - 1}$$  \hspace{1cm} (2)

where $q_{\text{panel}}$ is the heat supply rate of the floor heating panel (W), $e_{\text{PNL}}$ is the overall effectiveness of panel, $M_{\text{flow}}$ is the flow rate of supply water (kg/s), $C_{\text{pw}}$ is the specific heat of water (J/kg°C), $T_{\text{water}}$ is the supply water temperature (°C), $T_{\text{m}}$ is the mean temperature of heat extraction node (°C), $e_{\text{px}}$ is the heat transfer effectiveness of pipes in panel, $A_t$ is the floor area (m²), $C_f$ is the heat transfer rate from the upper and lower node (W/m²°C), and $\eta_p$ is the fin efficiency of the pipe embedded layer.

Conductive heat transfer inside the wall is analyzed as a one-dimensional unsteady-state heat transfer governed by the following fundamental Eq. (3).

$$\rho C_p \frac{\partial T}{\partial t} = \frac{\partial}{\partial x} (K \frac{\partial T}{\partial x}) + q$$  \hspace{1cm} (3)

where $\rho$ is the material density (kg/m³), $C_p$ is the material specific thermal capacity (J/kg°C), $T$ is the material temperature (°C), $x$ is the distance from the wall surface toward the heat flow direction (m), $k$ is the material thermal conductivity (W/m°C), and $q$ is the heat generation rate per unit material volume (W/m³).

The room air temperature is determined based on convective heat transfer at each surface of the walls, amounts of ventilation and infiltration, and internal heat gain. Heat gain by supply air from HVAC systems was also included to find the difference in material temperatures and VOC emissions between the floor heating system and the HVAC system. The employed equation on heat balance is as follows.

$$\rho_v \cdot C_{\text{pv}} \cdot V \frac{\partial T}{\partial t} = \sum q_k + q_{\text{vent}} + q_{\text{supply}} + q_{\text{cl}} + q_{\text{cp}} + q_{\text{ce}}$$  \hspace{1cm} (4)

where $\rho_v$ is the air density (kg/m³), $C_{\text{pv}}$ is the air specific heat (J/kg°C), $V$ is the room volume (m³), $T_r$ is the room air temperature (°C), $t$ is the time (s), $q_k$ is the convective heat transfer rate at the surface (W), $q_{\text{vent}}$ is the heat gain by infiltration or ventilation (W), $q_{\text{supply}}$ is the heat gain by supply air (W), $q_{\text{cl}}$ is the convective heat gain from lightings (W), $q_{\text{cp}}$ is the convective heat gain from people (W), and $q_{\text{ce}}$ is the convective heat gain from equipments (W).

**VOC Emission and Indoor Concentration Model**

Empirical models and physical models have been widely used in modeling VOC emissions from wet or dry building materials. Physical models are based on mass transfer principles; diffusion within the material as the result of concentration, pressure, and temperature gradients, and surface emissions between the material and the overlying air as a result of evaporation, convection and diffusion (Huang, 2003). In spite of some limitations, validated physical models are usually preferred, because these models can predict VOC emission for a wide range of conditions using known physical parameters (Hu et al., 2007).

Building materials can be classified into wet materials and dry materials in terms of VOC emission mechanism. In Korea, most residential buildings are finished with dry materials such as paper or PVC wall coverings and plywood or PVC floorings. This research has assumed that the materials were single homogeneous, and VOC were completely mixed in the room air. For simulating VOC emissions from dry building materials, several models using Fick’s second law were referred which have been developed and validated in previous researches (Huang, 2002; Haghighat, 2003). The governing equations describing the VOC emission from dry materials in the model are as follows.

