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THE EFFECT OF VACUUM CLEANING UPON HOUSEHOLD ATMOSPHERIC DUST

by

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B. S., Kansas State University, 1958

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A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Family Economics

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1966

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CHAPTER I

INTRODUCTION

The cleanliness of the home has been and will continue to be an important standard in man's society. There have been numerous means of minimizing and removing household dust and dirt. The cognizance of the cleaning problem is reflected by the development of household floor cleaning appliances. Allergies and their causes, of which household dust may be a contributor, are another important issue. There has been considerable research on industrial and outside atmospheres as summarized by Jacobs, Manoharan and Goldwater (1). However, there seems to be a void of research analyzing the atmosphere of the home, where a large percentage of one's life is spent.

Background Information

Air pollutants are generally divided into two types: gases and particulates. Household dirt and dust, examples of particulates, are the usual contamination in the home. Particulates may be transmitted into the home by shoes, transported objects or infiltration of air into the residence. Household tasks, or results of these tasks, may be another source of contamination of the inside atmosphere. Examples of these sources would be soot from incomplete combustion of residental fuel, body contaminants from people, smoke particles from tobacco smoking, results of cooking endeavors and lint from handling laundry and breaking off of carpet pile. In other words, routine actions or tasks bring about atmospheric contamination.

This particulate material will range in size from approximately 100 microns to smaller than one micron in diameter. The large, visible dust in the home will consist of lint, smoking ashes, powder silica, and other materials. The particles which can be seen are more than 10 microns in diameter. These visible particles are most troublesome to the homemaker during routine cleaning because they settle out on horizontal surfaces (2). However, according to Whitby, et al. (3) these particles account for less than one per cent, by count, of all the particulate material carried by inside atmospheric air.

The smaller particulate matter, of which the majority is less than three microns in diameter, can not be seen with the naked eye. Therefore, the fine particles escape specific housekeeping attention. The particles five microns and less in diameter are the air-borne dusts which result in long-term soiling and staining. Gravity has little influence on the invisible particles because of their small mass. Normal air motion keeps them suspended in the air unless they come in contact with a vertical or horizontal surface.

Particles of equal density but of different size settle in still air at rates varying inversely with the squares of their diameters. In other words, the large particle settles out of the air much faster than the smaller particle (2). These particles settle an average of 3 1/2 feet before alighting on furniture, window sills, woodwork or on the floor. The time for settling 3 1/2 feet in still air varies from two seconds for a 100-micron particle to four hours for a 1-micron particle. The sub-micron particles, such as smokes, remain permanently suspended in the air because gravity has little effect upon their small mass compared to normal air motion (2). The homemaker notices more dust settling out in the lower half of the room because this is where most dust originates.

The air of the home should be considered not only from the standpoint of cleanliness but also from that of health. All particles three microns and less in diameter can easily gain entrance into the lungs. It has been stated that up to a teaspoon of these particles enters the lungs of an individual every day (2). Various particles may be carriers of bacteria, mold spores, viruses, or pollens, depending on their relative size. Goldwater (4) states, "Years ago it was proven that pathogenic bacteria could be recovered from the air and dust near patients suffering from certain infectious diseases, notably tuberculosis."

Another health point of view is the discomfort caused to persons who suffer from chronic respiratory diseases. This chronic condition will be irritated when there is an increase in the particulate matter of the atmosphere in the household. The person will experience increased discomfort and disability with the increase of air pollution (5).

There seem to be many ways contaminants in the household atmosphere can be generated or increased. This study will be concerned with the possible influence of vacuum cleaning in generating or redistributing this particulate matter and increasing residential air contamination.

Objectives

The first objective of this study was to determine whether significant changes occurred in household air-borne dust concentration levels when vacuum cleaning under the potentially most contaminating conditions. These were assumed to be (1) a highly effective cleaner, (2) with a downward exhaust, (3) operated over the uncleaned portion of the carpet. Had no significant change been found in the room atmospheric dust concentration, the study would have been terminated at this point. If a significant increase was found, the second objective was to determine where the re-circulated dust in the room atmosphere originated--from dust passing through the filter bag or dust entrained off the carpet by the vacuum cleaner exhaust. A third objective, again assuming a change occurred, was to study the air-borne particle size distribution after vacuum cleaning.

CHAPTER II

EXPERIMENTAL ENVIRONMENT, EQUIPMENT AND METHODS

The data for the study were obtained in Margaret Ahlborn Lodge, a home management residence laboratory. No artificial dirt or dust was used. "Dirt," as used in this research, denotes large diameter inorganic or organic particles present in a household. "Dust" means the very small diameter inorganic or organic particles present in the household which are capable of temporary or permanent suspension in the air.

The carpet and floor area of the residence laboratory living room were vacuumed with a tank vacuum cleaner. Dust concentration was established by drawing room air through filter paper under vacuum. Glass fiber and membrane filters were used in this analysis of the dust concentration and particle size distribution, respectively.

Test Environment

Residence. Margaret Ahlborn Lodge is the west half of a two-story, duplex structure. The vacuum cleaning occurred only in the living room but due to the open floor plan the atmosphere sampled also included that of the dining room. Figure 1 is the floor plan for the bottom story of the duplex and shows the arrangement of the dining room-living room. The living room dimensions were 13.5 ft by 22.8 ft by 8.5 ft, with a total volume of 2582 cu ft. The dining room dimensions were 9.3 ft by 10.0 ft by 8.5 ft, for a total volume of 751 cu ft.

There were windows on the southwest and northwest corners of the living room area. The dining area had a south window. A window air conditioner was located in the southwest corner window of the living room. The windows were

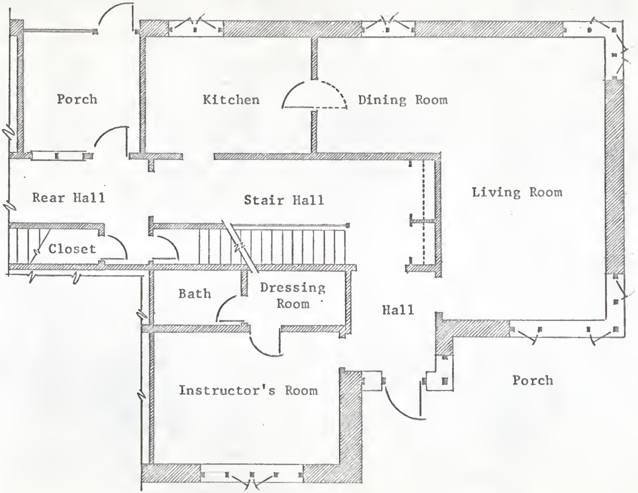


Fig. 1. Main floor plan of Margaret Ahlborn Lodge.

vertically pivoted casement windows which had coverings of bamboo blinds and window sill length draperies. Plate IA is the view of the dining area and living area.

Baragar (6) discussed the difficulty of developing a true mixture of artificial household dust and dirt for a particular region of the United States. The problem was to derive a mixture with all the actual ranges of particles in their correct proportions and de-agglomerated. For these reasons, as well as the uncertainty of applying an artificial mixture in a normal manner, this experimental study was made without the addition of dust and dirt to the room.

Vacuuming Areas. The living room floor was covered with a 22-ft by 12-ft carpet made of Lee's 501 nylon. The oak floor between the carpet and baseboard measured 6 in. to 1 ft in width. The carpet had been in use for three years and had never been commercially cleaned. In this study, vacuuming and spotting were the only cleaning jobs performed on the carpet.

A carpeted area was used for this study because of its apparent ability to collect and hold dust and dirt particles. Rugs or carpets have been incorporated into experiments when the area of study was efficiency of vacuum cleaners or analysis of residence atmospheres (5) (6) (7). In the research performed by Jacobs, Goldwater and Fergany (7) there were indications that carpeted rooms were dustier than uncarpeted rooms. However, their statistical evaluation showed no significant differences.

Occupancy of the Residence. This research experiment was undertaken during one school term during which time the house was occupied by one instructor and four or five female, college seniors on a group rotation plan. The instructor and girls maintained night lodging in the residence. A different group of students was assigned to the residence at the close of every third or fourth week.

Plate IA. Dining room-living room arrangement (arrow indicates sampling head).

Plate IB. Vacuum cleaner exhaust, "shield" modification and "vibra beat" nozzle.

In an effort to minimize additional variables in this study the importance of the experiment--its purpose, procedures and rules--was emphasized to each group of students. Nevertheless, the girls introduced many variables into the study, ranging from burning candles the evening before sampling to permitting boy friends to open windows during the sampling test.

The girls were instructed that during sampling sessions they were not to open any windows on the lower floor and were to keep individual room doors closed if second floor windows were open. They were also informed that the outside doors and the door between the kitchen and dining room area were to remain closed during these sessions. These precautions were taken to limit infiltration of air into the living room. No smoking was allowed in the living room area on sampling days, and candles could be burned only on the evening of each sampling day. The students performed their first-floor cleaning tasks--sweeping, dusting or scrubbing of the living room, dining room or hall--in the late afternoon after the sampling was finished. This rule was enforced to eliminate any unusual suspended dust in the living-dining room atmosphere on test-run days. Each group of students lived under similar conditions.

Test Equipment

Vacuum Cleaner. A Eureka tank vacuum cleaner, model 1015, with a "vibra beat" carpet attachment and a floor/rug nozzle was selected for this study. The carpet attachment had a plastic agitator roller which vibrated with the flow of air into the nozzle and cleaner. The disposable, paper filter bags, designed for the Eureka cleaner, were manufactured by Goodval Paper Products Corporation, New York, New York, and purchased from W. W. Grainger, Inc. (style No. 10/18).

This cleaner was selected because its use promised a near maximum dust generation. It had been rated by Consumers Union as being highly efficient. It also had a downward exhaust, which Harsh (5) stated could cause dust to re-circulate into the atmosphere after vacuuming.

As a vacuum cleaner is operated, dust and dirt collect in the filter bag, decreasing the suction available for cleaning (8). This decreased suction causes the cleaning efficiency of the cleaner to decrease gradually. For this reason a filter bag was used for only two vacuuming sessions before being replaced.

The "shield" was a device used for modification of the vacuum cleaner to redirect the exhaust air. It was a three-sided galvanized steel box, measuring 28 in. by 17.5 in. by 8 in., on which casters were installed. During "shield" runs, the vacuum cleaner was placed inside this enclosure. Plate IB shows the "shield", location of exhaust of vacuum cleaner and "vibra beat" nozzle.

Gas Meters. Bellow-type gas meters were used in determining the volume of air moving through the sampling system. Figure 2 is a schematic drawing of the sampling system showing the gas meters. Two American Meter Company, model 10B, gas meters (American Meter Company, Inc., Philadelphia, Pennsylvania) were connected individually to the two sampling heads. They had sweep observation dials and had been calibrated by the local utility company. One American Meter Company model AL 425 gas meter with a sweep dial, was substituted in the sampling system when the membrane filter sampling began. The reason for the change was the 10B meters were needed on another research project. Plate IIA illustrates the sampling arrangement with the one gas meter. The AL 425 had approximately the same capacity as the two 10B's. The volume of actual air sampled was held constant when changing from the two to one gas meter.

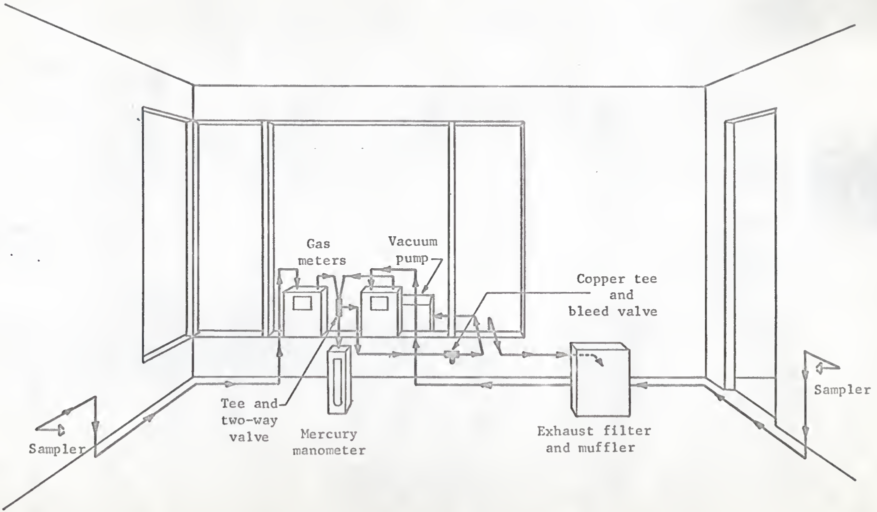


Fig. 2. Air sampling system

Manometer. A mercury manometer was located in the sampling system to determine the air pressure existing in the gas meters. Manometer readings, in inches of mercury vacuum, were taken at each gas meter at the beginning and the end of each sampling run.

