IAQ 2016 Defining Indoor Air Quality: Policy Standards and Best Practices

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IEA-EBC Annex 68
Indoor Air Quality Design and Control in Low Energy Residential Buildings

The effects of temperature and humidity on formaldehyde emission from building materials

Outline

- Brief introduction of the Subtask 2 of IEA Annex 68
- The effect of humidity on emission parameters of building materials
- The effect of temperature on emission parameters of building materials
- The combined effects of temperature and humidity on formaldehyde emission from building materials

Scope of Subtask 2

- ST2 will focus on the laboratory measurement of fundamental emission/sorption data and the development of mechanistic emission source/sink models (“small model”) for materials and assemblies used in residential buildings. The laboratory data will be used to determine the parameters of the mechanistic source/sink models, which will be used as input to the room or house models developed in ST3.

- ST2 will first collect data (both existing and new data) about properties for transport, storage and emission of chemical substances in materials and assemblies used in residential buildings under the influence of different indoor heat and moisture conditions. The interaction between pollution sources and sinks will also be studied. These data and “small models” will be used in ST3 for the development of room models (“big model”…)

- The measurements in the full-scale climate chamber (or field measurement in a test room) will be used for the validation.

- ST2 will also seek contributions on pollution loads due to outdoor pollutions (e.g., PM2.5, NOx, SOx, O3), occupant activities and secondary emissions due to chemical reactions (e.g., ozone interaction with surfaces soiled with skin oil components such as squalene). A literature review will be conducted to provide baseline data.

Participants of Subtask 2

More are welcome...

- **Nanjing University**
- Tsinghua University
- Shenzhen IBR
- Shanghai University of Science and Technology
- Hong Kong University **
- Dalian Technicial University **

Activities and Roadmap

Literature survey

- Major pollutant sources from materials and assemblies in residential buildings
- Existing emission models and model parameters
- Emission standards
- Database

Measurement tests

- Laboratory test of materials under various temperature, humidity and their combined effects
- Field measurement tests for model validation

Model improvement

- Correlations between emission parameters and key influencing factors
- Mass transfer emission models development
- Similarity between VOC/SVOC and moisture transport

Time schedule

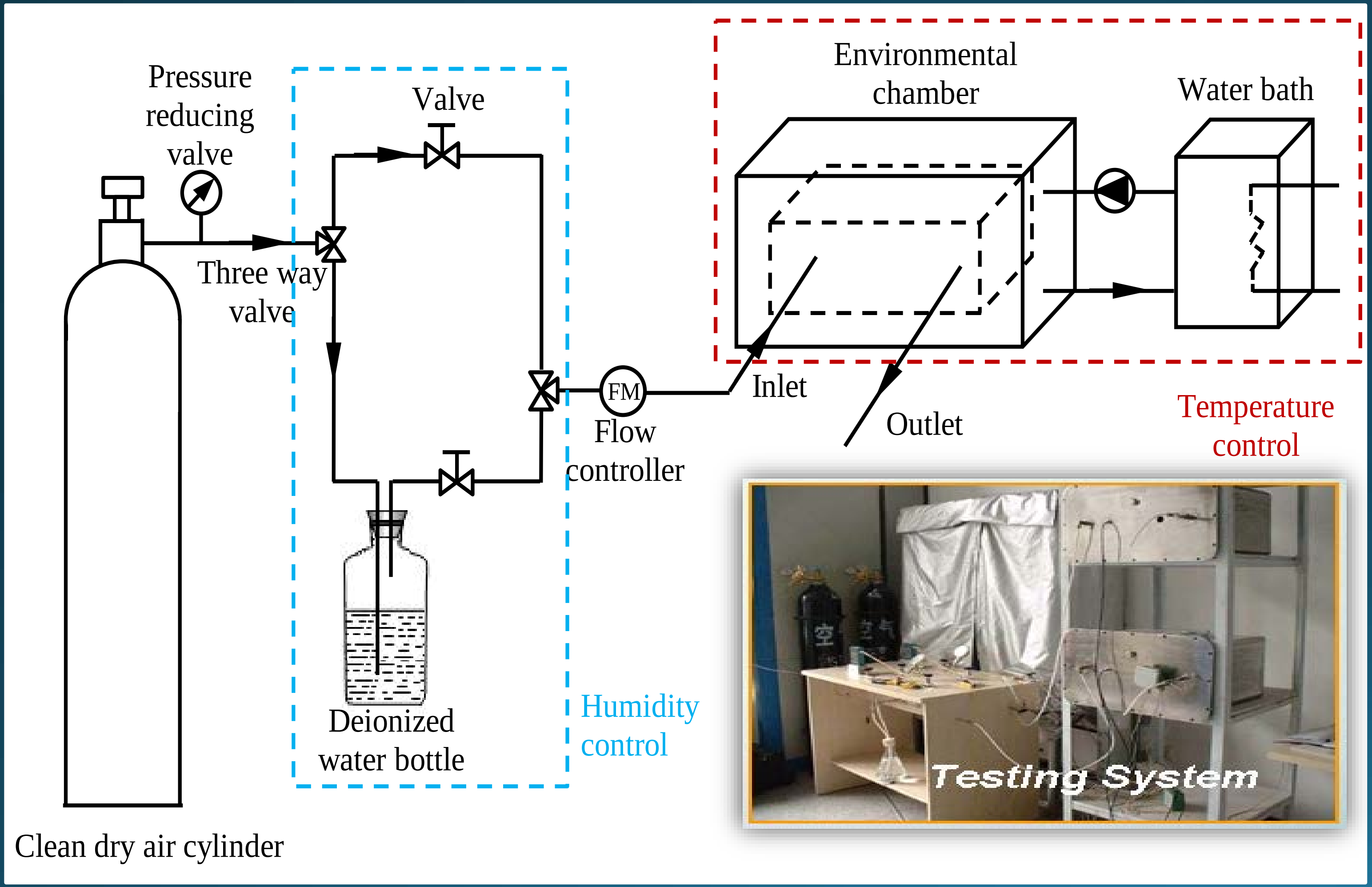
2015
- Stakeholders involve
- Preliminary studies

