RESEARCH REPORT

Indoor Particulate and Floor Cleaning: Appendices

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Indoor Particulate and Floor Cleaning APPENDICES

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A HOUSE CHARACTERISTICS

Common Features:

- single family detached residence
- continuously occupied during tests (i.e. not vacant)
- forced air heating system
- no smokers in household
- door to bedroom can be closed

Table A-13
House Characteristics

	H1	H2	H3U	H3D	H4	H5
Age of house	28 years	50 years	16 years	16 years	30 years	50 Years
Vacuum Normally Used	central	regular upright	filter upright	filter upright	cannister	central
Vacuum When	every 2 weeks	every 2 weeks	every 2nd day	unknown	weekly	weekly
Type of Carpet	wall to wall	wool area rug	wall to wall	area rug	wall to wall	wall to wall
Age of Carpet	more than 10 years	more than 35 years	more than 10 years	more than 10 years	more than 10 years	more than 10 years
Last cleaned carpet by outside service	don't know	5 years	less than 1 year	less than 3 years	less than 1 year	less than 3 years
Pets in the house	no	no	no	no	2 cats & 1 dog	dog
Remove shoes	yes	usually	yes	yes	yes	yes
Replace furnace filter	every 2nd month	every 6 months	every 2nd month	every 2nd month	every 3 months	every 3 months

B TESTING

B.1 Development of a Standard Activity Simulation:

The normal activities of persons within a home are by their very nature, variable. Reference 8 found that variability of PM resuspension was associated with the vigor of the activity and the flooring material. For example, dancing on a rug resulted in concentrations approximately 2.5 time higher than for simply walking on the same rug. This study also found that walking on a rug would produce PM concentrations changes of 6 to 12 times higher than walking on a smooth floor..

In order to assess the influence of a cleaning method on dust resuspension, it was necessary to rely on a normalized or "standard" activity which was repeatable for a given level of floor soiling, or particulate availability.

The target characteristics of the "Standard activity were set at:

- PM concentration rise of between 30 and 60 $\mu g/m^3$ PM10 on an unprepared, older carpet.
- capable of producing a quasi-steady state within a reasonable length of time (three consecutive reading at 75s intervals with less than 1% rise in PM concentration.)

The target concentration rises were based on records of daily activity in the bedroom of house 1 which was equipped with a wall-to-wall carpet of approximately 30 years of age. Other researchers have reported similar concentration rise associated with normal activities. For example, Reference 8 reported that two persons walking on a carpet produced a concentration rise of approximately 35 $\mu g/m^3$ PM5.

Several methods of resuspension were evaluated including:

- weighted roller drag.
- carpet-sweeper with cover removed
- corded "electric broom" with filters removed
- battery powered electric broom with filters removed
- remote-controlled electric vehicle
- walking alone

After 11 trials of different combinations of devices and methods, the following two "Standard Activity Situation Methods" were adopted for the cleaning apparatus experiments:

Method 1 - Battery-Powered Vacuum and Remote-Controlled Vehicle:
A battery-powered remote control vehicle was modified to drag a modified portable battery-powered vacuum cleaner for fifteen minutes in a repeating pattern. Details of modifications to the remote-control vehicle and the battery-powered vacuum cleaner are set out in appendices C.1 and C.2. The researcher controlled the movement of the truck with a remote control device while stationed in one corner of the room. All of these experiments were carried out by a single operator.

Method 2 - Battery-Powered Vacuum and Walk-about:
The modified battery-powered vacuum cleaner used in method 1 was moved in a repeating pattern around the room by a researcher at a "walking" pace for 15 minutes. This method was only repeatable for one operator, that is to say an activity simulation carried out by one operator was not consistent with an activity simulation carried out by another person. In order to remove these inconsistences, each house was assigned a single researcher, who carried out all of the experiments for that house.

It should be noted that these two methods were developed based on a series of experiments carried out on a carpeted floor. Although no experiments were carried out on a smooth floor, it seems that the protocol is also valid for smooth floors.