Vacuum Pump and Accessories. A Gast model 3040-V106 (Gast Manufacturing Company, Benton Harbor, Michigan) oil-less carbon-vane, 1/2 hp vacuum pump was used to pull the sample of air through the system. At the time of the change from two 10B meters to the one AL 425 meter, the 1/2-hp pump was exchanged for a Gast model 1550, 1-hp, pump.

The pump exhaust was brought back into the living-dining room, to equalize the air pressure, through a filtering exhaust muffler. The purposes of the exhaust filter and muffler were to eliminate the possibility of graphite from the pump entering the sampling atmosphere and to muffle the noise of the pump in the sampling area. The filter/muffler was a case, 4.5 in. by 18 in. by 18 in., with one sheet of fiber glass placed perpendicular to the flow of air for a filter and a fiber glass lining for muffling.

A bleed valve was initially located between the manometer and the pump in the system to help maintain a constant flow sampling rate. However, the vacuum of the system changed little as the filters loaded, so the valve was eliminated.

Sampling Filters and Holders. Plate IIB shows the main components of the sampling head. The head was designed for two-inch diameter filters. A porous stainless steel support held the filter and prevented rupture of the filter during sampling. A stainless steel or plexiglas sealing ring kept the filter in position to eliminate any chance of leakage around the filter. The "cone cap" was screwed to the support area of the holder to hold the sealing ring and filter in place.

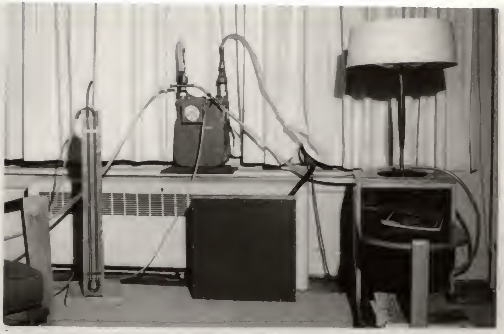


Plate IIA. Sampling arrangement, showing gas meter, manometer and filter/muffler.

Plate IIB. Sampling head which is assembled as follows: A. "cone cap" B. sealing ring C. filter D. support.

Clear, plastic tubing, 3/8-in. I. D., connected the sampling heads to the gas meters. Tubing of 5/8-in. I. D. was used in the system where the two air flows joined.

The selection of sampling media was based on the purpose for which the sample was to be taken. A high-efficiency glass fiber paper without a binder was suggested for determination of mass concentration of the atmospheric dust by the ASTM Standards on Methods of Atmospheric Sampling and Analysis (9). The two-inch diameter filters used in this study were cut manually out of sheets of type 1106BH glass fiber, ordered from the Mine Safety Appliances Company, Pittsburgh, Pennsylvania. Each filter, according to the sales literature, was constructed for efficient filtering of a wide range of particle sizes, which could include freshly formed tobacco smoke particles ranging from 0.05 to 0.1 micron diameter. There was no binding material used in this filter construction, thus eliminating the possible absorption of moisture which could influence the filter weight.

Factory-cut Gelman type-A filters (Gelman Instrument Company, Ann Arbor, Michigan) were used in the early stages of the study. These filters had been cut in mass production, resulting in tattered edges. The possibility of losing some of the shreds during the sampling could have resulted in inaccurate weight measurement. These glass filters, like the Mine Safety Appliances Company material, did not have a binder. The efficiency of the Gelman filters was 99.6 per cent for particles larger than 0.25 microns and greater than 98 per cent for particles as small as 0.05 microns.

A polyester membrane medium was the type of filter suggested for particle size distribution analysis by the ATSM Standards (9). Millipore type R.A., 47-mm diameter, filters (Millipore Filter Corporation, Bedford, Massachusetts) were used for this purpose in the experiment. They had a mean pore size of 1.2 micron, were ungridded, white and dissolvable in acetone.

Door Counter and Timer. During the course of study a door counter was attached to the front door of the entrance hall. The counter recorded the number of door openings during an air sampling session. A cumulative device was operated simultaneously with the door counter to register the total time the door was open during this period.

Balance. The glass fiber filters were weighed before and after each sampling test on an Ainsworth model 15294 (Wm. Ainsworth & Sons, Inc., Denver, Colorado) semi-micro balance. This laboratory analytical balance, type DLB, read to ± 0.1 mg, but it was capable, if used with exceptional care, of weighing ± 0.05 mg.

Procedures

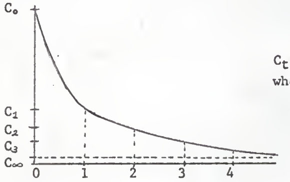
Procedural Philosophy. Ambient air sampling was the method employed in this study to determine the effect of vacuum cleaning on the room atmosphere. Alternative methods, such as comparing the vacuum cleaner filter bag weight increase to the dust concentration of either the intake air or the exhaust air of the cleaner were rejected. These other two means of analysis are theoretically more reliable, but mechanically they would have been very difficult to execute. Analyzing the change in the atmosphere, before and after the vacuum cleaning was the most feasible compromise in this situation.

Control sampling runs, done on days when cleaning was not performed, were designed to establish the normal difference, if any, between the morning and afternoon atmospheric dust concentrations. These runs alternated in general with vacuum cleaning runs. The normal difference data were necessary to accurately interpret and analyze the vacuum cleaning dust concentration data.

Vacuum cleaning was performed under various conditions. In the first stages of the study, cleaning was done with the downward-exhaust cleaner on a soiled area of the carpet or floor. This represented the worst possible condition for contamination of the room air. If no significant change in room atmosphere dust concentration had been detected, the study would have been terminated. The results at this point of the experiment showed a significant increase and justification for more study. The "shield" was designed and used as a modification of the cleaner to prevent any of the discharge from being directed to the carpet and floor areas.

The dust weight collected on the glass fiber filters was an actual average of the atmospheric dust concentration over the sampling time interval. Assuming the dust level of the infiltrated air was zero and the sampled air was uniformly mixed at all times, the dust concentration vs. time curve would theoretically be as follows:

Dust Concentration (gm/cu ft)



Time (hour)

$C_t = f(C_0, t)$
where C_t = concentration at any time, t

Tentative work indicated that the concentration probably decreases at a much faster rate than shown above with a C_t/C_∞ of approximately 1.05 at 1 hour. Therefore, if this research showed significant differences, however small, with average atmospheric dust concentration values, the concentrations immediately following vacuum cleaning, would result in highly significant differences.

Preliminary Development of Techniques. Many runs were made to test the procedures and conditions before the actual collection of data began for the study. After a month of experimenting, standard sampling routines were established and variable conditions were controlled where feasible.

An early problem involved the placement of the two sampling heads during the air sampling sessions. Initially, one sampling head was located 5 in. from one gas meter and the second head 2 1/2 ft from the other meter. Thus, both sampling heads were at one end of the living room, 2-3 ft above the floor. A more central and less concentrated location of the heads was expected to produce more representative samples. Therefore, one sampling head was moved to a 24-in. high end table located near the center of the west living room wall. The other sampling head was re-located atop a 43 1/2-in. high bookcase situated midway on the east living room wall. This arrangement used longer connective tubing, which lowered the free-air capacity of the sampling system.

Initially, the sampled air was exhausted directly by the pump, which was located on the porch. Later, this arrangement was altered to bring the exhaust air from the pump back into the living room. When the sampled air was exhausted to the outside the resultant negative pressure caused air to infiltrate from other rooms in the house and the outdoors in order to replace the displaced air. When the exhaust air was returned the amount of new air diffusing into the sampling area was reduced. The final sampling arrangement resulted in more accurate analysis of the original air in the living-dining area. The re-circulated sampled air was completely cleaned by filtering.

In this report the word "run" will denote the entire day of sampling and "sessions" will refer to the two parts of the sampling run--morning and afternoon. "Control" runs are those during which no vacuum cleaning was performed. "Vacuum cleaning" runs will refer to those runs in which carpet cleaning, with or without the "shield", was included.

As first initiated, the sampling sessions extended across the noon hour. This resulted in heavier dust concentration levels than those that were stopped before the noon hour. Margaret Ahlborn Lodge was located on a busy, one-way street, leading off the campus. The house was not air tight, as no house is, and the data showed the traffic dust to be infiltrating the house and altering the normal atmospheric dust concentration.

From these preliminary tests, the time periods for the control runs were established to miss the morning, noon and evening traffic. The vacuum cleaning runs were the same as control runs for each system of gas meter(s) in the morning, but differed during the afternoon sessions, when the actual vacuum cleaning of the carpet was performed. The cubic feet of air sampled was the value held constant in the different systems. The sampling time was shortened in order to evaluate reliably the effects of vacuum cleaning upon the atmospheric dust concentration. Two factors influenced the dust concentration--settling of the dust particles and cleaning of the air by the sampling filters. Since time influenced both of these factors, the sampling system was turned on immediately after vacuum cleaning. The sampling times were as follows:

For Dust Concentration	Two Gas Meters a.m.	Two Gas Meters p.m.	One Gas Meter a.m.	One Gas Meter p.m.
Control Run: Start	8:30	1:30	8:30	1:30
Stop	11:30	4:30	10:45	3:45
Vacuum Cleaning Run: Start	8:30	1:45	8:30	1:45
Stop	11:30	3:45	10:45	3:10
For Particle Size				
Control Run: Start			8:30	1:30
Stop			11:30	4:30
Vacuum Cleaning Run: Start			8:30	1:45
Stop			11:30	3:45

The cleaning was performed on a set sampling routine for each three or four week sampling period. At the beginning of the study the vacuuming was accomplished every fourth day of student occupancy of the residence laboratory. Where the living routine was interrupted by school breaks vacuuming was performed on Sunday to clean the carpet and a vacuum cleaning run on the following Thursday.

Fifteen minutes were allotted for vacuum cleaning of the 308 sq ft carpet and floor area or 0.34 sq ft per sec. This cleaning time was based on experiments performed by Baragar (8) who allowed 12 minutes to vacuum 108 sq ft of carpet, a rate of 0.15 sq ft per sec, and Harsh (5) who vacuumed five rugs totaling 576 sq ft in 20 minutes or 0.48 sq ft per sec. The carpet was vacuumed by moving laterally in three feet strips.

Another variable which eventually required regulation was the number of students sleeping in the resident laboratory. As the study was outlined four or five students were assigned to the residence. However, during one of the five-student periods three of the girls were married and, therefore, did not actually live in the residence. The married girls were only in the house for meals, meetings and performance of assigned household task. Also, during one of the very first experimental periods the instructor lived in the house alone. During these times there seemed to be a lower atmospheric dust concentration level in the residence, with the possible result that the character of dust would differ. Therefore, the student groups for all the sampling periods were arranged so that there were always four or five girls assigned to the residence, with at least four girls and the instructor in permanent residence.

Test Run Procedures. The same sampling system arrangement was used throughout the experiment. The main variation was in operational procedures when the sessions involved vacuum cleaning.

The sequence of operation for dust concentration control runs was:

1. Weigh morning and afternoon filters in research laboratory and carry in plastic containers to the test area.
2. Close and latch windows on first floor of duplex.
3. Assemble sampling apparatus in the living room. Remove filters from containers and fasten in sampling heads. Ready vacuum pump for operation. Take readings from the gas meter(s), door-opening counter and timer.
4. Begin experimental session at 8:30 a.m. Take mercury manometer readings to determine the vacuum existing in the gas meter(s).
5. Record another mercury manometer reading during last minutes of session.

6. Stop experimental session at 11:30 a.m. for two gas meters and 10:45 a.m. for one gas meter arrangement. Take readings from gas meter(s), door counter and timer.
7. Remove filters from the sampling heads and place in containers.
8. Check sampling apparatus for afternoon sampling. Check windows on first floor and place filters in sampling heads. Take readings from the gas meter(s), door-opening counter and timer.
9. Begin experimental session at 1:30 p.m. Take mercury manometer readings to determine the vacuum existing in the gas meter(s).
10. Record another mercury manometer reading during last minutes of session.
11. Stop experimental session at 4:30 p.m. for two gas meters and 3:45 for one gas meter arrangement. Take readings from gas meter(s), door counter and timer.
12. Remove filters from the sampling heads and place in containers. Disassemble sampling apparatus and place living room in order.
13. Re-weigh filters in the research laboratory.

The sequence followed for all vacuum cleaning test runs for dust concentration was:

1-8. Same as for atmospheric dust concentration control run.

9. Remove light, movable furniture from the living room area to hallway.
10. Assemble vacuum cleaner. Check filter bag or install a new bag depending on the number of times the filter bag has previously been used. (Install a clean filter bag every second vacuum cleaning session.)

11. Bring vacuum cleaner into room and position on the uncleaned carpet area when using without the "shield". When using the "shield" clean it with a damp sponge in the hallway, bring it into the living room and place vacuum cleaner in it.

12. Start cleaning at 1:30 p.m. Vacuum three-foot strips of carpet with "vibra beat" nozzle. Locate vacuum cleaner on dirty carpet or floor during the operation. Shift heavy furniture so the area underneath the items can be cleaned.

13. After approximately 13 minutes of cleaning, remove "vibra beat" attachment and attach the rug/floor nozzle and clean bare floor.

