DEVELOPMENT OF THE VOC REMOVAL FILTER FOR CEILING CASSETTE TYPE AIR CONDITIONERS AND APPLICATION TO AN EDUCATIONAL FACILITY

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ABSTRACT

The VOC removal filter for ceiling cassette type air conditioners was developed as a countermeasure against "sick school".

This paper illustrates basic performance of the developed filter, the detail of toluene removal examinations in an experiment room and the result of demonstration examinations in a school. The one pass examination showed that the filter had about 90% of toluene removal efficiency.

The toluene removal examination was conducted for 12 days to measure toluene removal efficiency in a mock-up experiment room. It is confirmed that soon after the ceiling cassette was operated, Toluene concentration was reduced and performance did not fall during the period of experiment.

The life of the filter was estimated by measuring the absorption and the breakthrough of the filter used for the experiment in the column examination. The life is estimated at around 1 year under the room condition of 260μg/m^3 of toluene concentration during 8 hours drive of the ceiling cassette.

Developed filters were applied to a newly-built school classroom for 24 days and VOC removal efficiency was measured. The examination proved that the filter had VOC removal efficiency of 80% or more. VOC removal efficiency did not change much over 24 days of the experiment.

KEYWORDS

VOC (Volatile Organic Compounds), Chemical filter, Ceiling cassette type air conditioner, Removal efficiency, School

INTRODUCTION

"Sick school" is a problem leading to deconditioning caused by volatile organic compounds (VOC) such as toluene, xylene and so on, which diffuse from building materials and furniture in schools. It is a serious issue to decrease indoor VOC concentration. Ministry of Education, Culture, Sports, Science and Technology recommends setting the indoor concentration at the criteria value as indicated in "the Guideline of School Environment and Welfare" [1)] or less; however, assured control methods are currently limited. We focused on 4-way air flow ceiling cassette type air conditioners (referred to as "ceiling cassettes", hereinafter) often installed in educational facilities and developed a VOC removal filter for ceiling cassette type air conditioners (referred to as "developed filter", hereinafter).

We will report on 1) the reduction of VOC using the developed filter in experiment rooms and the developed filter performance and 2) the result of verification testing in school for 24 days, where the developed filters were installed in a classroom of a newly built school where the ceiling cassette was installed.

Feature of the developed filter

The developed filter is a chemical filter having a pleated shape with a standard size of 505×505 mm

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and a standard thickness of 24 mm (Figure 1). The developed filter is attached to the 4-way type ceiling cassette grill as a replacement of the conventional “long life filter.” After the attachment, the ceiling cassette was operated. Indoor air passes through the developed filter and VOC is adsorbed to be removed from the air.

The relationship between the wind velocity and the pressure loss is shown in Figure 2. The volume reaches at about 25 Pa when the air passes at the wind velocity of 1 m/sec. The advantage of the developed filter is that a long life filter is not necessarily attached to the upper row, since dust can be removed.

