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Detection of Gaseous Indoor-Air Pollution Using Multisensor System

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Combustible gas (CGS), ammonia (AMS), carbon monoxide (COS), carbon dioxide (CO2S), nitrogen oxide (NXS), absolute humidity (AHS), relative humidity (RHS) and temperature (TMS) sensors are used to monitor indoor-air pollution. These sensors are connected to a microcomputer via an A-D converter. This system can measure the output from eight sensors sensitive to five gaseous indoor-air pollutants as a function of time. The pollutants are cigarette smoke, carbon dioxide gas, carbon monoxide gas, ethanol gas and commercial propane gas. CGS and AMS are sensitive to all gaseous pollutants, except carbon dioxide gas. All gas sensors are sensitive to cigarette smoke. Only CO2S is sensitive to carbon dioxide gas. CGS, AMS and COS are sensitive to carbon monoxide gas. Only CGS and AMS respond to propane and ethanol gases. The characteristics of CGS output are similar to those of AMS output for all experimental pollutants. Both sensors, however, are necessary for identification of the pollutants. *NDVA*, which is the output of AMS divided by the output of CGS, can also be used to identify the pollutants, and the differential coefficient of *NDVA* is almost constant when there is nobody in the experimental room. The system can also identify one out of five gaseous indoor-air pollutants.

1. Introduction

Many chemical sensors are used in domestic environments. In particular, humidity and gas sensors are most widely used. These sensors, however, are used to obtain only one kind of data, such as degree of humidity or gas concentration.(1) Recently, an investigation on sensor fusion has been carried out, the purpose of which is to obtain various types of information from a few sensors.(2) To this end, we have conducted research using a tin oxide gas sensor; however, we found it very difficult to achieve that purpose.(3) In this study, an indoor-air pollution detection method that uses eight sensors, five of which are tin oxide gas sensors, is described. Results show that the system can identify the kind of pollutant using only CGS.

In Japan, the maximum allowable concentrations of carbon monoxide and carbon dioxide gases in an indoor environment are regulated by law.(4) The maximum allowable concentrations of CO and CO_2 are 10 and 1000 ppm, respectively. There are, however, other air pollutants in indoor environments. A tin oxide gas sensor, which can detect combustible gases, has no selectivity for a specific gas but has sensitivity to various gases; thus, the sensor is suitable for detection of indoor-air pollution.(3) The sensor has been used in ordinary gas leakage detectors. The sensor can detect carbon monoxide, nitrogen oxide, ammonia, commercial propane, ethanol gas and cigarette smoke, but not carbon dioxide gas. CO_2 gas is not very harmful compared with these gases. Moreover, it is not generated by itself, but is usually generated with other gases which can be detected by CGS. It is therefore effective to use the sensor to detect indoor-air pollution.

The aim of this study is to establish whether indoor air quality (IAQ) can be detected accurately using only a tin oxide gas sensor.(3) Results indicate that the sensor can effectively detect IAQ, with the exception of CO_2 gas. However, the sensor cannot identify the gaseous pollutants.

2. Detecting System

Eight sensors are used in the experiment in order to provide more information than a conventional system. However, some of the eight sensors are not used to detect gaseous pollutants; they are used to control the indoor environment in the future. The eight sensors are combustible gas (FIGARO: CGS, TGS#800), ammonia gas (AMS, TGS#826), carbon monoxide gas (COS, TGS#2440), carbon dioxide gas (CO2S, 5577), nitrogen dioxide gas (NXS, TGS#211), absolute humidity (AHS, TGS#2180), relative humidity (YAMATAKE: RHS, HY7200A2004), and temperature (YAMATAKE: TMS, TY7203A1000) sensors. Of the eight sensors, CGS, AMS, COS, NXS and AHS are TGS type and are types of sintered tin oxide gas sensors. CO2S is electrolyte type and is structured such that a sodium ion electric conductor is sandwiched between two gold electrodes. A high-molecular-weight polymer thin film is used in RHS. A platinum electrical resistance thermometer is used in TMS. RHS and TMS are available commercially in Japan for measuring indoor humidity and temperature, respectively.