B.2 Schedule of Testing:

The following schedule is for H1 and H2. The schedule for H3U, H3D, H4 and H5 is similar except that only 5 vacuums and 4 sweeping devices were tested.

First Visit: (time approx 1 hour)
- Interview homeowner
- Complete questionnaire
- Obtain dust-mite sample

Second Visit (time approx 2.5 hours)
- Close room, carry-out standard activity simulation
- Vacuum with "Filter Cannister" (V1)
- Carry out standard activity simulation

Third Visit (time approx. 2.5 hours)
- Close room, carry-out standard activity simulation
- Vacuum with "Ordinary Upright" (V2)
- Carry out standard activity simulation

Fourth Visit (time approx 2.5 hours)
- Close room, carry-out standard activity simulation
- Vacuum with "HEPA Bagless" (V3)
- Carry out standard activity simulation

Fifth Visit (time approx 2.5 hours)
- Close room, carry-out standard activity simulation
- Vacuum with "Central" (V4)
- Carry out standard activity simulation

Sixth Visit (time approx 2.5 hours)
- Close room, carry-out standard activity simulation
- Vacuum with "Filter Upright" (V5)
- Carry out standard activity simulation

Seventh Visit (time approx. 2.5 hours)
- Close room, carry-out standard activity simulation
- Vacuum with "Wet Vacuum" (V6)
- Carry out standard activity simulation

After seventh visit, the study participant removed the carpet and installed smooth floor finish. The new flooring was "lived on" for at least 1 week (usually two) before testing resumed. If there was existing flooring underneath, no waiting period was allowed.

Eighth through-Twelfth Visit
- Close room, carry-out standard activity simulation
- For each visit, choose a vacuum to run on the smooth floor
- Carry out standard activity simulation

Thirteenth Visit (time approx 2.5 hours)
- Close room, carry-out standard activity simulation
- Sweep with "Dry Pad" (B1)
- Carry out standard Activity simulation

Fourteenth Visit (time approx 2.5 hours)
- Close room, carry-out standard activity simulation
- Sweep with "Wet Pad" (B2)
- Carry out standard Activity simulation

Fifteenth Visit (time approx 2.5 hour)
- Close room, carry-out standard activity simulation
- Sweep with "Dust Mop" dust mop (B3)
- Carry out standard Activity simulation

Sixteenth Visit (time approx 2.5 hour)
- Close room, carry-out standard activity simulation
- Sweep with House broom" (B4)
- Carry out standard Activity simulation

B.3 Detailed Cleaning Device Experiment Protocol

Initial Visit

- Set up a visit with homeowner at a convenient time.
- Review test room criteria & preparation.
- Interview homeowner to complete questionnaire
- Explain protocol schedule to homeowner
- Take a dust mite sample in the room
- Remind homeowner not to vacuum in between testings

Test Room Preparation

- Set up particle counter on tripod in corner of test room
- Seal supply registers and cold air returns with cardboard and duct tape
- Make sure windows are closed tight
- Turn on particle counter, exit room and close door
- Wait at least 15 minutes for particles to settle in room

Pre-activity simulation testing

- Check voltage charge on the activity simulation vacuum cleaner and record
- Check air pressure flow on the activity simulation vacuum cleaner and record
- Set timer for fifteen minute, enter room and close door
- Begin activity simulation process (either by truck or by walking)
- Exit after 15 minutes, shut door
- Take voltage charge and pressure reading and record
- Clean out any fluff that has collected in the vacuum.
- Record amount of fluff as small medium, large, or very large.

