Floor Coverings in Schools: Particle Buildup and Resuspension Characteristics based on Field and Chamber Studies

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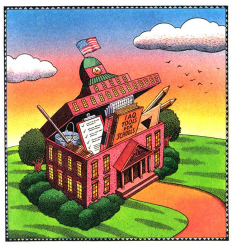
Background

- IEQ in schools is poor:
  - Ventilation inadequate
  - Temperatures elevated
- Poor IEQ in schools may affect students' performance (possibly teachers' too)
- School funding is minimal

Education for Schools
(In the USA have TFS kits))

School Administrators need definitive outcomes to divert funds to undertaking significant improvements to IAQ

Indoor Air Quality



Tools For Schools

Poor IAQ Impact

Sick Child at Home

- SCHOOL — Teacher Load, Administration
- MEDICAL — Direct Cost, Insurance
- PARENTS — Jobs, Reduced Activities
- SIBLINGS — Health Risk, Reduced Activities
- FRIENDS — Sick Child at Home, School, Medical ...

Source: Presenting The Built Environment, Dr. Michael Rees

Indoor Air Quality - Discussion

- **Thermal Environment**
- **Ventilation**
- **Flooring Aspects**
  - Thermal Comfort
  - Moisture Management
  - VOCs
  - Dust Factor

November 4, 2008

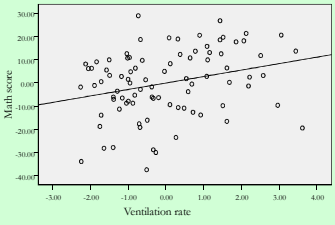
Breathing Dirty Air May Lower Kids' IQ

http://www.reuters.com/article/healthNews/idUSKUA57144920080215
reuters.com
by Anne Harding

Association between Sub-Standard Classroom Ventilation Rates and Students' Academic Achievement in the US

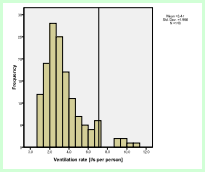
(Haverinen-Shaughnessy et al. Journal Indoor Air 2011)

- Results reveal linear association between ventilation rate and students' AP (independent of socioeconomic factors)

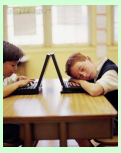


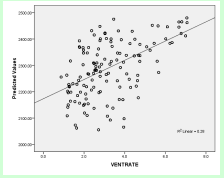
7

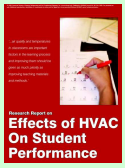
Preliminary results of Ventilation data from 2008-2010



- Of 140 classrooms inspected in the 70 schools, **94% had ventilation rates below ASHRAE guidelines**
- Preliminary results indicate ***significant associations between students' test scores and ventilation rate***







Parallel Studies

- Reducing moderately elevated classroom temperatures & increasing outdoor air supply rate improved the performance of schoolwork
- Speed at which the tasks were performed was improved; effect on errors more confounded

Wargocki and Lyons (2008)

Carpets and IAQ: Are they compatible?

Floor Coverings in Schools…. Creating Controversy

- Dybendal and Elsayed, 1994
- Hedge, 2001
- Ott, 1998
- Roberts, 1998
- Hodgson, 1999
- Chandra, 2000

Schools… A Growing Challenge to Clean

- **Limited maintenance/janitorial staff**
- **Outdated cleaning equipment**
- **Inadequate cleaning products**
- **No direct information on cleanliness**
  - **What is "clean"; how to measure?**
- **Poor staff training**

Carpet

- Can act as reservoir for more dust, proteins, and allergens per unit area, than hard floors
- Flooring surfaces can contribute to airborne levels
- Airborne levels reflective of surface contamination

Cole, et.al., 1996

Textile floor covering: not a homogeneous medium

- **Backing**
- **Carpet weave type**
- **Face weight**
- **Density (including stitches/inch)**
- **Adhesive requirements**

Flooring Categories

Hard Surface	Carpet
Types of Hard Surface:	Types of Carpet:
Wood	- Action Bac
Linoleum, Sheet Vinyl, Rubber	- Synthetic Latex
Terrazzo	- LifeSpan
Ceramic Tile	- LifeSpan MG
VCT	- Woven
	- Wireweave
	- Urethane
	- Cushion Vinyl
	- Hard Plate Vinyl





