Effects of temperature and humidity on VOC emissions from building materials

Speaker:

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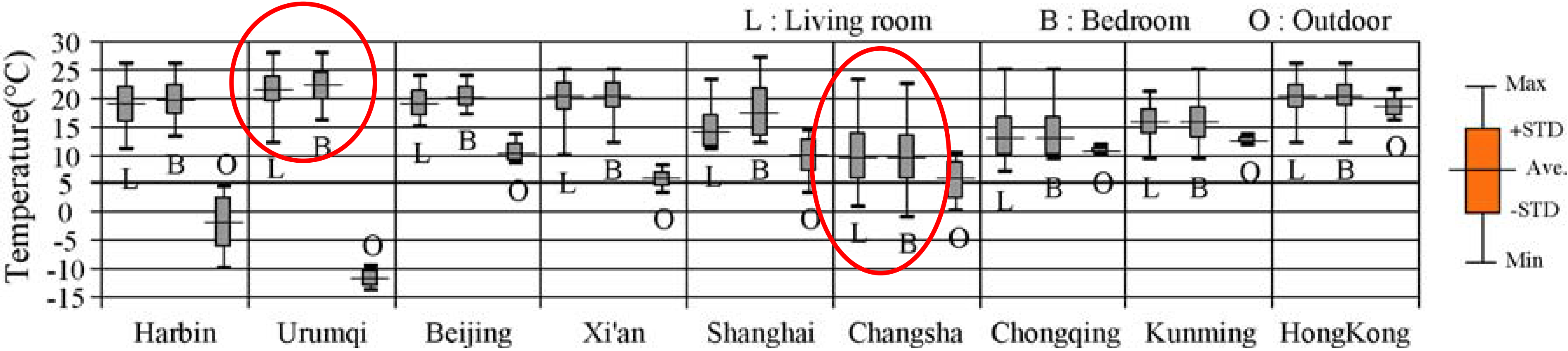
Introduction

- Indoor temperature and humidity variation



- Large variation range over the year and big difference between different seasons
- Related to outdoor environmental conditions
- Related to occupant behavior

Reference

[1] Yoshino et al. Energy and Building 2006, 38(11): 1308-1309

Introduction

Roadmap of subtask 2

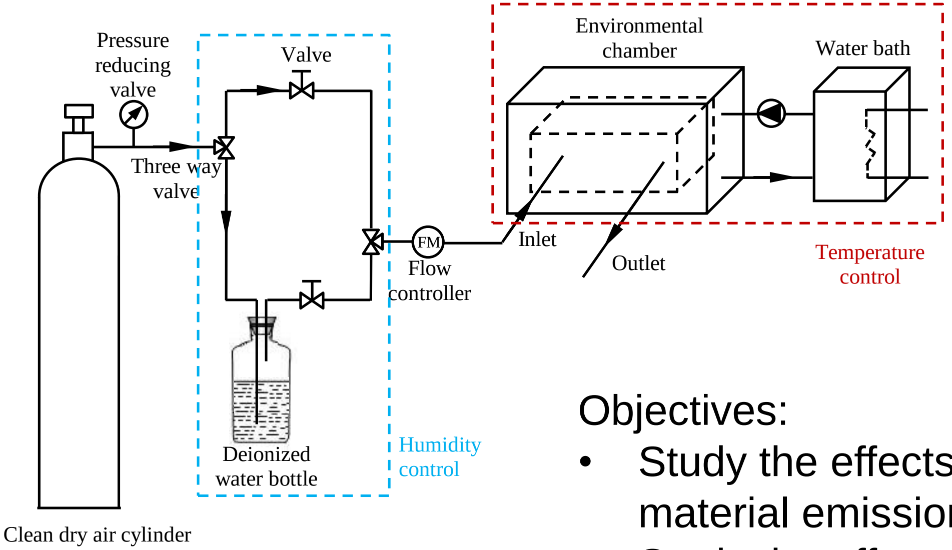
Literature survey	Measurement tests	Model development
➢Existing emission models ➢Emission standards ➢Emission Database	➢Laboratory test of material under various temperature, humidity and their combined effects ➢Field measurement tests for model validation	➢Correlations between emission parameters and key influencing factors ➢Mass transfer emission models development under various conditions

Time schedule

2015	2016	2017-2018	2019
• Stakeholders involve • Preliminary studies	• Literature survey • Preliminary studies	• Measurement test • Model development	• Reporting • Database development

Measurement method

- Environmental test



Objectives:

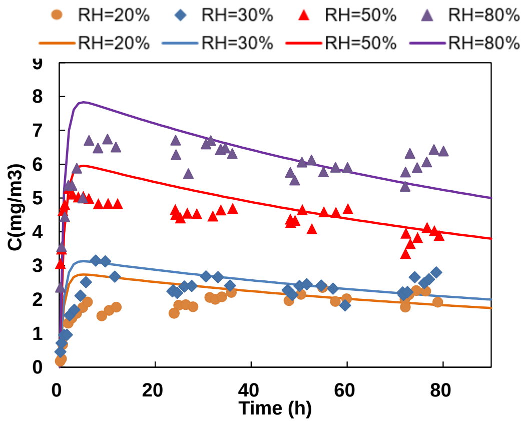
- Study the effects of temperature and humidity on dry material emissions
- Study the effects of temperature and humidity on wet material emissions