CGS has no gas selectivity but has sensitivity to almost all reducing gases.(3) Human activities such as entering and leaving a room can be detected by CGS, and the sensor can also detect domestic hazards, for example, smoldering fire, combustible gas leakage and generation of carbon monoxide gas due to incomplete combustion.(5) Computer analysis of sensor output variation as a function of time can provide us with much information. CGS is the main sensor among the eight sensors investigated in this study.

The outputs from these eight sensors are input to a computer (EPSON: PC-386 NOTE AR) via an A-D converter (HACHINOHE: 12 A/D-NL). In this system, temperature, relative humidity and concentrations of carbon monoxide and carbon dioxide gases are constantly displayed by seven segmental elements and the outputs as a function of time are indicated on the computer display.(6) The plotting interval can be changed by the second. The detection system is shown in Fig. 1(a) and the sensor unit in which eight sensors are assembled is shown in Fig. 1(b).

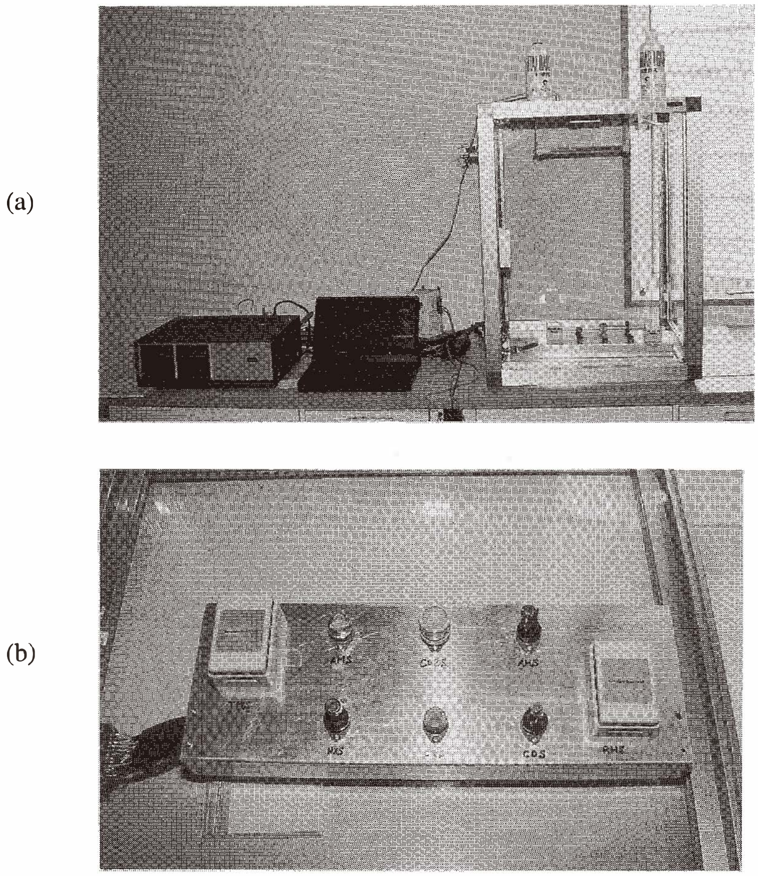

Fig. 1. Photographs of the experimental system. (a) The detection system and (b) the sensor unit.

3. Monitoring of Indoor Environment

The sensor outputs indicate the indoor environment, namely temperature, humidity and degree of indoor-air pollution. The sensitivities to five pollutants, which are the main pollutants in an indoor environment, are examined and summarized in Table 1. Cigarette smoke is composed of many kinds of gases and all five gas sensors are sensitive to it. CO2S, however, has low sensitivity to it. Only CO2S is sensitive to CO_2 gas. CGS, AMS and COS are sensitive to CO gas, with AMS having the lowest sensitivity. CGS and AMS are also sensitive to commercial propane and ethanol gases. The sensitivities of CGS and AMS to typical gases are shown in Figs. 2(a) and 2(b). Both sensors are sensitive to ethanol gas and play an important role in this study. We adopt a new coefficient *NDVA* (NormalizeD Value of Ammonia sensor output), which is the value obtained by dividing the output of AMS by the output of CGS, namely,

$$NDVA = V(AMS) / V(CGS). \tag{1}$$

The characteristics of *NDVA* as a function of time provide indoor environmental information, and the system can roughly identify one out of five gaseous pollutants. If the differential coefficient of *NDVA* is constant for a long time, the room is empty or there is no human activity.