Mass transfer within the material:

$$\frac{\partial C_m}{\partial t} = \frac{\partial}{\partial y} (D_m \frac{\partial C_m}{\partial y})$$  \hspace{1cm} (5)

Material/air interface:
\[ C_m = K \cdot C_m \]  \hspace{1cm} (6)  

Mass transfer in the boundary layer:

\[ E = h(C_m - C_a) \]  \hspace{1cm} (7)  

VOC concentration in the room:

\[ \frac{\partial C_a}{\partial t} = N(C_m - C_a) + \frac{A}{V} h(C_m - C_a) \]  \hspace{1cm} (8)

where, \( C_m \) is the VOC concentration in the material (\( \mu g/m^3 \)), \( D_m \) is the VOC diffusion coefficient of the material (\( m^2/s \)), \( y \) is the coordinate in which the VOC diffusion in the material take place (m), \( C_m \) is the VOC concentration at the material surface (\( \mu g/m^3 \)), \( C_a \) is the VOC concentration in the air near material surface (\( \mu g/m^3 \)), \( K \) is the material/air partition coefficient (\( \mu g/m^3 \)), \( E \) is the VOC emission rate (\( \mu g/m^2s \)), \( h \) is the convective mass transfer coefficient (\( m/s \)), \( N \) is the air change rate (h\(^{-1}\)), \( C_{ms} \) is the VOC concentration in the supply air (\( \mu g/m^3 \)), and \( A \) is the area of material (m\(^2\)).

As \( D_m \) is considered a thermally activated process (Yang, 1999), the temperature dependence of \( D_m \) can be analyzed by following Eq. (9), which is modified from Arrhenius type equation (Yang, 1998; Kato, 1999). \( D_m \) at a temperature \( T \) can be calculated from \( D_m \) at the reference temperature using Eq. (9).

\[ D_m(T) = D_{m,ref} \exp\left(-E \left(\frac{1}{T} - \frac{1}{T_{ref}}\right)\right) \]  \hspace{1cm} (9)

where \( D_m(T) \) is the VOC diffusion coefficient of the material at temperature \( T \) (\( m^2/s \)), \( D_{m,ref} \) is the VOC diffusion coefficient of the material at the reference temperature (\( m^2/s \)), \( E \) is the empirical constant, \( T \) is the temperature of the material (\( ^{\circ}C \)), and \( T_{ref} \) is the reference temperature (\( ^{\circ}C \)).

The temperature dependence of the VOC diffusion coefficient in the air can be expressed as Eq. (10) (Skelland, 1974).

\[ D_a = 5.398 \times 10^{-6} \left(\frac{T}{T_{ref}}\right)^{1.5} \]  \hspace{1cm} (10)

where \( D_a \) is the VOC diffusion coefficient in the air (\( m^2/s \)).

**Model Structure and Numerical Method**

Both parts of the model have been developed with the unsteady-state one-dimensional analysis using the finite difference method (FDM) for the accurate analysis of the time varying characteristics (Kim et al., 2008). The numerical solution of the FDM is attained by the Gauss-Seidel iteration method. Fig. 1 shows the structure of the coupled model and Fig. 2 shows the parameter flow diagram. In Fig. 2, parameters not underlined indicate the input data for thermal and mass transfer analysis such as material internal properties or environmental conditions, and underlined parameters are output data from numerical calculations. Weather data offered by public authorities can be used as inputs for the parameters in squares. Parameters in shadeless ovals are related to thermal analysis, including room temperature and material temperature, while parameters in shaded ovals are related to mass transfer analysis, including the VOC emission rate from materials and VOC concentration in the room.

Fig. 1. Structure of the coupled model.
Validation of the Coupled Model

The developed model was validated by comparing the simulation results with a mock-up test results. The predicted data and measured data were compared to validate the algorithm of the coupled model. The mock-up test was carried out in a test room of 2 m × 2 m × 2 m in size. The test room was finished with laminate flooring and wallpaper. The heating panel was installed on every surface of the test room to control the material surface temperature. In order to control the ventilation rate of the test room, a supply fan was installed at the bottom of the window and an exhaust fan was installed on the ceiling of the test room. A stainless steel pipe was installed for indoor air sampling through which the Tenax TA tubes were connected to the sampling pump with a long Teflon tube. As shown in Table 1, the test schedule was set up for two month to evaluate indoor air concentrations during the time from material installation to the dwelling period.

The wallpaper and the laminate flooring were nailed on the wall in order to exclude the adhesive as an emission source. As the flooring material and the wallpaper were installed, the VOC concentrations in the test room were significantly increased due to the high initial emission rates from the flooring material and the wallpaper. To reduce this peak levels, the test room was ventilated by operating the supply and exhaust fans with the rate of 10 ACH. The heating panel was turned on six days after the experiment started, and the test room was kept around 25°C. The measurements were carried out before and after every material installation. Fans were not operated during the measurement, and surface temperatures were measured throughout the entire experiment. Air samples (4.5 liters) were taken for 30 minutes, and the samples were analyzed using a thermal desorber and GC-MS.

