CALIFORNIA
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Appendix

Windows and Classrooms: A Study of Student Performance and the Indoor Environment

TECHNICAL REPORT

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Gray Davis, *Governor*

CALIFORNIA ENERGY COMMISSION

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PREFACE

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

This document is one of 33 technical attachments to the final report of a larger research effort called *Integrated Energy Systems: Productivity and Building Science Program* (Program) as part of the PIER Program funded by the California Energy Commission (Commission) and managed by the New Buildings Institute.

As the name suggests, it is not individual building components, equipment, or materials that optimize energy efficiency. Instead, energy efficiency is improved through the integrated design, construction, and operation of building systems. The *Integrated Energy Systems: Productivity and Building Science Program* research addressed six areas:

- ***Productivity and Interior Environments***
- ***Integrated Design of Large Commercial HVAC Systems***
- ***Integrated Design of Small Commercial HVAC Systems***
- ***Integrated Design of Commercial Building Ceiling Systems***
- ***Integrated Design of Residential Ducting & Air Flow Systems***
- ***Outdoor Lighting Baseline Assessment***

The Program's final report (Commission publication #P500-03-082) and its attachments are intended to provide a complete record of the objectives, methods, findings and accomplishments of the *Integrated Energy Systems: Productivity and Building Science Program*. The final report and attachments are highly applicable to architects, designers, contractors, building owners and operators, manufacturers, researchers, and the energy efficiency community.

This document is the Appendices to Windows and Classrooms (Product #2.4.10c) and contains the technical supporting analysis for the conclusions in the Windows and Classrooms Report.

The Buildings Program Area within the Public Interest Energy Research (PIER) Program produced these documents as part of a multi-project programmatic contract (#400-99-413). The Buildings Program includes new and existing buildings in both the residential and the non-residential sectors. The program seeks to decrease building energy use through research that will develop or improve energy efficient technologies, strategies, tools, and building performance evaluation methods.

For other reports produced within this contract or to obtain more information on the PIER Program, please visit www.energy.ca.gov/pier/buildings or contact the Commission's Publications Unit at 916-654-5200. All reports, guidelines and attachments are also publicly available at www.newbuildings.org/pier.

ABSTRACT

This document is the Appendices to Windows and Classrooms (Product #2.4.10) and contains the technical supporting analysis for the conclusions in the Windows and Classrooms Report.

TABLE OF CONTENTS

TABLE OF FIGURES

1. TECHNICAL DEFINITIONS

The following briefly describes key statistical terms in the report.

Term	Name	Definition
R	Correlation Coefficient *Or* Pearson correlation	Measures the strength of the linear relationship between two variables It can take on the values from -1.0 to 1.0, where -1.0 is a perfect negative (inverse) correlation, 0.0 is no correlation, and 1.0 is a perfect positive correlation.
p	p-value *Or* significance *Or* Sig.	A p-value is a measure of the certainty you have that a relationship exists between an explanatory variable (e.g., smoking) and an outcome variable (e.g., cancer). It is a measure of how much evidence you have that the null hypothesis – that no relationship exists – is not true. The p-value is the probability that you are *falsely* rejecting the null hypothesis, i.e., that you are *falsely* declaring that a relationship exists (e.g., between smoking and cancer.) The smaller the p-value, the more evidence you have. The probability of a false rejection of the null hypothesis in a statistical test is called the significance level. A p-value can vary from >.00 to <1.0. The significance level is 1-p, expressed as a percentage. So if a p-value is .01, the significance level is 99%. Typically, in statistical tests, one sets a threshold for an acceptable significance level. In such a case, if the p-value is less than some threshold (usually .05, sometimes a bit larger like 0.1 or a bit smaller like .01) then you reject the null hypothesis, and conclude that there is a reasonable likelihood of a relationship between the explanatory variable and the outcome.

Term	Name	Definition
R^2	Regression correlation coefficient	A value between 0 – 1.0 that indicates how well an X value (or the independent or explanatory variables in the regression) explains a Y value (the dependent variable). Technically, the regression equation is: $Y= B_0+B_1X_1+ B_2X_2+…+ B_nX_n+e$ where B_0= intercept, e=error, so as Xs change, Y, the dependent variable, also changes., and variations in X values cause variations in Y. R^2 is defined as the percentage of total variation in Y explained by the independent variables. If R^2 is equal to 1, then entire variation in Y is explained by the independent variables, i.e. the model is very good, and the X variables have perfect explanatory power (for explaining Y). So, the higher the value of R^2, the better the model is for that set of data. Models explaining data that have a high degree of inherent variation, such as individual behavior, will have a much lower R^2 than models explaining more predictable events, such as group averages.
B	B Coefficient	Technically, the regression equation is: $Y= B_0+B_1X_1+ B_2X_2+…+ B_nX_n+e$ where B_0 is the intercept (constant), and B_1 ,B_2 ,…,B_n are the slopes of the regression equation, or the coefficients of the Xs, (or the independent variables), and e is error. A particular B_i (i=1,2,…,n) shows how a particular X_i variable is related to Y. If a B_i coefficient is a positive number, an increase in X_i by one unit increases Y by the amount of the B_i coefficient.
F-Test		A statistical hypothesis test based on the F distribution where the null hypothesis is that a set of B coefficients are simultaneously zero. The alternative hypothesis is that there is at least one B coefficient in the set that is not zero.

Term	Name	Definition
df	Degrees of Freedom	The total number of observations minus the number of restrictions on the observations. For a regression model, the degrees of freedom is equal to the (number of observations - one) – (number of explanatory variables in the model). For example, the log models in this report consist of (73-1)-(11) = 72-11=61 degrees of freedom.

2. PHASE 1: ON-SITE DATA COLLECTION FORMS

2.1.1 School Survey Definitions

The following definitions were used to guide the surveyors in categorizing observations onto the survey forms.

Sky Conditions

- Dark Overcast: Dark overcast across whole sky, no shadows.
- Light oc: Light overcast, with slight shadows possible.
- Puffy: Puffy independent clouds, with substantial areas of blue sky
- High thin: High, cirrus clouds
- Very Clear: No clouds at all.

Location Near

- Freeway noise: Freeway within 1-2 blocks
- Adjacent blvd: Major boulevard with heavy traffic adjacent to school
- Airport flypath: Aircraft can be heard or low flying aircraft can be seen from school yard.
- Construction dust: Dust from construction, on or off site, was likely to have affected school in past year
- Construction noise: Noise from construction, on or off site, was likely to have affected school in past year
- Plowed fields: Plowed fields within 1-2 blocks of school
- Orchards: Orchards within 1-2 blocks of school
- Animals: Farm animals within 1-2 blocks of school

Neighborhood

- Residential only: Only residential areas within 1-2 blocks of school
- +Commercial: Residential with some commercial within 1-2 blocks of school
- Any industrial: Any industrial within 1-2 blocks of school

Neighborhood Age

- Pre war: Houses built before World War II, i.e. 1900 to 1940; mostly modest bungalows and some Victorian or Craftsman style two story homes
- 40/50s: Houses built during the 1940 and 50s; mostly modest stucco ranch houses. Trees quite large.

- 60/70s: Houses built during the 1960 and 70s; larger stucco ranch houses and common use of T-11 siding. Trees well established.
- 80/90s: Houses built during the 1980 and 90s. More elaborate exteriors, common use of tile roofs, two story homes. Trees modest to small.
- Brand new: Some homes still under construction. Trees recently planted.

Neighborhood Economic Status

- Non-res: No houses nearby.– All industrial or commercial
- Lower: Smaller, older homes; run down houses and yards; dirty, polluted or damaged streets
- Average: Small and medium homes; houses and simple yards maintained well; clean streets
- Upper: Medium and large homes; well kept houses and yards with some landscaping; clean, well maintained streets
- Very affluent: Large and very large homes; very well maintained houses and yards; elaborate landscaping prevalent; streets very clean and well maintained

School Maintenance Condition

- School construction: Evaluated on a 1-5 scale from None to Major
  - 1: No construction within the last year
  - 2: Minor disruption with no effect on school activities
  - 3: Moderate disruption with little effect on school activities
  - 4: Large disruption that affected school activities
  - 5: Major disruption to school activities
- Paint: Evaluated on a 1-5 scale from Dilapidated to Fresh
  - 1: Large bare sections of wall, mismatched paint
  - 2: Prevalent peeling paint with bare patches
  - 3: Occasional peeling paint with some small bare patches
  - 4: Solid color with very little peeling
  - 5: New paint within the last two years
- Play yard grass: Evaluated on a 1-5 scale from Bare dirt to Lush
  - 1: Bare dirt with little or no grass
  - 2: Grass mostly brown with large bare patches
  - 3: Mixed green and brown grass with some bare patches
  - 4: Generally green grass with some brown patches
  - 5: Lush green grass

- Play yard asphalt: Evaluated on a 1-5 scale from Deteriorated to Fresh

  1: Deteriorated, broken and buckled asphalt, in need of immediate repair; weeds growing

  2: Cracked asphalt with many holes

  3: Cracked but level asphalt with occasional small holes

  4: Generally black asphalt with some cracks, easily visible paint

  5: Fresh, black asphalt with no cracks, fresh paint

- Shade trees: Evaluated on a 1-5 scale from None to Many, big

  1: No trees

  2: Few trees (or tall palm trees) providing little shade

  3: A few large trees or many small trees

  4: Many trees but not all large

  5: Many large, leafy trees

2.1.2 Classroom Survey Definitions

Classroom Type: The classroom type section of the survey was based on the types of classroom configurations found in the FUSD.

- Single Loaded: Classroom in single rows, with at least two exterior walls and entrance from outside.
- Double Loaded: Classrooms back to back, with an exterior door on one side and a common wall on the other.
- Interior Corridor: Any classroom connected to others via an interior corridor.
- Portable 12: The most common type of re-locatable classroom used in the FUSD. 24' x40' with doors and windows on the narrow end and flat ceilings.
- Bungalow: Older type of re-locatable classroom installed in the1950s that has a peaked roof.
- Common Room: Classrooms with doors to a shared common activity space.
- Operable Wall: Classrooms have acoustic panel walls that could be relocated to change the size and configuration of the space. In practice, these are rarely, if ever, moved.
- Open: Connected classrooms without interior doors, so that they cannot be acoustically closed off from other adjacent spaces.
- Portable (other): All other types of portable classrooms.

- Trailers: State-owned emergency classrooms lacking permanent foundations and sitting about 2' to 3' above the asphalt.
- Other: All other configurations; if Other was marked, the surveyors described the layout.

Room Dimensions:

- Length and Width: For orthogonal rooms
- Total Area: For non-orthogonal rooms

Floor

- Slab on Grade: Concrete slab at ground level
- Wood at Grade: Wood frame recessed to ground level
- Above Grade: A floor 2 ' or more above grade
- 2nd Floor: A floor above grade with another level below it

Ceiling

- Raised: Ceiling corresponds to roof structure
- T-bar: Suspended, acoustic tile ceiling

Teach Wall

- White Board: white dry-erase board
- Green Board: green chalk board
- Black Board: black or brown chalk board
- Glare: veiling glare on teaching surface noticeable from seated student perspective

Sunlight Penetration

- Never: direct sunlight never penetrates the space
- Rare: less than 10% of the time, or small patches in non-critical areas

Figure 1: View looking East of a raised ceiling.

Figure 2: T-bar ceiling in a Portable 12 classroom.

Figure 3: Example of "Major Problem" sunlight penetration from a portable classroom. View looking southwest.

- Modest: 10-25% of the time, or small to medium patches in non-critical areas
- Serious: 25-50% of the time, or small to medium patches in critical teaching surfaces
- Major Problem: over 50% of the time, or large patches on critical teaching surfaces.

Window Glare

- Never:
- Rare: noticeable, but infrequent or avoidable. Example - View of N sky through tinted glass
- Modest: noticeable & occasionally annoying. Example - View of a partially shaded S wall
- Serious: frequent, unavoidable high contrast glare source within direct line of sight of teaching surface. Example - Diagonal view of a bright wall in sun or direct view of bright wall for 1-2 hours per day
- Major Problem: constant, unavoidable high contrast glare source within direct line of sight of teaching surface. Example - Direct view of white wall in direct sun (visible more than half of the school day). Example - View of concrete pavement in direct sun

View

- Includes Vegetation: Any trees, bushes or large patches of grass
- Activity: Any human activity
- Distance
- None:
- Near: within 25'
- Mid: 30'-65'
- Far: 70' or beyond
- Can't Tell: View temporarily blocked

Figure 4: Example of "serious" glare. The glare was downgraded from "major problem" because of the uniformly bright room surfaces. View looking northeast.

Figure 5: Example of a view with vegetation.

Figure 6: Example of a near view.

Operable Windows

- Cross ventilation available: Operable windows on opposite sides of the room
- Area of operable windows
- None:
- <12: Less than 12 square feet
- 15-36: Area between 15-36 square feet
- 40+: More than 40 square feet
- Can't Tell: Unable to determine if windows are operable or if teachers are allowed or capable of opening them

Window Control

- None:
- Screens: Interior or exterior translucent mesh for sun or view control – not insect screens
- Blinds: Either vertical or horizontal; can be drawn open in addition to an adjustable aperture
- Curtains: Opaque, or nearly opaque, fabric that can be drawn open and shut
- Louvers: Opaque slats, with or without adjustable apertures

Figure 7: Example of a blackout curtain.

