reducing of the amount of air by using only outdoor air. The recirculating air should not be set in because of air quality problems. Furthermore the plenum and the inner surfaces of the units needs a abrasionproof surface to prevent dust deposits and improve the cleaning possibilities. The humidifier and the filter has to be changed, because of the conditions in the components. If the leakages are closed and the dampers are in good conditions the main problems of the system

## ACKNOWLEDGEMENTS

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# STUDY ON CONTAMINATION CONTROL OF AIRBORNE PARTICLE FROM AIR CONDITIONING SYSTEMS IN JAPANESE BUILDINGS

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## ABSTRACT

Field studies were carried out on air contamination by dust particles from air conditioning systems in four buildings in Tokyo area.

We tried to investigate contamination of airborne particle and surface contamination by sedimentary dust in air duct, and considered a matter in all its aspects that caused indoor air pollution.

1. Time variations of airborne particle concentrations at supply outlet were influenced by the operation of air conditioning system.
2. Specially, maximum concentration was showed at the first one of the day.
3. The test on the opening of the service port door showed most significant in crease of the particulate generation.

## INTRODUCTION

Seventy percent of modern buildings in Japan completed in and after 1970 are equipped with air conditioning systems.

It is, therfore, necessary from the standpoint of controlling indoor air pollution to examine the quality of air supplied through air ducts to rooms of buildings equipped with air conditioning systems with a view to determining the degree of contamination and its possible causes and developing effective countermeasures.

Taking a stand on the prevention of indoor air pollution, researchers such as Yoshizawa, Fujii, and Irie pointed out contamination within air conditioning systems including air ducts.(1)(2) But only a small number of researches seem to have been made in Japan on contamination in air transmission lines from air conditioning systems to individual rooms. A few reports have been published on in-duct contamination by dust particles; Sato(3), Fujii(4) and others identified sedimentary dust in air ducts, and studied dust within a duct line by location and influences of start-ups and stoppages of air conditioning systems. More recently, Kuroda, Yamaoka and others examined sedimentary dust in air ducts, and compiled a comprehensive report(5) on acarian, allergen and metals based on the investigation of selected subjects ranging from organisms, biological activity and constituents.

However, there are still few reports leading to indoor air pollution control measures or constructive proposals relating to planning, designing, installation and maintenance of air conditioning systems due to insufficient amount of basic information concerning both air conditioning systems installed in the building such as system outlines including capacities of forced air draft and ventilation and buildings such as the manner in which they are used, locations and years in which they were completed.

Accordingly, we have conducted field studies$^{(6)}$ for the past several years in various buildings focused mainly on dust particulate and microbial contamination inside air conditioning systems and air transmission lines. We examined the actual conditions and causes of such contamination in air ducts of air conditioning systems and report part of the findings as follows:

## METHODS

Operations of air conditioning systems and methods of measurement

(1) Airborne particle concentrations at supply outlets upon start-up of air conditioning systems

Air conditioning systems are usually started about one hour before the opening of the office although exact timing may vary according to the season. Airborne particle concentrations at supply outlets were measured to determine influences of air duct vibration and starting air streams on particulate generation by assuming the beginning of the operation of the blower as that of air conditioning systems. Start-up operation may generally be considered as the maximum "contamination load" because it stirs up sedimentary dust particles accumulated after turning off air conditioning systems on the previous day which will be added to supply outlet concentrations. Relationships between concentrations at individual supply outlets of a given transmission line were also examined.

(2) Airborne particle concentrations at supply outlets during steady operation

Complaints of "occasional dust emissions from supply outlets" relate mainly to particulate generation during steady operation, providing extended contamination load coupled with regeneration of particles caused by steady air flow inside ducts.

(3) Airborne particle concentrations at supply outlets during a range of different operations of air conditioning systems

Direct influences were examined on equipment and air ducts given by the change in air stream and pressure within air conditioning systems associated with the opening of the service port door (access door) during steady operation. Particulate generation was measured during a range of operations which are not usually performed during steady operation such as opening/closing of air flow control damper and winding filters installed in air conditioning systems.

Airborne particle concentrations were measured simultaneously at several supply outlets per air conditioning system in above tests. Measuring apparatuses were particle counters (Rion KC-01), and sizes of particles subject to the measurement were from 0.3 to 5 µm.

Figure 1 shows measuring time schedule for repeated start-ups and stoppages of air conditioning systems (S building).