In parallel with the mock-up test, the small chamber tests were conducted to obtain the emission parameters of the materials. VOC emission rates from the wallpaper and laminate flooring were measured for 11 days and 6 days, respectively. Fig. 3 shows the comparison of predicted and measured TVOC emission rates. The parameters were obtained as shown in Table 2, and applied as the input for the coupled model.

Predicted results by the coupled model and measured data from the mock-up test were compared in a series of time as shown in Fig. 4. Table 3 shows the percentage error between the predicted data and measured data. The average percentage error was 11.8% after the heating panel was turned on. There is a relatively good agreement between the predicted and measured data except for some discrepancies during the initial hours. In general, it is considered that the coupled model is applicable to estimate the trend of VOC emission and indoor VOC concentration at different temperature conditions.

VOC EMISSION ANALYSIS

Simulation Cases

The developed modeling tool was applied to simulate VOC emission rates and indoor concentrations in a room in Fig. 5. This case study is concerned with the VOC emissions from flooring materials with different heating conditions. The simulation parameters for materials and structure composites were assumed as shown in Table 4 and Table 5. It was assumed that 12 mm (3 mm glass + 6 mm air + 3 mm glass) pair glass windows were installed on the north and the south wall of the room. The same rooms were assumed to be in the east and west side, and upper and lower floors. Only the south and north sides were directly facing outdoors.
Table 1. Experiment schedule of mock-up test

<table>
<thead>
<tr>
<th>Experiment schedule</th>
<th>Day</th>
<th>1</th>
<th>2</th>
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<th>11</th>
<th>12</th>
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<th>17</th>
<th>18</th>
<th>19</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>8°C/10ACH</td>
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<tr>
<td>Wallpaper installation</td>
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<tr>
<td>Laminate flooring installation</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>25°C/1ACH</td>
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</tbody>
</table>

Fig. 3. Comparison of the predicted and measured TVOC emission rates by the chamber tests.

Table 2. Material emission parameters for validation of the coupled model

<table>
<thead>
<tr>
<th>Emission coefficient</th>
<th>Wallpaper</th>
<th>Laminate flooring</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_o$ ($\mu g/m^3$)</td>
<td>$9 \times 10^7$</td>
<td>$7 \times 10^7$</td>
</tr>
<tr>
<td>$D_m$ ($m^2/s$)</td>
<td>$2.0 \times 10^{-13}$</td>
<td>$3.1 \times 10^{-13}$</td>
</tr>
<tr>
<td>$E$</td>
<td>10,000</td>
<td>10,000</td>
</tr>
<tr>
<td>$K$</td>
<td>3289</td>
<td>3289</td>
</tr>
</tbody>
</table>

Simulations were divided into three cases according to the heating condition; without heating, with convective heating, and with floor heating. Based on the regional weather data of Seoul (SAREK, 1996), a four-week period (03/Jan to 30/Jan) with the lowest outdoor air temperature was selected as the input for modeling the outdoor air condition. The set point of room air temperature was assumed to be 25°C, and the air change rate was assumed...
Table 3. Percentage error between the predicted and measured TVOC concentrations.

<table>
<thead>
<tr>
<th>Time (hr)</th>
<th>TVOC concentration in the test room (μg/m³)</th>
<th>Percentage error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Predicted</td>
<td>Measured</td>
</tr>
<tr>
<td>47</td>
<td>68.6</td>
<td>272.7</td>
</tr>
<tr>
<td>5</td>
<td>126.5</td>
<td>352.2</td>
</tr>
<tr>
<td>126</td>
<td>116.1</td>
<td>254.5</td>
</tr>
<tr>
<td>150</td>
<td>701.6</td>
<td>847.1</td>
</tr>
<tr>
<td>157</td>
<td>658.9</td>
<td>596.4</td>
</tr>
<tr>
<td>174</td>
<td>503.8</td>
<td>439.0</td>
</tr>
<tr>
<td>246</td>
<td>341.6</td>
<td>440.0</td>
</tr>
<tr>
<td>318</td>
<td>266.6</td>
<td>250.6</td>
</tr>
<tr>
<td>390</td>
<td>227.1</td>
<td>231.0</td>
</tr>
<tr>
<td>510</td>
<td>176.0</td>
<td>189.9</td>
</tr>
<tr>
<td>918</td>
<td>70.3</td>
<td>84.0</td>
</tr>
<tr>
<td>1086</td>
<td>48.0</td>
<td>40.8</td>
</tr>
<tr>
<td>1350</td>
<td>36.2</td>
<td>37.6</td>
</tr>
</tbody>
</table>