Security

- Broken Windows: One or more windows in room are broken
- Graffiti: Graffiti on classroom

Security Level

- None:
- Glazing: Plastic, wire mesh or laminated glass
- Mesh: Wire mesh over glazing
- Bars: Bars inside or outside of glazing
- Plywood: Boarded up windows

Luminaire Type

- Prismatic: Light directed downwards and/or to sides via plastic prismatic lens
- Louv'd: Light directed downwards, controlled with opaque louvers
- Dir/Ind: Light directed both up and down

- Indirect: All light directed upwards
- Other: All others with description

Luminaire Condition

- Deteriorated: Multiple missing lenses, yellowed or broken lenses, warped fixtures, or some non-functional fixtures
- Aged: Lenses have begun to yellow in the corners, fixtures show evidence of wear as well as maintenance neglect, such as mismatching lenses, dirt and loose or broken corners; paint discoloring
- Average: Three to five years old with matched lenses that had begun to dull, occasional cracks or dust, but still fairly clear; paint aging
- Good: One to three years old with clear, bright lenses and/or clean fresh paint
- Brand new: Less than 6 months old, with very clear, clean lenses

Lamp Color

- <3000: Less than 3000°K in color temperature (warmer color appearance than sample 3500°K CFL)
- 3500: 3500°K in color temperature (same color appearance as sample 3500°K CFL)
- >4000: greater than 4000°K (cooler color appearance than sample 3500°K CFL)
- Mixed Fl: A mixture of various colors of florescent lamps
- Fl & Inc: Both florescent and incandescent lamps used for the *primary* lighting system

Lighting Controls

- Not Working: Lighting controls don't work, still select control type
- Control Type
    - None:
    - 1 switch: Only one light level possible with manual on/off switch
    - 2+ switch: Two or more light levels possible
    - oc sen: Motion detecting occupancy sensor
    - photosensor: Light-level detecting automatic sensor

Illuminance Readings: In foot candles, all taken at four feet above finished floor, ±3"

- Window: Vertical, at center of room, facing primary window wall
- 2T: Vertical, at center of room, facing teaching wall
- 3: Vertical, at center of room, facing third wall (opposite primary window wall)

- 4: Vertical, at center of room, facing fourth wall
- Up: Horizontal, at center of room, facing up to ceiling
- Down: Horizontal, at center of room, facing down to floor
- 5' from window: Horizontal, five feet from center of primary window wall, facing up to ceiling
- 5' from opposite wall: Horizontal, five feet from center of wall opposite primary window wall, facing up to ceiling

HVAC System

- Unit: Individual heating/cooling system (not just fan) for each classroom
- Central: Larger, remote heating/cooling unit serves multiple classrooms

Heating

- None:
- Roof: Heated air delivered from ceiling-mounted register
- Wall: Heated air delivered through wall-mounted register
- Other: All others, describe

Cooling

- None:
- Same as heating: Cooling provided by same system as heating
- Other: All others, describe

HVAC Controls

- None: No controls in classroom
- Analog: Dial or level control, controllable by teacher
- Digital: Digital readout and selection control, controllable by teacher
- Locked: Controls present but physically locked

Mech Ventilation

- None:
- H/C only: mechanical ventilation only when the heating or cooling is running
- Always open: a vent to the exterior is always open allowing continuous ventilation

Manual override: the HVAC system can be overridden by the user to allow ventilation independently of heating and cooling.

2.1.3 School Data Collection Form

SCHOOL INFORMATION

Cross streets _____

Orientation off of true north? _____

Arrival time _____ **Initial daylight reading** _____ fc

Departure time _____ **Exit daylight reading** _____ fc

Cloud condition ☐ dark overcast ☐ light oc ☐ puffy ☐ high thin ☐ very clear

Sky condition ☐ stable ☐ changeable

Weather comments: _____

Location near ☐ freeway noise ☐ adjacent blvd ☐ airport flypath ☐ construction dust ☐ construction noise ☐ plowed fields ☐ orchards ☐ animals ☐ other: _____

Neighborhood ☐ residential only ☐ +commercial ☐ any industrial

Neighborhood age: ☐ pre war ☐ 40/50s ☐ 60/70s ☐ 80/90s ☐ brand new

Neighborhood econ status: ☐ non-res ☐ lower ☐ avg ☐ upper ☐ very affluent

School maintenance condition:		**1**	**2**	**3**	**4**	**5**	
Construction	None	☐	☐	☐	☐	☐	Major
Paint	Dilapidated	☐	☐	☐	☐	☐	Fresh
Play yard grass	Bare dirt	☐	☐	☐	☐	☐	Lush
Play yard asphalt	Deteriorated	☐	☐	☐	☐	☐	Fresh
Shade Trees	None	☐	☐	☐	☐	☐	Many, big

☐ recent changes What: _____

Other comments _____

2.1.4 Classroom Data Collection Form

Classroom Type: **Same as classroom #** _____ **Except per below** ☐

☐ single loaded ☐ double loaded ☐ interior corridor ☐ portable ☐ 12 ☐ bungalow

☐ common room ☐ operable walls ☐ open (no walls) ☐ portable __ ☐ trailer

Length _____ **Width** _____ or **Total Area** _____

Electric Lighting

Same as _____ **Except per below** ☐

Luminaire Type: fluorescent/HID dir/ind indirect other _____

☐ ☐ ☐ ☐ ☐

Luminaire Condition deteriorated/yellowed aged average good brand new

Ballast ☐ magnetic ☐ electronic can't tell ☐

Lamps ☐ T12 (34W) ☐ T8 (32W) ☐ other _____ _____ Wattage can't tell ☐

Count _____ # luminaires _____ lamps/luminaire _____ Total count lamps

Floor: ☐ slab on grade ☐ wood at grade ☐ above grade ☐ 2nd floor

Doors _____ # exterior _____ # interior # folding panels (3' to 4' wide)

Color <3000 3500 >4000 mixed FI FI&Inc can't tell

Flooring: _____ % carpet _____ % vinyl ☐ ☐ _____ % other, describe: ☐

Walls: _____ % hard _____ % vinyl none 1 switch 2+switch oc sen photosensor % other: can't tell

Ceiling: ☐ raised ☐ T-bar _____ min height, _____ max height

Controls ☐ ☐ ☐ ☐ ☐ ☐ ☐ not working

Illuminance Readings (remember to turn lights on upon entering classroom to warm up)

Teach wall: ☐ white board ☐ green board ☐ black board ☐ **glare?**

Amenities: ☐ sink ☐ built in storage ☐ int bathroom ☐ phone

Cubic, lights on ___ window ___ 2T ___ 3 ___ 4 ___ up ___ down

Condition: ☐ stale ☐ moldy/musty ☐ water damage ☐ all new

Horizontal, on _____ 5' from window _____ 5' from opposite wall

Equipment: ☐ TV _____ # computers ☐ other: _____

Cubic, lights **off** ___ window ___ 2T ___ 3 ___ 4 ___ up ___ down

Classroom Comments: _____

Horizontal, lights **off** _____ 5' from window _____ 5' from opposite wall

Lighting Comments: _____

Windows, primary wall: E W N S

a. above door _____ Total area _____

b. desk to door _____ Total area _____

c. below desks _____ Total area _____

Secondary window wall: E W N S

d. above door _____ Total area _____

e. desk to door _____ Total area _____

f. below desks _____ Total area _____

g. Other: _____ interior wall _____ roof monitor _____ skylights Total area _____

HVAC

Same as _____ **Except per below** ☐

System unit central can't tell

Heating none roof wall other can't tell

Cooling none same as heating other can't tell

Tint fc in / fc outside clear dbl can't tell

Tint color if other than gray: _____

Controls none / analog digital locked can't tell

☐ 2nd tint, where? _____

Sunlight Penetration never rare modest serious major problem

Mech Ventilation none H/C only always on/open manual overide can't tell

☐ user control available

Window Glare never rare modest serious major problem

Portable fan no yes can't tell

☐ user control available

View none near mid far can't tell

☐ includes vegetation ☐ activity

Operable windows none <12sf 15-36 40+

☐ cross ventilation available

Window control none screens blinds curtains louvers

Security none glazing mesh bars plywood

HVAC Comments: _____

General Comments: _____

3. PHASE 2: ONSITE DATA COLLECTION FORMS

3.1 Onsite Protocol

The Heschong Mahone Group, Inc., an energy research firm, conducted an observational study of selected classrooms in the Fresno Unified School District during the first and second weeks of February 2003. One (or two) surveyors from HMG visited each of 14 selected elementary schools during regular school hours. Following is an outline of the data collection procedures used by the surveyors on site:

Classroom Observations

For each classroom that we observed, we first obtained permission from the school office, and then when entering each classroom briefly introduced ourselves to the teacher.

The surveyor(s) stood in the back of the classroom for 10-15 minutes, noting the operation of windows, lights, mechanical system, and making subjective assessments of the acoustic, thermal and lighting environment. The surveyor also had a notebook with the information previously recorded about the classroom such as dimensions, surface materials, etc. (from Phase 1 site visits) and confirmed the accuracy of those observations.

Classroom Measurements

We also returned to each classroom when the children were absent, such as during recess or lunch or when it was least disruptive and took various measurements. We recorded a series of light levels readings across the width of the classroom (using a handheld Minolta light meter), radiant temperatures at various locations in the classroom (using a handheld radiant temperature “gun”, which uses a laser beam, similar to a presentation pointer, to assess the radiant temperature of surfaces), and took acoustic readings (using a handheld decibel meter).

Where it was easy and convenient to speak to the classroom teacher about his/her experience of the lighting, thermal and acoustic conditions in the classroom, we conducted an informal five minute interview.

Detailed Data Collection Description

(Most of the following observations were simply re-confirming previous observations made in Phase 1)

1. *Classroom geometry* – HMG had previously collected data on the classrooms on the geometric configurations of the classrooms and the surveyors confirmed the entries made previously for the following:

    a. Length, width and area of the classroom

b. Ceiling type (raised/ T-bar)

c. Ceiling height (minimum and maximum) and ceiling profile

d. Floor type (slab on grade, raised floor, above conditioned space)

e. Window orientations, areas

2. *Construction Type* - A quick visual observation of the construction both from the exterior and the interior was used to categorize the construction into the following construction types.

   a. Wall – Wood frame, block, concrete, other_____

      i. Insulation type, location and estimated thickness

   b. Floor – Wood frame, concrete, other_____

   c. Roof – Wood frame, metal deck, other_____

      i. Insulation type, location and estimated thickness

   d. Windows – wood frame, metal frame, glazing layers, tint, blinds/curtains

3. *Surface materials* – Apart from the construction type, we collected data on the surface materials, which would help in analyzing the radiant environment and acoustical quality of the space.

   a. Wall – wood paneling, plaster, acoustic tiles, vinyl, other____

      i. Percentage of wall covered in bulletin board or similar surface

      ii. Percentage of add'l wall covered in paper, fabric, or pictures

   b. Floor – wood panels, vinyl, concrete, stone tiles, other ____

   c. Ceiling – wood panels, acoustic tiles, stucco, concrete, other____

   d. Desks – wood, metal, other____

   e. Teaching wall – white board, green board, black board

4. *Window operation* – the surveyors observed the usage of the window features available in the classrooms and noted its impact on the visual and thermal comfort of the classroom.

   a. Operable window status - % windows open

b. Blinds/curtains usage – % of window area covered by the blinds/curtains, blind angle

c. Other window coverings such as paper, furniture etc

d. Daylight penetration – distribution patterns of daylight

e. Glare observations – glare on teaching wall as well as desks. Glare for students when facing windows.

5. Electric lights operation –

   a. Operation status - % ON.

   b. Distribution of electrical lighting

   c. User controls – ease of control of light fixtures

6. HVAC system –

   a. Heat/Cool status – ON/OFF

   b. Supply Fan status – continuous ON, intermittent ON, OFF

   c. Fan noise – hum, mechanical sounds

   d. Portable fans/heaters – number and locations

7. Ventilation quality – these set of observations accounted for distribution of air within the space as well as issues of dust, mold etc.

   a. Air circulation – inadequate, drafty etc

   b. Odor – Moldy, musty, dust, other chemical fumes

   c. Dampness of the air

<u>Measured data</u>

Apart from the observational data collected above, the surveyors also took some quantitative measurements to assess the environmental conditions in the classrooms.

1. Daylight and lighting levels – The surveyors used a handheld illuminance meter to record the ambient light levels in the classroom. Where the teacher or the students expressed interest in the instruments, the surveyors demonstrated the tools to them.
2. Thermal comfort – similar to the lighting measurements, the surveyors recorded the thermal comfort of the classrooms with two tools –

a. Digital thermometer – this tool recorded the ambient air temperatures in the space
b. Infrared thermometer – this tool is a handheld device that measures the radiant or surface temperatures of the various surfaces in the classroom.

3. Acoustic comfort – the surveyors recorded the acoustic levels in the classroom while the class was in session, and then again during unoccupied period to estimate the amount of noise present in the classroom, as well as sound penetration from other sources. A handheld decibel level meter was used for this purpose.

