Analysis of Building Characteristics and Indoor Environmental Quality in California Classrooms

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Overview

- Background
- Purpose
- Study Design
- Results
  - For both portable and traditional classrooms, unless specified otherwise
- Conclusions
- Recommendations

Background

- Mandated by:
  - Governor's Budget, FY 2000-2001
  - Assembly Bill 2872 (Shelley, 2000), Health & Safety Code § 39619.6
- PCS conducted jointly by ARB and DHS
- These analyses sponsored by ARB and the California Energy Commission

Overall Purpose of Study

- Characterize distribution of energy & comfort-related characteristics of portable & traditional classrooms in a statewide, representative sample of K-12 public classrooms from the California Portable Classrooms Study (PCS).

- Explore in detail the relationships among key building variables – eg, location, building age & ventilation system type & condition -- & indoor environmental quality (IEQ) measures in the PCS data set.

Specific Objectives

MV Characterize associations between ventilation rates/indicators &

- Levels of indoor air pollutants (VOC's, aldehydes, PM), CO_2, noise, teacher satisfaction, temperature, humidity, pollen & spores.

NV Characterize associations between natural ventilation (use of open doors & windows) &

- Levels of indoor air pollutants, moisture, noise, teacher satisfaction, & other factors measured in the PCS.

LT Characterize associations between lighting levels/type &

- teacher satisfaction & other factors.

SE Characterize the associations of pollutant levels with

- School SES indicators, eg, ethnicity, urbanicity, student participation in meals assistance and family aid programs, frequency of janitorial service, and proximity to nearby pollutant sources.

PCS Design: Phase I

- Mail Survey (Apr – Jul 2001)
- 1,181 classrooms in 426 schools
- Facility questionnaire I
  - School level & classroom level; conditions, operations, maintenance
- Teacher questionnaire I
  - Classroom level; observations of moisture, air quality, noise, lighting
- Formaldehyde sampling
  - 911 classrooms in 320 schools

PCS Phase II

- Field Study (Oct '01 – Feb '02)
- 201 classrooms in 67 schools
- 2 portables & 1 traditional per school
- Facility questionnaire II – School & classroom
  - Pollutant sources, conditions, operations, maintenance
- Teacher questionnaire II - Classroom
  - Pollutant sources; observe moisture, air quality, noise, lighting
- Classroom form
  - Pollutant sources; observe moisture, air quality, noise, lighting
- HVAC checklist & School Characteristics Form
  - Classroom & school; measure ventilation, noise, lighting
- Consultation with facilities & HVAC mgrs forms
  - Background, historical data; general data, including pesticides

Environmental Measurements: Airborne

- 13 Aldehydes including formaldehyde
- 9 VOC's including benzene & chlorinated hydrocarbons
- Mold Spores and Pollen, 22 species
- Culturable Microorganisms – in specially selected schools
- PM_{10} and $PM_{2.5}$