Fig. 4. Comparison of the predicted and measured TVOC concentrations by the mock-up test.

Fig. 5. Schematic diagram of the room model.
Table 4. Material parameters of the housing unit model.

<table>
<thead>
<tr>
<th>Material</th>
<th>Floor</th>
<th>Wall</th>
<th>Ceiling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plywood flooring</td>
<td>70.0 m²</td>
<td>84.0 m²</td>
<td>92.4 m²</td>
</tr>
<tr>
<td>Co (μg/m³)</td>
<td>$3.5 \times 10^7$</td>
<td>$1.1 \times 10^7$</td>
<td>$1.1 \times 10^7$</td>
</tr>
<tr>
<td>$D_m$ (m²/s)</td>
<td>$1.0 \times 10^{-12}$</td>
<td>$1.0 \times 10^{-13}$</td>
<td>$1.0 \times 10^{-13}$</td>
</tr>
<tr>
<td>$E$</td>
<td>15,000</td>
<td>10,000</td>
<td>10,000</td>
</tr>
</tbody>
</table>

Table 5. Building composites of the housing unit model.

<table>
<thead>
<tr>
<th>Component</th>
<th>Section</th>
<th>Composition</th>
<th>Thickness (mm)</th>
<th>Heat Conductivity (W/m°C)</th>
<th>Specific Heat (kJ/kg°C)</th>
<th>Density (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor</td>
<td></td>
<td>1. plywood flooring</td>
<td>8</td>
<td>0.12</td>
<td>2.30</td>
<td>550</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. mortar</td>
<td>45</td>
<td>1.30</td>
<td>0.79</td>
<td>2,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. light-weight concrete</td>
<td>45</td>
<td>0.15</td>
<td>1.09</td>
<td>600</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4. polystyrene</td>
<td>25</td>
<td>0.032</td>
<td>1.26</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5. concrete</td>
<td>180</td>
<td>1.20</td>
<td>0.81</td>
<td>2,400</td>
</tr>
<tr>
<td>Exterior wall</td>
<td>south/north</td>
<td>1. gypsum board</td>
<td>12</td>
<td>0.15</td>
<td>1.13</td>
<td>910</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. mortar</td>
<td>12</td>
<td>1.30</td>
<td>0.79</td>
<td>2,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. polystyrene</td>
<td>65</td>
<td>0.032</td>
<td>1.26</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4. concrete</td>
<td>200</td>
<td>1.20</td>
<td>0.81</td>
<td>2,400</td>
</tr>
<tr>
<td>Partition wall</td>
<td>east/west</td>
<td>1. mortar</td>
<td>15</td>
<td>1.30</td>
<td>0.79</td>
<td>2,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. concrete</td>
<td>150</td>
<td>1.20</td>
<td>0.81</td>
<td>2,400</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. mortar</td>
<td>15</td>
<td>1.30</td>
<td>0.79</td>
<td>2,000</td>
</tr>
</tbody>
</table>

to be 0.2ACH, 0.7ACH, and 2.0ACH, respectively. The air change rate of 0.2ACH represents the average tightness without intentional ventilation and 0.7ACH represents the Korean national ventilation rate standard for multi-family residential buildings (MOCT, 2006). The air change rate of 2.0ACH was assumed to represent well-ventilated conditions.

Results and Discussion

For the cases under different heating conditions or ventilation rates, results including indoor air temperature, material temperature, material VOC emission rate, and indoor VOC concentration were calculated by simulation with the modeling tool.