14. Same as procedure no. 4 of control run except begin session at 1:45 p.m. Return furniture to living room, remove the vacuum cleaner and "shield", if used.

15-18. Same as control run procedure nos. 5, 6, 12 and 13, except stop the experiment at 3:45 p.m. and 3:10 p.m. for the two gas meters and one gas meter systems, respectively.

The sequence of operation for all test runs involving control sampling with membrane filters for the size distribution analysis was as follows:

1-4. Same as atmospheric dust concentration control run procedure nos. 1, 3, 4 and 5.

5-10. Same as atmospheric dust concentration control run procedure nos. 6-11 except stop experiment sessions at 11:30 a.m. and 4:30 p.m.

11. Remove filters from the sampling heads and place in metal containers. Disassemble the sampling apparatus and place the living room in order.

12. Determine size distribution by MSA-Whitby sedimentation method (10).

The sequence followed for all test runs involving vacuum cleaning sampling for the dust size distribution analysis was:

1-17. Same as atmospheric dust concentration vacuum cleaning run procedure nos. 2 and 3-18 except stop experiment at 11:30 a.m. and 3:45 p.m.

The filters for this study were handled and transported to the areas in such a manner that contamination was minimized. They were always handled with tweezers rather than fingers. Glass fiber filters were weighed on the balance in pairs--two for the morning and two for the afternoon sessions. The balance was always checked for level and accuracy before starting the weighing process. It was balanced by weighing a 200 milligram weight rather than zeroing. This process eliminated the movement of the counterbalance weight and assured a correctly balanced instrument. The weight of the filters was read when the pointer had an even swing from one side of the scale to the other side.

Before using the membrane filters, they were stored in their shipping container. After sampling, they were transported in metal containers to the research laboratory where the size analysis was performed according to the method of Whitby, Algren and Annis (10) by Mr. Annis. Metal containers were used rather than plastic because static electricity charge caused filters to stick to top of plastic container and disturb the dust. Plate IIIA and B show the equipment used in the analysis.

The wind velocity and direction at 8:00 a.m. and 1:00 p.m. were recorded for each sampling run. This information was obtained from the

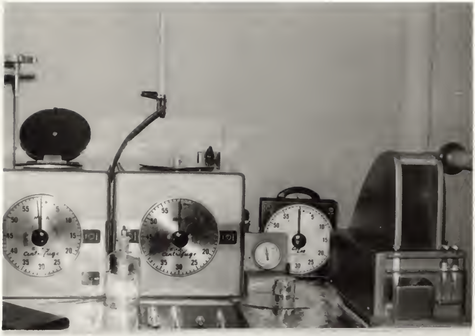


Plate IIIA. MSA-Whitby size analysis apparatus.

Plate IIIB. Size analysis sieves, feeding chamber and sedimentation tube.

Federal Aviation Agency at the Manhattan, Kansas airport. The weather station on campus did not record the needed wind information.

CHAPTER III

RESULTS AND DISCUSSION

Selection of Valid Runs

For this study 74 runs were performed during one school term (September, 1964 to June, 1965). Each run resulted in two sampling sessions, one in the morning and one in the afternoon. There were 61 completed dust concentration runs and 13 particle size distribution runs. Of the 61 dust concentration runs, 28 were control runs (no vacuum cleaning) and 33 test runs (vacuum cleaning). Of the particle size runs, six were vacuum cleaning runs and seven were control runs.

One broad criterion was established and followed for determining whether to discard a run. This criterion was:

> Any event, either before or during a run period, which could bias a normal air sampling (whether actually performed or not) is sufficient justification for discarding a run.

Such instances as the burning of the campus auditorium and the operation of the air conditioner for the first time of the season forced runs to be discarded. Smoke from the auditorium contaminated the outside air which, in turn, infiltrated into the living room and resulted in an abnormally high morning concentration. The air conditioner was used the day before sampling, causing the filter of the morning sampling session to be extremely heavy. The unit had collected dust during the winter months and expelled this dust into the room atmosphere on first operation.

Samples were irregular when the students entertained large groups in the living room the day or evening before a test run. If there was smoking, the morning sample would be extremely black and heavier than normal. On another occasion, a group was entertained on a rainy evening and apparently extra soil was tracked into the living room. This hypothesis was substantiated by the sample after vacuuming being extremely heavy, while the morning sample was seemingly normal. The assumption was that the vacuum cleaner recirculated the dust and dirt.

Burning candles, especially the "drip" type, had a marked effect on the appearance and weight of the sample filter. If candles had been burned the evening before a run, the morning dust concentration would be high but the air would be reasonably normal by the time of the afternoon sampling. Candle burning produced many fine particles which remained suspended in the air.

Consideration of wind velocity and number of door openings introduced another possible reason for discarding sample runs. An arbitrary rule was formulated to discard a run if:

(1) the number of door openings for the higher dust concentration exceeded that for the lower by more than five

<u>and</u>

the wind velocity for the higher dust concentration was 15 knots/hour (17.3 miles/hour) or greater,

<u>or</u>

(2) the wind velocity for the higher dust concentration exceeded that for the lower by 15 knots/hour (17.3 miles/hour), regardless of the door openings.

Some other data were discarded because of uncontrollable variables during the run such as contaminated filters or students cleaning the hallway between sampling sessions.

During one four week period only two students and the instructor maintained residence in the house. The level of dust concentration before and after cleaning was abnormally low. The vacuum cleaning data for this period was discarded.

Plate IV shows some of the actual filter samples. The caption indicates the circumstances under which each dust sample was taken.

Figures 3 and 4 are graphic presentations of dust concentration results before any of the runs were discarded. Figure 3 shows all the morning and afternoon concentrations for days that control runs were performed. Events which resulted in discarding the runs of particular days are as follows:

November 3--------contamination of a.m. filter.

November 10-------construction work on basement ceiling during p.m. session.

November 13-------wind and/or door rule.

December 8--------window in living room open during p. m. session.

January 21--------burned frosting evening before sampling.

February 21-------eight dinner guests (smoking) evening before sampling.

February 25-------wind and/or door rule.

April 20----------vacuum pump stopped during a.m. session.

May 2-------------wind and/or door rule.

May 6-------------student cleaned hallway during noon hour of sampling day.

Figure 4 gives the results of vacuum cleaning runs. The runs eventually discarded are as follows:

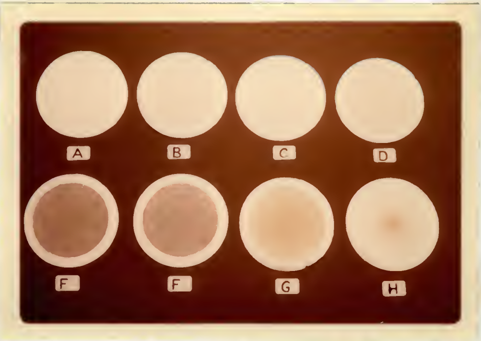


Plate IV. Examples showing the range of dust samples obtained:

Filter A---only instructor in residence.
Filter B---after vacuuming (Oct. 15).
Filter C---after vacuuming (Jan. 19).
Filter D---party evening before.
Filter E---burned "drip" candles evening before.
Filter F---burned frosting evening before.
Filter G---dusty, windy day.
Filter H---sampled over noon hour (coarse material)

Fig. 3. Control run data.

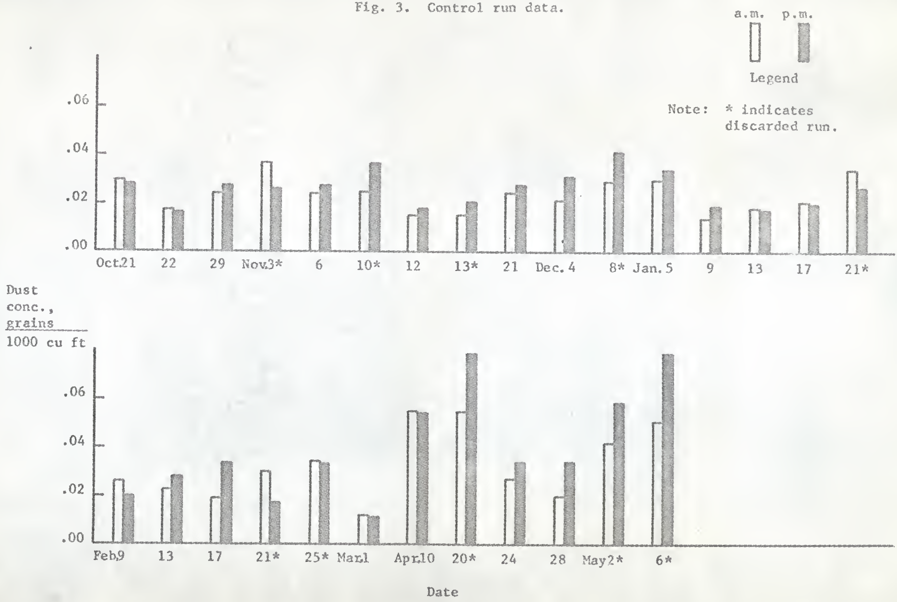
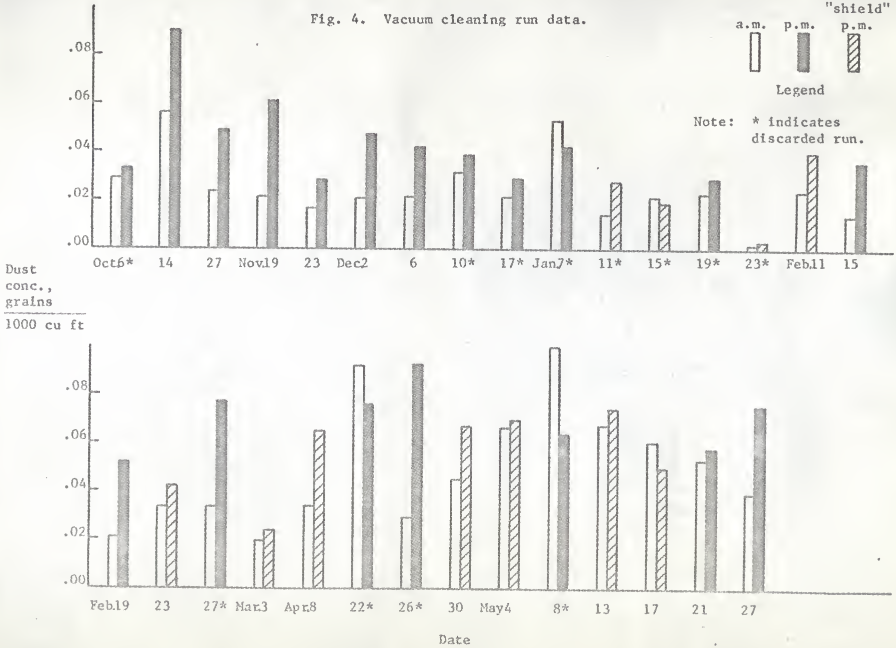


Fig. 4. Vacuum cleaning run data.



October 6---------exhaust air outside of residence.

December 10-------window in living room open during p.m. session.

December 17-------only two students and instructor in residence.

January 7---------candles burned evening before sampling.

January 11 & 19---only two students and instructor in residence.

January 15--------auditorium burned evening before sampling.

January 23--------inaccurate weighing of filters.

February 27-------found hole in dust filter bag after cleaning.

April 22----------first time of season air conditioner used.

April 26----------party evening before sampling.

May 8-------------students moved out of residence day before sampling.

Findings

Table 1 shows the form in which data were recorded for each dust concentration run and size distribution run, excluding the filter data. All original sampling data are given in Tables A-1 and A-2 of the Appendix.

Figure 5 shows the average particle size distributions for control runs, both a.m. and p.m. sessions, and for vacuum cleaning ("shield") runs, a.m. and p.m. The geometric mean diameter, by weight, for the control run data was approximately 3.8 microns for both a.m. and p.m., whereas the vacuum cleaning runs yielded 3.6 microns before cleaning and 4.3 microns after cleaning. Figure 5 also shows the size distribution for a national average as obtained by Whitby, et al. (3). This shows the geometric mean diameter of the particles by weight to be 3.3 microns with a geometric standard deviation of 2.721.

Table 1. Example of data record form.

Run 27. Dust concentration sampling, Margaret Ahlborn Lodge.

Date Dec. 17, 1964

Time 8:30 a.m.-11:30 a.m.

Wind	Gas meter					Manometer			Filter			Dust concentration	Door openings	
	Gas meter	Readings		Metered	Free	Vacuum			Weight		Dust weight,			
kts/hr	a.,b.	Initial, ft^3	Final, ft^3	flow, ft^3	air, ft^3	Initial, "H_g	Final, "H_g	Ave. total, "H_g	Initial, g	Final, g	g	grain/1000 ft^3	Number	Time
N 15	1823	215.68	876.91	661.23	474.72	4.12	4.04	8.18	0.22330	0.22480	0.00150	0.0230	-	-
						4.15	4.05							
NW 12-18	1824	202.60	936.17	733.57	529.18	4.11	3.96	8.08						
						4.10	4.00							

Description of operation.