Dry material: medium-density fiberboard without covering

Series No.	Temperature (°C)	RH (%)	AH (g/kg_{air})	Ventilation rate (h^{-1})	Dimensions (mm×mm×mm)	
S1	**25.5±0.5**	20±5	4.0±0.5	1±0.05	245×140×12	Humidity effect
	25.5±0.5	30±5	6.1±0.5	1±0.05	245×140×12	
	25.5±0.5	50±5	10.4±0.5	1±0.05	245×140×12	
	25.5±0.5	80±5	16.7±0.5	1±0.05	245×140×12	
S2	7.0±0.5	62.0±5	**4.0±0.5**	1±0.05	245×140×12	Temperature effect
	15.0±0.5	38.6±5	**4.0±0.5**	1±0.05	245×140×12	
	25.5±0.5	20.0±5	**4.0±0.5**	1±0.05	245×140×12	
	34.1±0.5	12.0±5	**4.0±0.5**	1±0.05	122×140×12	
S3	5.2±0.5	**50.0±5**	2.8±0.5	1±0.05	245×140×12	Combined effect
	15.0±0.5	**50.0±5**	5.2±0.5	1±0.05	245×140×12	
	25.5±0.5	**50.0±5**	10.4±0.5	1±0.05	245×140×12	
	35.0±0.5	**50.0±5**	17.8±0.5	1±0.05	122×140×12	

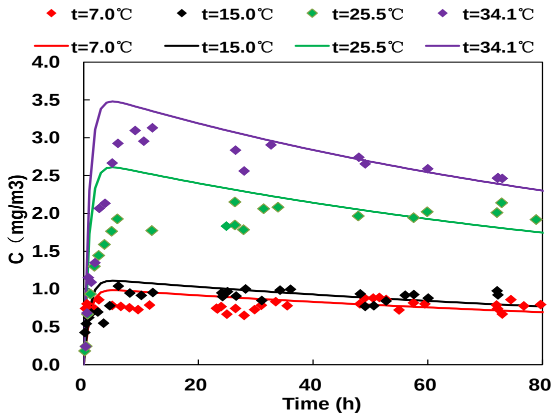
Dry material

S1



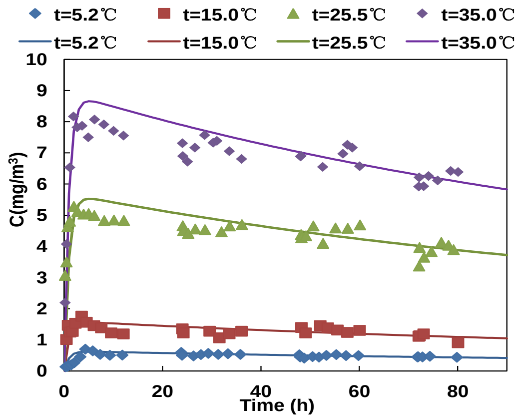
C_0 (mg/m³)	D_m (m²/s)	K (—)
1.75×10^6	3.40×10^{-14}	6340
2.00×10^6	3.36×10^{-14}	5514
3.80×10^6	3.50×10^{-14}	5340
5.20×10^6	3.14×10^{-14}	6128

S2



C_0 (mg/m³)	D_m (m²/s)	K (—)
7.90×10^5	3.00×10^{-14}	9467
8.50×10^5	3.15×10^{-14}	7844
1.75×10^6	3.40×10^{-14}	6340
4.30×10^6	3.57×10^{-14}	4570

S3

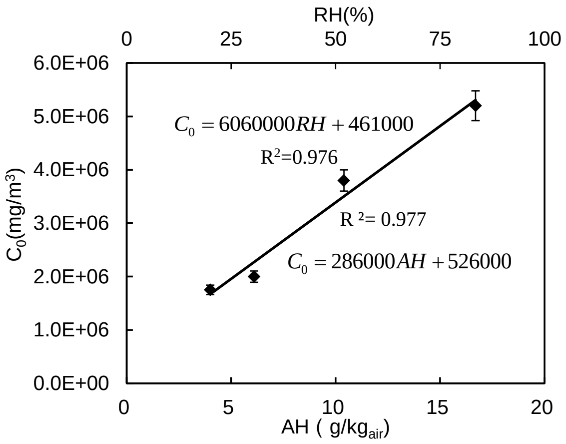


C_0 (mg/m³)	D_m (m²/s)	K (—)
4.93×10^5	2.90×10^{-14}	9752
1.14×10^6	3.15×10^{-14}	7280
3.80×10^6	3.50×10^{-14}	5340
1.10×10^7	3.60×10^{-14}	3450