3.2 Classroom Survey Form

Classroom Type: _____ grade level: _____ Teacher Name_____

Windows

Control: ☐ Blinds: % open _____ ☐ Curtains: % open _____
☐ exterior louvers: % open _____ angle_____
☐ cross ventilation available
☐ paper: % covered _____
☐ operable windows: % open _____ % area of total window_____

Ext. Door: ☐ # ext. doors _____ ☐ # doors open _____
☐ # int. doors _____ ☐ # int. doors open _____
☐ # common wall _____ ☐ % common wall open _____

Glare: ☐ source: _____ ☐ severity: _____
☐ surface: _____

Shadows: ☐ balanced ☐ strong side shadows ☐ strong overhead shadows

Lighting

Daylight: ☐ daylight code: _____ (1= no daylight, 5 ideal daylight)
☐ % floor area daylit: _____

Elec. Lights: ☐ % ON_____ ☐ lamp count_____ ☐ burnt out _____

comments:_____

_____

Construction

_____

_____

_____

_____

Insulation:

_____

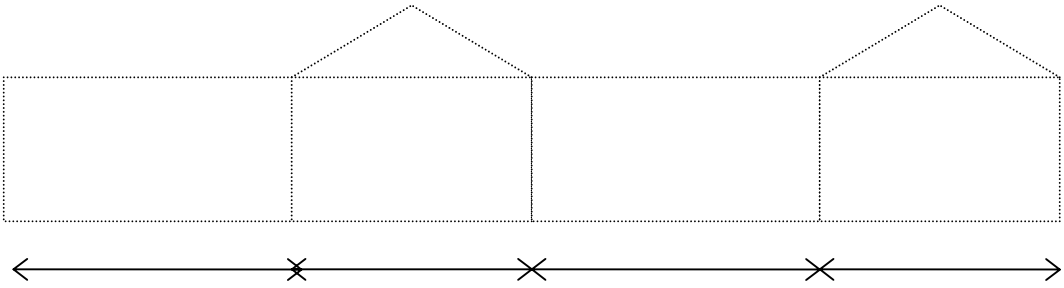
Surfaces

Flooring: ☐ vinyl____% ☐ carpet____% ☐ (_____)____ %

Walls: ☐ wood____% ☐ vinyl____% ☐ paper____% ☐ (_____)____ %

☐ Bulletin boards _____% ☐ blackboards in use____%

Ceiling: ☐ wood____% ☐ acoustic____% ☐ stucco____% ☐ (_____)____%



Environmental Conditions

Air Quality: ☐ stale ☐ moldy/musty ☐ drafty ☐ smell _____ ☐ gag reflex

Damage: ☐ structural ☐ mold ☐ water damage ☐ other _____

HVAC

Mech Ventilation ☐ON ☐OFF ☐ Fan noise, describe_____

Local controls ☐None ☐Manual Over-ride ☐Operational

Portable fan ☐ON ☐OFF ☐None

Teacher complaints & comments: _____

_____

_____

_____

_____

_____

_____

_____

Thermal Comfort

Surveyor comfort ☐hot ☐cold

Students ☐# kids _____ ☐# puffy jackets _____

☐# sweat shirts_____ ☐# short sleeves _____

Thermal comfort comments: _____

_____

_____

_____

Acoustic Conditions

Please note on the following scalar: 1=none/dead, 2=some/noticeable, 3=lively/distracting, 4=intolerable

	1	2	3	4
Traffic noise	☐	☐	☐	☐
Playground noise	☐	☐	☐	☐
Bldg. equipment	☐	☐	☐	☐
Other bldg. noise	☐	☐	☐	☐
Adjacent classroom	☐	☐	☐	☐
Reverberence in classroom	☐	☐	☐	☐

Teacher speech: ☐ very quiet ☐ normal/soft ☐ loud/normal ☐ stressed

Ambient sound level: _____ unoccupied classroom _____ occupied classroom

Illuminance Readings

Elec. Lights ☐ ON ☐ OFF **Blinds** ☐ closed ☐ open, %_____

Cubic _____ window _____ 2T ___ 3 ____ 4 _____ up ___ down

Horizontal _____ 5' from window _____5' from opposite wall

Elec. Lights ☐ ON ☐ OFF **Blinds** ☐ closed ☐ open, %_____

Cubic _____ window _____ 2T ___ 3 ____ 4 _____ up ___ down

Horizontal _____ 5' from window _____5' from opposite wall

Lighting Comments: _____

Temperature Readings

Surface (deg.F) _____ window _____ 1___ 2T ___ 3 _____ 4

_____ ceiling _____ floor

Air temperature _____ 5' from window _____5' from opp. wall ____

_____center of room _____ Supply air temp _____Outside air temp.

Temperature Comments: _____

_____

General Comments:

3.3 Teacher Survey Form

Dear FUSD Teacher,

The Heschong Mahone Group, Inc., an architectural research firm, has been working with the Fresno Unified School District on an innovative study of the relationship of the physical classroom environment and student performance. We are funded by the California Energy Commission to learn more about how teachers manage the physical environment in their classrooms.

Information from this survey will not effect any conditions in your classroom, or policies at the district. It will however, help to inform long term research on the best physical environment for a good learning in our schools.

Please fill out this brief questionnaire and return it to the school secretary some time this week. All responses will remain strictly confidential, and will not be released to the District, or to anyone outside of our immediate research team. Only summary data will be reported.

Thank you for your help!

Lisa Heschong
Principal,
Heschong Mahone Group, Inc.

We would like you to respond to the questions on the following page using the following scale:

N/A This is not possible in my current classroom

0. Never occurs
1. Rarely, occurs 1-5 days a year
2. Occasionally, occurs 6-12 times per year
3. Often, occurs 2-3 times per month
4. Frequently, occurs about once a week or more, all year
5. Almost always, occurs about once a day or more, all year

---

1. Over the course of a year, how often is the temperature in your classroom:

		Never					Always
	N/A	**0**	**1***	**2***	**3***	**4***	**5**
Comfortable	☐	☐	☐	☐	☐	☐	☐
Too hot	☐	☐	☐	☐	☐	☐	☐
Too cold	☐	☐	☐	☐	☐	☐	☐

2. Over the course of a year, how often do you have the following ventilation conditions:

The room has good ventilation	☐	☐	☐	☐	☐	☐	☐
Too drafty	☐	☐	☐	☐	☐	☐	☐
Too stale	☐	☐	☐	☐	☐	☐	☐
Has unpleasant smells	☐	☐	☐	☐	☐	☐	☐

3. Over the course of a year, how often do you have the following acoustic conditions:

	N/A	Never 0	1*	2*	3*	4*	Always 5
My students have a hard time hearing me	☐	☐	☐	☐	☐	☐	☐
Too much noise from outside the building	☐	☐	☐	☐	☐	☐	☐
Too much noise from other rooms	☐	☐	☐	☐	☐	☐	☐
Too much noise from bldg equipment	☐	☐	☐	☐	☐	☐	☐

4. Over the course of a year, how often do you have the following lighting conditions:

Too many reflections on the teaching board	☐	☐	☐	☐	☐	☐	☐
Too much glare from sunlight	☐	☐	☐	☐	☐	☐	☐
Too much distraction from windows	☐	☐	☐	☐	☐	☐	☐
Too much glare from electric lights	☐	☐	☐	☐	☐	☐	☐
Some areas are too dim	☐	☐	☐	☐	☐	☐	☐
Some areas are too bright	☐	☐	☐	☐	☐	☐	☐
Not enough control of the lighting conditions	☐	☐	☐	☐	☐	☐	☐
Not enough natural light	☐	☐	☐	☐	☐	☐	☐
I wish we had a better view of the outside	☐	☐	☐	☐	☐	☐	☐

5. Over the course of a year, how often have you taken any of the following actions?

Closed the window blinds or curtains	☐	☐	☐	☐	☐	☐	☐
Papered over all or part of a window	☐	☐	☐	☐	☐	☐	☐
Opened the windows for air	☐	☐	☐	☐	☐	☐	☐
Left the outside door open for air	☐	☐	☐	☐	☐	☐	☐
Turned on a personal portable fan	☐	☐	☐	☐	☐	☐	☐
Turned off a fan because it was too noisy	☐	☐	☐	☐	☐	☐	☐
Turned off some of the electric lights	☐	☐	☐	☐	☐	☐	☐
Turned off ALL of the electric lights	☐	☐	☐	☐	☐	☐	☐

A. Please provide the following information:

6. Current Grade Level Assignment: _____ School: _____
7. Your current room number (very important!): _____
8. How many years have you been in this classroom? _____
9. How many years have you been at this school? _____
10. Your Name (optional) :_____
11. Any comments?

_____

_____

4. MODEL DESCRIPTIONS AND RESULTS

4.1 Thematic Groups

Classroom Characteristics	***Air Quality***	***Window Characteristics***
Classroom size	School condition-construction	Exterior doors
Class type-Bugalow	School condition-paint	Primary window-none
Class type-common room	School condition-grass	Primary window-East
Class type-double loaded	School condition-asphalt	Primary window-West
Class type- interior corridor	School condition-trees	Prmary window-North
Class type- no doors	Floor type-2nd floor	Primary window-South
Class type-operable walls	Floor type- Slab on Grade	Window-above door area
Class type-single loaded	Floor type- wood grade	Window-desk door area
Teaching wall-Black	School location-dust	Secondary window
Teaching wall-Green	School location-agriculture	Window tint
Equipment-Sink	Room condition-stale	Sun penetration
Equipment-TV	Room condition-water damage	Glare
Equipment-Pet	Room condition-mold/must	View
Computers	Room condition-all new	Operable windows
Security	Room condition-pets	Window control
Room condition-Stale	Rodents	
Room condition-Mold/Must	Sink	
Room condition-water damage	Operable windows	
Room condition-all new	Central HVAC	
	Wall Heating	
	HVAC controls	
	Mechanical ventilation	
	Portable fan	
	Percentage carpet	
	Percentage vinyl wall	

Figure 8: Thematic group variables used for preliminary models (1 of 3)

Acoustics	***Socio-economic***
Classroom-shared wall	Mobility
Classroom-common room	English Learner (EL) %
Classroom-open	Free/Reduced Lunch %
School location-freeway	Average Parent Educ Level
School location-blvd	CalWORKS %
School condition-construction	
Percentage carpet	
Pecent acousitc wall	
Loud ballast hum	
Loud HVAC system	
Central HVAC system	
Operable windows	

Figure 9: Thematic group variables used for preliminary models (2 of 3)

School Characteristics	***Electric Lighting***
School population	Luminaire type-Other
School age	Luminaire type-Indirect
Location-Freeway	Luminaire type-Indirect/Direct
Location-Blvd	Luminaire Condition
Location-Agriculture	Luminaire-ElecBallast
Location-Construction noise	Lamp type-Other
School condition-construction	Lamp type-T8
School condition-paint	Lamp color-3035
School condition-grass	Lamp color-Mixed
School condition-asphalt	Horizontal elecric Illuminance
Shady trees	
Neighborhood-Residential/Commercial	
Neighborhood- lower economic status	
Neighborhood-upper economic status	
Neighborhood-prewar vintage	
Neighborhood-40s/50s vintage	
Neighborhood -80s/90s vintage	

Figure 10: Thematic group variables used for preliminary models (3 of 3)

4.2 Demographic Model

Variable Description	N	MIN	MAX	MEAN	STD	# Yes If Indicator
Fall Math RIT Score	8,518	137.00	255.00	198.02	17.61	
Re-Test for Fall Math	8,518	0.00	1.00	0.03	0.18	292
Third Grade	8,518	0.00	1.00	0.23	0.42	1943
Fourth Grade	8,518	0.00	1.00	0.27	0.44	2291
Fifth Grade	8,518	0.00	1.00	0.26	0.44	2183
% Attendance	8,518	47.20	100.00	95.86	4.26	
Qualified for/Enrolled in GATE	8,518	0.00	1.00	0.18	0.38	1506
Special Ed student	8,518	0.00	1.00	0.09	0.29	785
Student English development	8,518	3.00	6.00	5.69	0.80	
Free lunch	8,518	0.00	1.00	0.42	0.49	3605
Reduced lunch	8,518	0.00	1.00	0.10	0.30	858
Non-Standard living situation	8,518	0.00	1.00	0.01	0.12	117
Student gender	8,518	0.00	1.00	0.50	0.50	4249
Ethnic Student (Type 12)	8,518	0.00	1.00	0.40	0.49	3412
Ethnic Student (Type 13)	8,518	0.00	1.00	0.14	0.35	1189
Ethnic Student (Type 14)	8,518	0.00	1.00	0.10	0.30	840
Ethnic Student (Type 15)	8,518	0.00	1.00	0.01	0.10	81
Ethnic Student (Type 16)	8,518	0.00	1.00	0.01	0.07	43
Ethnic Student (Type 17)	8,518	0.00	1.00	0.00	0.06	31
Multi-Grade classroom	454	0.00	1.00	0.11	0.32	52
Annual salary (per $1000)	454	23.41	72.62	55.55	10.01	
# Years at FUSD	454	1.00	41.00	12.47	8.17	
Mentor teacher	454	0.00	1.00	0.07	0.26	34
Pre-Tenure teacher	454	0.00	1.00	0.03	0.18	15
Long-Term substitute teacher	454	0.00	1.00	0.05	0.22	24
Part time position	454	0.00	1.00	0.01	0.11	6
Outlier Student	8,518	0.00	1.00	0.00	0.01	1
Outlier Student	8,518	0.00	1.00	0.00	0.01	1
Outlier Student	8,518	0.00	1.00	0.00	0.01	1
Outlier Student	8,518	0.00	1.00	0.00	0.01	1
Outlier Student	8,518	0.00	1.00	0.00	0.01	1
Outlier Student	8,518	0.00	1.00	0.00	0.01	1
Outlier Student	8,518	0.00	1.00	0.00	0.01	1
Outlier Student	8,518	0.00	1.00	0.00	0.01	1
Outlier Student	8,518	0.00	1.00	0.00	0.01	1
Outlier Student	8,518	0.00	1.00	0.00	0.01	1
Outlier Student	8,518	0.00	1.00	0.00	0.01	1
Outlier Student	8,518	0.00	1.00	0.00	0.01	1
Outlier Student	8,518	0.00	1.00	0.00	0.01	1
Outlier Student	8,518	0.00	1.00	0.00	0.01	1
Outlier Student	8,518	0.00	1.00	0.00	0.01	1
Outlier Student	8,518	0.00	1.00	0.00	0.01	1
Outlier Student	8,518	0.00	1.00	0.00	0.01	1
Outlier Student	8,518	0.00	1.00	0.00	0.01	1