Vacuumed without "shield".

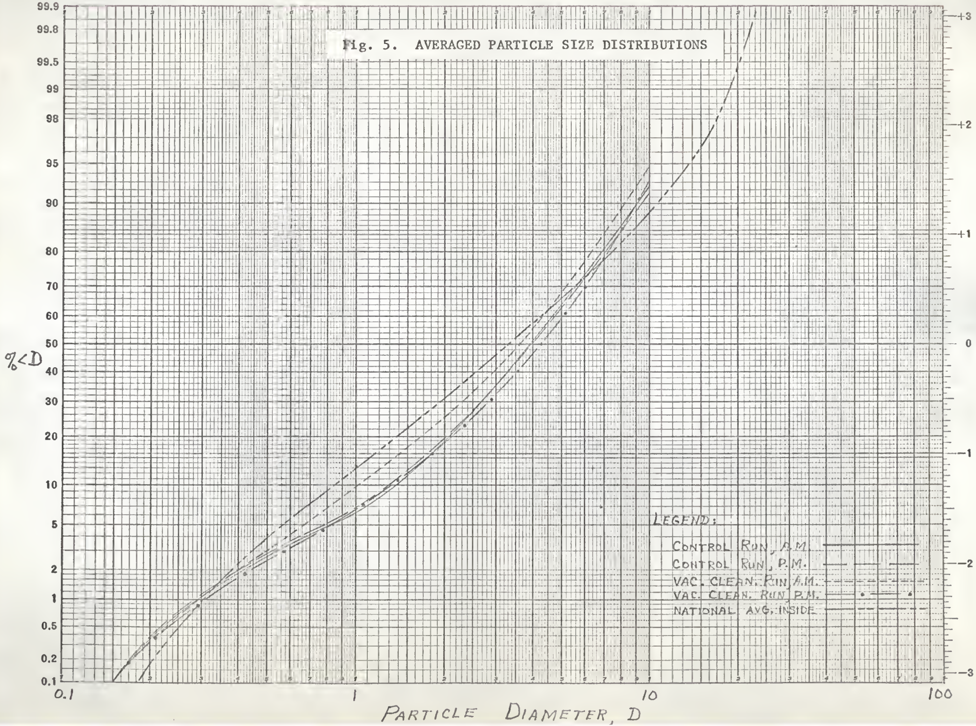


Fig. 5. AVERAGED PARTICLE SIZE DISTRIBUTIONS

Tables 2a and 2b summarize the particle size distribution study for vacuum cleaning and control runs. The tables show the geometric mean and geometric standard deviation of all the analyzed runs. The average inside dust concentration for this study was 0.025 grains/1000 cu ft.

Tables 3, 4a and 4b present the actual data analyzed in this study. Table 3 represents data of all valid control runs. Tables 4a and 4b show the vacuum cleaning runs without the "shield" and with the "shield", respectively.

Experimental Accuracy

During this study the atmospheric barometric pressure was assumed to be 29.00 inches of mercury. Previous sampling established a maximum range of 28.20 to 29.20 inches of mercury. Thus, the free air volume calculation would have a maximum error of one per cent if 29.00 was assumed. The maximum error in reading the mercury manometer would cause a 0.13 per cent error in the calculated free air volume. The gas meter reading error was insignificant, but a 0.25 per cent calibration error existed.

The error in determining the dust weight on the filters averaged 5 per cent, with a maximum possible of 10 per cent. This 10 per cent error resulted in a dust concentration error of 10 per cent, while the assumed barometric pressure caused a 1 per cent in the same value. Therefore, determination of the weight of dust on the filter was much more critical than the measurement of any of the other variables and the assumption of a standard barometric pressure was justified. Because of the magnitude of changes in uncontrollable variables, further error analysis would be meaningless.

Table 2a. Control run size distribution changes.

Run	Geometric mean diameter difference, X' (p.m.-a.m.=X'), micron	Geometric standard deviation, σ_g' [1]
1	.15	.10
3	-.85	.44
5	1.09	.01
7	.00	-.12
9	Lost sample during size analysis	
11	-.84	.26
14	.72	.05
Total	+.27	+.74
Average	+.05	+.12

Table 2b. Vacuum cleaning ("shield") run size distribution changes.

Run	Geometric mean diameter difference, X' (p.m.-a.m.=X'), micron	Geometric standard deviation, σ_g' [1]
2	.00	.00
4	.40	-.23
6	1.59	-.32
8	.23	-.63
10	.89	-.27
12	.76	.02
Total	+3.87	-1.43
Average	+.65	-.24

[1]Average geometric standard deviation, $\sigma'_g = \frac{D_{84\%}/D_{50\%} + D_{50\%}/D_{16\%}}{2}$

D = particle diameter, microns.

$D_{84\%}$ = particle diameter at 84% on curve ($+1\sigma_g$).

$D_{50\%}$ = particle diameter at 50% on curve (geometric mean).

$D_{16\%}$ = particle diameter at 16% on curve ($-1\sigma_g$).

Table 3. Acceptable control run data.

Date	Dust concentration of room air (gr/1000 ft^3)		Difference, X'
	a.m. session	p.m. session	(p.m.-a.m. = X')
October 21, 1964	.0294	.0278	-.0016
October 22, 1964	.0180	.0175	-.0005
October 29, 1964	.0241	.0267	.0026
November 6, 1964	.0239	.0276	.0037
November 12, 1964	.0156	.0181	.0025
November 21, 1964	.0248	.0268	.0020
December 4, 1964	.0216	.0312	.0096
January 5, 1965	.0308	.0340	.0032
January 9, 1965	.0147	.0193	.0046
January 13, 1965	.0187	.0174	-.0013
January 17, 1965	.0215	.0202	-.0013
February 9, 1965	.0260	.0199	-.0061
February 13, 1965	.0229	.0283	.0054
February 17, 1965	.0157	.0268	.0111
March 1, 1965	.0131	.0119	-.0012
April 10, 1965	.0558	.0556	-.0002
April 24, 1965	.0271	.0336	.0065
April 28, 1965	.0203	.0344	.0141

Table 4a. Acceptable vacuum cleaning ("shield") run data.

Date	Dust concentration of room air ($gr/1000\ ft^3$) a.m. session	p.m. session	Difference, X' (p.m.–a.m. = X')
February 11, 1965	.0243	.0402	.0159
February 23, 1965	.0331	.0413	.0082
March 3, 1965	.0185	.0222	.0037
April 8, 1965	.0346	.0651	.0305
April 30, 1965	.0460	.0676	.0216
May 4, 1965	.0672	.0706	.0034
May 13, 1965	.0685	.0741	.0056
May 21, 1965	.0535	.0583	.0048

Table 4b. Acceptable vacuum cleaning run data.

Date	Dust concentration of room air ($gr/1000\ ft^3$) a.m. session	p.m. session	Difference, X' (p.m.–a.m. = X')
October 14, 1964	.0577	.0912	.0335
October 27, 1964	.0251	.0509	.0258
November 19, 1964	.0227	.0621	.0394
November 23, 1964	.0174	.0292	.0118
December 2, 1964	.0231	.0486	.0255
December 6, 1964	.0227	.0428	.0201
February 15, 1965	.0114	.0362	.0218
February 19, 1965	.0209	.0531	.0322
May 27, 1965	.0399	.0762	.0363

Statistical Analysis of Results

The difference between morning and afternoon dust concentration on a given day, X', was the principal variable studied. Most attention was focused on the effect of vacuum cleaning on this variable although other factors were investigated as the statistical analysis proceeded.

Table 5 is a summary of the calculation of variances for the dust concentration data presented in Tables 3, 4a and 4b. The results of the tests of equality of variances for these data are presented in Table 6. The results

Table 5. Calculation of variances: effect of vacuum cleaning upon dust concentration.

Factor	Vacuum cleaning: "Shield"	Vacuum cleaning: No "shield"	Control
$\sum_i X^2_{ij}$	0.00179651	0.00736352	0.00059257
$\sum_i X_{ij}$	0.0937	0.2464	0.0531
$(\sum_i X_{ij})^2$	0.00877969	0.06071296	0.00281961
$(\sum_i X_{ij})^2/N_j$	0.00109746	0.006745884	0.001566450
s_j^2	0.0000998642	0.0000772045	0.0000256426

Table 6. Test of equality of variances: effect of vacuum cleaning upon dust concentration.

Run comparisons	Degrees of freedom[1]		Calculated F-value[2]	F-table value (α=.05)	$\sigma_1'^2=\sigma_2'^2$	$\sigma_1'^2\neq\sigma_2'^2$
No "shield" / "shield"	8	7	1.294	3.50	Incon-clusive	Assume yes
"Shield" / control	7	17	3.894	2.61	No	Yes
No "shield" / control	8	17	3.011	2.55	No	Yes

[1]Degree of freedom, n=N-1.

[2]Based on Duncan (11), p. 403.

of this test indicated that the variances of the "shield" and no "shield" runs were individually different from the variance of the control runs. However, the test for equality of variance for the two types of vacuum clearing runs was inconclusive. For the t-test of the means, these variances were assumed to have been equal. The conclusions of the F-test were necessary for the choice of the proper t-test.

The t-test was performed on data from Tables 3, 4a and 4b to determine if significant differences existed between dust concentration changes (p.m.-a.m.) for the two types of vacuum cleaning runs and the control run. The null hypothesis for this was: $\overline{X}'_1 = \overline{X}'_2$. The t-test was executed on the basis of findings from the F-test. The Type II error, acceptance of a hypothesis when it is false, was not considered during this analysis. The calculation of the mean concentrations is presented in Table 7 and the t-tests summarized in Table 8. The t-test conclusions rejected the null hypotheses in all run comparisons. There were significant increases in the dust concentration resulting from vacuum cleaning and vacuum cleaning without the "shield" produced significantly more dust than cleaning with the "shield".

Regression analysis was performed on the relationship between the dust concentration and a number of variables capable of affecting it. The analysis investigated to what extent variation in one factor caused variation in the amount of atmospheric dust present. The test analyzed the relationship between the mean of one set of values ($\overline{X}_1$) and the mean ($\overline{X}_2$) of another set. Table 9 is a resume of these analyses.

The degree of association between two variables is determined by a coefficient of correlation ($\hat{r}$), which is an outcome of the regression analysis (11). The value of $\hat{r}$ depends on the slope of the regression line and the

Table 7. Changes in dust concentrations[1], a.m. to p.m.

Factor[2]	Vacuum cleaning runs		Control runs
	"Shield"	No "shield"	
ΣX_i	.0937	.2464	.0531
$\bar{X}_i = \frac{\Sigma X_i}{N}$	.0117	.0274	.0030
Sample size, N	8	9	18

[1]grains/1000 cu ft.

[2]X_i = (p.m. concentration) - (a.m. concentration); algebraic signs observed.

Table 8. Results of tests for significant changes in dust concentrations.

Run comparisons	Degrees of freedom	F-test conclusions $\sigma'^2_i = \sigma'^2_j$	Calculated t-value	t-table value (α= 0.05)	Null hypothesis $\bar{X}'_i = \bar{X}'_j$
"Shield" vs. no "shield"	15	Inconclusive	3.444	2.131	Reject
"Shield" vs. control	24	No	2.346[1]	2.339	Reject
No "shield" vs. control	25	No	7.734[1]	2.278	Reject

[1]Due to inequality of variances and sample size, the critical t was based on theory in Duncan (11), page 397-398. See appendix for calculations.

Table 9. Linear regression analysis of dust concentration and experimental variables.

Variables comparisons	Slope	Regression coefficient of variation[1]	Coefficient of correlation, $\hat{r}$	$\hat{r}^2$	Interpretation of $\hat{r}^2$
Dust concentration vs. number door openings.	Moderately negative	33%	.305	.093	$\hat{r}^2$ was meaningless because of negative slope.
Dust concentration difference (p.m.-a.m.) vs. difference in number of door openings (p.m.-a.m.).	Small positive	97%	.175	.030	3% of variance in dust concentration differences between a.m. and p.m. due to frequency of door openings difference between a.m. and p.m.
Dust concentration vs. total elapsed time door was open	Small negative	37%	-	-	Because of negative slope did not calculate $\hat{r}^2$.
Dust concentration difference (p.m.-a.m.) vs. difference in seconds door was open (p.m.-a.m.).	Approximately zero	0%	.000	.000	The combination as compared showed no linear relationship.
Dust concentration difference (p.m.-a.m.) vs. difference in wind velocity (p.m.-a.m.).	Small positive	35%	.000	.000	The combination as compared showed no linear relationship.
Dust concentration vs. $V^{m} \cdot t$.	Small positive	46%	.227	.051	3% of variance in dust concentration attributed to the $V^{m} \cdot t$ variable.