Vacuum testing

- Choose cleaning device. If a bag is required in a vacuum, insert a new one
- Enter room 15-20 minutes after pre-activity simulation completed
- Close door, set timer and turn on vacuum cleaner
- If on carpet, vacuum three strokes; up, down, up, over the same area.
- On the 4^{th} stroke, move vacuum to new position and repeat same pattern.
- If vacuuming on smooth floor, vacuum two strokes, then move to new position.
- Continue vacuum until all areas of the rug that are easily accessible are covered.
- Cleaning intensity 0.67 to 1.0 minutes per m^2
- Do not vacuum under the bed.
- Turn off vacuum, note time and exit room.
- Close door.
- Record start and stop times for vacuuming.
- Discard bag
- Wait 15 minutes or more for particles to settle

Broom testing

- Choose broom according to model chart.
- Push broom three strokes, up, down, up, over the same floor area.
- On the 4^{th} stroke, move broom to a new position and repeat the same pattern.
- For B4, sweep 2 strokes towards body and then move to a unswept area.

Post-activity simulation testing

- Check voltage charge on the activity simulation vacuum cleaner and record
- Check air pressure flow on the activity simulation vacuum cleaner and record
- Enter room, close door and set timer for 15 minutes
- Begin activity simulation process (either by truck or by walking)
- Exit after 15 minutes, shut door
- Take voltage charge and pressure reading and record
- Clean out any fluff that has collected in the vacuum.
- Record amount of fluff as small medium, large, or very large
- Post sign on bedroom door not to open for 20 minutes nor to vacuum.
- Re-enter room after 15 minutes.
- Disconnect particle counter, unseal registers and vents
- Replace furniture or belongings removed prior to pre-activity simulation testing

C INSTRUMENTATION

C.1 Remote Control Vehicle

Radio Shack Catalogue number 60-4261, modified by reducing wheel diameter to 57 mm.

C.2 Activity Simulation Device

The activity simulation device was constructed using a portable battery-powered vacuum cleaner (Eureka "The Boss"). The internal filters and screen were removed and the battery capacity was increased by adding 2, 6-volt 2.5 amp-hour lead acid batteries in parallel with the standard battery.

C.3 Particle Counter

a) Particle counter: Bio-Test APC 1000, laser particle counter with continuous data collection in four channels:

0.3 to 0.5 μm
0.5 to 1.0 μm
1.0 to 5.0 μm
5.0 μm & above

b) The particle counter was calibrated using latex-polystyrene spheres by their respective approved calibration lab.

c) All of the counts were below the threshold of coincident error for this device.

D OCCUPANT SURVEY

1. Do you own or have regular use of a vacuum cleaner? . . . . . ☐ Yes ☐ No

2. What model of vacuum cleaner to you use?
   - ☐ Central Vac
   - ☐ Upright
   - ☐ Cannister
   - ☐ HEPA Filter
   - ☐ Other

3. How often do you vacuum this room?
   - ☐ Everyday
   - ☐ very second day
   - ☐ Twice per Week
   - ☐ Once per Week
   - ☐ Every second week
   - ☐ Less than every 2nd week

4. Do you move furniture when you vacuum in this room? . . . . . ☐ Yes ☐ No

5. What do you use to dust the surfaces in the room?
   - ☐ Wet cloth
   - ☐ Dry cloth
   - ☐ Vacuum Brush
   - ☐ Other
   - ☐ Don't dust

6. How often do you dust in the room?
   - ☐ Everyday
   - ☐ Every second day
   - ☐ Twice per Week
   - ☐ Once per Week
   - ☐ Every second week
   - ☐ Less than every 2nd week
   - ☐ other _____

7. Does your vacuum cleaner have a power nozzle with revolving brush? ☐ Yes ☐ No

8. What kind of carpet do you have in the room?
   - ☐ Area rug
   - ☐ Wall to wall covering

9. What is the approximate age of the carpet?
   - ☐ Less than one year
   - ☐ 1-3 years
   - ☐ 4-5 years
   - ☐ 6-10 years
   - ☐ More than 10 years
   - ☐ Don't know

10. When did you last clean your carpet?
    - ☐ Less than one year
    - ☐ 1-3 years
    - ☐ 4-5 years
    - ☐ 6-10 years
    - ☐ More than 10 years
    - ☐ Don't know