Figure 11: Base demographic model- math descriptive statistics

Variable Description	B	Std. Error	t	Sig.
Constant	28.47	1.99	14.32	0.000
Fall Math RIT Score	-0.15	0.01	-25.32	0.000
Re-Test for Fall Math	3.52	0.36	9.85	0.000
Third Grade	-1.22	0.24	-5.06	0.000
Fourth Grade	-2.71	0.20	-13.68	0.000
Fifth Grade	-1.06	0.18	-5.74	0.000
% Attendance	0.09	0.02	5.61	0.000
Enrolled in GATE	3.34	0.20	16.45	0.000
Special Ed Student	-2.32	0.24	-9.72	0.000
Student English development	0.48	0.09	5.52	0.000
Free lunch	-0.60	0.14	-4.36	0.000
Student gender	-0.91	0.13	-7.12	0.000
Ethnic Student (Type 12)	-1.18	0.15	-8.09	0.000
Ethnic Student (Type 13)	-1.68	0.21	-8.06	0.000
Ethnic Student (Type 15)	-1.35	0.67	-2.02	0.043
Ethnic Student (Type 16)	1.67	0.90	1.85	0.064
Multi-Grade classroom	-1.43	0.22	-6.44	0.000
Annual salary (per $1000)	0.03	0.01	3.44	0.001
# Years at FUSD	-0.02	0.01	-2.14	0.033
Mentor teacher	1.07	0.25	4.22	0.000
Pre-Tenure teacher	0.96	0.38	2.53	0.011
Outlier Student	-23.78	5.90	-4.03	0.000
Outlier Student	-24.54	5.92	-4.14	0.000
Outlier Student	23.87	5.89	4.05	0.000
Outlier Student	34.89	5.89	5.92	0.000
Outlier Student	31.22	5.89	5.30	0.000
Outlier Student	-28.65	5.89	-4.87	0.000
Outlier Student	26.11	5.89	4.43	0.000
Outlier Student	-21.87	5.89	-3.71	0.000
Outlier Student	23.02	5.88	3.91	0.000
Outlier Student	21.68	5.89	3.68	0.000
Outlier Student	20.60	5.90	3.49	0.001
Outlier Student	23.53	5.89	3.99	0.000
Outlier Student	19.24	5.88	3.27	0.001
Outlier Student	-24.35	5.90	-4.13	0.000
Outlier Student	-20.22	5.89	-3.43	0.001
Outlier Student	22.92	5.90	3.89	0.000
Outlier Student	19.81	5.88	3.37	0.001
Outlier Student	-23.16	5.90	-3.93	0.000

Model Summary:	
RMSE	5.88
R^2	17.0%

Figure 12: Base demographic math model

Variable Description	N	MIN	MAX	MEAN	STD	# Yes If Indicator
Fall Reading RIT Score	8342	138	252	195.60	18.15	
Re-Test for Fall Reading	8342	0	1	0.06	0.23	466
Third Grade	8342	0	1	0.23	0.42	1907
Fourth Grade	8342	0	1	0.27	0.44	2252
Fifth Grade	8342	0	1	0.26	0.44	2129
% Attendance	8342	52.2	100	95.85	4.26	
Qualified for/Enrolled in GATE	8342	0	1	0.18	0.38	1463
Special Ed Student	8342	0	1	0.09	0.29	754
Student English Development	8342	3	6	5.68	0.80	
Free lunch	8342	0	1	0.42	0.49	3543
Reduced lunch	8342	0	1	0.10	0.30	838
Non-Standard living situation	8342	0	1	0.01	0.12	115
Student gender	8342	0	1	0.50	0.50	4150
Ethnic Student (Type 12)	8342	0	1	0.40	0.49	3331
Ethnic Student (Type 13)	8342	0	1	0.14	0.35	1157
Ethnic Student (Type 14)	8342	0	1	0.10	0.30	829
Ethnic Student (Type 15)	8342	0	1	0.01	0.10	82
Ethnic Student (Type 16)	8342	0	1	0.01	0.07	44
Ethnic Student (Type 17)	8342	0	1	0.00	0.06	29
Multi-Grade classroom	452	0	1	0.12	0.32	52
Annual salary (per $1000)	452	23.41	72.62	55.50	10.02	
# Years at FUSD	452	1	41	12.45	8.18	
Mentor teacher	452	0	1	0.08	0.26	34
Pre-Tenure teacher	452	0	1	0.03	0.18	15
Long-Term substitute teacher	452	0	1	0.05	0.22	24
Part time position	452	0	1	0.01	0.11	6
Outlier Student	8342	0	1	0.00	0.01	1
Outlier Student	8342	0	1	0.00	0.01	1
Outlier Student	8342	0	1	0.00	0.01	1
Outlier Student	8342	0	1	0.00	0.01	1
Outlier Student	8342	0	1	0.00	0.01	1
Outlier Student	8342	0	1	0.00	0.01	1
Outlier Student	8342	0	1	0.00	0.01	1
Outlier Student	8342	0	1	0.00	0.01	1

Figure 13: Base demographic model- reading descriptive statistics

Variable Description	B	Std. Error	t	Sig.
Constant	38.72	1.81	21.43	0.000
Fall Reading RIT Score	-0.19	0.00	-42.42	0.000
Re-Test for fall reading	2.46	0.28	8.93	0.000
Fourth Grade	-1.14	0.15	-7.55	0.000
Fifth Grade	-0.76	0.16	-4.81	0.000
% Attendance	0.05	0.02	3.23	0.001
Enrolled in GATE	1.36	0.19	7.16	0.000
Special Ed student	-2.03	0.23	-8.71	0.000
Student English development	0.46	0.08	5.48	0.000
Free lunch	-0.42	0.14	-3.13	0.002
Non-Standard living situation	-1.37	0.54	-2.54	0.011
Student gender	-0.27	0.13	-2.17	0.030
Ethnic Student (Type 12)	-0.59	0.14	-4.19	0.000
Ethnic Student (Type 13)	-1.25	0.20	-6.19	0.000
Multi-Grade classroom	-0.97	0.21	-4.54	0.000
Annual salary (per $1000)	0.01	0.01	2.20	0.028
Outlier Student	-21.29	5.72	-3.72	0.000
Outlier Student	-24.01	5.72	-4.20	0.000
Outlier Student	24.71	5.71	4.32	0.000
Outlier Student	21.28	5.72	3.72	0.000
Outlier Student	-19.24	5.72	-3.37	0.001
Outlier Student	-20.17	5.71	-3.53	0.000
Outlier Student	-21.40	5.72	-3.74	0.000
Outlier Student	-21.31	5.71	-3.73	0.000
Outlier Student	21.86	5.72	3.82	0.000

Model Summary:	
RMSE	5.71
R^2	23.5%

Figure 14: Base demographic reading model

4.3 Final Models

Variable Description	N	MIN	MAX	MEAN	STD	# Yes If Indicator
Math Gain	8518	-18	50	9.04	6.44	
Student level variables						
Fall math RIT score	8,518	137.00	255.00	198.02	17.61	
Re-test for fall math	8,518	0.00	1.00	0.03	0.18	292
Third grade	8,518	0.00	1.00	0.23	0.42	1943
Fourth grade	8,518	0.00	1.00	0.27	0.44	2291
Fifth grade	8,518	0.00	1.00	0.26	0.44	2183
Percentage attendance	8,518	47.20	100.00	95.86	4.26	
Qualified for/Enrolled in GATE	8,518	0.00	1.00	0.18	0.38	1506
Special Ed Student	8,518	0.00	1.00	0.09	0.29	785
Student English development	8,518	3.00	6.00	5.69	0.80	
Free lunch	8,518	0.00	1.00	0.42	0.49	3605
Student gender	8,518	0.00	1.00	0.50	0.50	4249
Ethnic student (Type 12)	8,518	0.00	1.00	0.40	0.49	3412
Ethnic student (Type 13)	8,518	0.00	1.00	0.14	0.35	1189
Ethnic student (Type 15)	8,518	0.00	1.00	0.01	0.10	81
Ethnic student (Type 16)	8,518	0.00	1.00	0.01	0.07	43
Teacher level variables						
Multi-grade classroom	454	0.00	1.00	0.11	0.32	52
Annual salary (per $1000)	454	23.41	72.62	55.55	10.01	
Number of years at FUSD	454	1.00	41.00	12.47	8.17	
Mentor teacher	454	0.00	1.00	0.07	0.26	34
Pre-tenure teacher	454	0.00	1.00	0.03	0.18	15
School Socio-economic Characteristics						
School mobility	36	0.042	0.677	0.35	0.16	
School English learner (EL)%	36	0.014	0.505	0.21	0.14	
School free/reduced lunch %	36	0.093	0.982	0.67	0.29	
School parent education	36	1.6	3.89	2.57	0.65	
School CalWork%	36	0	0.573	0.26	0.16	
School Characteristics						
Number of students in school	36	298.00	871.00	635.94	138.94	
Age of school in 2000	36	20.00	60.00	41.36	11.54	
School near freeway or flypath	36	0.00	1.00	0.17	0.38	6
School near bvd	36	0.00	1.00	0.53	0.51	19
School near agriculture (fields/orchard/animals)	36	0.00	1.00	0.08	0.28	3
School near construction noise	36	0.00	1.00	0.19	0.40	7
Neighborhood is residential and commercial	36	0.00	1.00	0.33	0.48	12
Neighborhood is lower economic status	36	0.00	1.00	0.19	0.40	7
Neighborhood upper/affluent economic status	36	0.00	1.00	0.28	0.45	10
Neighborhood is prewar vintage	36	0.00	1.00	0.08	0.28	3
Neighborhood is 40s/50s vintage	36	0.00	1.00	0.36	0.49	13
Neighborhood is 80s/90s vintage	36	0.00	1.00	0.06	0.23	2
Site construction (1-5 = None - Major)	36	1.00	5.00	2.03	1.61	
Paint condition (1-5 = Dilapidated - Fresh)	36	2.00	5.00	3.53	0.88	
Grass condition (1-5 = Bare Dirt - Lush)	36	2.00	5.00	2.97	0.94	
Asphalt condition (1-5 = Deteriorated - Fresh)	36	1.00	4.00	2.83	0.85	
Shade trees (1-5 = None - Many, big)	36	1.00	5.00	2.81	0.98	

Figure 15: Final math descriptive statistics (1 of 2)

Variable Description	N	MIN	MAX	MEAN	STD	# Yes If Indicator
Classroom Characteristics						
Room area (sf)	454	1.00	3.00	1.74	0.53	
Bungalow classroom	454	0.00	1.00	0.02	0.13	8
Portable classroom	454	0.00	1.00	0.54	0.50	246
Common Room classroom	454	0.00	1.00	0.07	0.26	34
Double Loaded classroom	454	0.00	1.00	0.07	0.26	33
Interior Corridor classroom	454	0.00	1.00	0.02	0.13	8
No Doors classrooms	454	0.00	1.00	0.07	0.26	32
Operable Walls classroom	454	0.00	1.00	0.06	0.24	27
White teaching board	454	0.00	1.00	0.52	0.50	238
Black teaching board	454	0.00	1.00	0.07	0.26	34
Sink in classroom	454	0.00	1.00	0.43	0.50	197
No TV in classroom	454	0.00	1.00	0.28	0.45	128
Number of computers	454	0.00	20.00	2.27	2.91	
Security measures on windows	454	0.00	1.00	0.12	0.32	54
Window Characteristics						
Daylight Code	454	0.00	5.00	2.12	1.27	
Two exterior doors	454	0.00	1.00	0.08	0.27	38
No primary window wall	454	0.00	1.00	0.01	0.09	4
Primary window wall faces east	454	0.00	1.00	0.10	0.31	47
Primary window wall faces west	454	0.00	1.00	0.07	0.26	33
Primary window wall faces south	454	0.00	1.00	0.32	0.47	144
Window area above door	454	0.00	33.20	3.30	6.95	
Window area desk-door	454	0.00	19.20	6.21	3.62	
No secondary window wall	454	0.00	1.00	0.32	0.47	147
Tint	454	0.00	2.00	0.73	0.81	
Sun penetration	454	0.00	4.00	1.89	1.33	
Glare from windows	454	0.00	4.00	2.20	1.01	
View distance	454	0.00	3.00	2.37	0.86	
Not operable windows	454	0.00	1.00	0.29	0.45	130
No blinds or curtains	454	0.00	1.00	0.46	0.50	207
Vegetation in view	454	0.00	1.00	0.91	0.28	411
Activity in view	454	0.00	1.00	0.91	0.28	411
Air Quality & HVAC Characteristics						
Construction dust	454	0.00	1.00	0.19	0.40	88
water damage	454	0.00	1.00	0.03	0.16	12
Musty/Moldy air in classroom	454	0.00	1.00	0.10	0.31	47
All new classroom	454	0.00	1.00	0.01	0.10	5
Pets in classroom	454	0.00	1.00	0.02	0.13	8
Rodents under or in classroom	454	0.00	1.00	0.04	0.18	16
Central HVAC system	454	0.00	1.00	0.39	0.49	177
Wall mounted heating unit	454	0.00	1.00	0.42	0.49	189
No controls for HVAC in classroom	454	0.00	1.00	0.43	0.50	196
No mechanical ventilation control	454	0.00	1.00	0.35	0.48	157
Portable fan	454	0.00	1.00	0.07	0.25	30
Percentage of floor that is carpet	454	0.00	100.00	83.70	34.31	
Percentage of wall that is vinyl	454	0.00	100.00	80.52	32.39	
Electric Light Characteristics						
Luminaire is Indirect	454	0.00	1.00	0.06	0.24	28
Luminaire is Indirect/Direct	454	0.00	1.00	0.08	0.27	35
Luminaire condition	454	0.00	3.00	1.83	0.80	
Electronic ballast	454	0.00	1.00	0.09	0.29	41
T8 lamp	454	0.00	1.00	0.09	0.29	41
Lamp color is <3500	454	0.00	1.00	0.10	0.31	47
Mixed florescent or can't tell	454	0.00	1.00	0.19	0.39	86
Ave horizontal electric illuminance	454	0.00	110.50	43.62	17.68	
Acoustic Characteristics						
Pecent acousitc wall	454	0.00	70.00	3.80	10.71	
Loud ballast hum	454	0.00	1.00	0.04	0.20	19
Loud HVAC system	454	0.00	1.00	0.04	0.19	17

Figure 16: Final math descriptive statistics (2 of 2)