[1] Regression coefficient of variation, $\% = \dfrac{\left[\sum_{i=1}^{n} \dfrac{(X_{1ai})-(X_{1ri})}{X_{1ri}}\right]}{n}$ X 100; see footnote, p. 43.

deviation of the data points from the line. The coefficient of correlation is positive or negative, respectively, for a positive or negative slope. When $\hat{r}=0$ there is no linear correlation between the two variables, as they are compared in that analysis. There is no scatter around the line of regression when $\hat{r} = \pm 1$. "Therefore, $\hat{r}^2$ is the fraction of the total variance that is 'accounted for' by the regression." (11)

If the slope of the linear regression line was positive this indicated that X_1 tended to increase with X_2. A negative slope resulted when X_1 decreased with increasing X_2.

The regression coefficient of variation determined the mean percentage scatter of the actual data points from the regression line. This value was established by the following formula:[1]

$$\% = \frac{\sum_{i=1}^{n} \left[\frac{(X_{1ai})-(X_{1ri})}{X_{1ri}} \right]}{n} \times 100$$

X_{1ai} = each variable of the sample.

X_{1ri} = regression value of each X_{1a}.

This statistic, in contrast to $\hat{r}$ or $\hat{r}^2$, considered only the scatter of the data points from the line of regression and helped determine the possible reason for low $\hat{r}^2$ values.

A regression analysis was performed on the dust concentration, during multiple residency, and several variables that could influence the weight of atmospheric dust infiltrating during door openings. These variables included

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[1]This original coefficient was suggested by Mr. J. C. Annis in private conversations. It parallels the coefficient of variation for mean values.

the total elapsed time the door was open, the door area, the velocity of air passing through the door and the outside dust concentration. The outside concentration was further assumed to be some function of the wind velocity raised to a power, n. The weight of dust infiltrating is then given by the following proportionality:

$$Wt \sim A \cdot V \cdot C_o \cdot t$$

$$C_o \sim V^n$$

Since A is a constant,

$$Wt \sim V \cdot V^n \cdot t$$

$$Wt \sim V^m \cdot t$$

A=area of door

V=wind velocity

n=arbitrary power

m=n+1

C_o= outside dust concentration

Wt=weight of dust infiltrating with outside air

t=time door was open

The one analysis performed with the ($V^m \cdot t$) data resulted in the conclusion that only 5% of the variance in atmospheric dust concentration was due to changes in ($V^m \cdot t$). The nature of the velocity data made it apparent that the regression could not be improved with a change in the value of n. It is possible that this simple relationship did not adequately describe the process of dust infiltration during door openings.

Table 9 indicates that no correlations existed between dust concentration and experimental variables tested. The regression coefficient of variation indicated the average percentage scatter of data points from the regression line. This value was extremely large in the analysis of the dust concentration differences (p.m.-a.m.) compared to difference in number of door openings (p.m.-a.m.), indicating extreme scatter which greatly influenced $\hat{r}^2$. However, the regression coefficient of variation was lower for other analyses, which for low values of $\hat{r}^2$ meant that the small slope of the line was quite important. A large degree of scatter could mean that improved techniques or more data were needed.

Table 10 is a summary of the analysis of data analyzed to determine if the number of residents influenced the dust concentration. The single resident dust concentration did not change significantly between the morning and afternoon which was opposite of the findings of the multiple residency dust concentration data. The conclusion was formed that the number of occupants in the residence influenced the level of dust concentration.

Table 10. Tests to determine if multiple residency[1] influenced atmospheric dust concentration.

Tests whether:	Null hypothesis	F-test	$\sigma'^2_1=\sigma'^2_2$	t-test[4]	$\bar{X}'_1 \neq \bar{X}'_2$
Change in dust concentration (p.m.-a.m.), single resident[2], differs from 0.	$\bar{X}'_1-\bar{X}'_2=0$ or $\bar{X}'_1 = \bar{X}'_2$	-	-	Inconclusive[3]	No
Change in dust concentration (p.m.-a.m.), multiple residency, differs from 0.	$\bar{X}_1-\bar{X}_2=0$ or $\bar{X}'_1 = \bar{X}'_2$	-	-	Reject[3]	Yes
Variance of dust concentration, single resident, (a.m. and p.m.) was significantly different than variance of dust concentration, multiple residency, (p.m.).	$\sigma'^2_1=\sigma'^2_2$	Reject	No	-	-
Variance of dust concentration (a.m. vs. p.m.), single resident, was significantly different than variance of dust concentration (a.m. vs. p.m.), multiple residency. (sign not considered).	$\sigma'^2_1=\sigma'^2_2$	Inconclusive	Inconclusive[5]	-	-
Dust concentration, single resident, (a.m. and p.m.) = dust concentration multiple residency, (p.m.).	$\bar{X}'_1 = \bar{X}'_2$	-	-	Inconclusive	No
Difference in dust concentration (a.m. vs. p.m.), single resident, = difference in dust concentration (a.m. vs. p.m.), multiple residency. (sign not considered).	$\bar{X}'_1 = \bar{X}'_2$	-	-	Inconclusive	No

[1]Multiply residency includes that data when students and instructor resided in Margaret Ahlborn Lodge.

[2]Single resident includes that data when instructor was only occupant of Margaret Ahlborn Lodge.

[3]When standard deviation unknown and sample size small used t-test on page 365, Duncan (11).

[4]Type II error not considered.

[5]Assume $\sigma'^2_1 \neq \sigma'^2_2$.

CHAPTER IV

CONCLUSIONS AND OBSERVATIONS

There is a statistically significant increase in the dust concentration in the room atmosphere after vacuum cleaning. This increase is greatest when a downward-exhaust cleaner is operated over an uncleaned area of the carpet or floor. A lesser, but yet significant, increase is evidenced when the vacuum cleaner exhaust is directed upward and does not contact the carpet or floor dirt. Thus, the increase in air-borne dust is due to two factors--entrainment by the exhaust and penetration of the filter bag. The number of occupants in a residence also influences the dust level significantly.

The new air-borne dust has nearly the same size distribution as that normally present in residences. This fact supports the conclusion that a significant portion of the dust particles came through the vacuum cleaner filter bag.

An increase of all size particles automatically increases the number of fine particles. These stay permanently suspended in the atmosphere until they come in contact with some surface and are largely responsible for the staining and soiling of surfaces, such as walls and furnishings. Therefore, after vacuum cleaning there will be more small particles and a consequent increase in soiling and staining.

The concentration and size distribution of the inside residential dust encountered in this study are remarkably close to the national average. The concentration of 0.025 grains/1000 cu ft compares to 0.036 grains/1000 cu ft nationally and 0.027 grains/1000 cu ft for Minneapolis, Minnesota, a comparable non-heavy industry city (3). The size distribution is also not significantly different.

Observed in the study was the increase of household atmospheric dust concentration from many common activities of the home, such as the burning of "drip" candles or food, or from entertaining guests. In some instances these events resulted in larger increases of contaminant concentration than was experienced when cleaning with the downward-exhaust vacuum cleaner. Probably, the homemaker is no more aware, than were the experimenters initially, of the additional cleaning problem created by burning candles, expecially the "drip" type.

Applications of these observed facts for the homemaker might include the following suggestions:

1. Use a downward-exhaust vacuum cleaner only over previously cleaned areas.
2. Avoid use of downward-exhaust vacuum cleaners.
3. Avoid burning "drip" type candles.
4. Cover immediately any food burned during cooking or use an exhaust hood.
5. Clean any air conditioning systems before first seasonal use.

Additional productive research would involve comparisons of the air-borne dust generated by use of different types of vacuum cleaners and filter bags. It seems possible that the material and efficiency of the filter bag would vary with brand and types. Further research might lead to the development of more efficient filters, although it would be difficult to develop a bag which would retain high percentages of all size particles without overly restricting the movement of air through the cleaner. A greater understanding of the inherent deficiencies of a portable vacuum cleaner may help to encourage wider acceptance of the centrally installed vacuum cleaning system.

CHAPTER V

ACKNOWLEDGEMENT

Sincere appreciation is expressed to Patty J. Annis, Assistant Professor, Department of Family Economics, and Jason C. Annis, Instructor, Department of Mechanical Engineering, for their efforts, guidance and helpful criticisms throughout the course of this investigation and preparation of the manuscript.

Gratitude is also expressed to Dr. Richard L. D. Morse, Professor and Head of the Department of Family Economics, for his constructive reading and criticism of the manuscript.

CHAPTER VI

LITERATURE CITED

1. Jacobs, M. B., Manoharan, A., and Goldwater, L. J. "Comparison of Dust Counts of Indoor and Outdoor Air," International Journal of Air and Water Pollution, VI (May/August), p. 205-213.

2. ________________. "Air-Cleaning Fundamentals," Internal Report 70-9703. Honeywell, Inc. p. 1-8.

3. Whitby, K. T., Algren, A. B., Jordon, R. C. and Annis, J. C. "The ASHAE Airborne Dust Survey," Heating, Piping and Air Conditioning, XI (November, 1957), p. 185-192.

4. Goldwater, L. J., Manoharan A., and Jacobs, M. B. "Suspended Particulate Matter. Dust in 'Domestic' Atmospheres," Archives of Environmental Health, II (May, 1961), p. 35-39.

5. Harsh, G. F. "A Study of the Dust, Mold and Bacteria Content of the Exhaust of Various Types of Vacuum Cleaners," Annals of Allergy, XII (1954), p. 705-709.

6. Baragar, A. "Procedures for Measuring the Rug Cleaning Ability of Vacuum Cleaners," Research Bulletin No. 195. Agricultural Experiment Station, University of Nebraska College of Agriculture. (March, 1961).

7. Jacobs, M. B., Goldwater, L. J., and Fergany, A. "Comparison of Suspended Particulate Matter of Indoor and Outdoor Air," International Journal of Air and Water Pollution, XI (September/October, 1962), p. 377-380.

8. Baragar, A. "Rug-cleaning Ability of Vacuum Cleaners," Journal of Home Economics, LI (February, 1959), p. 115-118.

9. ASTM Committee D-22 on Methods of Atmospheric Sampling and Analysis. ASTM Standards on Methods of Atmospheric Sampling and Analysis, 2nd edition. Philadelphia, Pennsylvania: American Society for Testing Materials, (1962), p. 116-124.

10. Whitby, K. T., Algren, A. B. and Annis, J. C. "Centrifuge Sedimentation Size Analysis of Samples of Airborne Dusts Collected in Membrane Filters," Symposium on Particle Size Measurement. Special Technical Publication No. 234, American Society for Testing Materials, (1958), p. 1-9.

11. Duncan, A. J. Quality Control and Industrial Statistics, Homewood, Illinois: Richard D. Irwin, Inc., 1955.

APPENDIX

Appendix A

ORIGINAL DATA

Table A-1. Dust concentration sampling data and calculations.

Date	Session	Free air sampled, cu ft	Dust weight collected, gram	Dust conc., grains/1000 cu ft	Wind velocity, miles/hr	Door openings and time, min.:sec.	Operation	Remarks
October 6, 1964	a.m.	1073.91	.00210	.0301	calm	-	Vacuumed without "shield"	Exhaust air to outside
	p.m.	720.36	.00165	.0352	6.9	-		
October 8, 1964	a.m.	995.26	.00340	.0526	calm	-	Stationary cleaner	Started exhausting air back into room
	p.m.	658.92	.00195	.0456	13.8	-		
October 14, 1964	a.m.	988.71	.00370	.0577	calm	-	Vacuumed without "shield"	
	p.m.	650.81	.00385	.0912	13.8	-		
October 15, 1964	a.m.	984.52	.00235	.0368	calm	-	Stationary cleaner	
	p.m.	662.91	.00245	.0569	17.3 to 26.5	-		
October 21, 1964	a.m.	939.58	.00180	.0294	calm	-	Control	Instructor living alone
	p.m.	939.52	.00170	.0278	11.5	-		
October 22, 1964	a.m.	937.67	.00110	.0180	8.0	-	Control	Instructor living alone
	p.m.	965.73	.00110	.0175	15.0	-		
October 27, 1964	a.m.	981.16	.00160	.0251	calm	-	Vacuumed without "shield"	Instructor living alone
	p.m.	650.40	.00215	.0509	15.0	-		
October 29, 1964	a.m.	957.80	.00150	.0241	3.5	-	Control	Instructor living alone
	p.m.	981.51	.00170	.0267	11.5	-		

Table A-1. Dust concentration sampling data and calculations. (cont.)