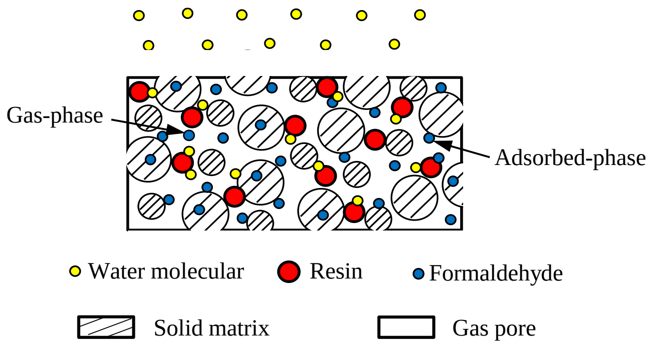
Dry material

Correlation between emission parameters and temperature and humidity

Humidity effect



Combined effects



Empirical correlation

$$C_0 = C_1 \times AH + C_2$$

$$C_0(t) = (1 + C_1 \times AH(t))C_2 T(t)^{-0.5} \exp\left(-\frac{C_3}{T(t)}\right)$$

$$D_m(t) = B_1 T(t)^{1.25} \exp\frac{B_2}{T(t)} \qquad K(t) = A_1 T(t)^{0.5} \exp\frac{A_2}{T(t)}$$

Dry material

Field study

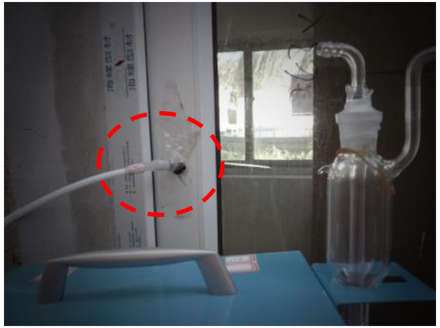
- The houses

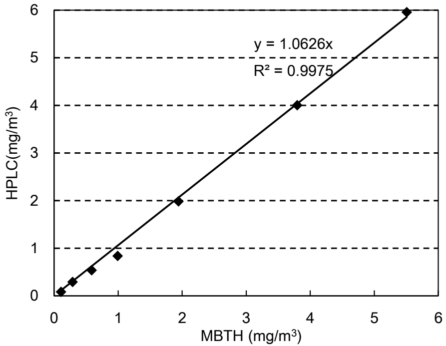
Simple than a real used house, but close-to-real

  - Outdoor environmental condition, change seasonally
  - Windows and doors closed
  - Indoor environmental condition change seasonally but very slowly
  - Real house size, different layout
  - Building construction completed one year ago, empty houses
  - Unoccupied, no human-related emission

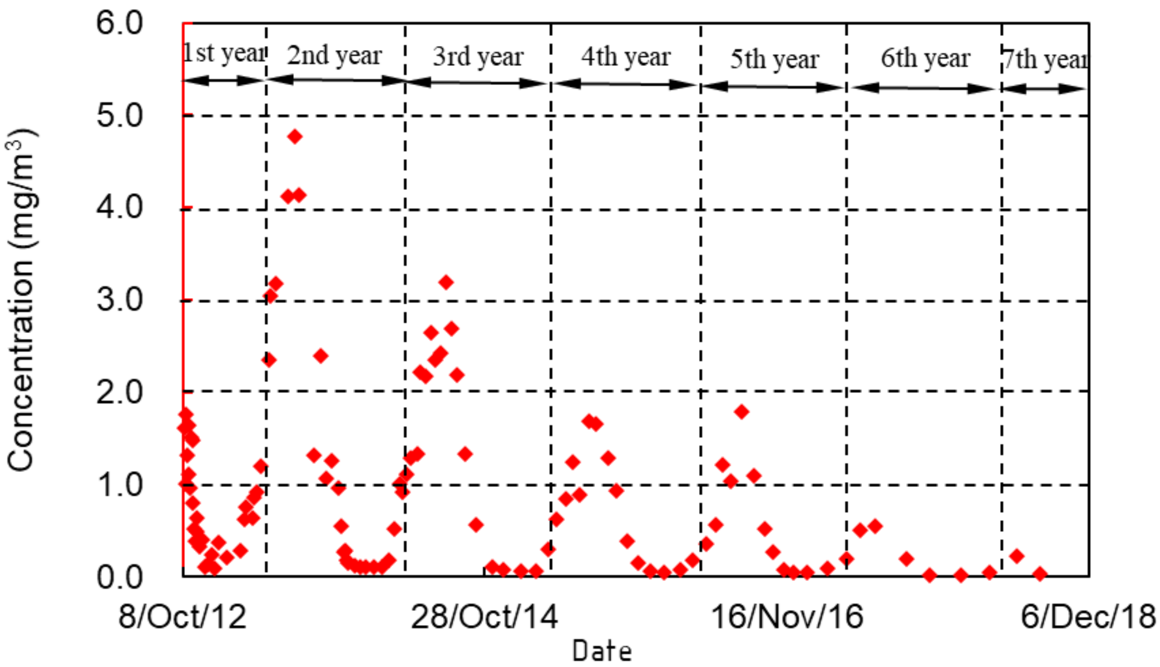
The Sampling

- Measurement conducted from outdoor,
- Parallel sampling (3 samples per room)
- Sampling time interval: 1-2 weeks
- Measurement duration: ~7 years
- MBTH solution + Ultraviolet-visible (UV-VIS) spectrophotometer