The system is set up in a Japanese style room (13.2 m^2), which is located next to the dining room and kitchen. The layout of the experimental house is shown in Fig. 3. The monitored results are shown in Fig. 4. The characteristics are measured in winter. One of the house occupants got up at about 6:50 and entered the dining room. The person lit an oil stove and used a gas range to make breakfast. The stove was turned off at 8:30, turned on again 9:30 and off at about 11:00. It was turned on at 15:30 and off at about 19:00. The oil stove was located in the dining room (13.2 m^2). The sensor outputs fluctuate during breakfast, supper and preparation of these meals.

Table 1
Output sensitivities of five sensors for five gaseous indoor-air pollutants. ◎, ○, △ and blank indicate excellent, good, average and no response, respectively.

Sensor	Pollutant				
	Cigarette smoke	CO_2	CO	Propane	Ethanol
CGS	◎		○	◎	◎
AMS	◎		△	○	◎
COS	◎		◎		
CO2S	△	◎			
NXS	◎				

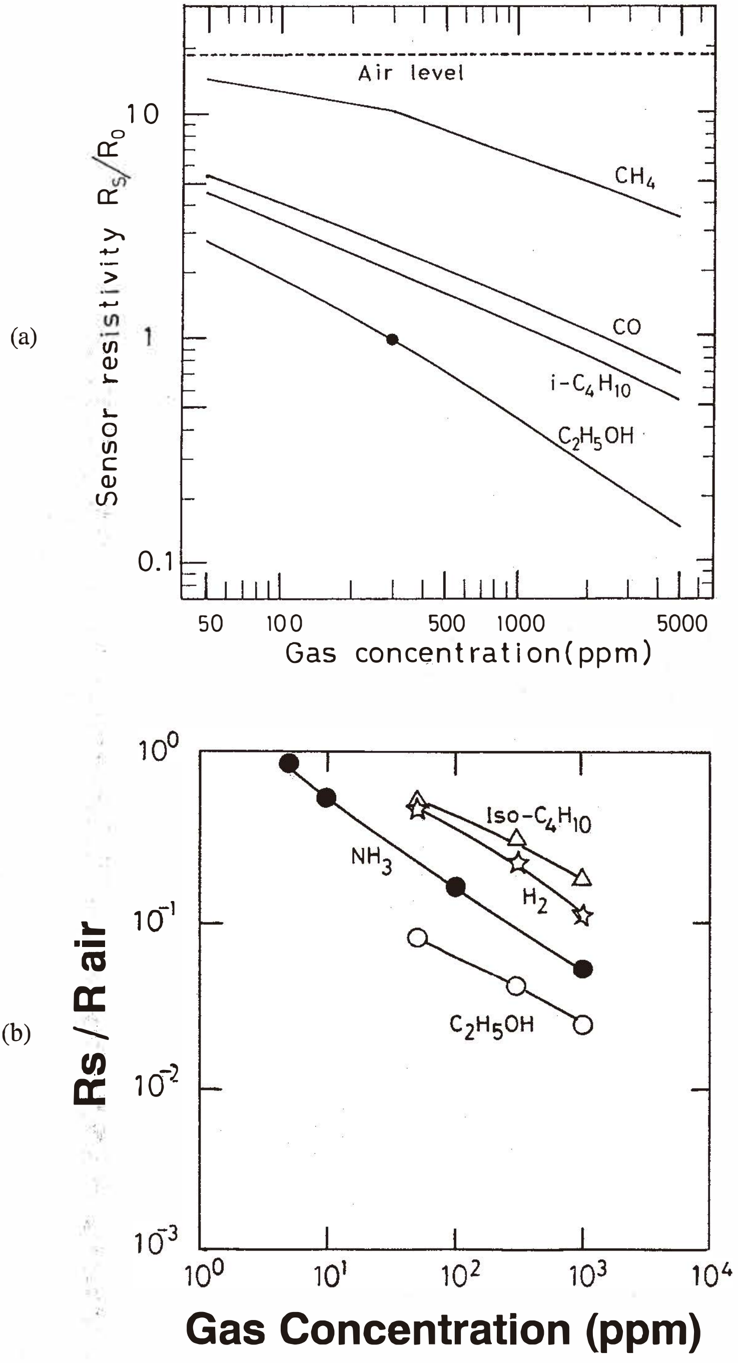

Fig. 2. Gas sensitivities of CGS and AMS to typical gases. (a) CGS and (b) AMS.