Variable Description	B	Std. Error	t	Sig.	Consistent
Constant	29.51	2.25	13.10	0.000	
Fall math RIT score	-0.16	0.01	-26.98	0.000	
Re-test for fall math	3.54	0.35	9.99	0.000	
Student level variables					
Third grade	-1.39	0.25	-5.62	0.000	
Fourth grade	-2.80	0.20	-14.03	0.000	Yes
Fifth grade	-1.01	0.19	-5.35	0.000	
Percentage attendance	0.08	0.02	5.01	0.000	
Enrolled in GATE	3.32	0.21	15.61	0.000	Yes
Special Ed student	-2.52	0.24	-10.58	0.000	Yes
Student English development	0.37	0.09	4.08	0.000	Yes
Free lunch	-0.47	0.14	-3.34	0.001	Yes
Student gender	-0.91	0.13	-7.20	0.000	Yes
Ethnic student (Type 12)	-0.91	0.15	-6.06	0.000	Yes
Ethnic student (Type 13)	-1.54	0.21	-7.27	0.000	Yes
Ethnic student (Type 15)	-1.17	0.66	-1.76	0.078	
Ethnic student (Type 16)	1.80	0.89	2.02	0.044	
Teacher level variables					
Multi-grade classroom	-1.23	0.23	-5.27	0.000	Yes
Annual salary	0.04	0.01	3.80	0.000	
Number of years at FUSD	-0.03	0.01	-2.65	0.008	
Mentor teacher	0.76	0.27	2.83	0.005	
Pre-tenure teacher	1.15	0.38	2.98	0.003	
School Socio-economic Characteristics					
School English learner (EL)%	3.30	1.37	2.41	0.016	Reverses
School parent education	0.97	0.25	3.90	0.000	Yes
School Characteristics					
Age of school in 2000	-0.03	0.01	-4.33	0.000	
Neighborhood is lower economic status	-1.16	0.28	-4.13	0.000	
Neighborhood is prewar vintage	1.48	0.43	3.45	0.001	Yes
Neighborhood is 40s/50s vintage	0.63	0.17	3.68	0.000	
Paint condition	0.22	0.10	2.17	0.030	
Classroom Characteristics					
Interior corridor classroom	-2.73	0.71	-3.83	0.000	
Operable walls classroom	1.26	0.31	4.08	0.000	
White teaching board	0.75	0.15	4.96	0.000	
Computers	0.15	0.03	5.86	0.000	Yes
Security measures on windows	-0.82	0.24	-3.36	0.001	Yes
Window Characteristics					
Daylight Code	-0.40	0.13	-3.17	0.002	Yes
Primary window wall faces east	-1.12	0.23	-4.96	0.000	Yes
Window area above door	0.06	0.02	2.59	0.010	
Glare from windows	-0.20	0.08	-2.54	0.011	
No blinds or curtains	-0.42	0.16	-2.72	0.007	
Vegetation in view	0.93	0.26	3.53	0.000	
Air Quality & HVAC Characteristics					
Pets in classroom	-1.88	0.59	-3.20	0.001	
Central HVAC system	-0.64	0.25	-2.53	0.011	
Wall mounted heating unit	0.44	0.15	2.85	0.004	
No teacher control of fan	0.63	0.25	2.53	0.011	
Acoustic Characteristics					
Loud HVAC system	-1.52	0.40	-3.79	0.000	

Model Summary:	
RMSE	5.81
R^2	19.2%

Figure 17: Final math model results

Variable Description	N	MIN	MAX	MEAN	STD	# Yes If Indicator
Reading Gain	8410	-17	37	8.47	6.51	
Student level variables						
Fall reading RIT Score	8342	138	252	195.60	18.15	
Re-test for fall reading	8342	0	1	0.06	0.23	466
Fourth grade	8342	0	1	0.27	0.44	2252
Fifth grade	8342	0	1	0.26	0.44	2129
Percentage attendance	8342	52.2	100	95.85	4.26	
Qualified for/Enrolled in GATE	8342	0	1	0.18	0.38	1463
Special ed student	8342	0	1	0.09	0.29	754
Student English development	8342	3	6	5.68	0.80	
Free lunch	8342	0	1	0.42	0.49	3543
Non-Standard living situation	8342	0	1	0.01	0.12	115
Student gender	8342	0	1	0.50	0.50	4150
Ethnic student (Type 12)	8342	0	1	0.40	0.49	3331
Ethnic student (Type 13)	8342	0	1	0.14	0.35	1157
Teacher level variables						
Multi-grade classroom	452	0	1	0.12	0.32	52
Annual salary (per $1000)	452	23.41	72.62	55.50	10.02	
School Socio-economic Characteristics						
School mobility	36	0.04	0.68	0.35	0.16	
School English learner (EL)%	36	0.01	0.51	0.21	0.14	
School free/reduced lunch %	36	0.09	0.98	0.67	0.29	
School parent education	36	1.60	3.89	2.57	0.65	
School CalWork%	36	0.00	0.57	0.26	0.16	
School Characteristics						
# of students in school	36	298.00	871.00	635.94	138.94	
Age of school in 2000	36	20.00	60.00	41.36	11.54	
School near freeway or flypath	36	0.00	1.00	0.17	0.38	6
School near blvd	36	0.00	1.00	0.53	0.51	19
School near agriculture (fields/orchard/animals)	36	0.00	1.00	0.08	0.28	3
School near construction noise	36	0.00	1.00	0.19	0.40	7
Neighborhood -residential and commercial	36	0.00	1.00	0.33	0.48	12
Neighborhood- lower economic status	36	0.00	1.00	0.19	0.40	7
Neighborhood upper/affluent economic status	36	0.00	1.00	0.28	0.45	10
Neighborhood is prewar vintage	36	0.00	1.00	0.08	0.28	3
Neighborhood is 40s/50s vintage	36	0.00	1.00	0.36	0.49	13
Neighborhood is 80s/90s vintage	36	0.00	1.00	0.06	0.23	2
Site construction (1-5 = None - Major)	36	1.00	5.00	2.03	1.61	
Paint condition (1-5 = Dilapidated - Fresh)	36	2.00	5.00	3.53	0.88	
Grass condition (1-5 = Bare Dirt - Lush)	36	2.00	5.00	2.97	0.94	
Asphalt condition (1-5 = Deteriorated - Fresh)	36	1.00	4.00	2.83	0.85	
Shade trees (1-5 = None - Many, big)	36	1.00	5.00	2.81	0.98	
Classroom Characteristics						
Room area (sf)	452	1.00	3.00	1.74	0.53	
Bungalow classroom	452	0.00	1.00	0.02	0.13	8
Portable classroom	452	0.00	1.00	0.54	0.50	246
Common room classroom	452	0.00	1.00	0.08	0.26	34
Double loaded classroom	452	0.00	1.00	0.07	0.26	33
Interior corridor classroom	452	0.00	1.00	0.02	0.13	8
No doors classrooms	452	0.00	1.00	0.07	0.25	31
Operable walls classroom	452	0.00	1.00	0.06	0.24	27
White teaching board	452	0.00	1.00	0.52	0.50	236
Black teaching board	452	0.00	1.00	0.08	0.26	34
Sink in classroom	452	0.00	1.00	0.43	0.50	195
No TV in classroom	452	0.00	1.00	0.28	0.45	128
Numberof computers	452	0.00	20.00	2.29	2.92	
Security measures on windows	452	0.00	1.00	0.12	0.32	53

Figure 18: Final reading descriptive statistics (1 of 2)

Variable Description	N	MIN	MAX	MEAN	STD	# Yes If Indicator
Window Characteristics						
Daylight Code	452	0.00	5.00	2.12	1.27	
Two exterior doors	452	0.00	1.00	0.08	0.27	38
No primary window wall	452	0.00	1.00	0.01	0.09	4
Primary window wall faces east	452	0.00	1.00	0.10	0.31	47
Primary window wall faces west	452	0.00	1.00	0.07	0.26	33
Primary window wall faces south	452	0.00	1.00	0.32	0.47	143
Window area above door	452	0.00	33.20	3.27	6.94	
Window area desk-door	452	0.00	19.20	6.21	3.62	
No secondary window wall	452	0.00	1.00	0.33	0.47	147
Tint	452	0.00	2.00	0.72	0.81	
Sun penetration	452	0.00	4.00	1.89	1.34	
Glare from windows	452	0.00	4.00	2.20	1.00	
View distance	452	0.00	3.00	2.38	0.86	
Not operable windows	452	0.00	1.00	0.29	0.45	130
No blinds or curtains	452	0.00	1.00	0.46	0.50	206
Vegetation in view	452	0.00	1.00	0.91	0.28	412
Activity in view	452	0.00	1.00	0.91	0.28	412
Air Quality & HVAC Characteristics						
Construction dust	452	0.00	1.00	0.19	0.40	88
water damage	452	0.00	1.00	0.03	0.16	12
Musty/Moldy air in classroom	452	0.00	1.00	0.10	0.30	45
All new classroom	452	0.00	1.00	0.01	0.10	5
Pets in classroom	452	0.00	1.00	0.02	0.13	8
Rodents under or in classroom	452	0.00	1.00	0.04	0.19	16
Sink in clasroom	452	0.00	1.00	0.43	0.50	195
Central HVAC system	452	0.00	1.00	0.39	0.49	175
Wall mounted heating unit	452	0.00	1.00	0.42	0.49	188
No controls for HVAC in classroom	452	0.00	1.00	0.43	0.50	194
No mechanical ventilation control	452	0.00	1.00	0.34	0.48	155
Portable fan	452	0.00	1.00	0.06	0.25	29
Percentage floor that is carpet	452	0.00	100.00	83.41	34.59	
Percentage wall that is vinyl	452	0.00	100.00	80.90	32.08	
Electric Light Characteristics						
Luminaire is indirect	452	0.00	1.00	0.06	0.24	28
Luminaire is indirect/direct	452	0.00	1.00	0.08	0.27	35
Luminaire condition	452	0.00	3.00	1.83	0.79	
T8 lamp	452	0.00	1.00	0.09	0.29	41
Lamp color is <3500	452	0.00	1.00	0.10	0.31	47
Mixed florescent or can't tell	452	0.00	1.00	0.19	0.39	86
Ave horizontal electric illuminance	452	0.00	110.50	43.70	17.73	
Acoustic Characteristics						
Pecent acousitc wall	452	0.00	70.00	3.86	10.76	
Loud ballast hum	452	0.00	1.00	0.04	0.20	19
Loud HVAC system	452	0.00	1.00	0.04	0.19	17

Figure 19: Final reading descriptive statistics (2 of 2)

Variable Description	B	Std. Error	t	Sig.	Consistent
Constant	37.59	2.71	13.87	0.000	
Fall reading RIT score	-0.20	0.00	-43.69	0.000	
Re-test for fall reading	2.53	0.27	9.35	0.000	
Student Level Variables					
Fourth grade	-1.09	0.15	-7.11	0.000	Yes
Fifth grade	-0.74	0.16	-4.68	0.000	
Percentage attendance	0.04	0.02	2.52	0.012	Yes
Enrolled in GATE	1.33	0.22	6.18	0.000	Yes
Special Ed student	-2.27	0.23	-9.79	0.000	Yes
Student English development	0.30	0.09	3.45	0.001	Yes
Free lunch	-0.45	0.14	-3.23	0.001	Yes
Non-standard living situation	-1.32	0.53	-2.48	0.013	
Student gender	-0.22	0.12	-1.75	0.079	Yes
Ethnic student (Type 12)	-0.33	0.15	-2.26	0.024	Yes
Ethnic student (Type 13)	-0.97	0.20	-4.74	0.000	Yes
Teacher Level Variables					
Multi-Grade classroom	-0.62	0.22	-2.77	0.006	Yes
Socio-economic Characteristics					
School mobility	8.69	2.15	4.05	0.000	
School English learner	-7.77	1.84	-4.22	0.000	Reverses
School free/reduced lunch	2.69	1.17	2.30	0.022	
School parent education	1.02	0.46	2.22	0.027	Yes
School CalWork	-6.09	2.29	-2.66	0.008	
School Characteristics					
Students in school	-0.004	0.001	-4.22	0.000	
School near blvd	0.52	0.27	1.93	0.054	
School near construction noise	1.08	0.22	4.96	0.000	
Neighborhood is residential/commercial	1.42	0.31	4.66	0.000	
Neighborhood is upper economic status	1.18	0.37	3.16	0.002	
Neighborhood is prewar vintage	0.94	0.44	2.15	0.032	Yes
Grass condition	0.37	0.09	3.91	0.000	
Classroom Characteristics					
Room area	0.31	0.18	1.70	0.088	
No doors classrooms	-1.04	0.39	-2.65	0.008	
Number of computers	0.09	0.03	3.10	0.002	Yes
Security measures on windows	-0.71	0.26	-2.70	0.007	Yes
Window Characteristics					
Daylighting Code	-0.49	0.12	-3.97	0.000	Yes
Two exterior doors	0.86	0.37	2.30	0.022	
Primary window wall faces east	-0.65	0.24	-2.65	0.008	Yes
Primary window wall faces south	-0.76	0.15	-5.05	0.000	
Window area desk-door	0.12	0.04	2.78	0.006	
No blinds or curtains	-0.40	0.16	-2.56	0.010	
Activity in view	0.52	0.27	1.96	0.050	
Air Quality Characteristics					
Water damage visable	-1.29	0.51	-2.53	0.012	
Musty/Moldy air in classroom	-0.85	0.26	-3.30	0.001	
No teacher control of fan	0.87	0.24	3.67	0.000	
Percentage carpet	0.01	0.00	2.24	0.025	
Electric Light Characteristics					
T8 lamps	1.00	0.59	1.70	0.090	
Lamp color is warm (CCT<3500)	-1.33	0.58	-2.28	0.022	
Mixed fluorescent (poor lighting maintenance)	-0.47	0.22	-2.13	0.033	
Acoustic Characteristics					
Loud ballast hum	-1.59	0.34	-4.70	0.000	