Measurement results

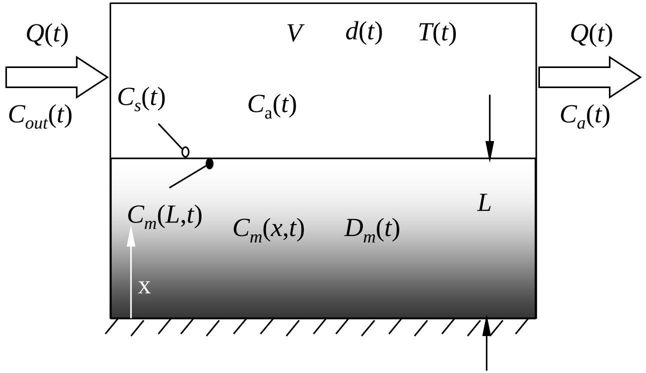


(1) Seasonal variation， no “steady state”

(2) Highest concentration occurred in the summer instead of at the beginning of the study

(3) Significant difference of the emission characteristics between the experimental house and environmental chamber

Model development



Diffusion through the material slab

$$\frac{\partial C_m(x,t)}{\partial t} = D_m(t)\frac{\partial^2 C_m(x,t)}{\partial x^2}$$

At the bottom surface of the material

$$\frac{\partial C_m(x,t)}{\partial t} = 0 \qquad t > 0,\ x = 0$$

At the material-air interface

$$E(t) = -D_m(t)\frac{\partial C_m(x,t)}{\partial x} = h_m(C_s(t) - C_a(t)) \quad t > 0, x = L$$

$$C_m(x,t) = K(t)C_s(t) \qquad t > 0, \quad x = L$$

Initial condition

$$C_m(x,t) = C_0(x, t = 0)$$

Mass balance equation

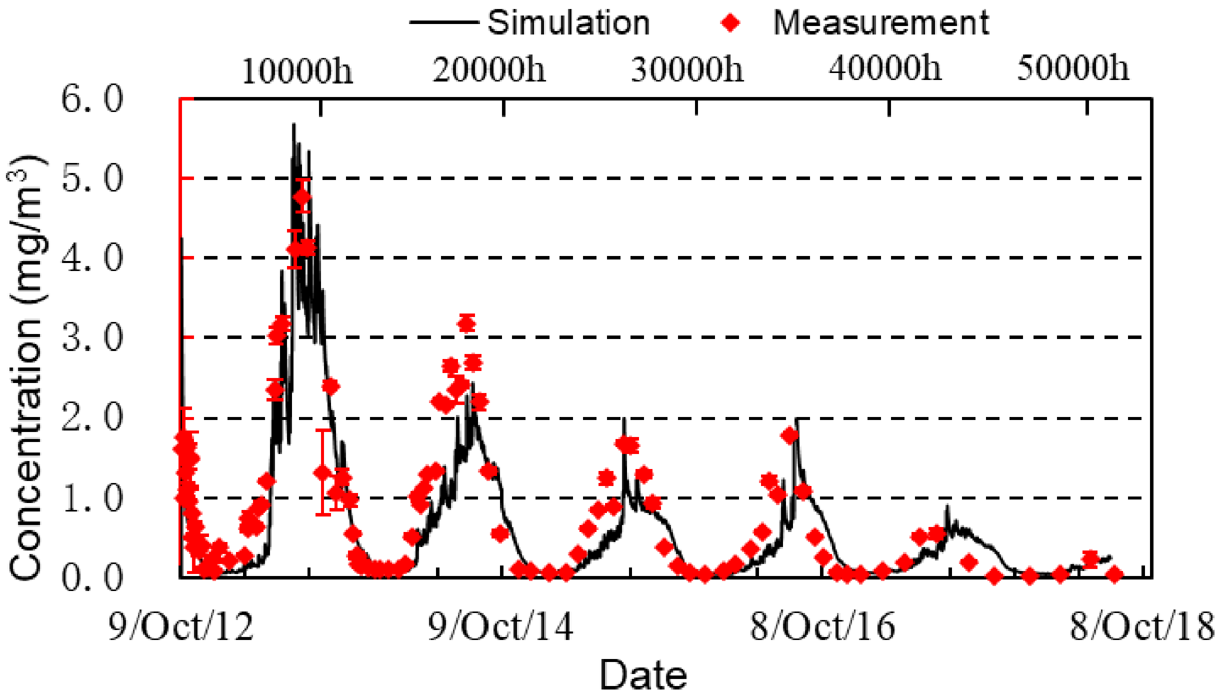
$$V\frac{dC_a(t)}{dt} = A \times E(t) + Q(t)C_{out}(t) - Q(t)C_a(t)$$

The combined effects

$$C_0(t) = (1 + C_1 \times AH(t))C_2 T(t)^{-0.5}\exp\left(-\frac{C_3}{T(t)}\right)$$

$$D_m(t) = B_1 T(t)^{1.25}\exp\frac{B_2}{T(t)} \qquad K(t) = A_1 T(t)^{0.5}\exp\frac{A_2}{T(t)}$$