11. Do you have pets in the house? . . . . . ☐ Yes ☐ No

12. Do you take your shoes off at the door? . . . . . ☐ Yes ☐ No

13. How do you heat your house?
    - ☐ Forced air (Includes Gas, oil or electric furnace)
    - ☐ Radiator (includes hot water, electric baseboard or wood stove)
    - ☐ Not sure

14. Do you have air conditioning? . . . . . ☐ Yes ☐ No

15. If you have forced air heating, how often do you replace your filter?
    - ☐ every month
    - ☐ every second month
    - ☐ Twice per year
    - ☐ Once per year
    - ☐ Less than once per year
    - ☐ Don't know

16. Have you done renovations in the last 6 months? . . . . . ☐ Yes ☐ No

E OTHER RESEARCH

E.1 Ferro, Kopperud & Hildemann, (Ref. 8)

1. Used laser particle counters collocated with gravimetric samples.
2. Measured PM 2.5, PM 5 and PM 10
3. Mean daytime exposures 1.4 times (PM 2.5) and 1.7 times (PM5) greater than indoor concentration and 6 times (PM 2.5) and 17 times (PM 5) above background concentration during prescribed activities. Background is mean 2-hour concentration taken in room before activities begin.
4. Activities releasing the highest concentrations of PM identified are those associated with disturbing dust reservoirs; dry dusting, folding clothes and blankets, making a bed.
5. Vigor of activity and type of flooring also influenced concentrations.
6. Good discussion fo res-suspension vs generation as a factor in a person's exposure inside the home.
7. Measurements in one house for 5 consecutive days in April 2000 in Redwood City, California.
8. Windows closed during experiments, mean ACH rate 0.5 ACH.
9. All prescribed activities for 15 minutes with 45 minute period following with no activity. (Prior measurement?) 3-minute time-slice dat intervals.
10. 2 persons walking carpet? produced rise of about 35 $\mu g/m^3$ PM5
11. Vacuum first floor (characteristic?) Rise of about 20 $\mu g/m^3$ PM5
12. Vacuum bedrooms produced flat or negative PM5 rise.
13. Ambient 5-hour averages were 19 $\mu g/m^3$ (PM 2.5) and 51 $\mu g/m^3$ (PM5) above back ground for "activity days".
14. Vigor changes resuspension dancing on rug approx 2.5 (PM2.5, PM5, PM10) times higher rise than walking.
15. Walking on rug 6 (PM2.5) to 12 (PM5) times higher than wood floor in same location.
16. Walking also included sitting on furniture, so could not separate activity.
17. Dry-dusting = rise of 32 $\mu g/m^3$ PM 2.5
18. One person walking (assume on a rug or carpet) 15 $\mu g/m^3$PM2.5.
19. Conclusions:
    a) Vacuuming had low exposures compared to other activities.
    b) Activities which disturb dust reservoirs on furniture and textiles are most important.
    c) Activities such as folding clothes, making a bed, sitting on upholstered couch may be important contributors to human exposure.
    d) Continuous walking around (15 minutes) and sitting on furniture produced approximately the same amount as vacuuming.
    e) Further characterization of sources necessary to develop relationship between source emission rates and variable such as dust loading and air exchange rate to establish availability of personal exposure from specific human activities.

E.2 White & Dingle (Ref. 9)

1. 19 Houses vacuumed, 17 control homes
2. Control homes had in-room air filters with filters removed (note that this would tend to increase dust-fall slightly by turbulent precipitation)
3. Intervention reduced airborne PM by 50%
4. PM10 and PM2.5 measured
5. At end of interventions, indoor PM reduced to approximately the same as outdoor PM. (21$\mu g/m^3$ PM10 and 14$\mu g/m^3$ PM2.5)
6. Protocol is one intense cleaning (4 min/m^2) followed by less intense vacuuming of 1 min/m^2 can produce substantial results.
7. Our vacuuming intensity is between 0.67 and 1.0 min/m^2
8. Don't know if windows were open or closed during testing, or if season was winter or summer.