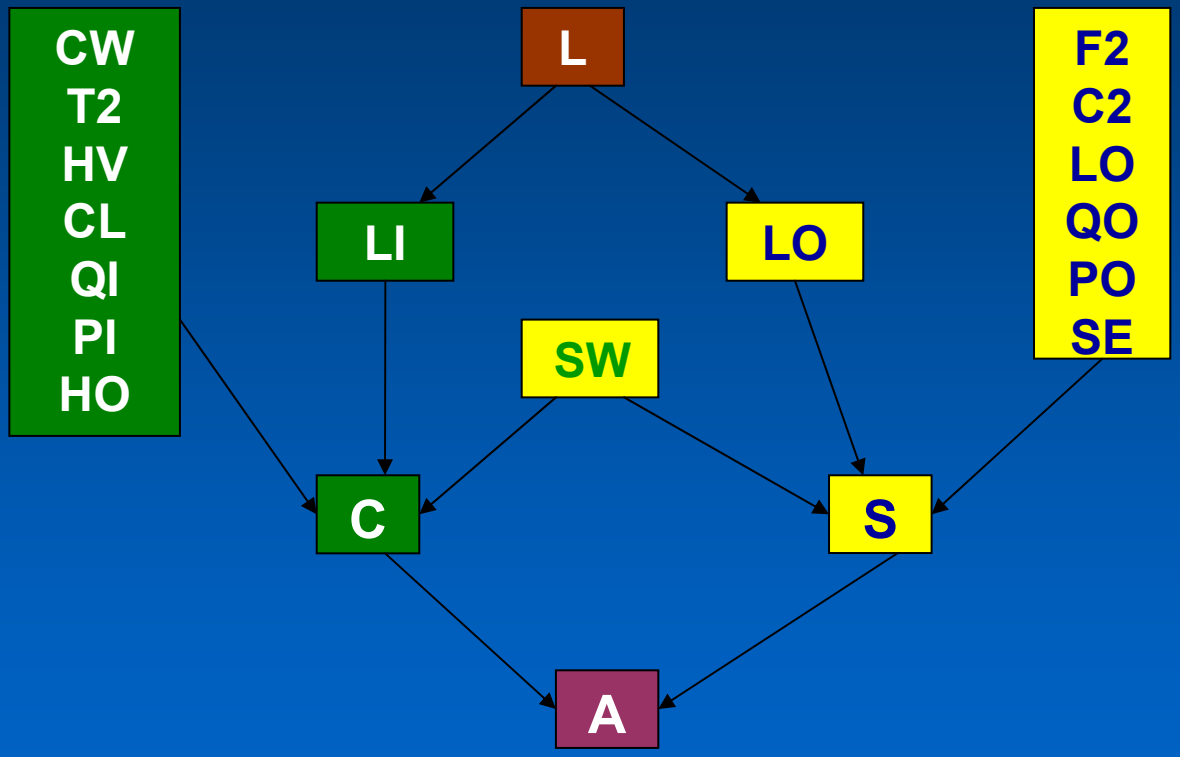
Environmental Measurements: Floor Dust

- 20 Pesticides
- 18 Metals including lead
- 16 PAH's
- Allergens
  - Cat, dog, 2 dust mites, cockroach

Environmental Measurements: Other

- CO_2
- CO
- Temperature
- Relative Humidity
- Noise
- Light
- Moisture

Database Processing



Analysis Approach - Models

Models for MV, NV, SE were of the following form:

$$Y = R + Z + R*Z + X + W + X*W$$

Where

- Y is the dependent IEQ variable
- R is the room type indicator
- Z is the outdoor measure of the IEQ variable (when present)
- X is the vector of variables of interest
- W is a vector of variables that may affect the relationship between X and Y

Categorical variables X with > 2 levels were represented by indicator variables

Models – Lighting

For LT, models of the following form were fit :

$$Y = R + X + W + X*W$$

Where

- Y is the dependent lighting variable
- R is the room type indicator
- X is the vector of variables of interest
- W is a vector of variables that may affect the relationship between X and Y

Categorical variables X with > 2 levels were represented by indicator variables

Mechanical Ventilation Variables

- Outdoor air flow per chair, when operating
- Outdoor air flow per sq ft, when operating
- Indoor-Outdoor CO_2 average difference
- Supply air flow per person (cfm/chair)
- Indoor – Outdoor Absolute Temperature Difference
- Ease of access to AHU interior
- HVAC mode during the visit
- HVAC System Replacement
- HVAC System Repaired
- HVAC inspection period
- Primary energy type
- Air handling unit location
- Type of heating system
- Noise level when HVAC on, center of room
- Noise level when HVAC on, near register
- Teacher ever turn off heater or AC due to noise
- Supply air flow (cfm)

Natural Ventilation Variables

- Sides of the room which have windows
- Did the students stay in the classroom or change each period
- How many windows were open today?
- How many doors open to the outside?
- Was any classroom door(s) left open today?
- Today's weather: rain

Lighting Variables

- Total skylight area
- Sides of the room which have windows
- Presence of blinds or curtains
- Items obstruct daylight through windows
- Reports of glare problems
- Weather, sunny or cloudy

Socioeconomic Variables

- Percent of Hispanic Students
- Percent of African American Students
- Percent of White Students
- Percent of English learner students
- Percent of full credentialed teachers
- Academic Performance Index (API) Score
- Average class size (school wide)
- Students per computer

General Variables

- Region – North or South
- School type – Elementary, Middle, High
- Awareness/use of EPA IAQ Tools
- General instruction classroom – Yes or No
- School location - urban, suburban, or rural
- Number of students in the school
- Room size (# chairs)
- Classroom Age (Year Categories)
- Room type – traditional or portable