Model Summary:	
RMSE	5.64
R^2	25.5%

Figure 20: Final reading model results

Variable Description	Order of Entry	Partial R^2
Fall math RIT score	1	0.043
Enrolled in GATE	2	0.028
Fourth grade	3	0.015
Re-test for fall math	4	0.012
School English learner (EL)%	5	0.010
Special Ed student	6	0.010
Student gender	7	0.005
Outlier student	8	0.003
Percentage attendance	9	0.003
Multi-grade classroom	10	0.003
Outlier student	11	0.003
Outlier student	12	0.003
Primary window wall faces east	13	0.003
Ethnic student (Type 13)	14	0.002
Ethnic student (Type 12)	15	0.004
Outlier student	16	0.002
Outlier student	17	0.002
Number of computers	18	0.002
Outlier student	19	0.002
Security measures on windows	20	0.002
Age of school in 2000	21	0.002
School English development	22	0.002
Outlier student	23	0.002
Outlier student	24	0.002
Outlier student	25	0.002
Outlier student	26	0.002
Outlier student	27	0.001
Outlier student	28	0.001
Outlier student	29	0.001
Outlier student	30	0.001
Outlier student	31	0.001
Outlier student	32	0.001
Outlier student	33	0.001
Mentor teacher	34	0.001
Outlier student	35	0.001
Free lunch	36	0.001
White teaching board	37	0.001
Fifth grade	38	0.001
Third grade	39	0.003
Operable walls classroom	40	0.001
Neighborhood is 40s/50s vintage	41	0.001
Wall mounted heating unit	42	0.001
Loud HVAC system	43	0.001
Pets in classroom	44	0.001
Pre-tenure teacher	45	0.001
Annual salary (per $1000)	46	0.001
Number of years at FUSD	47	0.001
School parent education	48	0.001
Vegetation in view	49	0.001
Glare from windows	50	0.001
Neighborhood-lower economic status	51	0.001
Interior corridor classroom	52	0.001
Neighborhood is prewar vintage	53	0.001
No blinds or curtains	54	0.000
Ethnic student (Type 16)	55	0.000
Paint condition, worse to better	56	0.000
Ethnic student (Type 15)	57	0.000
Daylight Code	58	0.000
Window area above door (high)	59	0.001
Central HVAC system	60	0.000
No teacher control of fan	61	0.001

Figure 21: Partial R^2 values for math model

Variable Description	Order of Entry	Partial R^2
Fall reading RIT score	1	0.183
School English learner %	2	0.011
Special Ed student	3	0.009
Re-test for fall reading	4	0.007
Enrolled in GATE	5	0.004
Fourth grade	6	0.004
Fifth grade	7	0.004
School near construction noise	8	0.002
Loud ballast hum	9	0.002
Ethnic student (Type 13)	10	0.002
Outlier student	11	0.002
Outlier student	12	0.002
Outlier student	13	0.001
Outlier student	14	0.001
Outlier student	15	0.001
Security measures on windows	16	0.001
Primary window wall faces south	17	0.001
Outlier student	18	0.001
Outlier student	19	0.001
Outlier student	20	0.001
Free lunch	21	0.001
Outlier student	22	0.001
School English development	23	0.001
Percentage attendance	24	0.001
Daylighting Code	25	0.001
No blinds or curtains	26	0.001
Multi-grade classroom	27	0.001
Non-standard living situation	28	0.001
Primary window wall faces east	29	0.001
Neighborhood is residential and commercial	30	0.001
Musty/Moldy air in classroom	31	0.001
No teacher control of fan	32	0.000
Ethnic student (Type 12)	33	0.000
T8 lamp	34	0.000
Window area desk-door	35	0.000
Mixed florescent or can't tell	36	0.000
School near blvd	37	0.000
Number of computers	38	0.000
Grass condition (1-5 = Bare Dirt - Lush)	39	0.000
School mobility	40	0.000
Student gender	41	0.000
No doors classrooms	42	0.000
# of students in school	43	0.000
Neighborhood is prewar vintage	44	0.000
Lamp color is <3500	45	0.000
Percentage of floor that is carpet	46	0.000
Neighborhood is upper economic status	47	0.000
Two exterior doors	48	0.000
Water damage	49	0.000
School CalWork%	50	0.000
Room area (sf)	51	0.000
Activity in view	52	0.000
School free/reduced lunch %	53	0.000
School parent education	54	0.001

Figure 22: Partial R2 values for Reading Model

5. MEAN RADIANT TEMPERATURE ANALYSIS

5.1.1 Introduction

This study was done to make an assessment of thermal comfort conditions due to radiant heat from the surroundings surfaces inside two types of typical classrooms of the Fresno Unified School District (written as FUSD from here on). Our hypothesis was that thermal comfort of students in a classroom with larger windows and old construction would be different from one with smaller windows and newer construction, and hence has an effect on their performance. It was assumed that air temperature was maintained constant by the classrooms' HVAC system at a comfortable temperature and hence the contribution of heat transfer through convection on the students' thermal comfort was neutral.

On the other hand, radiant temperature of wall, roof and floor surfaces in an indoor environment can have a major influence on the thermal comfort of an occupant. Heat transferred by radiation between the occupants' body and the surrounding surfaces can alter the perception of warmth or cool by the occupant.

In this study, we have used mean radiant temperature (written as MRT from here on) to assess comfort due to radiant heat transfer. To get an hourly assessment of MRT, simulation software called RadTherm was used.

Two types of classrooms were modeled in RadTherm, a typical finger plan and a typical pinwheel plan. These two classroom types exemplify the extremes of conditions found in FUSD. The finger plan classroom typifies the FUSD classroom with the maximum amount of daylight, while the pinwheel plan typifies those classrooms with minimal daylighting. Using the TMY weather files for Fresno, and also for Seattle and Capistrano, simulations were run for the first three days of February, May, August and October for each of the two classroom types. These four months were chosen to consider the extreme winter and summer conditions (February and August) and to capture conditions for fall and spring months during which tests are given to students (May and October).

This report describes the methodology and results of the analysis done on radiant comfort.

5.1.2 Simulation Capabilities of RadTherm

RadTherm is a proprietary[1] thermal analysis software for computer aided engineering applications. RadTherm utilizes a state-of-the-art radiation module and a user friendly graphical user interface to set up boundary conditions for

[1] RadTherm is a property of ThermoAnalytics Inc.

multi-mode heat transfer: multi-bounce radiation, conduction and convection with one-dimensional fluid flow.

In RadTherm, boundary conditions for natural environments can be imported from weather files and solar loads predicted from RadTherm's built-in solar model or applied from measurements. This capability of RadTherm made it possible to model a building (or part of building as in our case) and measure its indoor mean radiant temperature. The heat transfer design codes in RadTherm evaluate solar loading, multiple bounce radiation exchange, interaction with the terrain, shadows, wind, rain, and interior/exterior convection. It also models direct solar radiation through transparent objects such as windows.

The simulation in RadTherm was run at a 30-minute time step for three consecutive days for each of the four months considered. The program creates a graphic output, which is viewed as an animation on the screen with color codes designating the temperature of the various thermal nodes in the building. A final output in the form of a text file giving temperature readouts at every time step can be generated for any thermal node in the building or averaged for a part such as a wall or a roof etc.

A model is constructed in RadTherm using elements. A larger number of elements result in higher accuracy. Each element has a view factor to the background, sky, and other elements. The energy that each element emits and absorbs from other elements is dependant on the surfaces' emissivity values. Radiant energy is emitted according to the Stephan-Boltzmann equation. The total radiation will be the net result of emitted radiant energy, incoming solar radiance, and incoming radiant energy (reflected or emitted from other elements). The program automatically accounts for multiple bounce reflections.

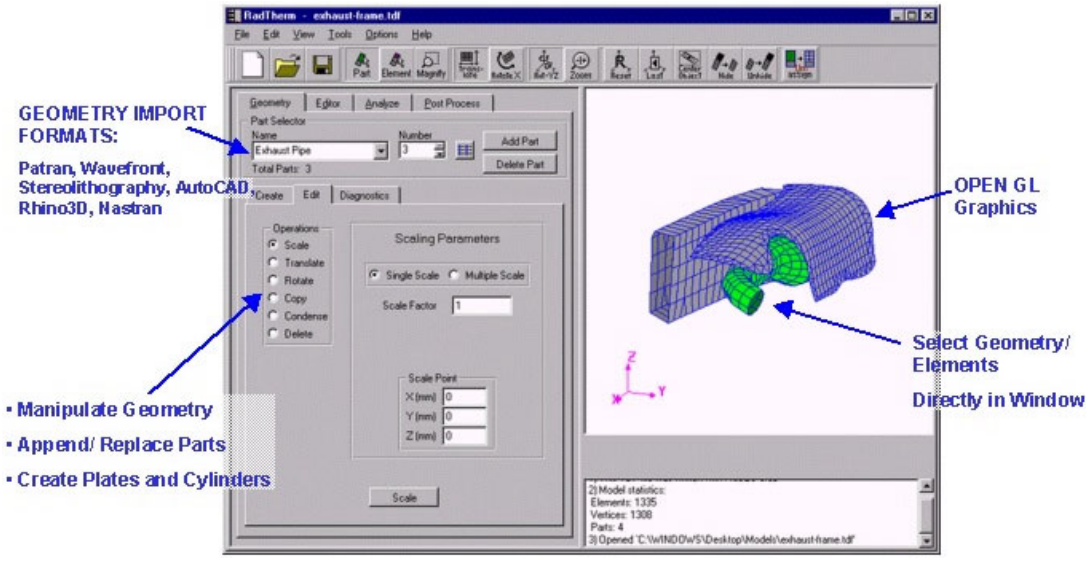


Figure 23: Sample input screen from RadTherm

A further description of RadTherm's capabilities in modeling radiation, conduction and convection is given below.

Radiation

RadTherm employs an accurate solar model to calculate the sun position and intensity as a function of latitude, longitude, date, and time of day. The sky temperature and solar readings (explained below) account for environmental radiation exchange. The absorbtivity property of a material determines the amount of incident solar energy absorbed. In RadTherm, the magnitude of incident solar energy is taken as a combination of the Direct Solar Irradiance, Diffuse Solar Irradiance and Reflected Solar.

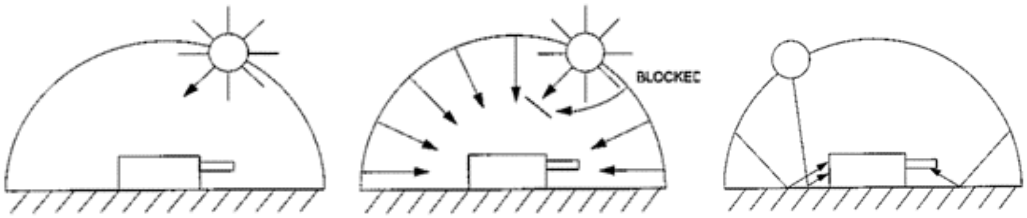


Figure 24: Direct Solar Irradiance, Diffuse Solar Irradiance and Reflected Solar

Convection

There are two types of convection modeled in RadTherm: environmental (wind) and fluid film. For film convection, the convection coefficient is specified. The environmental convection algorithm calculates the convection coefficient based on wind direction and wind speed. The wind convection model also accounts for the heat transfer due to rain (if any).

The film convection model can be selected to simulate the regulated temperature inside a building; where as the outside of the walls can be assigned environmental convection. Environmental convection is computed by calculating the direction of the wind relative to each element and the temperature difference between the air and the element.

Conduction

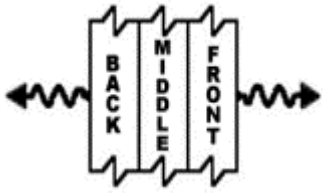


Figure 25: 3-layer part in RadTherm

RadTherm allows the use of single layer parts or three layered parts to be assigned as walls or roofs. For example, in a roof modeled as a three layered part the outer layer represents siding or shingles; the middle layer models the insulation, and all internal components; while the inner later represents gypsum

board. Material properties of density, specific heat and conductivity along with thickness are assigned to each layer of each part.

Outputs

RadTherm generates an output file for temperature for any of the parts of the mesh model created. To obtain hourly mean radiant temperature from RadTherm, a small black copper cube, about 6" in length, width and height, was created and placed inside the classroom space to act as a globe thermometer. The six surfaces of the cube were given properties of 1mm thick copper and a surface condition of black paint. The back-side (inside) of the copper cube was made insulated.

At the end of the simulation, an output of the averaged temperature of the six sides of the cube for every time step was generated for each day of the study period. The temperature readout from the output file was the mean radiant temperature for that classroom, or the given position of the globe thermometer.

RadTherm does not create an output for thermal comfort parameters such as predicted mean vote (PMV) or predicted percent dissatisfied (PPD). PMV is an index that predicts the mean value of the votes of a large group of persons on thermal comfort on a 7-point thermal sensation scale. PPD is an index that predicts the number of thermally dissatisfied persons among a large group of people. To calculate PMV and PPD, data on many other environmental conditions besides MRT are required viz. ambient air temperature, relative humidity, room air velocity, subject surface area, clothing insulation and metabolic rate. This would require too much careful calibration of real conditions, which was beyond the scope of this study.

Making an assumption that the environmental condition mentioned above are more or less constant, we decided to use MRT as a means of comparing thermal comfort for the students in the classrooms.

5.1.3 Description of Models and Assumptions

An AutoCAD 3D mesh model of the two classrooms was created. The 3D mesh is composed of polygons called elements. This model was then exported in dxf format to be imported into RadTherm. For the walls and roofs, a 3-layer part was used to model insulation packed between an outer front material and an inner back material. RadTherm creates thermal nodes on each side of each element in the model. At every time step an iterative calculation is done for each thermal node.

Accuracy of temperature calculations in RadTherm increases with an increase in the number of elements in the mesh. At the same time, the amount of time taken to complete a simulation increases with increasing number of elements. To be able to complete the simulation runs in a reasonable time, the number of elements had to be decreased. We chose to decrease the number of elements in

the adiabatic (internal) walls, since they contributed the least to the MRT of the classroom, and the roof, since heating and cooling of the roof was more uniform than the other parts like walls and floor.

The film convection model was selected to simulate the regulated temperature inside the classrooms. The needed convection coefficients were obtained from the ASHRAE Handbook. The handbook lists resistance (R) values for a variety of surfaces. The convection coefficient (h) is the reciprocal of the resistance value. For the inside of the walls, a value of 0.880551Btu/hr-ft^2-°R was used.

For the front surfaces of the walls and roofs, which face outside, environmental convection was assigned. The convection coefficient for the environmental convection was calculated by the program based on wind direction and wind speed.

To obtain hourly mean radiant temperature for the study days, a small black copper cube was created as described above to act as a globe thermometer. The cube was placed in the classroom at about 4ft height from the ground and about 8ft from the external wall where it was expected to get the maximum temperature variation (the worst case position).