Date	Session	Free air sampled, cu ft	Dust weight collected, gram	Dust conc., grains/1000 cu ft	Wind velocity, miles/hr	Door openings and time min.:sec.	Operation	Remarks
November 3, 1964	a.m.	962.94	.00235	.0376	4.6	-	Control	Contaminated a.m. filters
	p.m.	949.65	.00160	.0259	15.0	-		
November 6, 1964	a.m.	966.77	.00150	.0239	6.9	-	Control	Instructor living alone
	p.m.	974.72	.00175	.0276	4.6	-		
November 8, 1964	a.m.	976.48	.00140	.0221	calm	-	Vacuumed without "shield"	No cleaner filter bag
	p.m.	659.90	.00245	.0572	20.7	-		
November 10, 1964	a.m.	977.56	.00180	.0283	8.0	-	Control	Construction on basement ceiling (p.m.)
	p.m.	985.73	.00235	.0367	18.4 to 26.5	-		
November 12, 1964	a.m.	987.12	.00100	.0156	16.1	-	Control	Instructor living alone
	p.m.	974.46	.00115	.0181	18.4 to 27.6	-		
November 13, 1964	a.m.	976.91	.00110	.0153	calm	-	Control	Instructor living alone
	p.m.	979.80	.00130	.0204	17.3 to 27.6	-		
November 19, 1964	a.m.	982.62	.00145	.0227	6.9	-	Vacuumed without "shield"	End of period of instructor living alone
	p.m.	659.84	.00266	.0621	17.3	-		
November 21, 1964	a.m.	961.27	.00155	.0248	25.3 to 34.6	-	Control	
	p.m.	977.29	.00170	.0268	24.2 to 34.6	-		
November 23, 1964	a.m.	973.83	.00110	.0174	15.0	-	Vacuumed without "shield"	
	p.m.	658.12	.00125	.0292	18.4	-		
December 2, 1964	a.m.	966.26	.00145	.0231	15.0	-	Vacuumed without "shield"	
	p.m.	649.47	.00205	.0486	16.1	-		

Table A-1. Dust concentration sampling data and calculations. (cont.)

Date	session	Free air sampled, cu ft	Dust weight collected, gram	Dust conc., grains/1000 cu ft	Wind velocity, miles/hr	Door openings and time min.:sec.	Operation	Remarks
December 4, 1964	a.m.	996.59	.00140	.0216	15.0	-	Control	
	p.m.	987.49	.00200	.0312	13.8	-		
December 6, 1964	a.m.	983.06	.00145	.0227	4.6	-	Vacuumed without "shield"	
	p.m.	664.91	.00185	.0428	6.9	-		
December 8, 1964	a.m.	989.83	.00185	.0288	calm	-	Control	Window open in p.m.
	p.m.	987.50	.00265	.0413	calm	-		
December 10, 1964	a.m.	1007.44	.00220	.0336	5.8	-	Vacuumed without "shield"	Window open in p.m.
	p.m.	675.07	.00175	.0399	5.8	-		
December 17, 1964	a.m.	1003.90	.00150	.0230	17.3	-	Vacuumed without "shield"	Only two girls living in residence
	p.m.	662.15	.00130	.0302	13.8 to 20.7	-		
January 5, 1965	a.m.	999.17	.00200	.0308	calm	-	Control	
	p.m.	995.08	.00220	.0340	6.9	-		
January 7, 1965	a.m.	988.43	.00350	.0545	calm	-	Vacuumed without "shield"	Burned candles evening before sampling
	p.m.	682.64	.00190	.0429	18.4	-		
January 9, 1965	a.m.	1046.78	.00100	.0147	8.0	-	Control	
	p.m.	1036.80	.00130	.0193	11.5			
January 11, 1965	a.m.	1028.46	.00105	.0157	13.8	-	Vacuumed with "shield	Only two girls living in residence
	p.m.	690.63	.00125	.0279	15.0	-		
January 13, 1965	a.m.	1029.32	.00125	.0187	8.0	-	Control	
	p.m.	1015.53	.00115	.0174	10.4	-		

Table A-1. Dust concentration sampling data and calculations. (cont.)

Date		Free air sampled,	Dust weight collected,	Dust conc.,	Wind velocity,	Door openings and time	Operation	Remarks
	session	cu ft	gram	grains/1000 cu ft	miles/hr	min.:sec.		
January 15, 1965	a.m.	1020.19	.00145	.0219	27.6 to 40.3	-	Vacuumed with "shield"	Auditorium burned evening before sampling
	p.m.	698.24	.00090	.0198	23.0 to 30.0	-		
January 17, 1965	a.m.	1035.30	.00145	.0215	16.1	-	Control	
	p.m.	1026.74	.00135	.0202	28.8	-		
January 19, 1965	a.m.	1035.11	.00155	.0230	32.3	-	Vacuumed without "shield"	Only two girls living in residence
	p.m.	695.01	.00135	.0299	41.5	-		
January 21, 1965	a.m.	1019.04	.00235	.0355	calm	-	Control	Burned frosting evening before sampling
	p.m.	1029.55	.00180	.0269	17.3	-		
January 23, 1965	a.m.	1040.63	.00015	.0022	3.5	-	Vacuumed with "shield"	Inaccurate procedures
	p.m.	684.20	.00015	.0033	20.7 to 31.1	-		
February 9, 1965	a.m.	1005.92	.00170	.0260	6.9	-	Control	
	p.m.	1044.43	.00135	.0199	9.2	-		
February 11, 1965	a.m.	1015.12	.00160	.0243	26.5 to 41.5	-	Vacuumed with "shield'	
	p.m.	767.08	.00200	.0402	20.7	-		
February 13, 1965	a.m.	1005.85	.00150	.0229	calm	-	Control	
	p.m.	1006.60	.00185	.0283	calm	-		
February 15, 1965	a.m.	1015.49	.00095	.0144	13.8 to 20.7	-	Vacuumed without "shield"	
	p.m.	681.42	.00160	.0362	20.7	-		
February 17, 1965	a.m.	1030.51	.00105	.0157	calm	-	Control	
	p.m.	1005.20	.00175	.0268	9.2	-		

Table A-1. Dust concentration sampling data and calculations. (cont.)

Date	Session	Free air sampled, cu ft	Dust weight collected, gram	Dust conc., grains/1000 cu ft	Wind velocity, miles/hr	Door openings and time, min.:sec	Operation	Remarks
February 19, 1965	a.m.	1031.27	.00140	.0209	calm	-	Vacuumed without "shield"	
	p.m.	682.75	.00235	.0531	6.9	-		
February 21, 1965	a.m.	1022.85	.00170	.0256	25.3 to 40.3	-	Control	8 dinner guests evening before sampling
	p.m.	1032.12	.00115	.0171	19.6 to 28.8	-		
February 23, 1965	a.m.	1022.76	.00220	.0331	17.3 to 25.3	16/2:30	Vacuumed with "shield"	
	p.m.	689.24	.00185	.0413	21.9 to 28.8	4/3:00		
February 25, 1965	a.m.	765.28	.00135	.0271	5.8	14/4:06	Control	
	p.m.	1059.16	.00185	.0269	17.3 to 25.3	25/1:24		
February 27, 1965	a.m.	1058.04	.00235	.0342	8.0	23/17:10	Vacuumed without "shield"	Hole in cleaner filter bag
	p.m.	680.45	.00340	.0770	23.0	10/1:22		
March 1, 1965	a.m.	1052.99	.00090	.0131	6.9	13/?	Control	
	p.m.	1040.21	.00080	.0119	18.4	4/:12		
March 3, 1965	a.m.	1038.71	.00125	.0185	5.8	9/:37	Vacuumed with "shield"	
	p.m.	934.10	.00135	.0222	11.5	4/:30		
April 8, 1965	a.m.	1068.04	.00240	.0346	23.0	2/:12	Vacuumed with "shield"	Started glass fibers filter series
	p.m.	686.85	.00290	.0651	23.0	5/:38		
April 10, 1965	a.m.	1090.70	.00395	.0558	15.0	4/2:05	Control	
	p.m.	1094.87	.00395	.0556	20.7	2/:11		

Table A-1. Dust concentration sampling data and calculations. (cont.)

Date	session	Free air sampled, cu ft	Dust weight collected, gram	Dust conc., grains/1000 cu ft	Wind velocity, miles/hr	Door openings and time: min.:sec	Operation	Remarks
April 20, 1965	a.m.	1000.55	.00360	.0555	16.1	9/:33	Control	Pump stopped in p.m.
	p.m.	378.60	.00195	.0794	10.4	8/:31		
April 22, 1965	a.m.	1018.20	.00605	.0916	calm	5/:25	Vacuumed with "shield"	Air conditioner turned on for 1st time of season evening before
	p.m.	618.59	.00305	.0760	11.5	?/?		
April 24, 1965	a.m.	909.71	.00160	.0271	11.5	8/:25	Control	
	p.m.	938.31	.00205	.0336	16.1	18/1:52		
April 26, 1965	a.m.	1018.91	.00195	.0295	5.8	2/:08	Vacuumed without "shield"	Party evening before sampling
	p.m.	620.50	.00375	.0932	8.0	4/:26		
April 28, 1965	a.m.	988.48	.00130	.0203	4.6	3/:14	Control	
	p.m.	987.44	.00220	.0344	4.6	10/:56		
April 30, 1965	a.m.	987.61	.00295	.0460	13.8	5/5:17	Vacuumed with "shield"	
	p.m.	626.89	.00275	.0676	17.3 to 25.3	11/:56		
May 2, 1965	a.m.	972.79	.00270	.0427	23.0	5/1:42	Control	
	p.m.	980.91	.00380	.0597	18.4 to 28.8	12/:32		
May 4, 1965	a.m.	964.07	.00420	.0672	13.8	6/:37	Vacuumed with "shield"	
	p.m.	633.46	.00290	.0706	17.3 to 25.3	5/:55		

Table A-1. Dust concentration sampling data and calculations. (cont.)

Date	Session	Free air sampled,	Dust weight collected,	Dust conc.,	Wind velocity,	Door openings and time	Operation	Remarks
		cu ft	gram	grains/1000 cu ft	miles/hr	min.:sec		
May 6, 1965	a.m.	955.05	.00315	.0509	20.7	10/6:21	Control	Girls scrubbed hallway during noon hour
	p.m.	961.92	.00495	.0793	17.3 to 26.5	16/2:05		
May 8, 1965	a.m.	985.69	.00700	.1094	16.1	1/:05	Vacuumed with "shield"	
	p.m.	638.93	.00265	.0639	19.6	3/:12		
May 13, 1965	a.m.	978.89	.00435	.0685	5.8	2/:08	Vacuumed with "shield"	
	p.m.	665.88	.00320	.0741	18.4	4/:40		
May 17, 1965	a.m.	959.34	.00385	.0618	13.8	4/:19	Vacuumed with "shield"	
	p.m.	609.98	.00225	.0510	16.1 to 27.6	3/:23		
May 21, 1965	a.m.	966.15	.00335	.0535	18.4	1/:05	Vacuumed with "shield"	
	p.m.	608.40	.00230	.0583	18.4 to 31.1	2/:16		
May 27, 1965	a.m.	946.57	.00245	.0399	17.3	4/:19	Vacuumed without "shield"	
	p.m.	597.13	.00295	.0762	17.3	3/:13		

Table A-2. Size distribution sampling data.

Date	Session	Free air sampled, cu ft	Wind velocity, miles/hour	Door openings and time min:sec	Operation
March 9, 1965	a.m.	1150.59	3.5	6 / :37	Control
	p.m.	1164.70	5.8	5 / :20	
March 11, 1965	a.m.	1165.56	Calm	5 / :16	Vacuumed with "shield"
	p.m.	791.54	11.5	1 / :03	
March 13, 1965	a.m.	1108.21	Calm	2 / :06	Vacuumed with "shield"
	p.m.	1107.63	17.3	2 / :08	
March 15, 1965	a.m.	1163.55	Calm	5 / :27	Vacuumed with "shield"
	p.m.	395.89[1]	5.8	7 / :46	
March 17, 1965	a.m.	1099.70	36.9 to 48.4	8 / :18	Control
	p.m.	1109.32	28.8 to 42.6	4 / :17	
March 19, 1965	a.m.	1060.88	9.2	4 / :21	Vacuumed with "shield"
	p.m.	717.34	Calm	4 / :45	
March 21, 1965	a.m.	1075.14	5.8	4 / :21	Control
	p.m.	1096.10	17.3	2 / :08	
March 23, 1965	a.m.	1048.22	17.3 to 24.2	14 / :51	Vacuumed with "shield"
	p.m.	695.17	17.3 to 25.3	3 / :11	
March 25, 1965	a.m.	977.88	16.1	8 / :44	Control
	p.m.	1003.61	15.0	6 / :41	
March 27, 1965	a.m.	987.66	15.0	8 / 1:04	Vacuumed with "shield"
	p.m.	677.82	13.8 to 21.9	16 / 2:29	
March 29, 1965	a.m.	994.90	15.0	3 / :10	Control
	p.m.	1030.72	11.5	10 / :46	
March 31, 1965	a.m.	1050.33	Calm	3 / :13	Vacuumed with "shield"
	p.m.	692.34	18.4	7 / :38	

Table A-2. Size distribution sampling data. (cont.)

Date	Session	Free air sampled, cu ft	Wind velocity, miles/hour	Door openings and time min:sec	Operation
April 2, 1965	a.m.	1047.22	15.0	12/4:00	Control
	p.m.	1099.64	13.8	40/5:15	
April 6, 1965	a.m.	1035.72	11.5	3/:12	Control
	p.m.	1024.97	15.0	10/14:00	

[1]Pump tripped off during afternoon session.