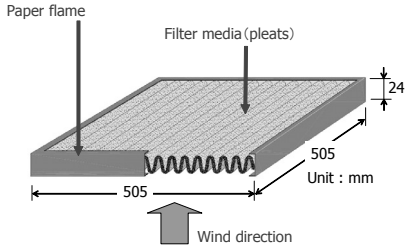


Figure 1.
Cross section of the developed filter

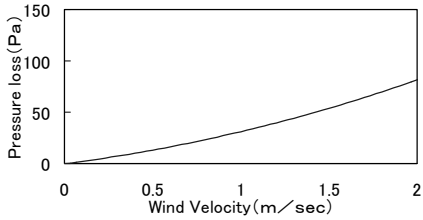


Figure 2.
Relationships between wind velocity and pressure loss

Toluene removal experiment by one-pass examination method

Experiment method

The toluene removal testing was performed by the one-pass examination in order to understand the basic VOC removal efficiency of the developed filter. By using the calibration gas generating system (Permeater : Gastec) as a testing device （Figure 3）, the toluene concentration on the filter upper stream side was adjusted to maintain 500～600 $\mu g/m^3$ with the wind velocity of 0.9m/sec. The testing condition is shown in Table 1. After the toluene concentration in the duct was stabilized, a 300 mm square shape test filter was attached to the testing duct. 2 hours after the attachment, the toluene concentration was sampled in the upper and lower filter stream using Tenax-GR tube. Qualitative and quantitative analyses were performed by GC/MS (Gas Chromatograph-Mass Spectrometry). As comparisons, the measurement was conducted under the same condition for the other 2 kinds of deodorizing filters A and B, having honeycomb structure with activated carbon impregnated type, made by the other companies.

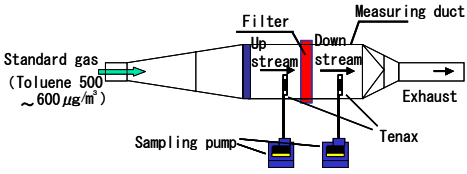


Figure 3.
One-pass examination device for filter

Table 1
Testing condition for one-pass examination using toluene gas

Standard gas	Toluene
Filter size (mm)	300×300×25
Wind velocity (m/sec)	0.9
Sampling tube	Tenax-GR
Sampling rate (ml/min)	50
Standard gas emission method	Diffusion tube

Measurement result and discussion

The measurement results are shown in Table 2. Whereas the developed filter achieved a litte fewer than 90% of toluene removal efficiency, the filter A and B did only about 50%. The high toluene removal efficiency of the developed filter was confirmed.

Table 2
Results of toluene removal efficiency one-pass examination

	Developed filter	Deodorant filter A	Deodorant filter B
Upstream ($\mu g/m^3$)	589	603	554
Downstream ($\mu g/m^3$)	81	337	258
Efficiency(%)	86	44	53

Toluene removal experiment in a mock-up room

Assuming the real installation, the experiment to understand the VOC removal efficiency in a real long-term circumstance was conducted under a condition to circulate the air in the ceiling cassette.

The experiment room was built as shown in Figure 4. In a common classroom, 4 sets of 4-way air flow ceiling cassette type air conditioners were assumed to be installed. Therefore, a ceiling cassette was fixed to the ceiling of the center of the experiment room, where the room size was set to be about 1/4 of the real classroom. A fan with variable rotation frequency was installed in the air intake and exhaust duct to control the air volume and it enabled to change the ventilation frequency.

Experiment method

The room air changes per hour guided in “the Guideline of School Environment and Welfare” are 2.2 times per hour or more in a kindergarten and elementary school facility and it is the fewest among facilities mentioned in the guideline[1]. Therefore, the air intake and exhaust fan was adjusted to ventilate 2.2 times per hour in this experiment.

The experiment condition is as shown in Table 3. First, a long life filter was attached to the grill part of the ceiling cassette. The wind velocity was set in “high“ and toluene was constantly supplied into the experiment room through the air intake duct by using a standard gas generator to maintain the toluene concentration of about 200 ppb during the mechanical ventilation was operated. After the concentration was stabilized, the long life filter was exchanged to the developed filter to measure toluene concentration for 12 straight days by using toluene detector tube （type 721： Komyo Rikagaku Kogyo） in the center of the room before and during the operation.