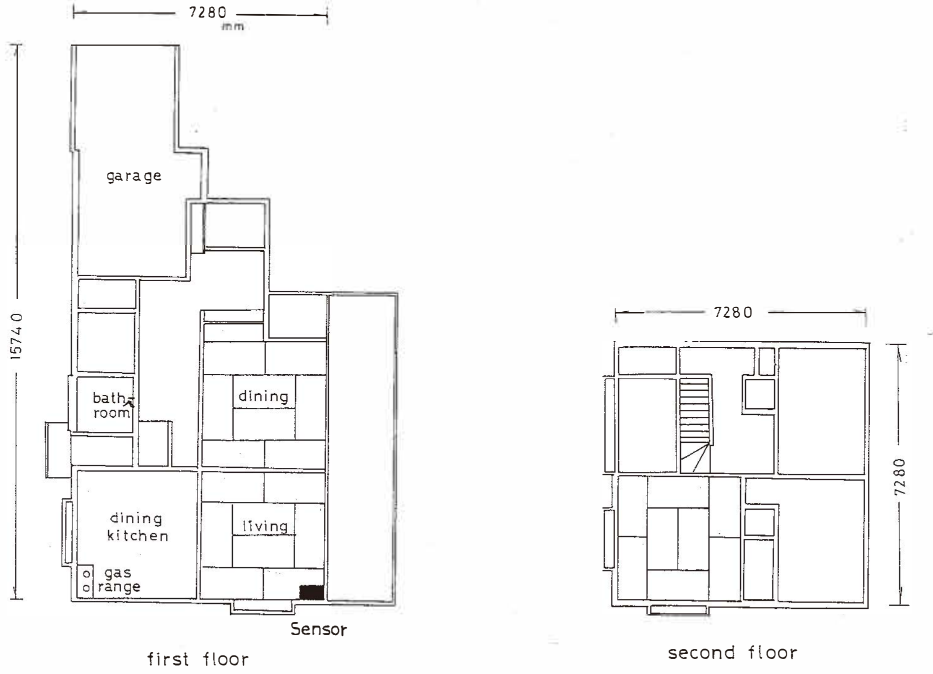

Fig. 3. Layout of an experimental house.

The output of NXS decreased while the oil stove was on. In contrast, the output of CO2S increased. NO_2 and NO gases are generated by the oil stove. This nitrogen oxide gas sensor is ten times more sensitive to NO_2 gas than to NO gas. NO_2 gas acts as an oxidizing gas and the resistance of NXS increases. Therefore, the output voltage of NXS (*V(NXS)*) decreases, and this behavior of NXS differs from that of other gas sensors. The behavior of NXS is opposite that of CO2S .

The characteristics of CGS, COS, AMS and CO2S output are similar and analogous in function, but the slopes and peaks of these characteristics are different. Since the source of air pollution in a domestic environment generates several gaseous pollutants, all gas sensors respond to the source. If we can understand the characteristics of sensor outputs for various pollutants, the pollutants can be identified by only one or two sensors. CGS has the potential of becoming the most effective sensor in the future because CGS has the highest sensitivity to air pollutants so far.(7) The monitoring results of other seasons are shown in Fig. 5 and Fig. 6. The results shown in Fig. 5 were measured on May 11, 1996, while those in Fig. 6 were measured on Jun. 12, 1996.

The outputs of humidity and temperature sensors are also indicated in these figures. The output voltages can be converted to real humidity and temperature using the following equations.