Fig. 6 shows the floor surface temperatures of three cases in different heating conditions at 0.2 ACH. In the case that the heating system is not operated, material temperatures are predicted to be similar to indoor air temperatures ranging from 5°C to 7°C. For convective heating, both material temperatures and indoor air temperatures are kept to be around the set temperature of 25°C, and there is little difference between floor surface temperatures and wall surface temperatures. On the other hand, the floor surface temperature reaches up to 28°C to 35°C at the floor heating condition shown in Fig. 7.

Fig. 8 shows the predicted TVOC emission rates of each case. Compared to the unheated condition, the average TVOC emission rate from flooring materials was predicted to be about 12 times higher for the floor heating condition and about 9 times higher for the convective heating condition. It was found that the peak TVOC concentration level at the beginning of heating would be a serious problem to occupants in new apartment buildings with a floor heating system. Flooring materials might be the major cause for this peak level in concentration, for which temperatures increased significantly. When the indoor air temperatures are maintained to the set-point temperature, the floor surface temperatures for the floor heating condition are relatively higher than those for the convective heating condition. While this resulted in increased VOC emissions from flooring materials and worse indoor air quality, VOC concentrations inside the materials were relatively lower after 28 days. Therefore, the floor heating system has an advantage of reducing the VOC emission period, as long as the indoor air quality is effectively controlled with sufficient ventilation.

As ventilation is one of the most common and effective ways to mitigate indoor air pollution, VOC emission characteristics and concentration were investigated with the variation of the air change rate. With the increase in the air change rate from 0.2ACH to 0.7ACH and 2.0ACH during heating, the overall floor surface temperatures rose because the floor heating system was operated more often to compensate for internal heat loss due to ventilation.
Fig. 6. Predicted floor surface temperatures at different heating conditions (0.2 ACH).

Fig. 7. Material temperature variations at continuous floor heating conditions.

Fig. 8. Predicted TVOC emission rates at different heating conditions (0.2 ACH).
VOC emission rates from flooring materials were also increased with the rise of temperatures as shown in Fig. 9. On the contrary, indoor VOC concentrations were decreased as shown in Fig. 10, in spite of the increases of VOC emissions. The VOC emission rate depends on material temperature, but indoor VOC concentration is mainly affected by the air change rate rather than the emission rate.

Based on the predicted VOC concentration and emission characteristics, an apartment building with a floor heating system may be at a disadvantage for maintaining low indoor VOC concentrations, because flooring material temperatures with such a system are much higher than indoor air temperatures or those under the convective heating condition. On the contrary, floor heating systems have the advantage of accelerating the VOC emission from materials and reducing total VOC amounts inside the materials, which ultimately results in low emission rates.

CONCLUSIONS

This paper presents the development of a coupled thermal and VOC emission model for simulating the effect of temperature variation on VOC emission, considering a wide range of outdoor temperature variation throughout the year and floor heating systems. The developed model was validated by means of the mock-up experiment. The predicted results using the coupled model and measured data from the experiments show relatively good agreement. Practical use of the model is also demonstrated by applying it to VOC emission and indoor concentration in a housing unit with different heating conditions.

The emission of VOC from flooring materials predominantly increases as the floor temperature rises during the heating condition. The emission characteristics from flooring materials in the floor heating condition were investigated by numerical analysis. It was found that the peak level in indoor VOC concentration poses a serious problem to occupants in new residential units during the heating period. As the ventilation rate increased, the indoor concentrations decreased, but the emission rates increased.
The developed model allows the prediction of dynamic profiles of VOC emission rates and concentration in buildings with different heating conditions. Based on the predicted VOC concentration and emission characteristics by the coupled model, indoor air quality control strategies can be developed, including material selection, ventilation, and heating system control.

There are some limitations in the developed model because it does not cover VOC sink model and air-flow network model for more accurate prediction of indoor air quality. It is necessary to update the model for analyzing the effect of other environmental factors such as humidity and surface air velocity. This model can also achieve more benefits, such as evaluating the economic performance and environmental quality of developed control strategies, if it can cover building energy performance and comfort modeling.

REFERENCES


Received for review, November 30, 2011

Accepted, May 6, 2012