Table A-3. Control run size analysis results.

Run	Geometric mean diameter (by weight), micron	Diameter at $+1\sigma_g(84\%)$, micron	Diameter at $-1\sigma_g(16\%)$, micron	Average geometric standard deviation[1]
1 a.m.	4.20	7.05	1.80	2.01
1 p.m.	4.35	8.60	1.95	2.11
3 a.m.	4.25	7.45	2.05	1.91
3 p.m.	3.40	7.60	1.38	2.35
5 a.m.	4.31	8.50	1.90	2.12
5 p.m.	5.40	10.02	2.25	2.13
7 a.m.	5.00	9.80	2.62	1.94
7 p.m.	5.00	8.59	2.62	1.82
9 a.m.	Run no. 9 lost during analysis.			
9 p.m.				
11 a.m.	2.86	7.40	1.25	2.44
11 p.m.	2.02	5.75	0.79	2.70
14 a.m.	2.88	5.25	1.24	2.07
14 p.m.	3.60	6.65	1.50	2.12

Table A-4. Vacuuming cleaning run size analysis results.

Run	Geometric mean diameter (by weight), micron	Diameter at $+1\sigma_g(84\%)$, micron	Diameter at $-1\sigma_g(16\%)$, micron	Average geometric standard deviation[1]
2 a.m.	4.65	8.40	1.70	2.28
2 p.m.	4.65	8.40	1.70	2.28
4 a.m.	3.50	6.60	1.49	2.12
4 p.m.	3.90	6.40	1.82	1.89
6 a.m.	3.41	6.46	1.38	2.18
6 p.m.	5.00	8.95	2.60	1.86
8 a.m.	4.22	7.95	1.59	2.77
8 p.m.	4.45	8.10	1.82	2.14
10 a.m.	3.49	6.95	1.10	2.58
10 p.m.	4.38	8.10	1.58	2.31
12 a.m.	2.50	5.47	1.18	2.16
12 p.m.	3.26	6.70	1.41	2.18

[1]Average geometric standard deviation, $\sigma_g = \dfrac{D_{84\%}/D_{50\%} + D_{50\%}/D_{16\%}}{2}$

Appendix B

SAMPLE CALCULATIONS FOR DUST CONCENTRATION AND SIZE ANALYSIS

Example calculations for the dust concentration data are as follows:

Total volume, metered air---------------1719.98 cu ft

Average meter vacuum-------------------- 13.04 in. Hg

Atmospheric barometric pressure---------- 29.00 in. Hg

Dust weight on filter------------------- 0.00245 gm

1. Free Air Calculation:

$$\left.\begin{array}{l}\text{Volume free air}\\ \text{sampled, cu ft}\end{array}\right\} = (\text{metered air, ft}^3)\left[\frac{(\text{bar. pressure})-(\text{meter vacuum})}{\text{barometric pressure}}\right]$$

$$\text{Free air, ft}^3 = \left(1719.98\ \text{ft}^3\right)\left[\frac{(29.00\ \text{in. Hg})-13.04\ \text{in. Hg})}{29.00\ \text{in. Hg}}\right]$$

$$= \left(1719.98\ \text{ft}^3\right)\left[\frac{(15.96\ \text{in. Hg})}{29.00\ \text{in. Hg}}\right]$$

$$= 946.57\ \text{ft}^3$$

2. Dust Concentration Calculation:

$$\text{Concentration, gr/ft}^3 = \left(\frac{\text{dust weight on filter, gm}}{\text{volume free air, ft}^3}\right)\left(\frac{1\ \text{lb}_m}{454\ \text{gm}}\right)\left(\frac{7000\ \text{gr}}{1\ \text{lb}_m}\right)$$

$$= \left(\frac{0.00245\ \text{gm}}{1003.90\ \text{ft}^3}\right)\left(\frac{1\ \text{lb}_m}{454\ \text{gm}}\right)\left(\frac{7000\ \text{gr}}{1\ \text{lb}_m}\right)$$

$$= 3.99 \times 10^{-3}\ \text{gr/ft}^3 \text{ or } 0.0399\ \text{gr/1000 ft}^3$$

Table B-1 presents a sample of the experimental values obtained from one morning air sampling filter. The size analysis study presents the percentage of various particle diameters found in the air of the room.

Table B-1. Example of size analysis record form.

MSA-Whitby centrifugal sedimentation size analysis

of atmospheric dust, 70F.

(all centrifuge)

Sample No. I (a.m.) Run 1 a.m. Date of analysis 3/9/65

Sample description Margaret Ahlborn Lodge, K. S. U. - morning atmosphere

Operator J. Annis Actual room temp. 71° F

$K_g = 4.56 \times 10^4$; $\rho_p = 2.10$; sedimentation liquid: 100% acetone; feeding liquid: 85% acetone, 15% Skellysolve "S". (3/6/65 correction factors used: 1, 3, 23 sec.)

Particle Diam. microns	RPM	Time-min & sec.	Read	% > Diam.	% < Diam.
10	600	17	0.6	2.8	97.2
6	↓	29	5.6	26.2	73.8
4	↓	56	11.7	54.7	45.3
2.5	1200	41	16.0	74.8	25.2
1.6	↓	1:34	18.6	86.9	13.1
1.0	1800	2:10	19.8	92.5	7.5
0.6	↓	5:35	20.7	96.7	3.3
0.35	↓	16:07	21.1	98.6	1.4
0.2	↓	49:26	21.3	99.6	0.4
0.15	↓	57:23	21.4	99.9+	0.1-

Appendix C

STATISTICAL ANALYSIS SAMPLE CALCULATIONS

Sample of F-test Calculations[1]

Null hypothesis: $\sigma_1'^2 = \sigma_2'^2$ (no difference in universe variance.)

$$\frac{s_1^2 \sigma_2'^2}{s_2^2 \sigma_1'^2}$$ is distributed in the form of a F-distribution.

Since $\sigma_1'^2 = \sigma_2'^2$ by hypothesis, check $\frac{s_1^2}{s_2^2}$ against values in F-tables.

$$s_1^2 = \frac{N_1 \sigma_1^2}{N_1 - 1} = \frac{\sum_i (X_{1i} - \bar{X}_1)^2}{N_1 - 1} = \frac{\sum X_{1i}^2 - N_1 \bar{X}_1^2}{N_1 - 1}$$

$$= \frac{\sum_i X_{1i}^2 - \frac{(\sum X_{1i})^2}{N_1}}{N_1 - 1}$$

or in general, $s_j^2 = \dfrac{\sum_i X_{ij}^2 - (\sum_i X_{ij})^2 / N_j}{N_j - 1}$

s_1^2 and s_2^2 are biased estimates of $\sigma_1'^2$ and $\sigma_2'^2$, respectively.

Obtain values of F for parameters, n_1 and n_2.[2]

$n_1 = N_1 - 1$, $n_2 = N_2 - 1$, where n_1 corresponds to the "s^2" used in the numerator of $\frac{s_1^2}{s_2^2}$.

s_1 = vacuum cleaning with "shield" data.

s_2 = vacuum cleaning without "shield" data.

s_3 = control data.

$N_1=8$, $n_1=9$, $n_2=8$; $N_3=18$, $n_3=17$.

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[1]Equations based on Duncan (11), p. 402-404.

[2]Table J, p. 618, Duncan (11).

$$s_j^2 = \frac{\sum_i X^2_{ij} - (\sum_i X_{ij})^2 / N_j}{N_j - 1}$$

$$s_1^2 = \frac{0.00179651 - 0.00109746}{8 - 1} = \frac{0.00069905}{7}$$

$$= 0.0000998642$$

$$s_2^2 = \frac{0.00736352 - 0.00674588}{9 - 1} = \frac{0.00061764}{8}$$

$$= 0.0000772045$$

$$s_3^2 = \frac{0.00059257 - 0.00015665}{18 - 1} = \frac{0.00043592}{17}$$

$$= 0.00002564264$$

$$\frac{s_1^2}{s_2^2} = \frac{0.0000998642}{0.0000772045} = 1.294$$

$$\frac{s_1^2}{s_3^2} = \frac{0.0000998642}{0.0000256426} = 3.8944$$

$$\frac{s_3^2}{s_3^2} = \frac{0.0000772045}{0.0000256426} = 3.0107$$

<u>Sample of t-test Calculations</u>

Assuming $\sigma_1'^2 = \sigma_2'^2$.

X_1 = difference in a.m. and p.m.

$\overline{X}_1$ = mean difference in a.m. and p.m.

$$\overline{X}_1 = \frac{\sum X}{N} \qquad n = N_1 + N_2 - 2$$

$$\overline{X}_1 = \frac{0.0937}{8} = 0.0117$$

$$\overline{X}_2 = \frac{0.2464}{9} = 0.02738$$

$$\bar{X}_3 = \frac{0.0531}{18} = 0.00295$$

$$t = \frac{\bar{X}_2 - \bar{X}_1}{s\sqrt{\frac{1}{N_1} + \frac{1}{N_2}}}$$

$$s = \sqrt{\frac{\left[\sum_i X_{1i}^2 - (\sum_i X_{1i})^2 / N_1\right] + \left[\sum_i X_{2i}^2 - (\sum_i X_{2i})^2 / N_2\right]}{N_1 + N_2 - 2}}$$

$$s_1 = \sqrt{\frac{(\sum_i X_{1i}^2) + (\sum X_{1i})^2 / N_1}{N_1 - 1}}$$

$$(\sum X_{1i})^2 = (0.0937)^2 = 0.00877969$$

$$(\sum X_{2i})^2 = (0.2464)^2 = 0.06071296$$

$$(\sum X_{3i})^2 = (0.0531)^2 = 0.00281961$$

$$\frac{(\sum X_{1i})^2}{N_1} = \frac{0.00877969}{8} = 0.00109746$$

$$\frac{(\sum X_{2i})^2}{N_2} \quad \frac{0.06071296}{9} = 0.006745884$$

$$\frac{(\sum X_{3i})^2}{N_3} = \frac{0.00281961}{18} = 0.0001566450$$

$$s = \sqrt{\frac{0.00069905 + 0.00061764}{8 + 9 - 2}} = \sqrt{\frac{0.00131669}{15}}$$

$$= 0.009369$$

$$t = \frac{\bar{X}_2 - \bar{X}_1}{s\sqrt{\left(\frac{1}{N_1}\right) + \left(\frac{1}{N_2}\right)}}$$

$$= \frac{0.02738 - 0.0117}{0.009369 \sqrt{\frac{1}{8} + \frac{1}{9}}}$$

$$= \frac{0.01568}{(0.009369)\sqrt{0.125000 + 0.111111}}$$

$$= \frac{0.01568}{(0.009369)\sqrt{0.236111}} = \frac{0.01568}{(0.009369)\ (0.4859125)}$$

$= 3.444$

Assuming $\sigma_1'^2 \neq \sigma_3'^2$

Due to inequality of variances and sample size, the critical t was based on following calculations:[1]

Compute estimates of variances for the two samples:

$$s_1^2 = \frac{\sum x_1^2}{N_1 - 1}, \text{ where } x = X - \bar{X} \text{ and } s_3^2 = \frac{\sum x_3^2}{N_3 - 1}$$

Compute estimates of variances of the two sample means:

$$s^2_{\bar{X}_1} = \frac{s_1^2}{N_1} \qquad s^2_{\bar{X}_3} = \frac{s_3^2}{N_3}$$

$$s^2_{\bar{X}_1} = \frac{0.0000998642}{8} = 0.0000124830$$

$$s^2_{\bar{X}_3} = \frac{0.00002564264}{18} = 0.00000142459$$

$t_1 = t$ for $N_1 - 1$. $8 - 1 = 7$; $t_1 = 2.365$

$t_3 = t$ for $N_3 - 1$. $18 - 1 = 17$; $t_3 = 2.110$

Compute weight average of the two t's:

$$\text{Critical t for test} = \frac{s^2_{\bar{X}_1} t_1 + s^2_{\bar{X}_3} t_3}{s^2_{\bar{X}_1} + s^2_{\bar{X}_3}}$$

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[1]t-test based on page 398, Duncan (11).

$$t = \frac{(0.0000124830)\ (2.365) + (0.00000142459)\ (2.110)}{0.0000124830 + 0.00000142459}$$

$$= \frac{0.00002952230 + 0.000003005906}{0.00001390760}$$

$$= 2.339$$

$$\text{Statistic } t = \frac{\bar{X}_1 - \bar{X}_3}{\sqrt{s^2_{\bar{X}_1} + s^2_{\bar{X}_3}}}$$

$$t = \frac{0.0117 - 0.00295}{\sqrt{0.0000124830 + 0.00000142459}}$$

$$= \frac{0.00875}{\sqrt{0.00001390760}} = \frac{0.00875}{0.00372928}$$

$$= 2.346$$

$$t_{calc.} = 2.346 > t_{tab.} = 2.339$$

Reject $\bar{X}''_1 = \bar{X}'_3$, therefore $\bar{X}'_1 \neq \bar{X}'_3$

<u>Sample of Regression Analysis Calculations</u>

Regression study of dust concentration on door openings.