Variables for Specific Analyses - 1

- **Temperature** - outdoor temperature, thermostat setting
- **Humidity** - outside temperature & humidity, lawn sprinklers; measures of effects of moisture - musty odors, mold on walls, water stains, algae, moss, plant growth
- **Noise, HVAC on** – AHU vibration noise, location of AHU, exterior noises, presence of carpets or rugs
- **Noise, HVAC off** – exterior noises, presence of carpets or rugs

Variables for Specific Analyses - 2

- **Aldehydes** – Sources, outdoor measurements of aldehydes, chemicals in the classroom, indoor activities that could increase aldehydes in air - new carpet, selected office equipment, outside activities that could increase aldehydes in air - commercial activities or busy roads.
- **VOCs** – Sources, outdoor VOC measurements, chemicals in classroom, indoor activities that could increase VOCs in air - stoves, carpet or fresh paint, outside activities that could increase VOCs in air - commercial activities or busy roads
- **PM** – Outdoor PM measurements, presence & characteristics of indoor sources of PM - condition of HVAC coils & filter, carpets, cleanliness of registers; presence & characteristics of outdoor sources of PM - types of ground cover near classroom, nearby activities - agricultural, commercial, busy roads, equipment with diesel engines, waste facilities

Variables for Specific Analyses - 3

- **CO_2** – Outdoor CO2 measurements, presence of parking lot or roadway within 50 f of classroom, nearby roadways, other combustion processes
- **Pollen** – outdoor pollen, presence of carpets, frequency of their cleaning
- **Fungal spores** – outdoor fungal spores, other sources of spores - carpets, measures of moisture & its effects - humidity, lawn sprinklers, musty odors, mold on walls, water stains, algae, moss, plant growth
- **Teachers' assessments of ventilation, noise, light, temperature, and humidity** – thermostat setting, teacher's ability to control thermostat or HVAC

Dependent Indoor IEQ Variables for MV, NV, SE - 1

Temperature	% of time T < 20° C	MV	NV	SE
	% of time T > 26 ° C	MV	NV	SE
Humidity	% time > 60%	MV	NV	
	Average Humidity	MV	NV	
Noise	dbA Near Register, HVAC on	MV	NV	SE
	Average dbA HVAC off	MV	NV	SE
Aldehydes	Log10(Formaldehyde)	MV	NV	SE
	Log10(Acetyldehyde)	MV	NV	SE
VOCs	Log10(Chloroform)	MV	NV	SE
	Log10(Tetracloroethylene)	MV	NV	SE
	Log10(Toluene)	MV	NV	SE
	Log10(m,p-Xylene)	MV	NV	SE
	Log10(Benzene)	MV	NV	SE

Dependent Indoor IEQ Variables for MV, NV, SE - 2

CO_2	average CO_2 In/Out difference)		NV	SE
	% time CO_2 > 1000		NV	SE
	Max 1-hour indoor CO_2		NV	SE
PM	log10(avg # particles < 2.5 μm)	MV	NV	SE
	log10(avg # particles < 10 μm)	MV	NV	SE
Pollen & Spores	Log10(Pollen Count)	MV	NV	
	Log10(Total Fungal Spores)	MV	NV	
Teacher Satisfaction	Satisfaction with ventilation	MV	NV	
	Satisfaction with noise	MV	NV	
	Satisfaction with temperature	MV	NV	
	Satisfaction with humidity	MV	NV	

Dependent Outdoor Variables for SE

Aldehydes	Log10(Formaldehyde)
VOCs	Log10(Benzene)

PM	log10(avg # particles < 2.5 μm)
	log10(avg # particles < 10 μm)

Dependent Variables for LT

Light	Light near windows
	Light away from windows
Teacher Satisfaction	Satisfaction with light

Stepwise Regression

- Sequentially selects the candidate independent variable most closely associated with the dependent variable
- Then selects the independent variable that, conditional on the first independent variable being in the model, is most closely associated with the dependent variable
- Then iteratively adds more variables in the same way until a pre-selected stopping criteria is achieved
- SUDAAN REGRESS, RLOGIST

Focus on Significant Models

Model P-Value < 0.05

(P-value for F test of overall model)