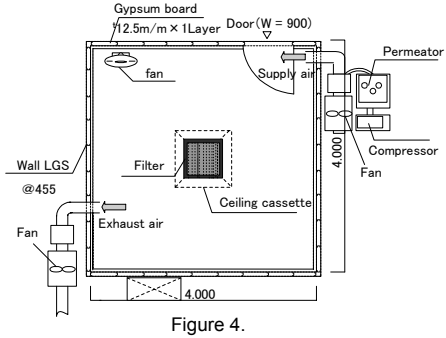


Figure 4.
Floor plan for mock-up experiment room

Table 3 Testing condition

Early stage of toluene concentration(ppb)	200
Indoor temperature(℃)	21
Ceiling cassette set up mode	Horizon, Ventilation
Wind velocity through filter(m/sec)	0.9
Measuring point	Center of the room
Air exchange rate (times/h)	2.2

Experiment result and discussion

The change in in-room toluene concentration with time from the right after the ceiling cassette operation is shown in Figure 5. Significant toluene removal efficiency was measured from the initial stage of operation and it was confirmed that the efficiency had been lasted over the whole operation period.

Also, a deodorizing filter and a long life filter made by the other companies were installed as well and

the ceiling cassette was operated in the same condition as in Table 3 to measure the toluene concentration using Tenax trapping tube after 24 hours of operation. As a result, the developed filter was confirmed to have significant removal efficiency comparing to the other 2 filters (Figure 6).

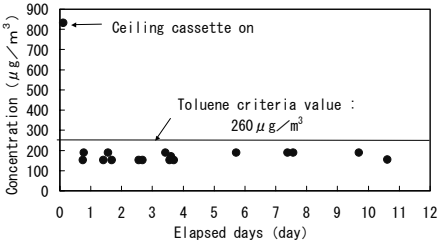


Figure 5.
Result of toluene concentration experiment

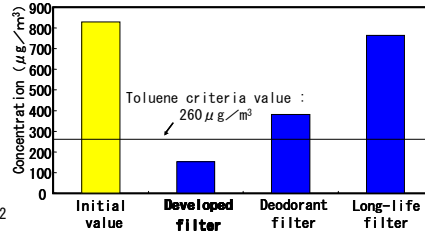


Figure 6.
Toluene concentration among filters over 24 hours

Filter life testing

Testing method

After the 12 days of the experiment of the developed filter used in the experiment in the prior section, the filter for the testing was cut and a piece of the filter was set in a column and the adsorption/breakthrough testing was conducted using toluene as standard gas. Also, the testing was conducted for an unused filter to measure the filter life to the toluene adsorption volume. The testing device is shown in Figure 7 and the experiment condition in Table 4.

From the result of the column testing, the filter life was considered to end when the toluene removal efficiency was reduced to 50%. At the end of the filter life, the wearing rate W of the used filter was found from the adsorption volume difference between the unused and used filter.

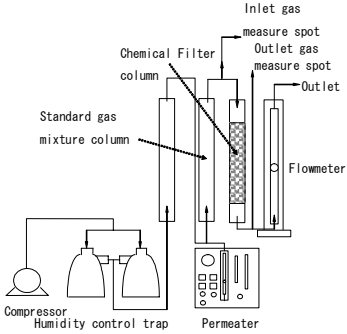


Figure 7.
Experiment apparatus measuring life for chemical filter experiment

Table 4
Experiment condition for column examination

Standard gas	Toluene
Concentration(ppm)	20
Wind velocity(m/sec)	0.1
Column diameter(mmΦ)	25
Inner column temperature(℃)	25
Inner column humidity(%RH)	50
Standard gas emission method	Diffusion tube
Detector tube	122L(Gastec)

Testing result and discussion

The testing result is shown in Figure. 8. The toluene adsorption volume until the removal efficiency was reduced to 50% was 103.6 g/sheet for the filter after 12 days of use and 145.7 g/sheet for the unused filter.

W is defined in the formula (1) and the filter life L (day) for toluene is defined in formula (2).

$$W = (A_n - A_u) / A_n \qquad (1)$$

$L = F_d / F_l$ (2)

provided that W : Wearing rate [-]

A_n : Toluene adsorption volume for an unused filter [g/sheet]

A_u : Toluene adsorption volume for an used filter [g/sheet]

F_d : Number of days that filter used [day]

F_l : Number of days that filter lasted [day]

The value of toluene was 3 times more than the value that the Ministry of Health, Labor and Welfare guided, which was 200 ppb (≒754 μg/m^3).