2016
- Literature survey
- Preliminary studies

2017-2018
- Measurement test

2019
- Reporting
- Database development

Laboratory test of materials under various temperature, humidity and their combined effects



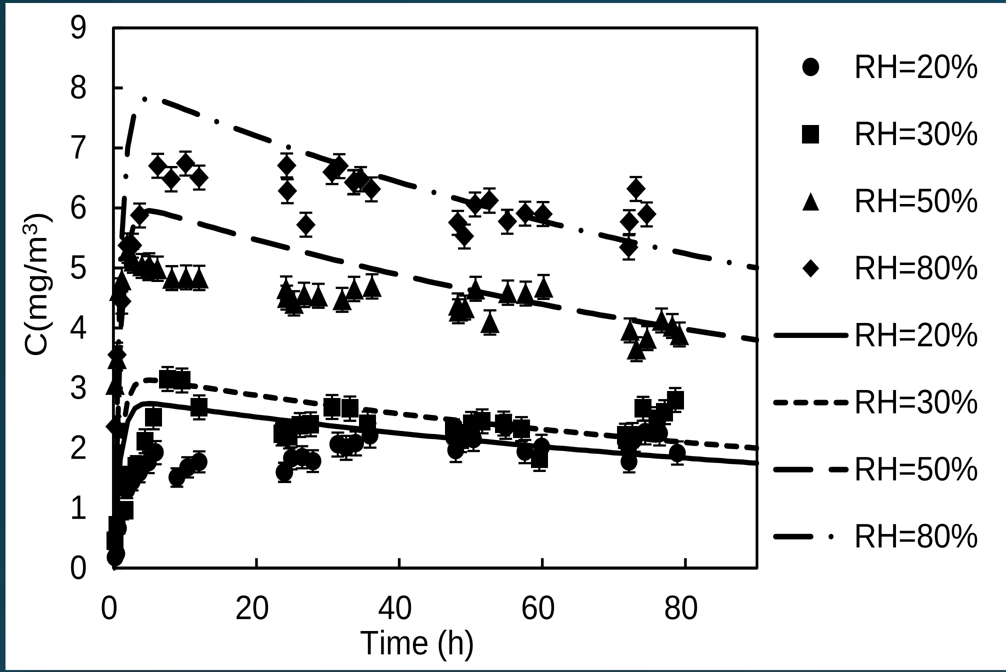
Small-scale and large-scale environmental chambers @ NJU