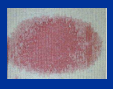




Flooring Categories

Carpet	Variable Cushion Tufted Textile (VCT
Types of Carpet:	Types of VCTT:

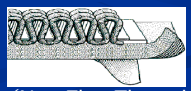
- Action Bac
- Unitary
- Woven
- Urethane
- Hard Plate Vinyl
- Modular Tile

Front **Back**

✓Flow Through

- Closed cell cushion
- Recycled content (closed cell cushion)
- Non-PVC (closed cell cushion)



✓Non-Flow Through

(water proof seams)

Questions:

- **How much dust is there in a square meter of carpeted floor near the doorway of a elementary school classroom?**
- How much time does is take to remove this dirt using a typical vacuum cleaner?

Preliminary School Recovery

- **Discussion**
  - **Baseline was established by recovery efforts (78 sets) in 11 schools from 5 districts in Northeastern Oklahoma (High Schools, Middle Schools & Elementary Schools were sampled)**

Schools study carpeted floor covering

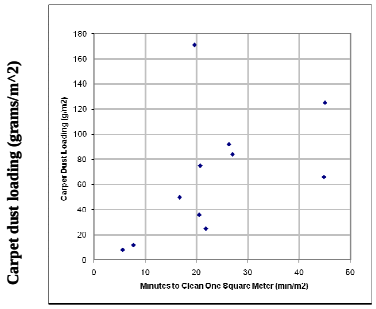
- Light traffic area:
  - 9.6 g/m2 ; 30 sample population, range: 0.8-27.8 g/m2
- Medium traffic area:
  - 52.5 g/m2 ; 24 sample population, range: 21.7-99.0 g/m2
- Heavy traffic area:
  - 192.5 g/m2; 24 sample population range: 69.5 -504 g/m2

Shaughnessy, Brennan, Cole & Turner; 2005

Question:

- How much dust is there in a square meter of carpeted floor near the doorway of a elementary school classroom?
- **How much time does is take to remove this dirt using a typical vacuum cleaner?**

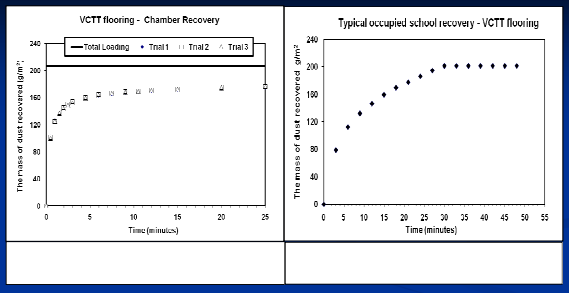
Carpet dust loading vs time to clean one square meter



Roberts, J.W., "Reducing Dust, Lead, Dust Mites, Bacteria and Fungi in Carpets by Vacuuming", Environmental Contamination and Toxicology 1999

Chamber Recovery

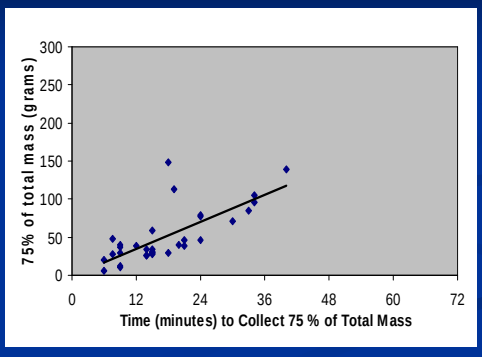
- Flooring Types (new product used each test)
  - **Flow Through Carpeting**
  - **VCTT– Low to Medium face weights (14 to 20 ounces pile weight per square yard – (400-550 g/m^2) with a closed cell cushion backing**
  - **190 grams per square meter loading**



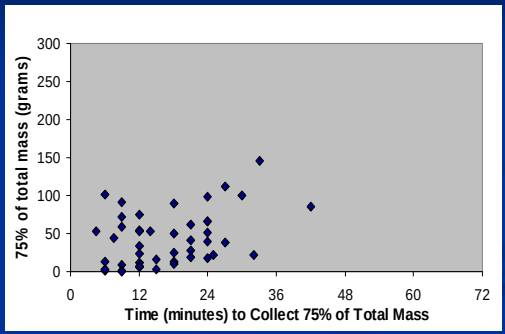
Recovery time reduced for new product as compared to collection in schools

These data reinforce the above hypotheses associated with the difficulty in recovering dirt in school environments with aged flooring material.