At the end of the simulation, an output of the averaged temperature of the 6 sides of the cube for every time step was generated for each day of the study period.

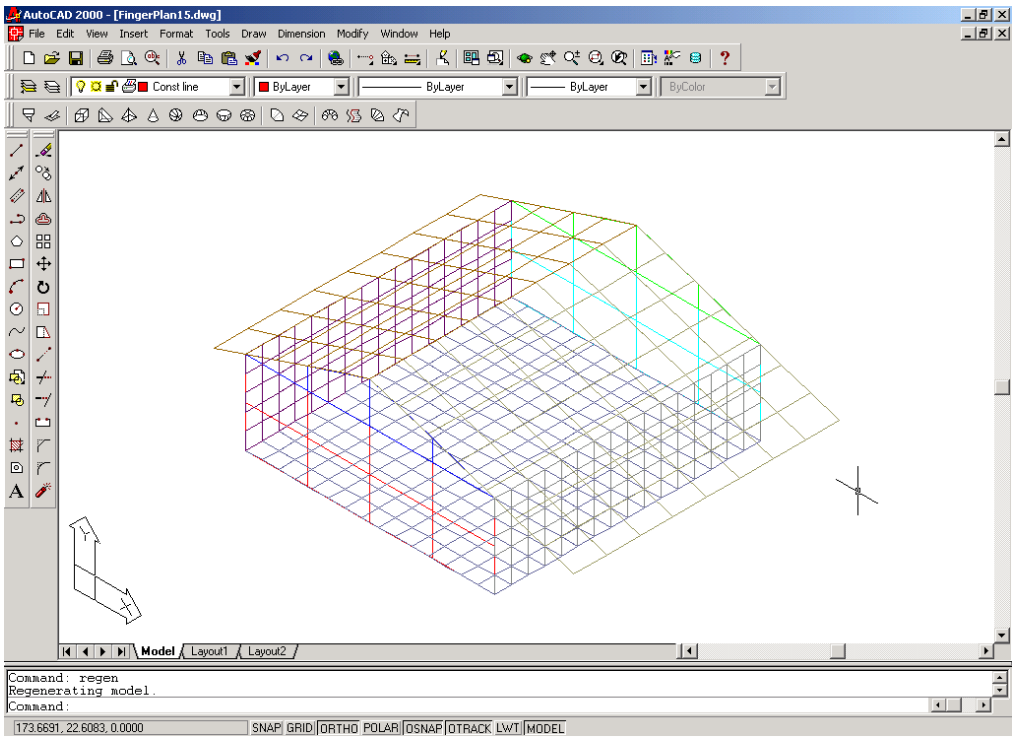


Figure 26: AutoCAD 3D mesh model of finger plan classroom

Finger Plan Classroom

The finger plan classroom is characterized by a large north-facing window, with north and south walls exposed to the environment, and east and west walls as internal walls connecting similar classrooms on each side. The front side (outside) of the east and west walls were made adiabatic (given infinite R value) to ensure that no heat transfer occurs through them, yet the thermal nodes on the back side (inside) of the walls are active to receive and emit heat through radiation from other elements in the model.

The south wall includes the door and a strip window at a height of 6ft. The wall is well shaded by an overhang and has a concrete walkway next to it.

The globe thermometer is positioned 8ft away from the north wall. This position has found to show more variation in temperature than the position 8ft away from the south wall.

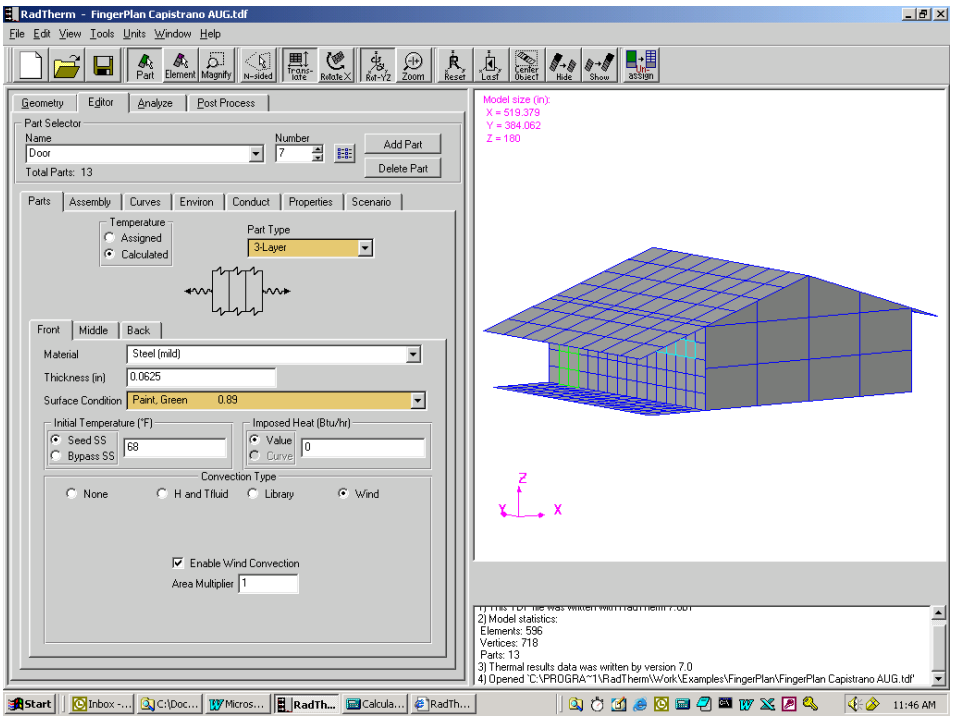


Figure 27: Finger plan classroom modeled in RadTherm

Showing south wall with overhang and the shaded sidewalk pavement.

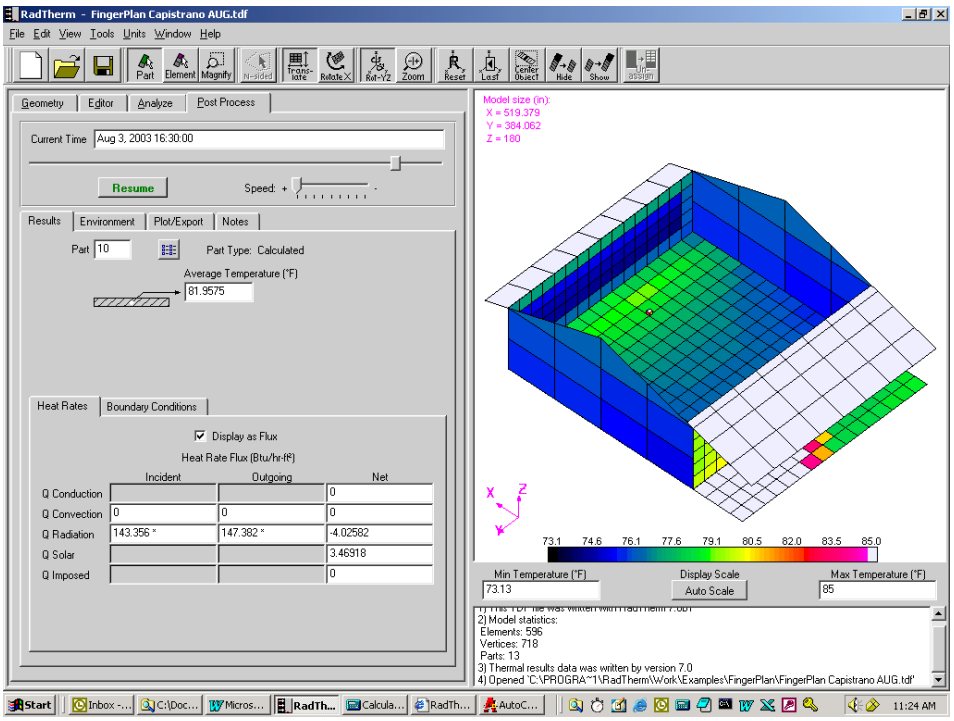


Figure 28: Screen shot from RadTherm (roof not shown in figure)

Variation in temperature across the floor at 16:30 on Aug 3rd for finger plan classroom. Hotter temperatures are represented with white color and cooler with dark colors

All assigned material properties for the finger plan classroom model are given in Figure 29.

	Front		*Middle*		*Back*	
	Material	*Surface Condition*	*Material*	*Surface Condition*	*Material*	*Surface Condition*
Ext. Wall	1" stucco concrete	Yellow paint	Mineral Fiber Batt Insulation (R-11)	-	½" gypsum board	Nylon cloth
Int. Wall	Insulated	-	-	-	½" gypsum board	Nylon cloth
Roof	¼" asphalt shingles	Asphalt	Mineral Fiber Batt Insulation (R-11)	-	½" plywood	Nylon cloth
Floor	6" Concrete	Unpainted wood	-	-	Insulated	-
Glass	Clear glass	Default	-	-	-	Default
Door	1/16" Mild Steel	Green Paint	1 ½" Air	-	1/16" Mild Steel	Green Paint
Walkway	Light colored concrete sidewalk	-	-	-	-	-
Terrain	Short grass, w/ moderate surface and bulk moisture, intermediate growth and cover	-	-	-	-	-

Figure 29: Finger plan classroom assigned material properties

Pinwheel Classroom

The pinwheel plan has classrooms arranged in a pinwheel fashion around a double loaded central corridor. Classrooms have one external wall and three internal walls. The most amount variation in temperature was expected in the classroom with the south facing wall. The external wall has a door and small windows arranged on the side and above that door. The three internal walls were made adiabatic in the same way as described for the finger plan classroom.

The globe thermometer was positioned 4ft away from the south wall, since the south wall was the only external wall and the most variation in temperature could be expected there.

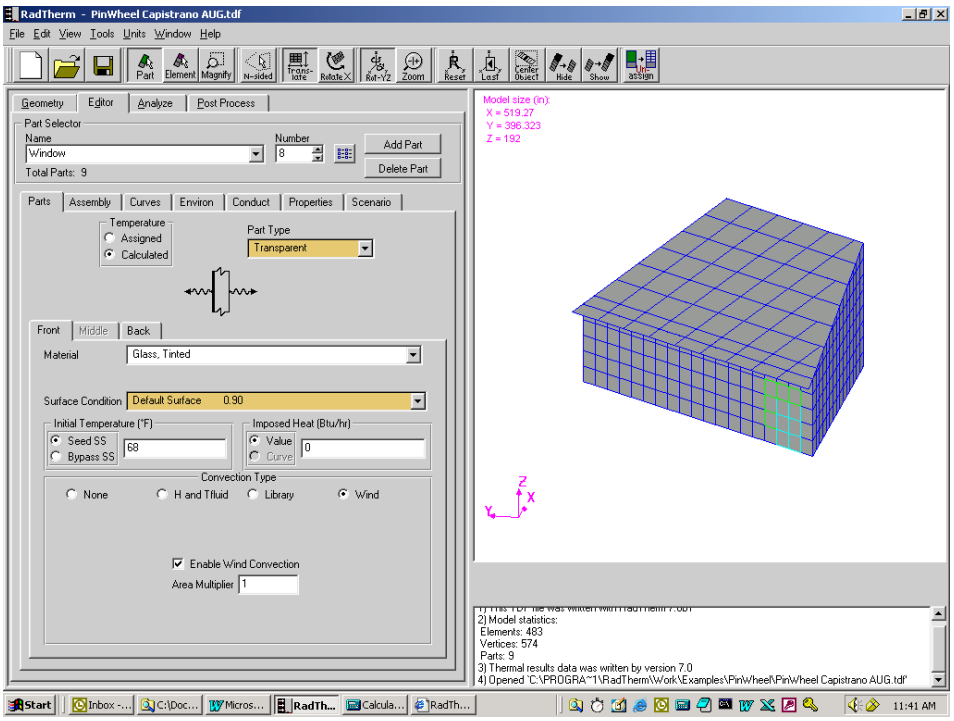


Figure 30: Pinwheel plan classroom modeled in RadTherm
Showing un-shaded exterior south wall.

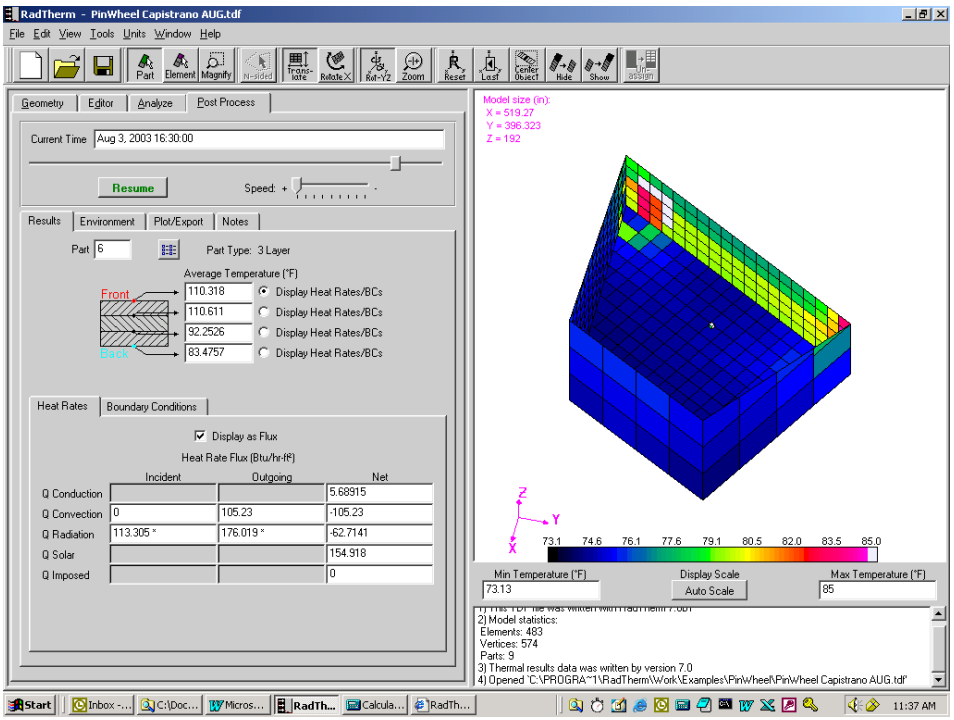


Figure 31: Screen shot from RadTherm (roof not shown in figure)

Variation in temperature across the floor and south wall at 16:30 on Aug 3rd for pinwheel classroom. Hotter temperatures are represented with white and cooler with dark colors

	Front		*Middle*		*Back*	
	Material	*Surface Condition*	*Material*	*Surface Condition*	*Material*	*Surface Condition*
Ext. Wall	1" stucco concrete	Yellow paint	Mineral Fiber Batt Insulation (R-11)	-	½" gypsum board	Nylon cloth
Int. Wall	Insulated	-	-	-	½" gypsum board	Nylon cloth
Roof	¼" asphalt shingles	Asphalt	Mineral Fiber Batt Insulation (R-19)	-	½" plywood	Nylon cloth
Floor	6" Concrete	Carpet	-	-	Insulated	-
Glass	Tinted glass	Default	-	-	-	Default
Door	1/16" Mild Steel	Green Paint	1 ½" Air	-	1/16" Mild Steel	Green Paint
Terrain	Light colored concrete sidewalk	-	-	-	-	-

Figure 32: Pinwheel plan classroom assigned material properties

Finger Plan Classroom with High Performance Glass

A third hypothetical case was also studied which was the same as the finger plan classroom except that the glass used was not single pane ordinary glass, but a high performance glass. The glass used in the large north window and the strip window in the south was changed to a double pane glass with argon filling and a low-e coating. Figure 33 gives the optical properties of the high performance glass. The analysis for this type of classroom was performed to see if by choosing high performance glass, the high MRT for finger plan classroom due to heat from the large north window could be lowered. The simulations were run for the cities of Fresno and Capistrano only.