9. Location is Australia during April 2000.
10. Homes vacuumed every 2 weeks over 14 weeks (7 cleaning events)
11. First cleaning event was 4 min/m^2 plus 1 min/m^2 on upholstered sofa's and bed.
12. Second cleaning event was 2 min/m^2 and subsequent 5 were 1 min/m^2
13. Gravimetric sampling on 8-hour average with filters at PM 2.5, PM10 and PM100?
14. Monitoring took place between 11 am and 7 pm (4hrs before and 4 hours after school), 5 tines per house. (No monitoring after 4^{th} and 6^{th} cleaning event).
15. Intervention reduced levels form 45 to 22 µg/m^3PM10 and form 25 to 14 µg/m^3 PM2.5 in vacuumed homes, but no statistically significant change on non-vacuumed homes.
16. Weighted mass of vacuum cleaner bags (they vacuumed the whole house). Mass gradually decreased with vacuuming.

E.3 Nastov, Tan & Dingle (Ref. 7)

1. Sponsored by floor cleaning company.
2. Hand floor cleaning only (no vacuums)
3. Reports much higher particulate rise for broom and dustpan cleaning method when compared to :"dust fibre floor cleaner"
4. Author posits that hard floor are cleaned more often than carpets because they become visually "dirty" more quickly than carpets.
5. Floor cleaning twice per week, min 3 days between cleaning.
6. Study in December/Jan/feb in Perth Australia = Summer , temp in 30's hot, dry windows probably open (no note of this in text).
7. Three fibre floor cleaners plus 4 generic floor cleaning brands.
8. Sponge mop tested with and without detergent.
9. Two cleaning products per house, one for first 4 weeks, then other for last 4 weeks, 8 houses in all.
10. Pre-post samples obtained at each cleaning immediately before and after.
11. Pre-post sampling is gravimetric, 8 hour average.
12. During samples using TSI dust-trak with PM10 nozzle.
13. Broom and dustpan method increased PM10 form 21 µg/m^3 to 37 µg/m^3 in house 6. (PM2.5 increased form 15 to 23 µg/m^3)
14. During cleaning showed spikes of 40 to 100 µg/m^3 for broom method but 20 µg/m^3 or less for most other methods.
15. Kitchens and living areas cleaned and monitored
16. No particular account given of activity control during monitoring period.
17. Quote "The broom and dustpan method significantly increased the inhalable particulate concentration in the 8 hours following cleaning in one house".
18. Quote " Other dry cleaning methods (dust fibre floor cleaner and dust mop) did not increase levels of PM10.
19. Quote " Cleaning with sponge mop and detergent significantly increased PM10 concentration in one house."

E.4 Long, Suh & Koutrakis (Ref. 10)

1. Continuos size and mass monitoring equipment, backed by conventional gravimetric samples, inside and out, two seasons, week-long periods.
2. Semi-continuous air-exchange measurements (SF6)
3. Houses with gas stoves and without.
4. Monitoring in summer and winter
5. Detailed track of activities (occupant diary), window opening and scripted activities.
6. Found vigorous walking on carpet raised PM10 above background by 41 µg/m^3.
7. 15 vigorous walking experiments had mean rise of PM2.5 12 µg/m^3 (+/- 9) above background.
8. Findings support findings of other studies that carpets are significant long-term reservoirs of resuspendable particles.

9. One vigorous walking event on carpeted floor had rise of 86 $\mu g/m^3$ above background
10. Found direct evidence of terpene/ozone reactions resulting in elevated PM2.5.
11. Found that even the most dominant indoor events cannot be quantified using traditional time-integrated 12 or 24 hour samples.
12. Re-suspension activities such as walking, dusting, vacuuming identified as important indoor particle sources.
13. PM2.5 concentration rise of more than 30 $\mu g/m^3$ recorded for pine-sol terpene event.
14. Indoor/outdoor relationships are masked by indoor particles sources and events. This interferes with under-lying assumptions of indoor-outdoor ratios which are used in public health.