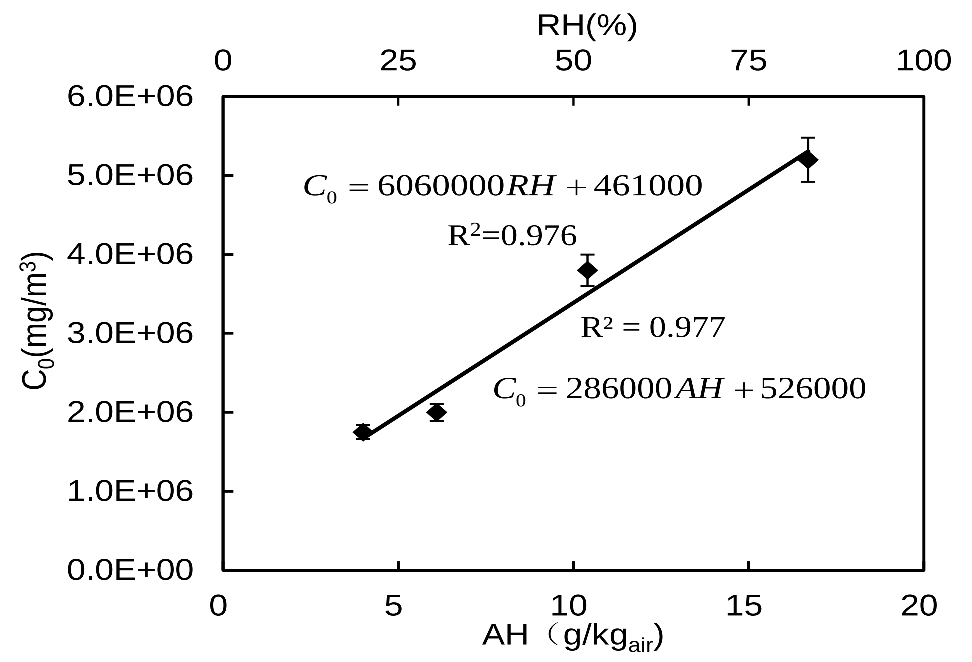
Humidity effect

Experimental settings and optimum regressed emission parameters of the small-scale environmental chambers tests

Temperature (°C)	RH (%)	Absolute humidity (g/kg_{air})	Ventilation rate (h^{-1})	Dimensions (mm×mm×mm)	C_0 (mg/m^3)	D_m (m^2/s)	K (—)
25.5±0.5	20±5	4.0±0.5	1±0.05	245×140×12	1.75×10^6	3.40×10^{-14}	6340
25.5±0.5	30±5	6.1±0.5	1±0.05	245×140×12	2.00×10^6	3.36×10^{-14}	5514
25.5±0.5	50±5	10.4±0.5	1±0.05	245×140×12	3.80×10^6	3.50×10^{-14}	5340
25.5±0.5	80±5	16.7±0.5	1±0.05	245×140×12	5.20×10^6	3.14×10^{-14}	6128