## RESULTS

Concentrations by number of particles of sizes 0.5 µm and over at supply outlets on the 6th floor of M building (completed in 1965) are shown in Figure 2 while correlation (air conditioning system start-up - ON1) between particles of sizes 1.0 µm and 5 µm at two supply outlets on the same floor are shown in Figure 3.

Due to influences on particulate generation of the cleaning of fins inside air conditioning system carried out after work on the previous day, the concentration peaked at 120 seconds after the first start-up of the system and was declined to constant value after 240 to 300 seconds. In contrast, particles of sizes 5 µm and over peaked after 40 seconds and was declined after 160 seconds, showing distinctive differences in changes with the passage of time by particle size.

A close positive correlation was demonstrated between particles of sizes from 0.3 µm to 2.0 µm irrespective of differences in the speed of air blown off (correlation coefficient $r=0.98$) while lower degree of correlation was observed between particles 5 µm and over ($r=0.72$). This seems to indicate that while little difference was observed for small particles at individual supply outlets, dispersing patterns of larger particles within air ducts and from air conditioning system were different and dust particles were generated due mainly to the influences of air duct vibration and initial streams of air upon start-up of the system. The second and subsequent start-up operations of the system did not cause any significant increase in particulate generation. Accordingly, particulate generation associated with start-ups of air conditioning systems at usual intervals seems to occur mainly because of the influence of dust particles accumulated after turning off the systems on the previous day.

In addition, as especially high concentrations were observed immediately after cleaning inside air conditioning systems, it seems particularly necessary to provide certain countermeasures to cope with particulate generation at the first start-up of the system for the day.

Figure 4 shows time variations of particles 1 µm and over at supply outlets on the 6th and 17th floors of T building (completed in 1975) by applying loads described in (3) above to the air conditioning system. Influences of opening and closing of service port doors were observed mainly on particles 1 µm and over with the highest concentration at 1,000 pieces/0.00147 cf at the first door opening (reduced to about one-fifth or 185 at the second opening). Particulate generating influences decline in the descending order of opening/closing of air flow control dampers on each floor and winding filters.

Figure 5 shows quantities of airborne particles generated at supply outlets of S building (completed in 1974) by the number of times of starting the air conditioning system (ON1 to ON4), treating five minutes of operation of air conditioning system as one operation.

Particulate generation along the downstream of the air conditioning system remained constant even after repeated start-up operations or when observed by different particle sizes of 0.5 µm, 1.0 µm and 2.0 µm. Assuming that initial streams of air from the blower give uniform influences and that co-efficient of filtering being is constant, dust particles deposited and accumulated inside casings on upstream side of filters in the air conditioning system and circulating air ducts seem to have been added and mixed with dust particles in returning air and fresh air intake, forming particulate generation sources close to making constant value of airborne particle concentrations.

Compared with the inside of the air conditioning system, distinctive characteristics were observed for particles of sizes 1.0 µm, 2.0 µm and over at supply outlets, and particulate generation showed marked declines as start-up operations were repeated. In contrast, this tendency was not observed for particles 0.5 µm and over. Moreover, the larger the particle sizes, the larger the differences between concentrations in downstream of the air conditioning system and those at supply outlets. These results demonstrate that relatively large particles of sizes 1.0 µm, 2.0 µm and over are generated from air duct surfaces upon start-up of air conditioning systems. They also suggest that it is more difficult for larger particles to contain particulate generation to a certain level by inducing particulate generation from duct surfaces through repeated start-up operations alone. Duct surfaces may be concluded as one of the release sources of larger particles, cause of complaints often heard during working hours that "dust particles seem to come out from supply outlets occasionally."

The results of airborne particulate generation (values at five minutes after start-up; ON1, values at one minute after start-up; peak values, and values at one minute before stoppage; constant valves at supply outlets of S building obtained from concentrations at supply outlets multiplied by air quantity are shown in Table 1. Table 2 shows dimensionless numbers excluding influences of air quantity from peak values/stationary values (ratio of generation) in Table 1. We believe it is possible to assess particulate generation in air ducts using this ratio. In H building completed in 1966 and T building which is newer by about 10 years, the larger the particle size, the higher the ratio of generation while the more times start-ups were repeated, the lower the rate of generation of particles of sizes 1.0, 2.0, 5.0 µm and over. Similar results were obtained for S building.

Though completed in 1974 and newer than H building, S building showed about five (1.0 µm) to 13 times (2.0 µm) higher in the ratio of generation of particles 1.0 µm and over with respect to surface contamination by sedimentary dust in air ducts. The clear evidence of duct surface contamination in S building indicates significant influences brought about by quality of maintenance of air conditioning system. For effective control of airborne particles, maintenance and management should be more emphasized than a little difference in years of completion such as that between H and S buildings.