Upon completing of calculations for Table C-1 continue computations as follows:[1]

$$\bar{X}_i = \frac{\sum X_i}{N_i}$$

$$\bar{X} = \frac{0.7982}{20} = 0.03991$$

$$\bar{X}_2 = \frac{151}{20} = 7.55$$

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[1]Based on Duncan (11), p. 495-507.

Table C-1. Calculations for regression analysis of dust concentration (X_1) on door openings (X_2).

(1) X_1	(2) X_2	(3) X_1X_2	(4) X_1^2	(5) X_2^2	(6) (X_1+X_2)	(7) $(X_1+X_2)X_1$	(8) $(X_1+X_2)X_2$
0.0131	13	0.1703	0.00017161	169	13.0131	0.17047161	169.1703
0.0119	4	0.0476	0.00014161	16	4.0119	0.04774161	16.0476
0.0185	9	0.1665	0.00034225	81	9.0185	0.16684225	81.1665
0.0346	2	0.0692	0.00119716	4	2.0346	0.07039716	4.0692
0.0558	4	0.2232	0.00311364	16	4.0558	0.22631364	16.2232
0.0556	2	0.1112	0.00309136	4	2.0556	0.11429136	4.1112
0.0271	8	0.2168	0.00073441	64	8.0271	0.21753441	64.2168
0.0336	18	0.6048	0.00112896	324	18.0336	0.60592896	324.6048
0.0203	3	0.0609	0.00041209	9	3.0203	0.06131209	9.0609
0.0344	10	0.3440	0.00118336	100	10.0344	0.34518336	100.3440
0.0460	5	0.2300	0.00211600	25	5.0460	0.23211600	25.2300
0.0672	6	0.4032	0.00451584	36	6.0672	0.40771584	36.4032
0.0685	2	0.1370	0.00469225	4	2.0685	0.14169225	4.1370
0.0618	4	0.2472	0.00381924	16	4.0618	0.25101924	16.2472
0.0535	1	0.0535	0.00286225	1	1.0535	0.05636225	1.0535
0.0399	4	0.1596	0.00159201	16	4.0399	0.16119201	16.1596
0.0271	14	0.3794	0.00073441	196	14.0271	0.38013441	196.3794
0.0269	25	0.6725	0.00072361	625	25.0269	0.67322361	625.6725
0.0427	5	0.2135	0.00182329	25	5.0427	0.21532329	25.2135
0.0597	12	0.7164	0.00356409	144	12.0597	0.71996409	144.7164
0.7982	151	5.2268	0.03795944	1875	151.7982	5.26475944	1880.2268

Checks: [Σcolumn (1)+ Σcolumn (2) = Σcolumn (6)] or 0.7982+151=151.7982
[Σcolumn (3)+ Σcolumn (4) = Σcolumn (7)] or 5.2268+0.03795944= 5.26475944
[Σ column (3)+ Σcolumn (5) = Σcolumn (8)] or 5.2268+1875=1880.2268

$\Sigma x_1x_2 = \Sigma X_1X_2 - N\bar{X}_1\bar{X}_2$

$\Sigma x_1x_2 = 5.2268 - (20)(7.55)\ (0.0399)$

$= 5.2268 - (20)\ (0.3012)$

$= 5.2268 - 6.0240$

$= -0.7972$

$\Sigma x_2^2 = \Sigma X_2^2 - N\bar{X}_2^2.$

$\Sigma x_2^2 = 1875 - (20)\ (7.55)^2$

$= 1875 - 1140.050$

$= 734.95$

$b_{1\ 2} = \dfrac{\Sigma x_1x_2}{\Sigma x_2^2}$

$b_{1\ 2} = \dfrac{-0.7972}{723.95}$

$= -0.001084699$

$a_{1.2} = \bar{X}_1 - b\bar{X}_2$

$= 0.03991 - (-0.0010847)\ (7.55)$

$= 0.04810$

Estimated regression:

$X_{1r} = 0.04810 - (-0.0010847)\ X_2$, with origin at $X_1 = 0$, $X_2 = 0$.

$\Sigma x_1^2 = \Sigma X_1^2 - N\bar{X}_1^2$

$\Sigma x_1^2 = 0.03795944 - (20)\ (0.0399)^2$

$= 0.00611924$

$\Sigma v_{1.2}^2 = \Sigma x_1^2 - b\,\Sigma x_1x_2$

$= 0.00611924 - (-0.0010847)\ (-0.7972)$

$= 0.00611924 - 0.00086423$

$= 0.00525501$

$$s_{1.2}^2 = \frac{\Sigma v_{1.2}^2}{N - 2}$$

$$s_{1.2}^2 = \frac{0.00525501}{18}$$

$$= 0.000291945$$

$$s_{1.2} = \sqrt{0.000291945}$$

$$= 0.017086$$

Coefficient of correlation:

$$\hat{r}_{1\,2}^2 = 1 - \frac{(N - 1)\ (\Sigma v_{1.2}^2)}{(N - 2)\ (\Sigma x_1^2)}$$

$$\hat{r}_{1\,2}^2 = 1 - \frac{19\ (0.00525501)}{18\ (0.00611924)}$$

$$= 1 - \frac{0.09984519}{0.11014632}$$

$$= 1 - 0.90647765$$

$$= 0.09352235$$

$$\hat{r}_{1\,2} = 0.305814 \text{ or } 0.305$$

Fig. C-1. Linear regression for regression of dust concentration (X_1) on door openings (X_2).

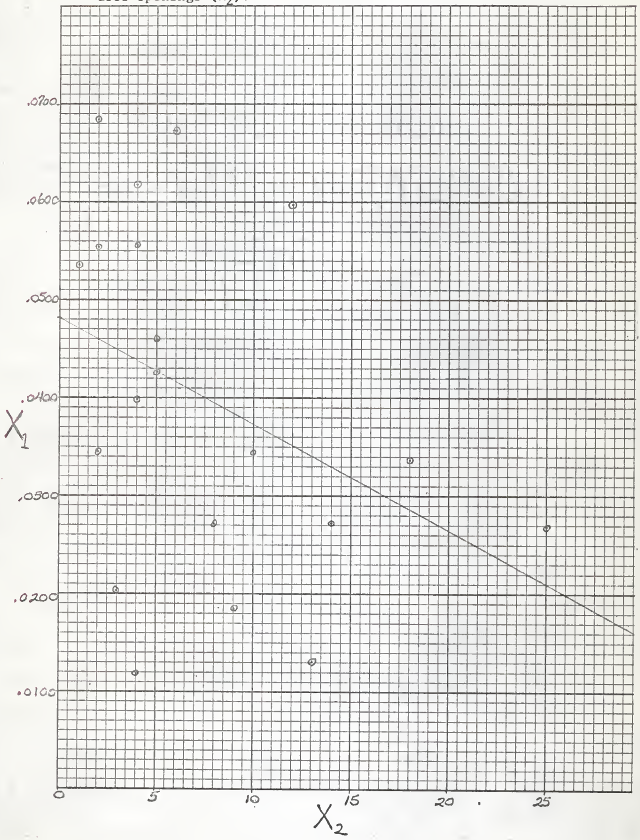

Table C-2. Estimated regression of dust concentration on experimental variables.

Variables comparisons:	Estimated regression, X_{1r} (origin at X_1=0, X_2=0).
Dust concentration vs. number door openings.	$0.04810 + (1.0847 x 10^{-3})\ X_2$
Dust concentration difference (p.m.-a.m.) vs. difference in number of door openings (p.m.-a.m.).	$-0.00410 + (4.792 x 10^{-4})\ X_2$
Dust concentration vs. total elapsed time door was open.	$0.04022 + (1.634 x 10^{-5})\ X_2$
Dust concentration difference (p.m.-a.m.) vs. difference in seconds door was open (p.m.-a.m.).	$1.69505 + (0.1044820)\ X_2$
Dust concentration difference (p.m.-a.m.) vs. difference in wind velocity (p.m.-a.m.).	$0.02623 + (2.2775 x 10^{-4})\ X_2$
Dust concentration vs. V^m.t.	$0.03325 + (5.9938 x 10^{-8})\ X_2$

Sample of Regression Coefficient of Variation Calculations:[1]

Dust concentration on door openings.

$$\text{Average }\% = \left[\frac{X_{1a} - X_{ra}}{X_{1ra}} + \frac{X_{1b} - X_{1rb}}{X_{1rb}} + \ldots \Big/ N\right] \times 100$$

$$\% = \left[\frac{0.0535 - 0.0471}{0.0471} + \frac{0.0556 - 0.0460}{0.0460} + \frac{0.0685 - 0.0460}{0.0460} + \frac{0.0558 - 0.0438}{0.0438} + \frac{0.0618 - 0.0438}{0.0438} + \frac{0.0427 - 0.0427}{0.0427} + \frac{0.0460 - 0.0427}{0.0427} + \frac{0.0672 - 0.0416}{0.0416} + \frac{0.0597 - 0.0352}{0.0352} + \frac{0.0336 - 0.0287}{0.0287} + \frac{0.0269 - 0.0211}{0.0211} + \frac{0.0346 - 0.0460}{0.0460} + \frac{0.0203 - 0.0449}{0.0449} + \frac{0.0399 - 0.0438}{0.0438} + \frac{0.0119 - 0.0438}{0.0438} + \frac{0.0271 - 0.0395}{0.0395} + \frac{0.0185 - 0.0384}{0.0384} + \frac{0.0344 - 0.0373}{0.0373} + \frac{0.0131 - 0.0341}{0.0341} + \frac{0.0271 - 0.0330}{0.0330} \Big/ 20\right] \times 100$$

$$= \left[\frac{0.0064}{0.0471} + \frac{0.0096}{0.0460} + \frac{0.0225}{0.0460} + \frac{0.0120}{0.0438} + \frac{0.0180}{0.0438} + \frac{0.0000}{0.0000} + \frac{0.0033}{0.0427} + \frac{0.0256}{0.0416} + \frac{0.0245}{0.0352} + \frac{0.0049}{0.0287} + \frac{0.0058}{0.0211} + \frac{0.0114}{0.0460} + \frac{0.0246}{0.0449} + \frac{0.0039}{0.0438} + \frac{0.0319}{0.0438} + \frac{0.0124}{0.0395} + \frac{0.0199}{0.0384} + \frac{0.0029}{0.0373} + \frac{0.0210}{0.0341} + \frac{0.0059}{0.0330} \Big/ 20\right] \times 100$$

$$= \frac{6.6705}{20} \times 100$$

$$= 0.3335 \text{ or } 33\%$$

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[1]Original coefficient suggested by Mr. J. C. Annis in private conversation. Parallels the coefficient of variation for mean values.

THE EFFECT OF VACUUM CLEANING UPON
HOUSEHOLD ATMOSPHERIC DUST

by

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B. S., Kansas State University, 1958

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

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1966

This study was concerned with the effect of vacuum cleaning on the atmospheric dust of a room in a residence. First considered was the influence of downward-discharge vacuum cleaning on the air-borne dust concentration in a room. After it was established that this method of vacuum cleaning, potentially the most contaminating, did add dust to residential air, tests were devised to determine where the re-circulated dust of the room originated. A method of vacuum cleaning that deflected the exhaust air upward was introduced and the particle size distribution of the air-borne dust was compared to that normally existing in the room.

The experiment was performed in a home management laboratory residence in which four or five female, college students and an instructor lived for four week periods.

A vacuum air sampling system with filters was used to collect room air dust samples. Samples were collected on glass fiber filters for gravimetric dust concentration measurement and membrane filters for particle size analysis. The particle size distribution was established by the MSA-Whitby centrifuge sedimentation method.

The room carpet and floor area were cleaned for 15 minutes with a tank vacuum cleaner. No artificial dust or dirt was added to the cleaning areas.

Three types of sampling runs were performed--control, vacuum cleaning without "shield" and vacuum cleaning with "shield". A "run" consisted of morning and afternoon sampling sessions on a single day. The control run was performed without any cleaning activity. The vacuum cleaning runs were those in which carpet cleaning, with or without a "shield", was conducted. The "shield" was a modification which prevented the downward-exhaust from being directed to the cleaning area. A run was performed every second day of student occupancy of the residence.

The atmospheric dust concentration in the room increased significantly after vacuum cleaning. The greatest increase was experienced when the downward-exhaust cleaner was operated over the uncleaned carpet or floor area. When the "shield" was used, there was a lesser but significant increase than when the vacuum cleaner exhaust was downward. A significant difference also existed between the two types of vacuum cleaning.

The size analysis showed no significant shift in the particle distribution after vacuum cleaning. Therefore, the increased mass concentration caused an increase in all the various size particles, including the fine particles. These small particles resulted in long-term soiling and staining as they remained suspended until they came in contact with a wall or furnishings.

This research should be extended to study the different types of vacuum cleaners and filter bags. Central vacuum cleaner systems could be explored to determine if they relieve the household of re-circulating dust.