And

R^2 >= 0.2

(Model "explains" 20% or more of the variability in the dependent variable)

Mechanical Ventilation & Temperature

Dependent Variable	Significant Independent Variables			
	MV	**NV**	**Source**	**General**
% time Temperature > 26° C	Teacher ever turn off heater or AC due to noise	NA	None	None
% time Temperature < 20° C	None	NA	None	Awareness/Use of EPA IAQ tools Room type

Mechanical Ventilation & RH

	Significant Independent Variables			
	MV	**NV**	**Source**	**General**
Average humidity	Primary energy type Air handling unit location HVAC mode	Num. doors open to outside	Average Temperature Lawn sprinklers spray outside Walls	School type General instruction classroom School location Room type Ht of foundation skirt (portable)
% time Relative Humidity > 60%	HVAC mod	NA	# mold stains On walls Seen algae On Walls # water stains on walls	Room type Building foundation – other Region School type General instruction Classrooms Ht of foundation skirt (portable)

Mechanical Ventilation and Pollutants

	Significant Independent Variables			
	MV	**NV**	**Source**	**General**
Log10 (formaldehyde)	None	# open windows	Presence of air freshener Signs of leakage/overflow from gutters Lab Chemicals in room Seen plant growth on walls	Room type
Log10 (acetaldehyde)	None	Rain Students stay in classroom or change	Tackboard walls Signs of leakage/overflow from gutters	School Location School type
Log10 (tetrachloro-ethylene)	None	NA	Outdoor avg. VOC Presence of air freshener	Room type Carpet/Rugs on floor

Mechanical Ventilation & PM

	Significant Independent Variables			
	MV	**NV**	**Source**	**General**
Log10 (Avg. # Particles < 2.5μm)	None	None	Rain Parking lot/roadway within 50ft Dirt loading on filter Carpet/Rugs on floor New construction Size of gap around filter Office equipment	Room size Region School type General instruction Classroom Room size – # chairs
Log10 (Avg. # Particles < 10μm)	None	NA	Parking lot/Roadway within 50 ft Rain Carpets/rugs on floor	School type Region Roomtype General instruction classroom School location

Natural Ventilation & Temp, RH

	Significant Independent Variables			
	MV	**NV**	**Source**	**General**
% time Temp. < 20° C	NA	None	None	Awareness/Use of EPA IAQ tools Room type
Average humidity	NA	Rain	Average temperature	General instruction classroom School location Room type Number of students If portable, height of foundation skirt
% time Relative Humidity > 60%	NA	None	Seen algae on walls # water stains on walls	Room type Building foundation – other Region School type General instruction classroom If portable, height of foundation skirt

Natural Ventilation & Pollutants

	Significant Independent Variables		
	NV	**Source**	**General**
Log10 (formaldehyde)	# open windows	Presence of air freshener Signs of leakage/ overflow from gutters Lab chemicals in room Seen plant growth on walls Office equipment	Room type
log10 (acetaldehyde)	# open windows Rain Students stay In classroom or change	Outdoor avg aldehyde Fiber/ Particleboard/ Plywood walls Tackboard walls Signs of leakage/overflow from gutters	General instruction Classroom Room type Sch. location School type
log10 (tetra-chloroethylene)	Rain # doors open to outside	Carpet/Rugs on floor Outdoor avg. VOC Presence of air freshener Sewer/Compost odor at times	General Instruction classroom Room type
Log10 (benzene)	None	Rain	School type

Natural Ventilation & CO_2, PM, Spores

	Significant Independent Variables			
	MV	**NV**	**Source**	**General**
% time CO_2 >1,000 ppm	NA	# open windows	Rain	Genl instruction Classroom School type Room type # students
Log10 (Avg. # particles < 2.5µm)	NA	None	Rain Parking lot/ roadway within 50ft Dirt loading on filter Carpet/Rugs on Floor	Region School type Genl instruction classroom
Log10 (Avg. # particles < 10µm)	NA	None	No nearby roadways Rain Parking lot/ roadway within 50 ft Carpet/rugs on floor	School location Region Genl instruction classroom
Log10 (Total fungal spores)	HVAC mode	None	Outdoor fungal spores # mold stains on walls	None