## CONCLUSION

(1) For the purpose of ensuring desirable indoor air environment, the Building Standards Act and the Building Maintenance Act (alias) point out the importance of preserving environmental sanitation within air conditioning system including air ducts.

(2) Relatively large particles (1 µm and over) seem to be generated from duct surfaces forming indoor particulate contamination load upon start-up of the air conditioning system which is usually carried out once a day. Source of this contamination seems to be sedimentary dust in air ducts.

(3) Air duct contamination can be assessed by observing changes in ratio of generation (peak values/stationary values) while repeating start-up operations of the air conditioning system.

(4) About ten years differences in years of completion do not affect much on duct surface contamination of buildings. Differences in quality of maintenance of the air conditioning system in terms of sanitation relate more closely to airborne particulate generation, indicating needs for cleaning air ducts.

(5) Starting air streams and vibration given by fans represent impact causing particulate generation at the start-up of air conditioning systems. Quantitative determination of such impact is necessary for effective control of particulate generation. Future tasks include the development and designing of new materials for air duct systems so that adhesion of contaminants can be prevented (or vice versa).

(6) Regular cleaning of air ducts and means to cope with particles which have come off from duct surfaces immediately after cleaning are also required. Attempts should be made to ensure more sanitary living environment by providing hatches to air ducts at every turn and

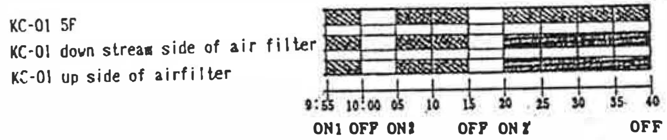

Fig. 1. Measuring time schedule (S build.).

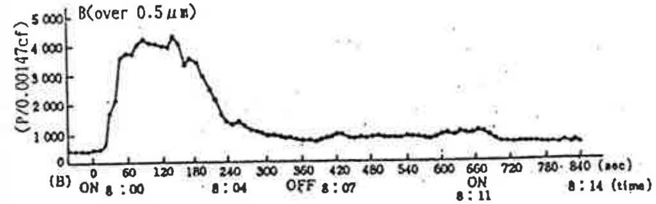

Fig. 2. Time variations of particles at supply outlets (A and B) (M build.).

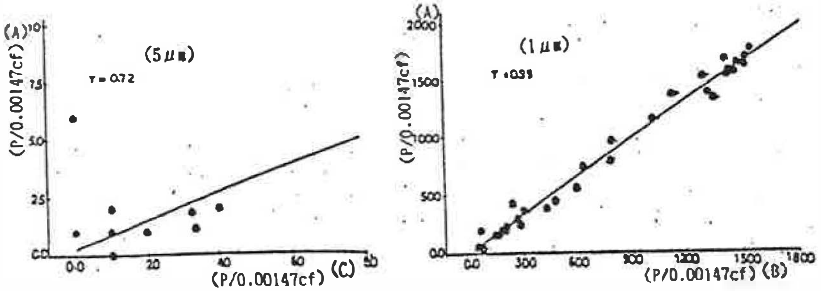

Fig. 3. Correlation of airborne particle concentrations (1+5 µm) between A and B or C supply outlets (M build.).

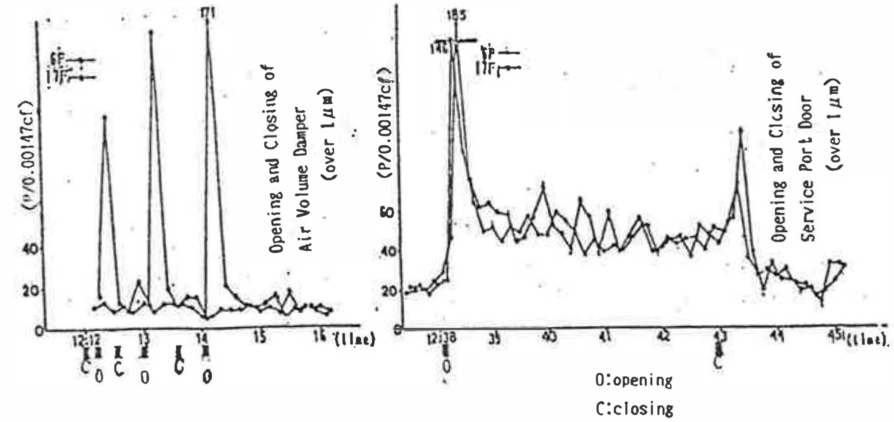

Fig. 4. Time variations of particles at supply outlet by giving load (T build.).