School Recovery
VCTT

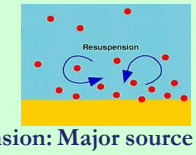


School Recovery
Flow Through Carpets



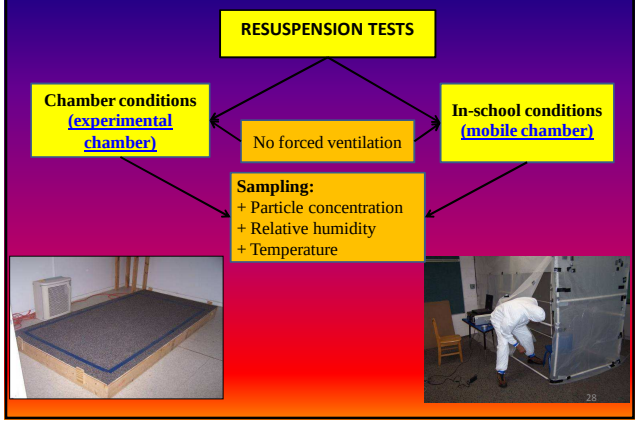
Factors influencing removal of dirt may include:

- Flow thru recovery inconsistent as compared to non-flow thru in the field data…. Why? :
  - The open weave backing of the flow through carpet allows passage of debris beyond the product backing
  - Deep cleaning solutions and extraction process residue buildup on the fibers
  - Inadequate maintenance may result in embedment of dirt into the carpet



Particle resuspension: Major source of indoor pollutant hazard for human health (Rosati et al., 2008).

RESUSPENSION TESTS



RESUSPENSION TESTS

Model of particle resuspension rate

Qian, 2008, utilized a material balance equation to introduce a set of equations to calculate the rate of particle resuspension for static sealed chamber

$$RR = \frac{V}{A_r L(t)}\left[\frac{C_i(t+\Delta t) - C_i(t)}{\Delta t} + kCi\right]$$

A_r, A, A_y - Resuspension area, m^2

V - Test space volume, m^3

k - Deposition loss rate, 1/min

RR - Resuspension rate (RR), 1/min

n - Vacuum rate, 1/min

C_i - Concentration inside chamber, particles/m^3

L - Floor loading in size range of interest, particles/m^2

29

Research (2005 – 2011): RESUSPENSION TESTS

In experimental chamber test runs:

- 18, 100, 150g/m^2 of floor dust loading were applied for FT and VCTT test runs
- 18g/m^2 floor dust loading was utilized for VCT hard flooring test runs

In-school test runs

- The data gathered from on-site classrooms were grouped together for comparison purposes based on the total amount of dirt collected, subsequent to test run completion. The groupings consisted of:
  - + Dirt collected range from 50 to 100 grams per square meter
  - + Dirt collected range from 100 to 200 grams per square meter

The majority of this research studied the resuspension of particles of two size ranges at 0.8-1.5µm and 1.5-3.0µm

30

RESUSPENSION RATES

Chamber resuspension data

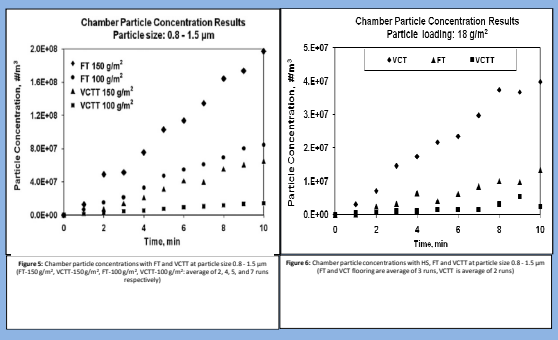


Figure 5: Chamber particle concentrations with FT and VCTT at particle size 0.8 - 1.5 µm (FT-150 g/m², VCTT-150 g/m², FT-100 g/m², VCTT-100 g/m²: average of 2, 4, 5, and 7 runs respectively)