Humidity effect





- Humidity effect on Dm and K were not significant

- C_0 is linear related to absolute and relative humidity

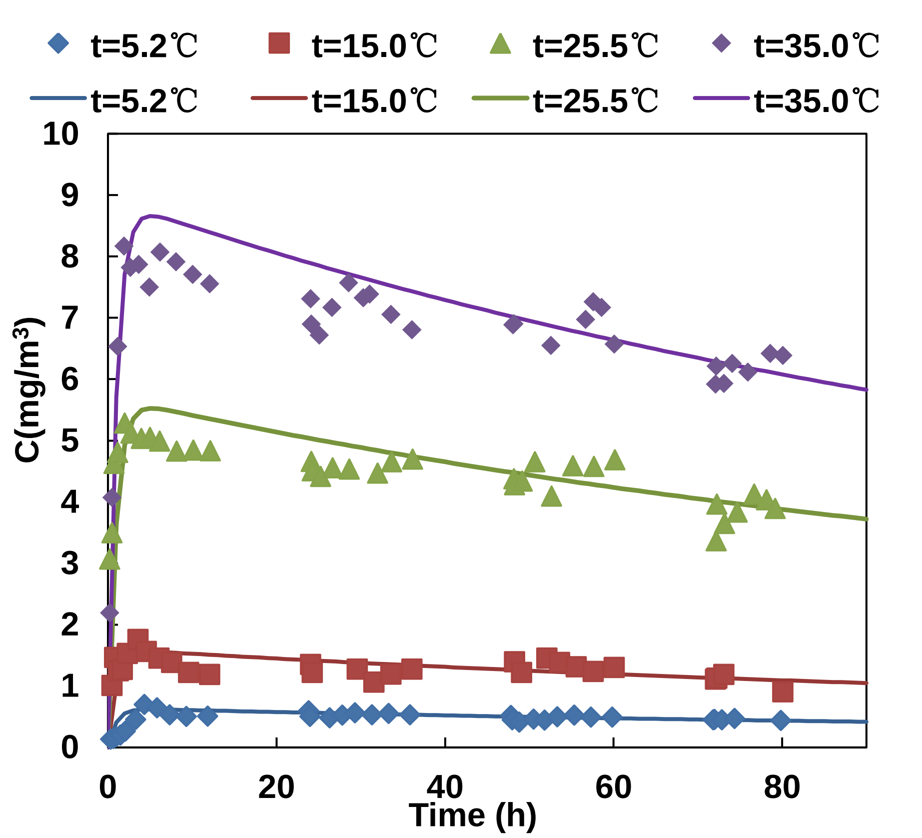
Temperature effect

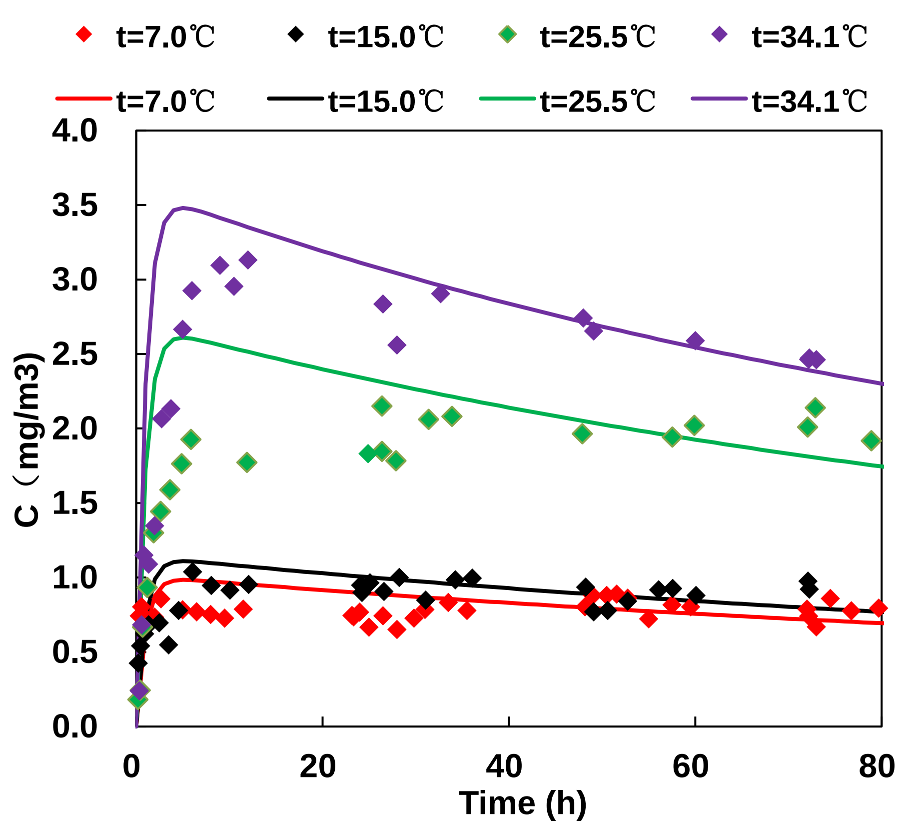
Experimental settings of temperature and combined effects of temperature and humidity of the small-scale environmental chambers tests