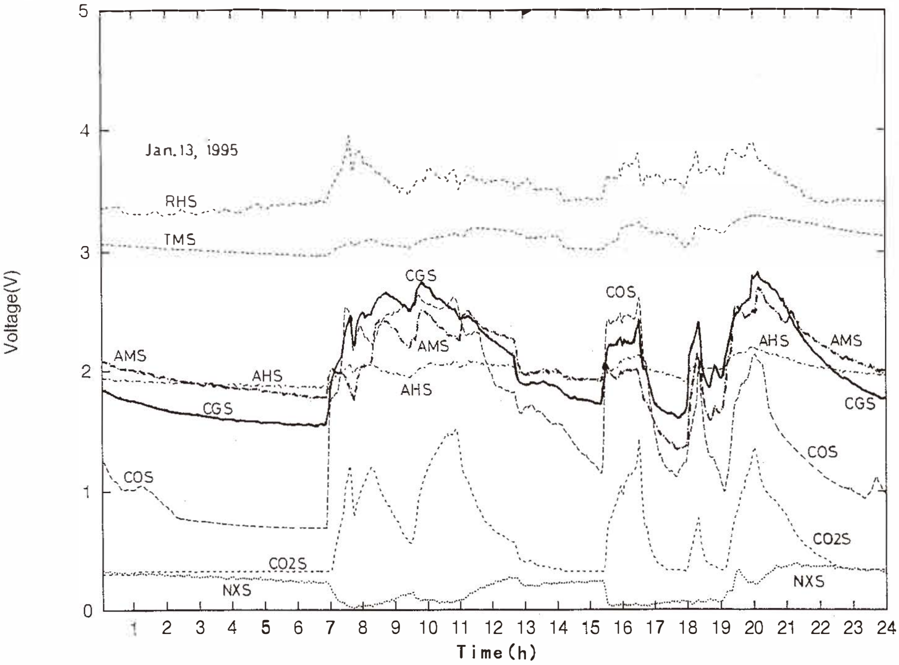

Fig. 4. Daily periodical patterns of eight sensors in a domestic environment on Jan. 13, 1995.

$$Y(°C) = V(TMS) * 22.53 - 60.39 \qquad (2)$$

$$Y(\%) = V(RHS) * 24.57 - 27.21 \qquad (3)$$

The characterisitics of *NDVA* for Fig. 4 are shown in Fig. 7. When the house is empty or the room is unoccupied, the differential coefficient of *NDVA* is almost constant, that is, the inclination of *NDVA* characteristic is constant and the value of *NDVA* is about 1.15. If the differential coefficient of *NDVA* is almost constant, there is no human activity in the experimental room. Specifically, there is no human activity from 0 to 6:30, 11:30 to 15:30 and from 21:30 in Fig. 7. The value of ranges from about 0.85 to 1.05 for cigarette smoke, and from 0.3 to 0.85 for commercial propane, ethanol and carbon monoxide gases. In Fig. 7, *NDVA* is less than 1 when the oil stove and the gas range are used. The system can also identify whether there is a contaminating source due to a combustion apparatus, based on output levels of sensors and *NDVA*.

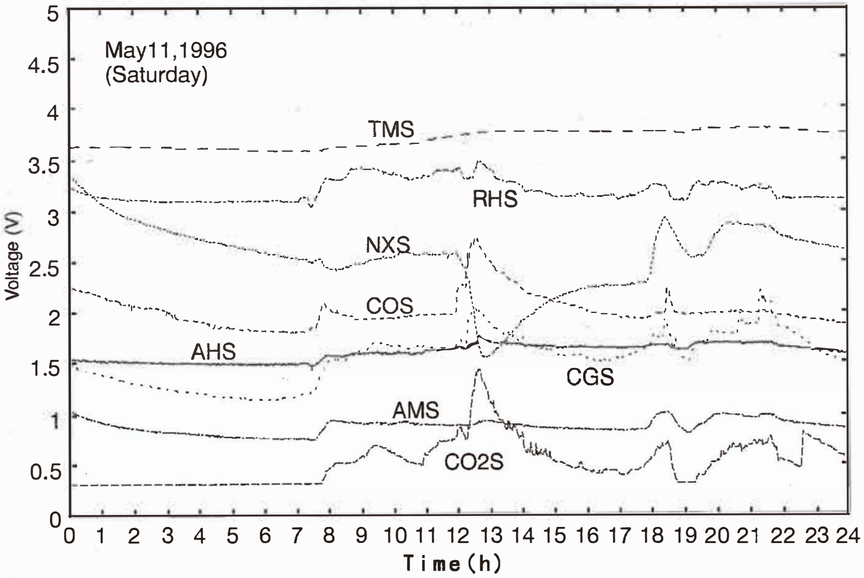

Fig. 5. Daily periodical patterns of eight sensors in a domestic environment on May 11, 1996.