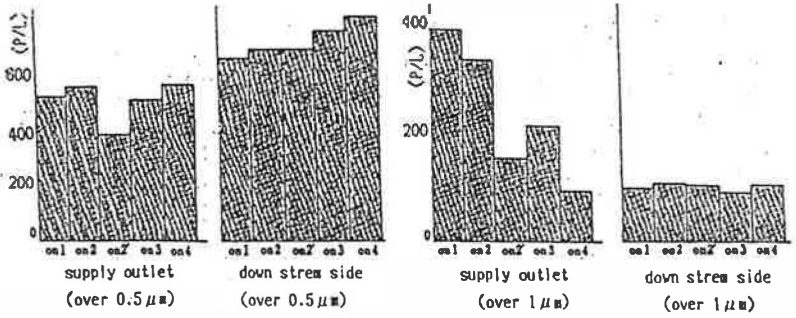

Fig. 5. Particle generation by starting times of airconditioning systems (S build.).

Table 1. Particle generation at supply outlet (S build.)

(P/h×10$^6$)

| size | ON | peak | constant |
|---|---|---|---|
| 0.3μm | 5679.8 | 6183.7 | 5704.7 |
| 0.5μm | 331.2 | 500.5 | 295.2 |
| 1 μm | 85.2 | 369.0 | 27.7 |
| 2 μm | 22.1 | 117.6 | 3.1 |
| 5 μm | 2.2 | 16.1 | 0 |

Table 2. Generation rate of particles at supply outlet (peak/constant) (S,H,T build.).

| starting NO. | size | peak/constant | | |
|---|---|---|---|---|
| | | S | H | T |
| ON 1 | 0.3μm | 1.08 | 1.10 | 1.23 |
| | 0.5μm | 1.70 | 1.35 | 1.48 |
| | 1 μm | 13.33 | 2.80 | 2.27 |
| | 2 μm | 37.94 | 3.00 | 2.75 |
| | 5 μm | -- | -- | -- |
| ON 2 | 0.3μm | 1.11 | 1.14 | -- |
| | 0.5μm | 1.88 | 1.08 | -- |
| | 1 μm | 7.62 | 1.70 | -- |
| | 2 μm | 14.63 | 1.20 | -- |
| | 5 μm | -- | -- | -- |

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# QUALITY OF CLEANING QUANTIFIED

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## ABSTRACT

Threshold limit values for concentration of dust on non-textile furniture and floors, and carpets are suggested. They are based on experience from about 5000 single surface dust samples in Scandinavia, mainly offices. A sampling strategy is formulated, and simple decision rules for compliance are given. The whole concept is closely linked to a special surface dust sampling method.

## INTRODUCTION

Cleaning is a multibillion ECU per year business in the Scandinavian countries. Do the customers get what they are paying for, and how would they know? Would the indoor air quality benefit from spending more? Is it necessary to spend so much? Which of the many cleaning methods are most effective?

In an effort to answer some of these questions, a comprehensive approach towards quantification and evaluation of the quality of cleaning was thus initiated. The first step was the development of a simple field method for evaluation of the quality of cleaning of floors, carpets, and furniture (1). Hard surfaces are sampled by gelatine foils. Dust from carpets is resuspended along a 4 m track, by a special vacuum cleaner mouth piece, providing a measure of resuspendable dust. A fraction of this dust is then deposited onto the same type of gelatine foil by impaction. Dust from carpets is thus measured as an index only, closely linked to the sampling method. The amount of dust on the foils is determined as total projected area by a laser light extinction meter. One sampling and analysis lasts less than one minute, slightly more for carpets.

The next step was to gain insight into typical levels of surface contamination levels in the indoor environment, as measured with this equipment (1,2).

This paper reports on the third step: an attempt to formulate a set of norms for cleaning.

How can such guidelines be established? A simple relation between dust on surfaces and airborne dust, expressed as the resuspension factor cannot be found (3). Furthermore, it is not likely that a simple dose response relation will be found in the near future, if ever, due to the complex nature of SBS. It is however beyond doubt that the more dust is allowed to accumulate on the surfaces, the greater is the potential for resuspension. Guidelines for evaluation of indoor surface contamination will thus be suggested on the basis of what is achievable by "good engineering practice".

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