Temperature (°C)	RH (%)	Absolute humidity (g/kg_{air})	Ventilation rate (h^{-1})	Dimensions (mm×mm×mm)	C_0 (mg/m^3)	D_m (m^2/s)	K (—)
7.0±0.5	62.0±5	4.0±0.5	1±0.05	245×140×12	7.90×10^{5}	3.00×10^{-14}	9467
15.0±0.5	38.6±5	4.0±0.5	1±0.05	245×140×12	8.50×10^{5}	3.15×10^{-14}	7844
25.5±0.5	20.0±5	4.0±0.5	1±0.05	245×140×12	1.75×10^{6}	3.40×10^{-14}	6340
34.1±0.5	12.0±5	4.0±0.5	1±0.05	122×140×12	4.30×10^{6}	3.57×10^{-14}	4570
5.2±0.5	50.0±5	2.8 ±0.5	1±0.05	245×140×12	4.93×10^{5}	2.90×10^{-14}	9752
15.0±0.5	50.0±5	5.2±0.5	1±0.05	245×140×12	1.14×10^{6}	3.15×10^{-14}	7280
25.5±0.5	50.0±5	10.4±0.5	1±0.05	245×140×12	3.80×10^{6}	3.50×10^{-14}	5340
35.0±0.5	50.0±5	17.8±0.5	1±0.05	122×140×12	1.10×10^{7}	3.60×10^{-14}	3450

Temperature effect

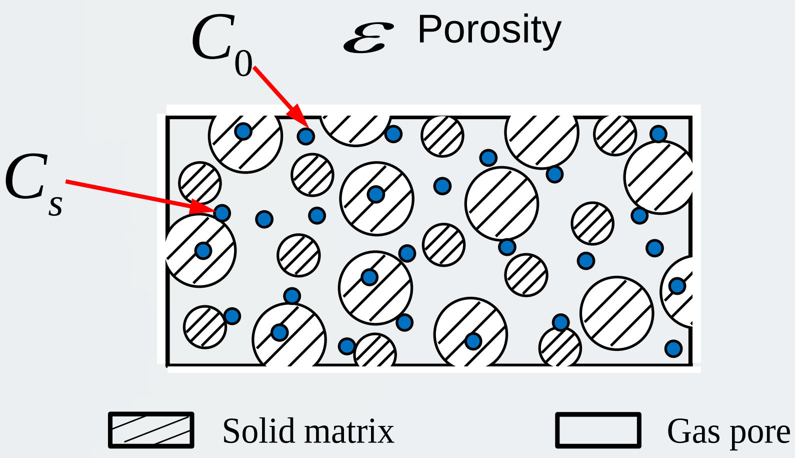
Measurement results





The effect of temperature is more obvious at identical RH than identical AH condition

Temperature effect



$$\varepsilon \frac{\partial C}{\partial t} + \frac{\partial C_{ad}}{\partial t} = D_{e,g} \frac{\partial^2 C}{\partial y^2} + D_{e,ad} \frac{\partial^2 C_{ad}}{\partial y^2}$$

Gas-phase diffusion adsorbed-phase diffusion

1. Correlation between the gas-phase concentration and initial emittable concentration (C_0) could be expressed as $C_0 = \varepsilon C_a$

2. Equilibrium is assumed to be established between the gas-phase and adsorbed-phase

$$C_s = K_s C_a$$

3. Total formaldehyde concentration in the material ($C_{0,\ total}$ (mg/m$^3_{\text{material}}$)) is the sum of C_a and C_s