Model validation



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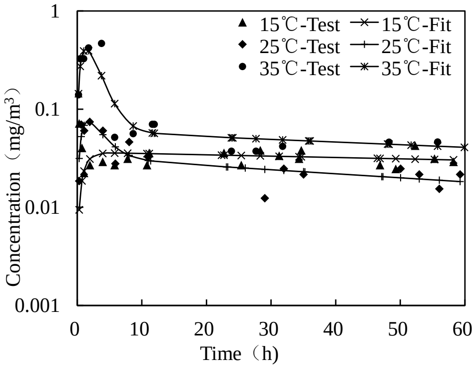
Wet material- wood lacquer

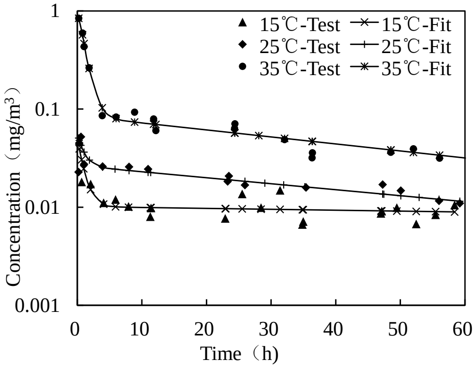
Series No.	Temperature (℃)	RH (%)	ACH (h^{-1})	Substrate	Dimensions (mm*mm)	Applied amount (g)	
S1	15.0±0.5	50.0±5.0	1.0±0.05	Glass	150*150	3.219	Temperature effect
	25.0±0.5	50.0±5.0	1.0±0.05	Glass	150*150	3.215	
	35.0±0.5	50.0±5.0	1.0±0.05	Glass	150*150	3.341	
S2	25.0±0.5	30.0±5.0	1.0±0.05	Glass	150*150	3.218	Humidity effect
	25.0±0.5	50.0±5.0	1.0±0.05	Glass	150*150	3.215	
	25.0±0.5	80.0±5.0	1.0±0.05	Glass	150*150	3.207	

Wet material-temperature effect

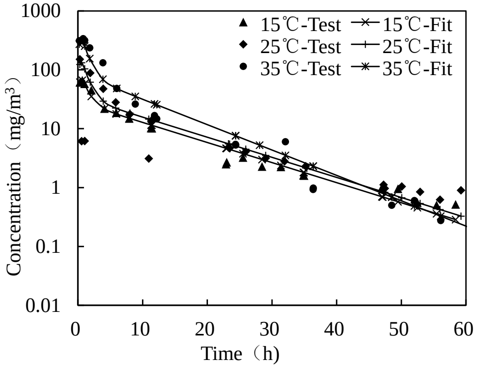
Formaldehyde



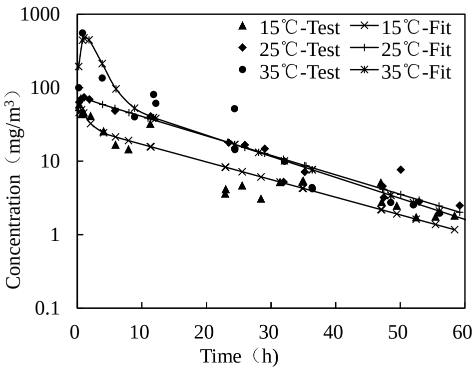
Benzene



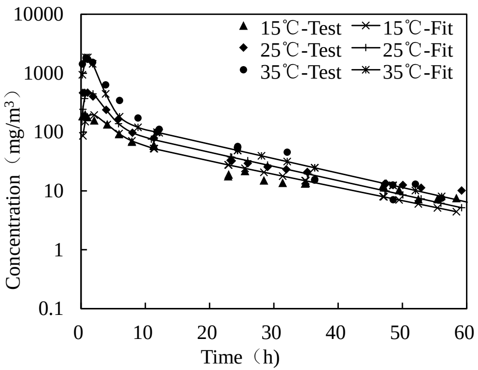
Toluene



Xylene



TVOC



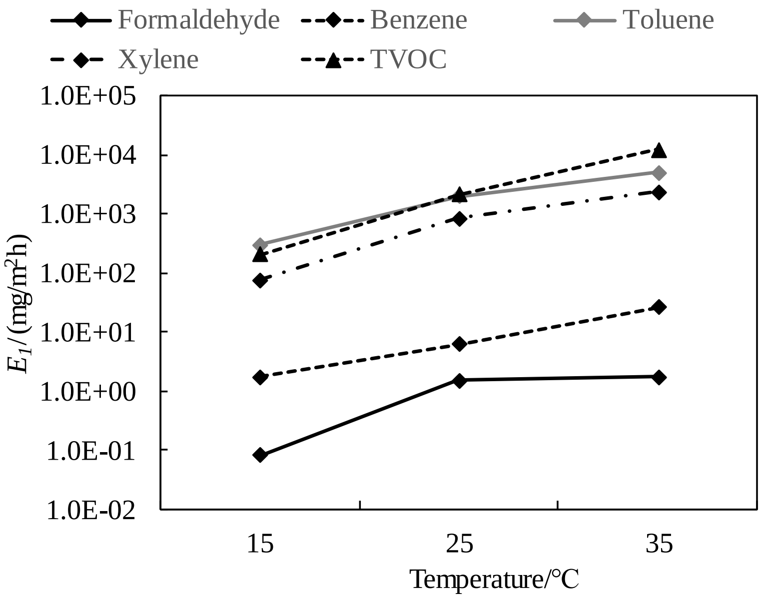
Big differences of the peak concentrations among different temperatures.