Figure 6: Chamber particle concentrations with HS, FT and VCTT at particle size 0.8 - 1.5 µm (FT and VCT flooring are average of 3 runs, VCTT is average of 2 runs)

31

RESUSPENSION RATES

In-field classroom resuspension data

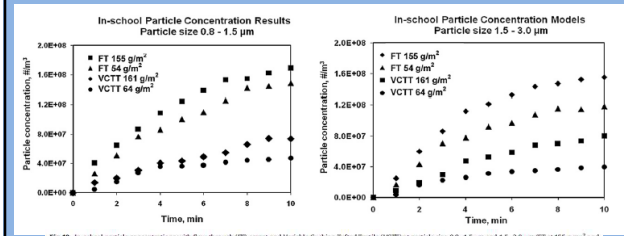
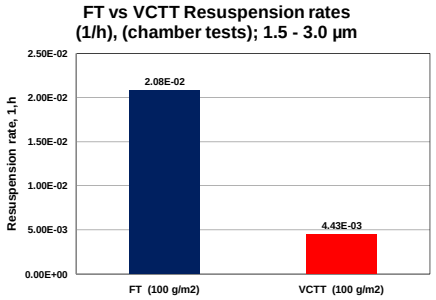
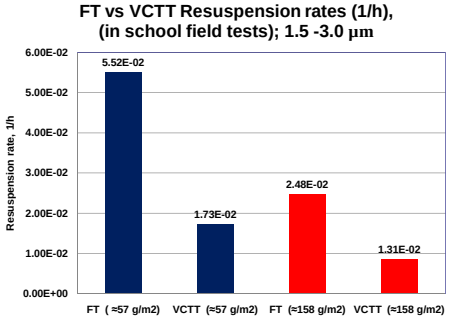


Fig. 10. In-school particle concentrations with flow through (FT) carpet and Variable Cushion Tufted Textile (VCTT) at particle size 0.8–1.5 µm and 1.5–3.0 µm (FT at 155 g m^{-2} and VCTT at 161 g m^{-2} ; average of 5 runs; FT at 54 g m^{-2} and VCTT at 64 g m^{-2}; average of 4 runs).

32

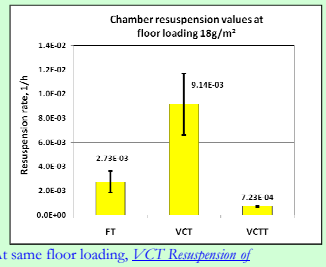


Type of flooring & loading



Type of flooring & loading

Resuspension rates based on flooring type



- At same floor loading, *VCT Resuspension of particles is 3 to 12 times greater than that from a textile floor*

Shaughnessy & Vu, 2012, "PARTICLE LOADINGS AND RESUSPENSION RELATED TO FLOOR COVERINGS IN CHAMBER AND IN OCCUPIED SCHOOL ENVIRONMENTS", Atmospheric Environment, 10.1016/j.atmosenv.2012.04.008

35

Flooring - dirt accumulation tests

OBJECTIVE:

Determine accumulation of dirt per square meter of flooring over the course of one day for:

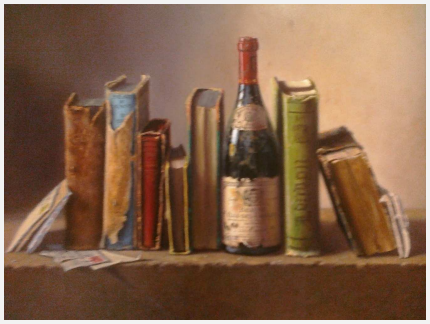
- textile surfaces (high & medium loads)
  - Carpet
  - VCTT
- Hard surfaces
- Data collected from 6 schools; 18 Paired sets of data (VCT & VCTT: VCT & FT)

In School Hard/Textile surface loading

- Summary - Textile to Hard Surface Ratios
  - Medium Traffic Areas: 12.8 (95% C.I.=6.9)
  - High Traffic Areas: 28.5 (95% C.I.= 7.9)

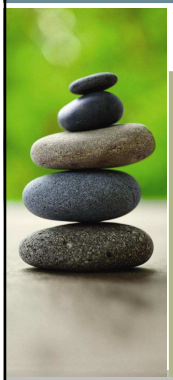
WHERE IS THE DIRT ON HARD FLOORING?