$$C_{0,\ total} = \varepsilon C_a + C_s$$

4. Correlation between one-phase partition coefficient K and the multi-phase partition coefficient K_s

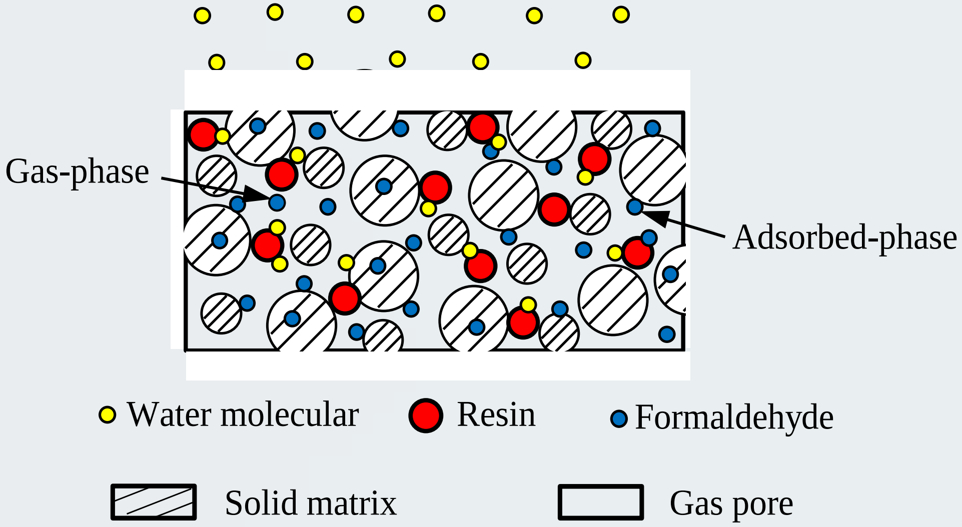
$$K = \varepsilon + K_s$$

5. Correlation between C_a and $C_{0,\ total}$ could be derived

$$C_a = \frac{C_{0,\ total}}{K}$$

$$C_0 = \varepsilon C_a = \frac{\varepsilon C_{0,\ total}}{K} = \frac{\varepsilon C_{0,\ total}}{A_1 T^{0.5} \exp \frac{A_2}{T}} = C_1 T^{-0.5} \exp(-\frac{C_2}{T})$$