W was found to be 0.29 under the circumstance.

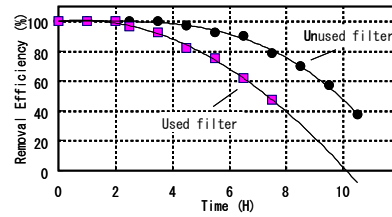


Figure 8.
Removal efficiency changes of the developed filter with standard toluene gas

Also, since the operation was done 24 hours/day for 12 days straight, when the actual operating time in a classroom was assumed to be 8 hours/day, the life L_1 can be found from the formula 2.

$L_1 = (24/8) \cdot 12/0.29 = 124.1$ (day)

When the actual toluene criteria value was assumed to be 260 μg/m^3 (L_2),

$L_2 = 124.1 \cdot (754/260) = 360$ (day)

is found and the life is presumed about 1 year.

Verification measurement in an actual classroom

Building overview

The classrooms used for the verification measurement were common 2 classrooms next to each other (classrooms A and B), located in the 4th floor of a 5-story RC building which was a newly built school just before the completion. The in-room air volume was each 230 m^3. The floor was finished with flooring,the wall was with emulsion paint and ceiling was with rock wool acoustical boards.

4 sets of the 4-way type ceiling cassettes that have cooling and heating capability were installed in classroom ceilings (Figure 9).

The wind volume per one ceiling cassette was 16 m^3/min. at the "high" setting.

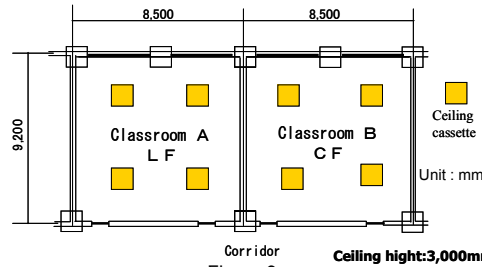


Figure 9.
Floor plan for classrooms to be measured

Room setting condition and measurement process

In order to confirm that there were not great differences in natural ventilation frequency in rooms A and B, the ventilation measurement was conducted prior to the experiment. SF_6 was used as tracer gas to measure the concentration damping using a photo acoustic multi gas monitor (INNOVA).

In room A, long life filters (LF) were attached to the ceiling cassette as usual and in room B, the developed chemical filters (CF) were attached (Figure 9). On the measurement day, the mechanical ventilation was not used in both rooms. When ceiling cassettes were operated, all 4 cassettes were operated with the setting of "cooling, 25℃, high wind velocity".

The measurement process is shown in Table 5. On the first day, LF and CF are attached to the ceiling cassettes. Then, from the next day, the ceiling cassettes were operated and the filter performances were examined. Samplings were conducted 2, 7, 17, and 24 days after the filters were installed. After the 30 minutes ventilation by windows opening, the windows and the doors were closed for 26 hours in a period from the 1st to 2nd days (#1) and the 23rd to 24th days (#4) to intentionally increase

the in-room concentration. And then the ceiling cassette was operated to measure the concentration after 2.5 hours. On the 7th (#2) and 17th (#3) days, samples were taken after the 30 minutes ventilation by windows and doors opening and closed for 5 hours. And then, the concentration were measured 2 hours after the ceiling cassette were operated.

On the other days, in room A, the ceiling cassettes with LF or CF were operated only in a daytime while the windows and the doors were kept closed for all day. In room B, the ceiling cassettes were operated only in a daytime while the mechanical ventilation was stopped all day to confirm the efficiency with CF alone (Table 6).

Measurement and analysis method

It was analyzed by high performance liquid chromatography（HPLC）after formaldehyde was collected by the DNPH cartridge.

VOC was analyzed by GC/MS: Tenax-GR were used for a trapping tube and qualitative and quantitative analysis was performed by GC/MS.