- More dirt is deposited on carpet as compared to hard surfaced rooms (typical order of magnitude greater on carpet on daily basis)
- Carpet acts as sink for dirt to a point
- Hard floors do not retain dirt on surface
  - Lost to resuspension
    - Deposits on shelving, bookcases, surfaces, clutter
    - Ventilation removal



***Settled dust:* Solid particles deposited onto a surface during a specific period of time.**

Settled Dust-Implications



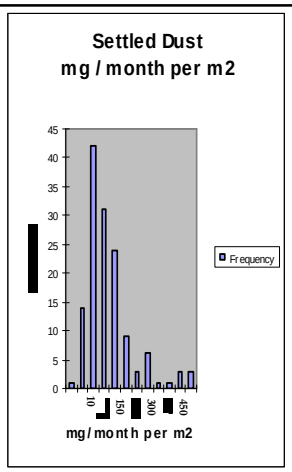
Research

Settled Dust (S.D.)

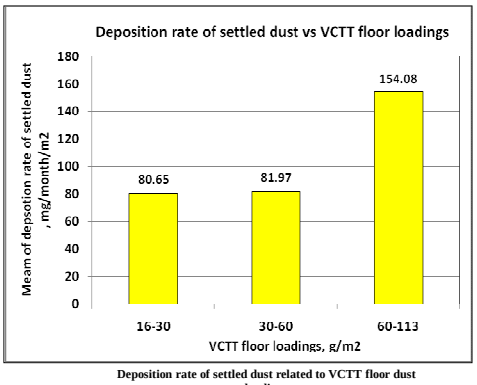
- S.D. accumulation related to sick building syndrome (shelf factor) Skov, Valbjorn, Danish Town Hall Study, 1987
- Symptom reports correlated to S.D. content (bacteria, fungi, allergen) Gyntelberg, 1990
- Health impact proportional to amount of dust

Settled dust measurements

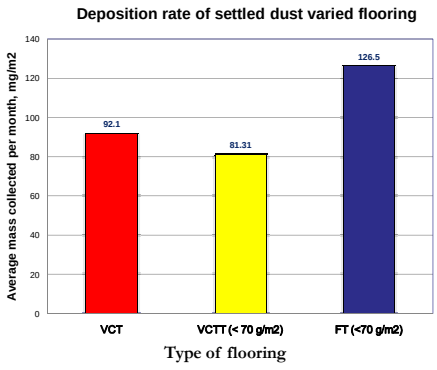
- Testing in 140 school classrooms Spring 2009
- Testing in 70 classrooms asst'd w/ ATP measurements, Spring 2010
- Standardized placement of collection containers in rooms; 2 month minimum collection
- Gravimetric determination/dust detector of accumulated dust



Mean = 159.4
Median = 127.5
Std Dev = 113
Range: min = 10.2
max = 572.4



Deposition rate of settled dust related to VCTT floor dust loadings



observations: VCT = 24; VCTT = 24; FT = 4

Summary

1) Particle resuspension and airborne concentration are a function of time of activity, type of floorings, and floor dust loadings
2) Flow through (FT) flooring exhibits significantly higher resuspension rates (RR) than VCTT floorings
3) VCT hard flooring displays significantly higher particle RRs as compared to VCTT and FT floorings in controlled chamber conditions and ***similar loading***
4) Typical floor dust loading on a given school day is significantly higher for textile surfaces as compared to VCT
5) Settled dust accumulation indicates no significant differences between VCT and VCTT over an extended period of exposure
6) Further research is needed to determine end points for resuspended dust from different flooring types