Lighting

No significant regressions

IAQ, Pollutants & SES - 1

Dependent Variable	Significant Independent Variables	
	Socioeconomic Status	General
% time temperature >26° C	None	Awareness/Use of EPA IAQ tool
Log10 (acetaldehyde)	None	School location Region School type Genl instruction classroom
Log10 (chloroform)	% Hispanic students	None
Log10 (tetrachloroethylene)	% African American students API scores	Number of students Region School type Genl instruction classroom
Log10 (toluene)	% English language learners	Number of students Room size - # chairs
Log10 (m,p-xylene)	% English language learners	Number of students Students per computer

IAQ, Pollutants & SES

Dependent Variable	Significant Independent Variables	
	Socioeconomic Status	**General**
Indoor-Outdoor [CO_2] difference	API scores	School location School type
% time CO_2 >1,000 ppm	None	School location Number of students School type Avg. class size
Log10 (Avg. # particles < 2.5μm)	None	Region Genl instruction classroom Room size – chairs Avg. class size
Log10 (Avg. # particles < 10μm)	None	Region Genl instruction classroom Room size - chairs Avg. class size
Outdoor log10 (formaldehyde)	% English learners % white students	Region School type
Outdoor log10 (benzene)	None	Room size Students per computer

Impact of Room Type

- Significant Predictor – alone or in an interaction term for
  - Percent time temperature < 20°C (Port colder that trad)
  - Average humidity (Port < RH)
  - Percent time humidity >60% (Port have lower RH)
  - Formaldehyde (Port > Trad)
  - Acetaldehyde (Port > trad)
  - Percent time CO_2 > 1,000 ppm (Port < trad)
  - Avg. number of particles < 10 µm (Port > Trad)
  - Teacher's assessment of ventilation (Port more acceptable than trad)
  - Teacher's assessment of humidity (urban & rural, trad more acceptable than port, reverse in suburban)


in cans not in cannots.
STAND UP FOR WHAT IS RIGHT
NO

Conclusions – 1

- Source-related measures and general characteristics of the schools and classrooms are better predictors of the IEQ measures than the mechanical and natural ventilation building characteristics.
- The same general variables tend to appear as significant in mechanical ventilation, natural ventilation and socioeconomic, regardless of which other independent variables are in the models.
- Mechanical ventilation variables had no statistically significant effect on most of the IEQ outcome measures.
  - However, the measurements available for use in the modeling limited possible analysis; further analysis based on peak measurements rather than averages.
- Increased natural ventilation, *e.g.,* having more doors or windows open, tended to be associated with lower levels of aldehydes and VOC's.
- None of the lighting models satisfied the significance criteria. However, the analysis was limited by the availability of data from the original study

Conclusions - 2

- The dependent variables tend to be “snap-shot” measurements taken on the day the PCS staff visited the schools, while the independent variables are a mixture of contemporaneous “snap-shot” measurements; long-term descriptions of the schools and occupants; and teachers’ subjective recalls. These factors tend to dampen the observable statistical associations among the variables.

- The original report indicated that one of the reasons fans on HVAC units do not operate all the time is that “…the thermostat control limits the amount of time the system fan is operating.” However, Cal-OSHA regulations require that the required operation be operational at all times the space is occupied. While only protective of the teacher by law, this regulation also protects the children whenever the teacher is present, virtually the entire time the students are present.

- Dirty filters tend to release accumulated particles when initially started after a quiescent period. The nature of ventilation system operation in schools indicates that systems are started and stopped at least once daily.

Recommendations

- This study underscores the importance of maintenance and shows that it can override system or building type contributions to indoor environmental quality.
- Replace noisy HVAC units with quieter ones.
- Ventilation and filtration should fit the site and perhaps, the day and season as outdoor air conditions vary greatly among the sites.
- Reduce indoor pollutant sources such as formaldehyde emissions from composite wood used during school construction, modernization, and repair.
- Reduce indoor moisture sources such as leaks in the building shell and gutters, poor drainage under crawlspaces, and foundation skirts with inadequate gaps.
- Increase the awareness of use of IAQ management tools such as US EPA's Tools for Schools and Healthy SEAT.
- To reduce indoor PM, improve the sealing and replacement of HVAC air filters, and reduce the proximity of classrooms to vehicle traffic.