Table 5
Conditions and measurement process

Measu-rement	Day	Time	Condi-tion	Windows・Doors open and close	Ceiling cassette type air conditioner	Mechanical ventilation
#1	1	8:30		Open	Off	Off
		9:00		Close		
	2	11:00	a			
		12:00			On	
		14:00	b		Off	Classroom A:On Classroom B:Off
		15:00				
#2 #3	7 17	8:30		Open		Off
		9:00		Close	Off	
		13:00	a			
		14:00			On	
		16:00	b			
		17:00			Off	Classroom A:On Classroom B:Off
#4	23	8:30		Open		Off
		9:00		Close		
	24	11:00	a			
		12:00			On	
		14:00	b			
		15:00				

a: Measurement before the ceiling cassette operation

b: Measurement after the ceiling cassette operation

Table 6
Conditions other than measurement days

Classroom	Classroom A	Classroom B
Windows・Doors open and close	Close	
Mechanical ventilation	On	Off
Ceiling cassette type air conditioners (8~22o'clock)	On	
Ceiling cassette type air conditioners (22~Next 8o'clock)	Off	
Filter	LF	CF

Mechanical ventilation operating control:Total heat exchange

Air volume:Low(About 640m^3/h)

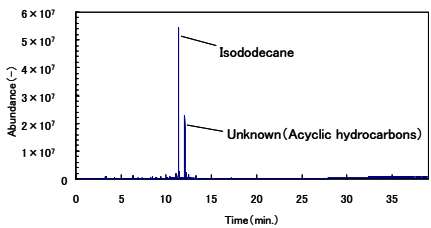
Result of ventilation frequency measurement

By tracing down the damping of SF_6 by the damping technique, the natural ventilation volume was calculated from an approximation formula to find out the natural ventilation frequency of rooms A and B. As a result, the values of 0.2 times/h were obtained for the both rooms and it was confirmed that there were not much difference between 2 rooms.

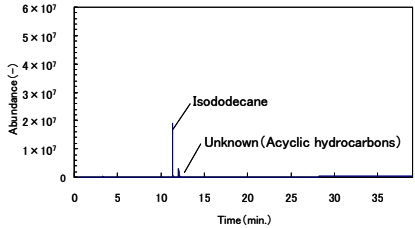
VOC measurement result

About 170 kinds of VOC were detected from the qualitative analysis using GC/MS. As an example, the total ion chromatogram (TIC) of GC/MS on the 7th day (#2) is shown in Figure 10. Regardless of whether the mechanical ventilation was used or not on days other than the measurement days, the concentration level before the ceiling cassette operation was about the same in rooms A and B and the qualitative materials had about the same constituents. However, unlike in room A, the value was reduced significantly after the ceiling cassette operation in room B (Figure 10). The substances guided by Ministry of Health, Labor and Welfare in Japan, such as toluene, xylene and so on, were detected, but the concentration levels were in the criteria value or less. Other than those substances

guided, a peak abundance of chain hydrocarbon including isododecane and so on were detected the most.



Room B Before ceiling cassette operation



Room B After ceiling cassette operation

Figure 10. TIC by GC/MS (#2)

Reduction rates of individual substance by the developed filter

The reduction rates of VOC substances are shown in below formula (3). They were found from the analyzed values of concentration before and after the ceiling cassettes were operated. They were sampled in #1 to #4.

$$\eta = 100(C_a - C_b)/C_a \qquad (3)$$

η : Reduction rate (%)

C_a : ceiling cassette concentration before the operation ($\mu g/m^3$)

C_b : ceiling cassette concentration after the operation ($\mu g/m^3$)

The objects are as follows; total volatile organic compounds (TVOC), formaldehyde, toluene, xylene ethylbenzene and styrene. TVOC analyzed by GC/MS was determined by the toluene conversion.