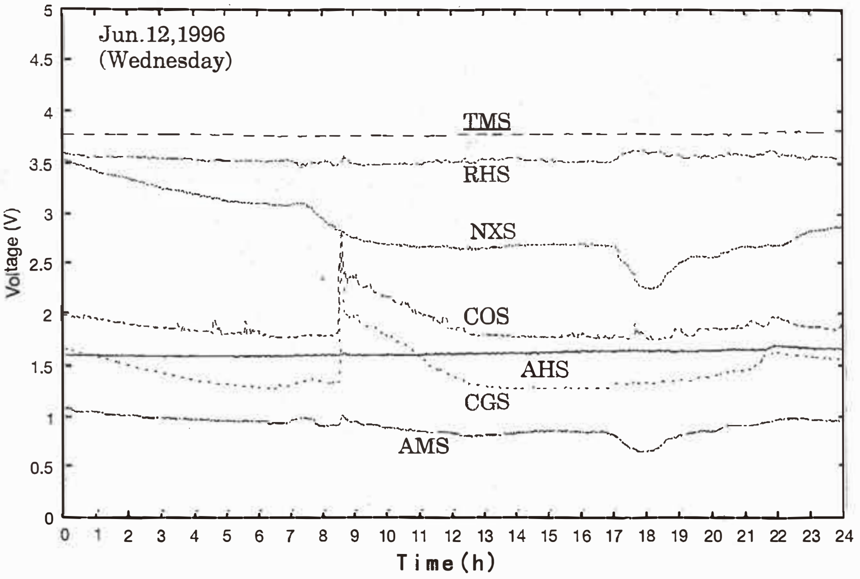

Fig. 6. Daily periodical patterns of seven sensors in a domestic environment on Jun. 12, 1996.

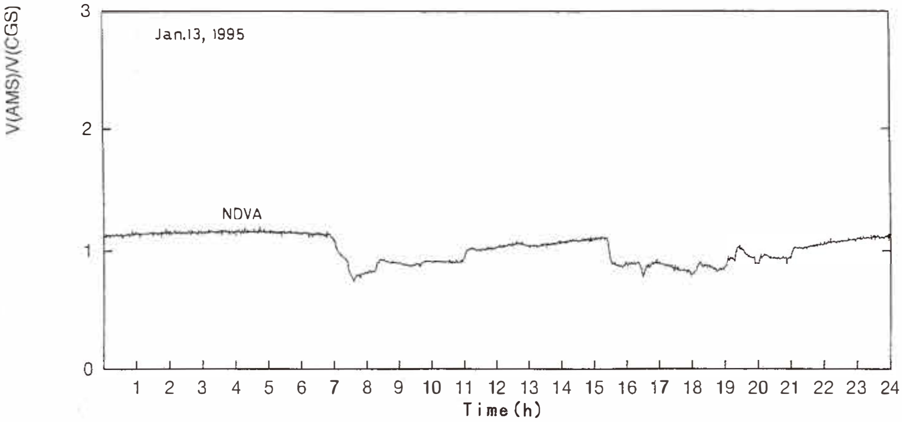

Fig. 7. *NDVA* characteristics for Fig. 4. *NDVA* = *V(AMS)* / *V(CGS)*.

4. Conclusions

Eight sensors are used to monitor gaseous indoor-air pollution and to identify the pollutants in a domestic environment. Results show that indoor-air pollution is generated mainly by combustion appliances in winter. The sensitivity characteristics of the four gas sensors are similar in terms of the monitoring curves. The system can also determine whether there are people in the room or not by examining the value and the differential coefficient of *NDVA*.

Hereafter, the characteristics of various indoor-air pollutants must be accumulated in detail and a recognition process for various pollutants developed. AHS, RHS and TMS are used to create a comfortable indoor environment. Five gas sensors are used to monitor indoor-air pollution. However, it is expected that only 3 sensors, namely CGS, AMS, and CO2S, will be needed to identify the pollutants. *NDVA* is also important for identifying both pollutants and human activities.

We conclude that various pollutants can be recognized using high-quality computer programming and the above three sensors (CGS, AMS, CO2S) in the future. After that, the type of pollutant can only be recognized from the characteristics of CGS output and the differential coefficient of *NDVA*.

Acknowledgments

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