Combined effect



Total formaldehyde in the material at dry condition

$$m_1 = \text{constant}$$

Formaldehyde induced by humidity effect

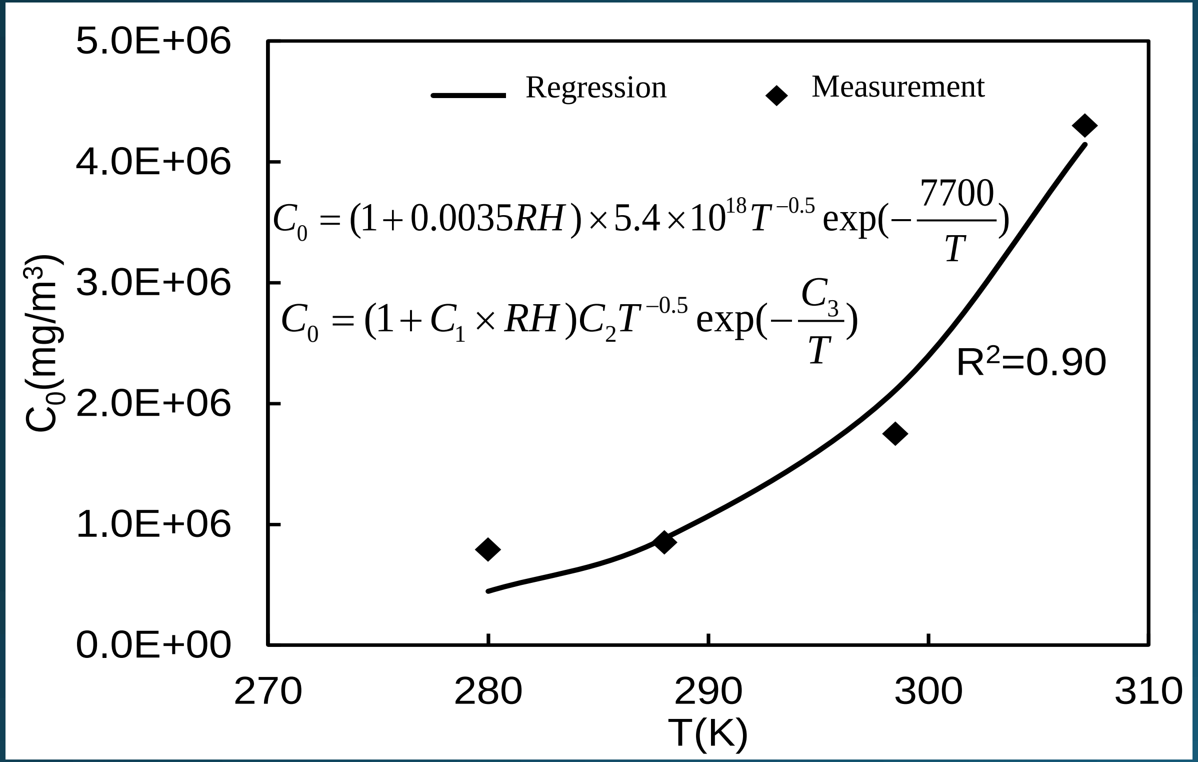
$$m_2 = C_1 \times AH + C_2$$

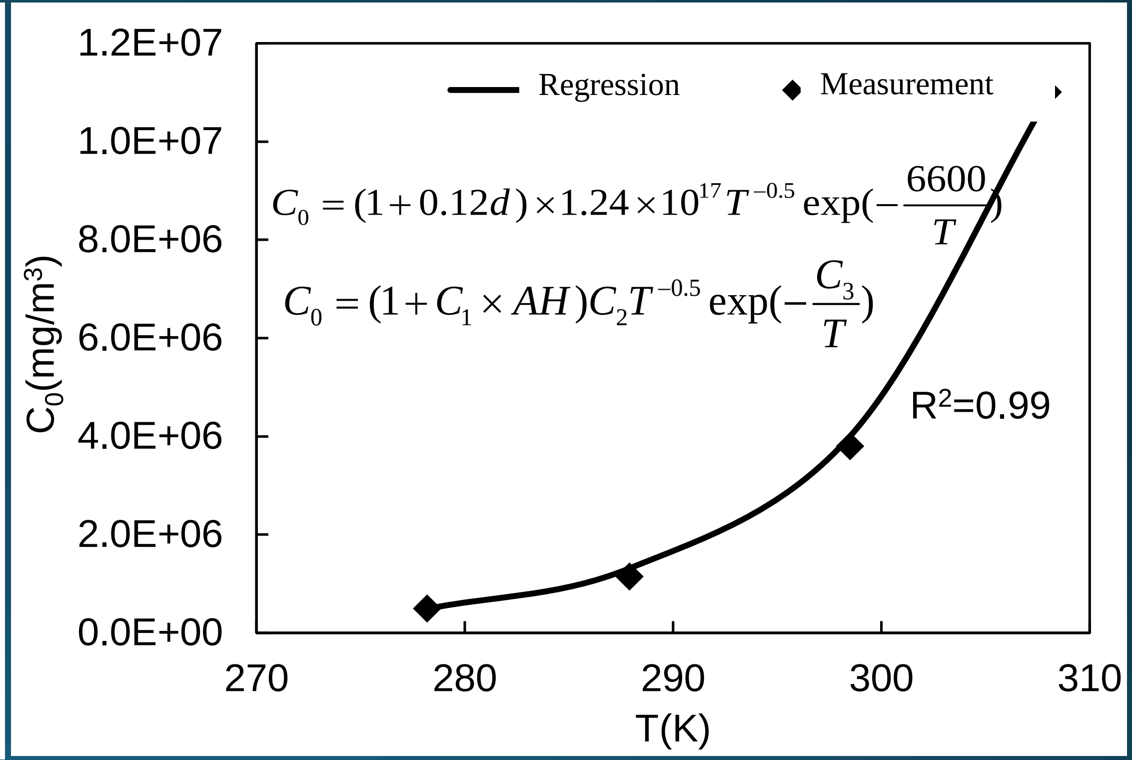
$$m_2 = C_1 \times RH + C_2$$

$$C_0 = \varepsilon C_a = \frac{\varepsilon C_{0,\,total}}{K} = \frac{\varepsilon(m_1 + m_2)}{K} = \frac{\varepsilon(m_1 + a_1 \times AH + b_1)}{K} = \frac{\varepsilon(m_1 + a_1 \times AH + b_1)}{A_1 T^{0.5} \exp\frac{A_2}{T}}$$

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

Experimental validation





	C_1	C_2	C_3
C_0	0.0035	5.4×10^{18}	-7700
D_m	7.14×10^{-17}	-284	
K	0.225	2188	

	C_1	C_2	C_3
C_0	0.12	1.24×10^{17}	-6600
D_m	5.18×10^{-17}	-194	
K	0.12	2376	

Conclusion

- A semi-empirical correlation between initial emittable concentration (C_0) and the combined effects of temperature (T) and humidity (absolute humidity AH or relative humidity RH) was derived

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

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

- Hydrolysis reactions affected by humidity and kinetic energy distribution of formaldehyde molecules affected by temperature were considered in the derivation process

- The good agreement between the correlation and measurement data demonstrated the effectiveness of this correlation

Bibliography

- Carsten Rode, Marc Abadie, Menghao Qin, John Grunewald, Jakub Kolarik, Jelle Laverge, Jianshun Zhang, 2016. An International Project on Indoor Air Quality Design and Control in Low Energy Residential Buildings. Presented at IAQ 2016 Defining Indoor Air Quality: Policy, Standards, and Practices, Alexandria, VA September 12-14.

Questions?

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