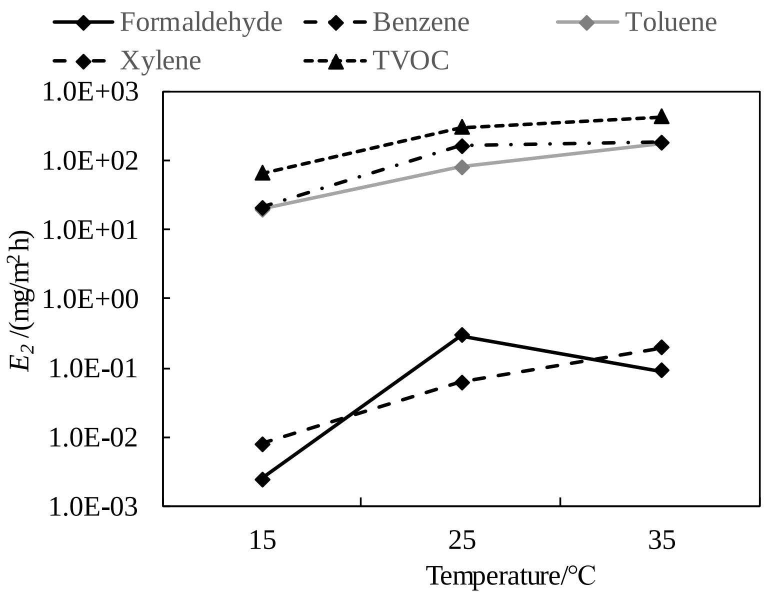
The variation patterns of toluene, xylene and TVOC were close to each other, showing the characteristics of strong emission and fast decay at the first stage

The effects of temperature were more obvious on formaldehyde and benzene than other pollutants

Wet material-temperature effect

- Double exponential emission model of wet material $E = E_1 e^{-k_1 t} + E_2 e^{-k_2 t}$





Wet material-temperature effect

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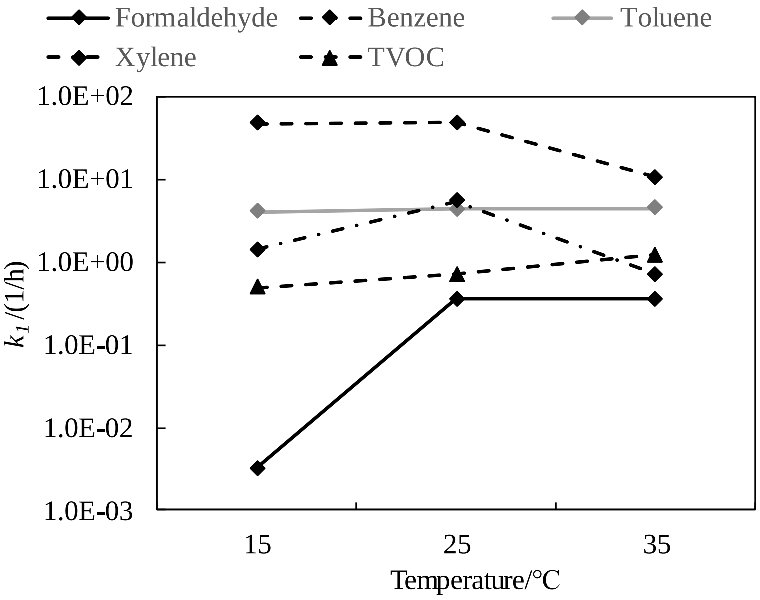

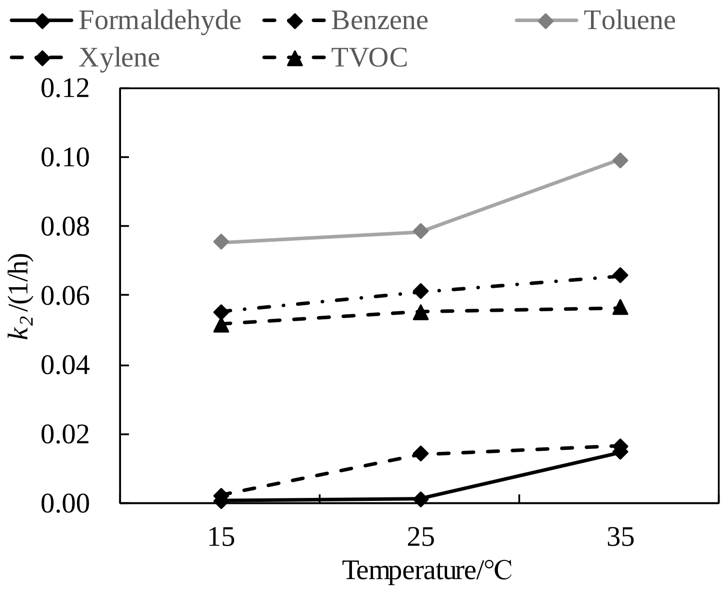

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Wet material-humidity effect