The reduction rates of individual substances in #1 to #4 are shown in the graphs in Figure 11. When the reduction rate was a plus value, the concentration was reduced. On the other hand, when it was a minus value, it meant the concentration was increased.

TVOC, aromatic or chain hydrocarbon, excluding formaldehyde often increased their concentration after the ceiling cassette operation, comparing to the concentration before the operation in room A. However, in room B, 80 to 90 % or more of reduction rates were obtained. This tendency was given not only during the initial period of filter installation, but also after the 24th day (#4), the reduction rates did not change. The reason is assumed that the filter has activated carbon with a porous body of carbon and a large surface area. This surface area is utilized to have a property to adsorb vapor and dissolved molecules from gas and liquid phases. Since the adsorption ability depends on van der Waals force, it is generally more excel in adsorbing a nonpolar substance than a polar substance. Therefore, hydrocarbon and its kinds with no polarity are assumed to be very easily adsorbed.

Meanwhile, the concentration of formaldehyde was reduced in both rooms A and B. The reason is assumed that since formaldehyde is a water-soluble substance, in room A, it was trapped by the drain water produced from the air conditioning [2)]. Also, in room B, because of the trapping to drain water and the removal by CF, it was assumed that the reduction rate had become a little larger than in room B. But the reduction rate was smaller than the other VOC's.

In room B with the filter installed, no mechanical ventilation was done during the experiment period but the significant VOC reduction was resulted. In fact, it is assumed that even in a room where mechanical ventilation cannot be done, only with the developed filter installation and its ceiling cassette operation, the VOC removal effect can be obtained. The experiment period was 24 days and the filter was able to maintain its high removal efficiency and the effect was confirmed to endure for a long period.

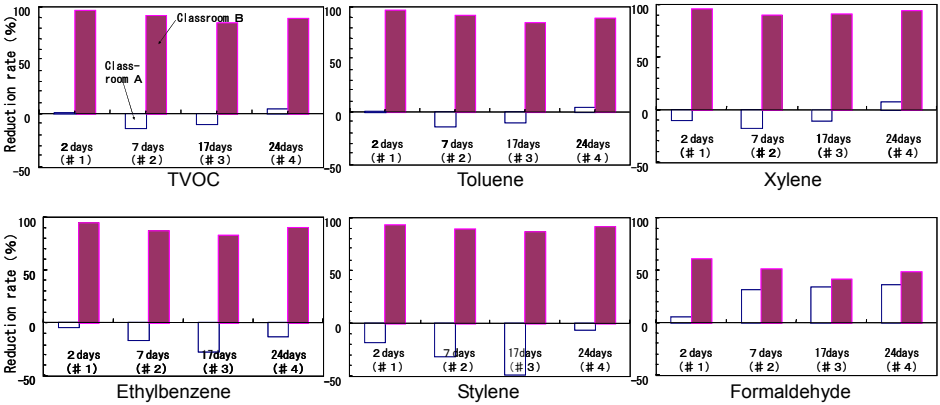


Figure 11. Reduction rates of individual VOC by developed filter

CONCLUSIONS

The chemical filter for the ceiling cassette was developed and high toluene removal efficiency was verified through the experiments by one-pass examination method and in the experiment rooms. The filter life testing resulted to estimate about 1 year life under the daytime ceiling cassette operation when the in-room toluene concentration was in a level of criteria value.

As a result of the developed filter installation to the ceiling cassette and its operation in a regular classroom in a newly built school, following matters are verified.

-The indoor VOC concentration was reduced in a short time after the ceiling cassette operation. TVOC was removed about 90%.

-The reduction rate of formaldehyde was lower than that of VOC.

-During the 24 days of the experiment period, the VOC removal rate did not change much and the removal efficiency was maintained.

-Depending on the windows and the doors closure time before the measurement, the removal efficiency tended to show different results.

In the future, we would like to apply the filter for facilities such as offices, not to limit only in school facilities.

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