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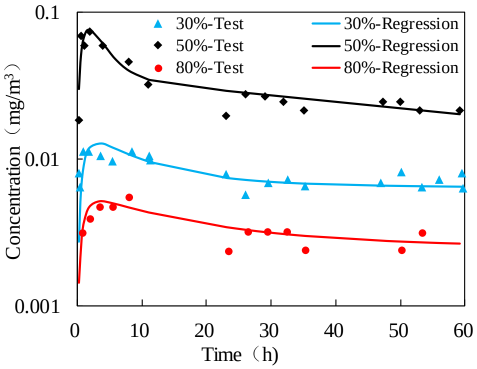
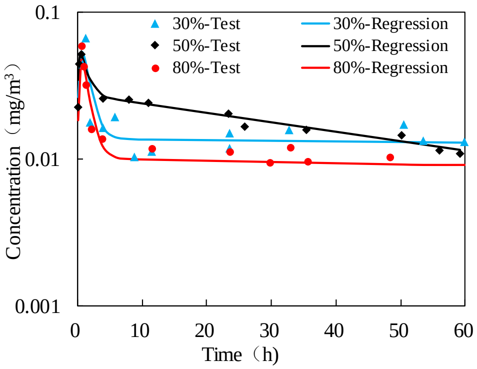
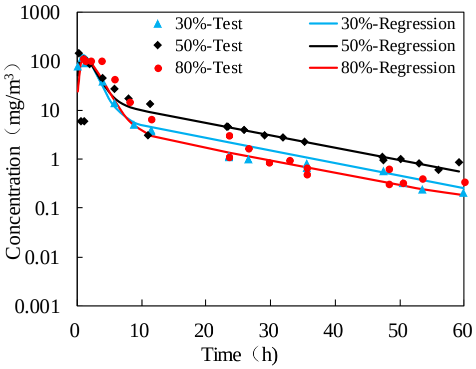
Formaldehyde



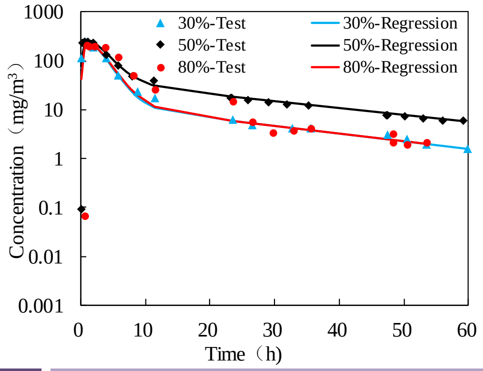
Benzene



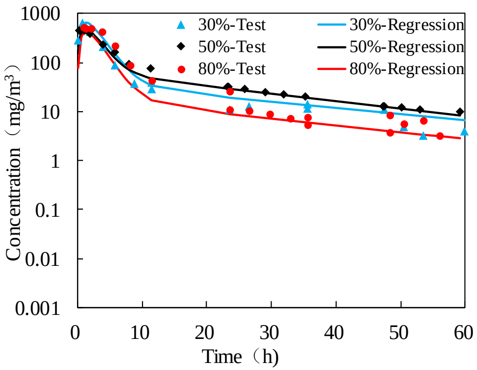
Toluene



Xylene



TVOC

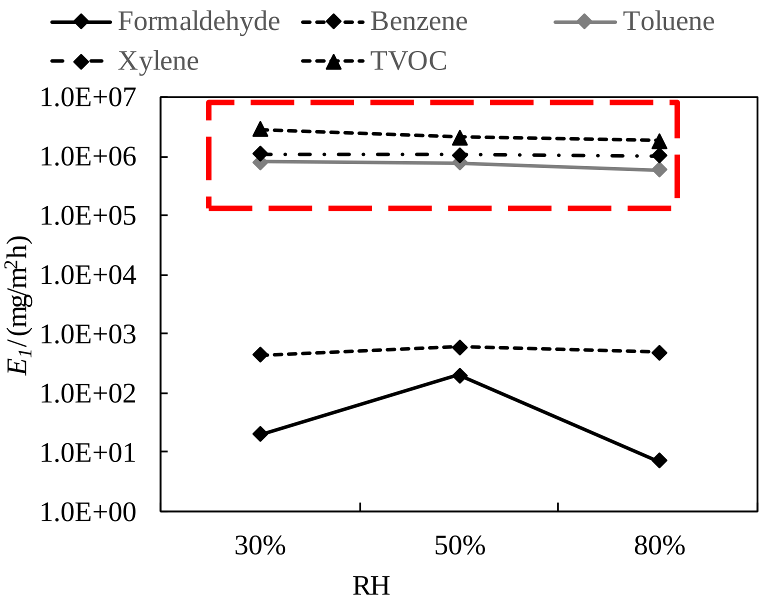


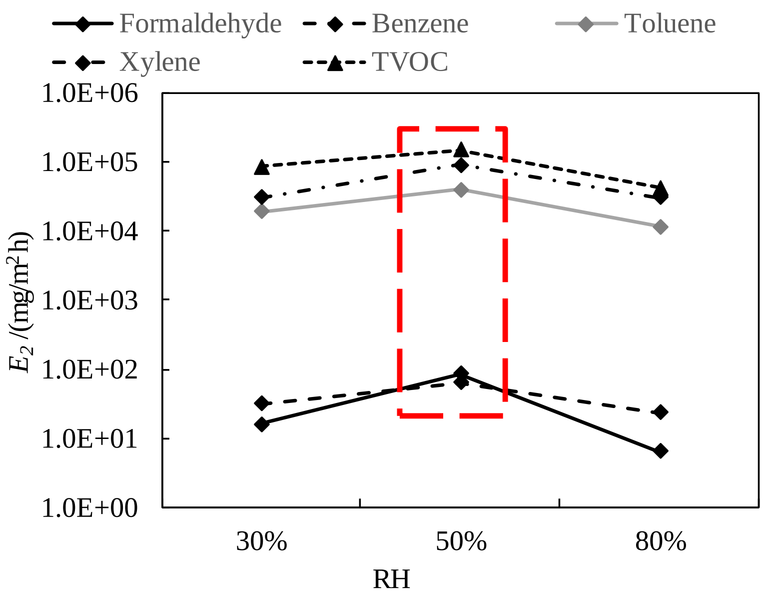
Generally speaking, VOC emissions are highest when RH=50% and lowest when RH=80%

The humidity effect on VOC emission at the first stage is not obvious for toluene, xylene and TVOC

Wet material-humidity effect

- Double exponential emission model of wet material $E = E_1 e^{-k_1 t} + E_2 e^{-k_2 t}$





Wet material-humidity effect

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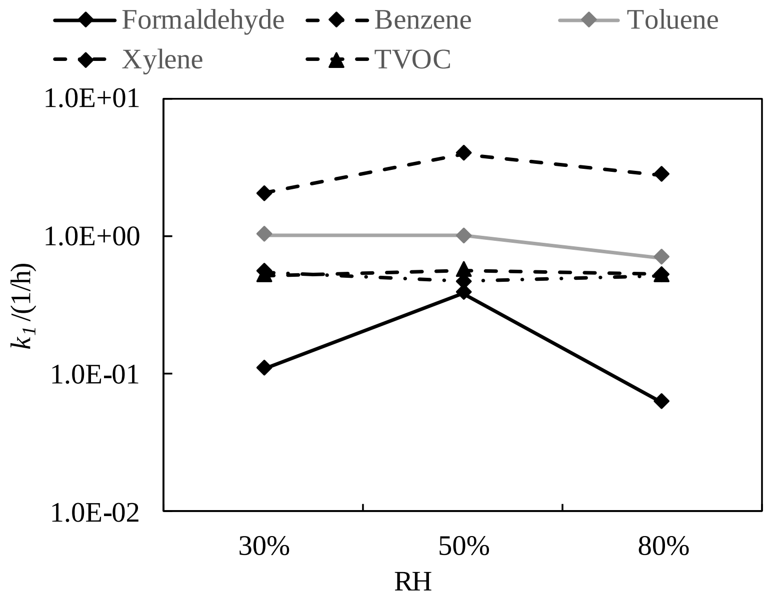

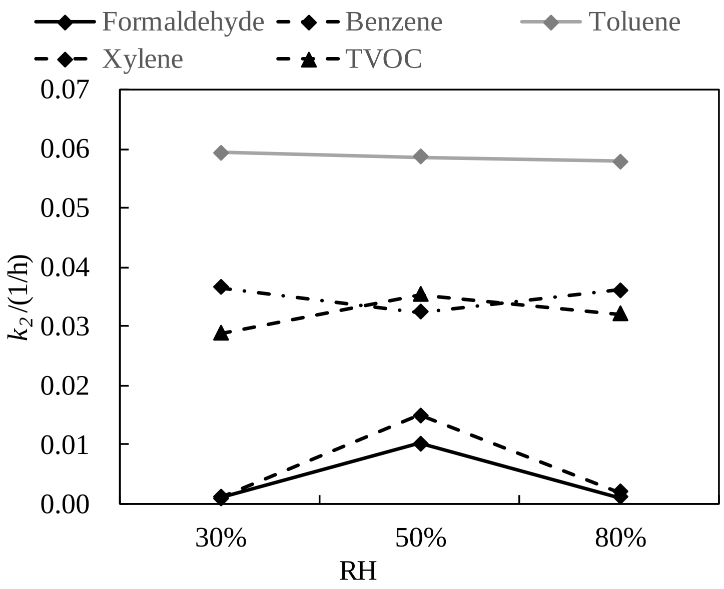

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Conclusions

- The effects of temperature and humidity on VOC emission from both dry and wet building materials were tested
- Temperature and humidity has positive effects on formaldehyde emissions from dry materials
- A dynamic emission model was developed and validated by long-term field measurement data
- Formaldehyde and VOC emissions from the wood lacquer are positive correlated with temperature (same as the temperature effect on the MDF)
- VOC emissions are highest when RH=50% and lowest when RH=80%

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thanks

Questions and Comments