Conductivity	0.24 Btu/hr-ft-F
Thickness	0.85 in.
Solar Reflectance	0.355
Solar Transmittance	0.407

Figure 33: Table of properties of high performance glass

5.1.4 Assumptions

A few simplifying assumptions were made to assist modeling of the classrooms in RadTherm.

The internal temperature was assumed to be 72 deg F at all times. The film convection assigned to the backside of the walls was given a fluid temperature of 72 deg F to simulate this effect in RadTherm. It can be argued that the teachers in the classroom can adjust the thermostat or the air conditioner could be turned off at times. Also thermostat settings for winter are typically different from those in summer. These effects could not be accurately modeled in RadTherm without a larger investment of time and effort.

The change in air temperature and radiant heat transfer between the classroom surfaces and the globe thermometer due to the presence of children in the classroom has not been taken into account. The classrooms have been modeled unoccupied.

5.1.5 Results from Simulation Runs

An output file was generated for the averaged temperature of the six sides of the globe thermometer placed in the classroom space. The output file generates this average temperature for every time step of the simulation (30 min in our case). This temperature is the mean radiant temperature of the space for the position of the globe thermometer.

Graphs for Mean Radiant Temperature

The results output from the RadTherm simulation runs were graphed and compared for the different simulation runs. These graphs are presented in the figures below. Figure 35 shows the mean radiant temperature of the finger plan classroom for February, May, August and October. Figure 34 shows the same for pinwheel classrooms, and Figure 36 for finger plan classroom with high performance glass.

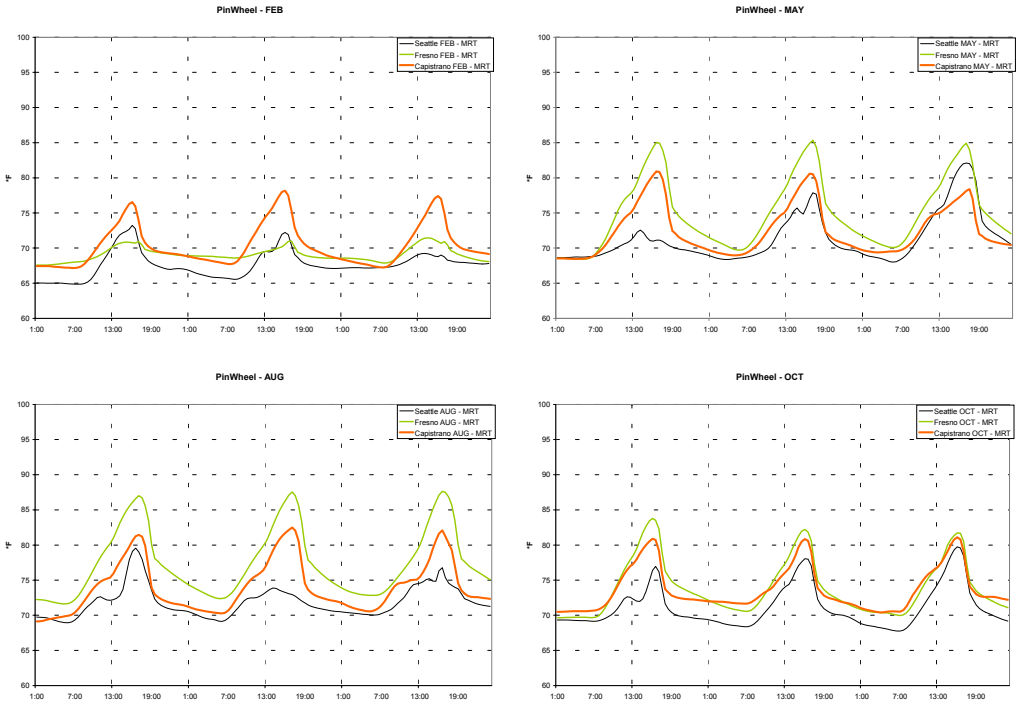


Figure 34: Mean Radiant Temperature – Pin Wheel Classroom.

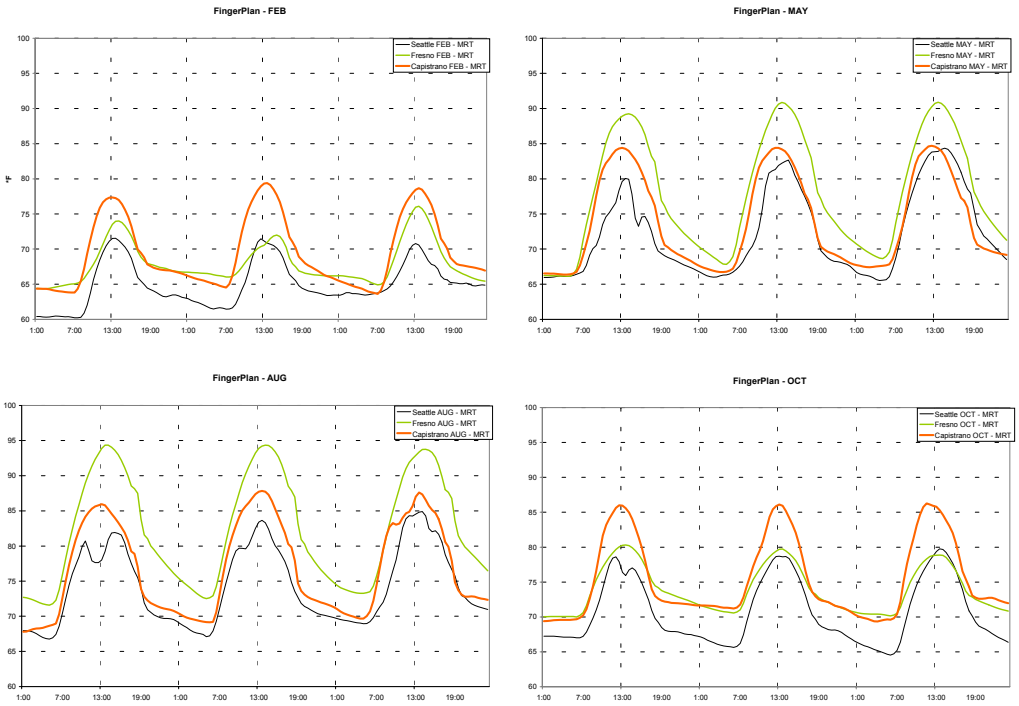


Figure 35: Mean Radiant Temperature – Finger Plan Classroom.

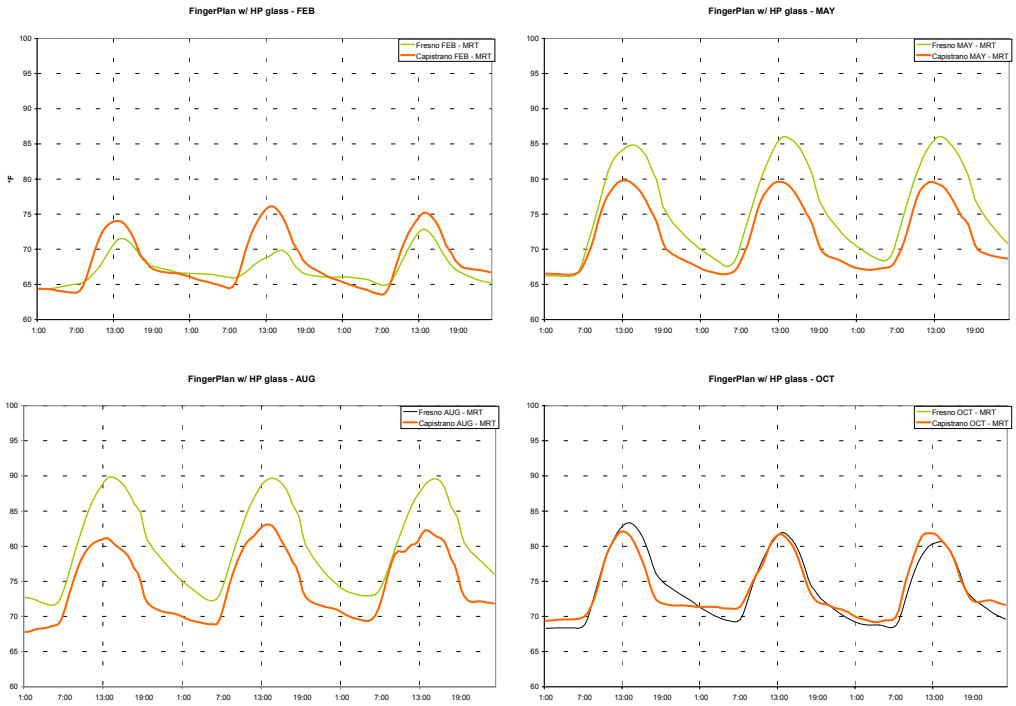


Figure 36: Mean Radiant Temperature – Finger Plan Classroom with High Performance Glass

5.1.6 Conclusions

The mean radiant temperature graphs above show that the finger plan classrooms have slightly higher temperatures in the summer months than the pinwheel classroom in all three climates. The classrooms in Fresno have slightly higher temperatures than Capistrano, with Seattle classrooms being the coolest comparatively in the summer months. However, in the spring and fall months the classrooms in Capistrano are the hottest with Fresno and Seattle in second and third places respectively.

The differences in mean radiant temperatures between the three locations for both the finger plan and pinwheel classrooms are not significant during the fall, spring and winter months. Since the classrooms are not in session during the summer months, the impacts of higher temperatures in Fresno would not have an impact on the student performance.

An interesting observation was that the profile of MRT for the Pin Wheel classrooms shows a peculiar pointed peak in the noontime as compared to the profile of the Finger Plan classrooms. This peak is on account of the un-shaded south wall in the Pin Wheel classrooms. The finger plan classrooms have shaded windows and hence they do not display the peaks in temperatures as shown by the pinwheel classrooms.

Addition of high performance glass to the finger plan classrooms helps in reducing the mean radiant temperatures significantly, with an average drop of around 10 degrees in the fall, spring and winter month peaks. The summer peak MRT also drops around 6-8 degrees, and makes the thermal performance of the finger plan classrooms significantly better. The MRT for the modified finger plan classroom is almost similar to that in the pinwheel classrooms minus the peak effect discussed above.

6. CLASSROOM ACOUSTIC ANALYSIS

6.1.1 Introduction

Among the classrooms studied in the Fresno Unified School District (FUSD), it was observed by the surveyors that the daylit classrooms had poorer acoustic quality than those with less or no daylighting.

Also, it was observed that daylit classrooms like the finger plan classrooms had more resilient surfaces such as linoleum floors and large north facing windows while non-daylit classrooms like the pin-wheel classrooms had more absorbent surfaces such as carpeted floors. It was hypothesized that this difference in surfaces must significantly affect their acoustic quality.

An initial investigation was made into various methods available for calculation of reverberation time for classrooms and to assess their acoustic quality. We found three methods to do this analysis.

The first method was to use an acoustic software program called Acoustic2D or Acoustic3D. These are freeware programs available from University of Michigan. The programs create a two-dimensional or a three dimensional analysis of the multiple reflections of sound waves with the various surfaces in a room. An output file is generated giving a detailed description of sound waves and their decibel levels after multiple reflections. Reverberation time can then be calculated from this output. The output was found to be too detailed for our purpose and it did not directly give reverberation time. Also, detailed data about positions of various surface materials were required in the room model.

As the second method, another software program called ODEON was examined, which is professional software for acoustic engineers. The software is capable of multi-bounce sound interaction in three dimensions. The program runs an iterative model for a detailed acoustical analysis, which includes an output for reverberation time at any point in the space of the room. The inputs for the software were found to be very detailed and required precise data about surface materials and their positions in the rooms.

The third method explored was to use the Sabine formula for a simple analysis of reverberation time using absorption coefficients for materials and calculating effective absorbing area of all surfaces in the room. This method was found to be most suitable for our purpose as it gave us the required results without the need for overly detailed inputs.

An analysis using Sabine's formula was made to examine and compare the acoustic quality for two extreme conditions in our sample of FUSD classroom, a typical finger plan classroom and a typical pinwheel classroom. A modified finger-plan classroom with an improved acoustic design was also compared. Results of the analysis are presented in this report.

6.1.2 Description of Interior Surfaces of Classrooms

Interior surfaces in the classrooms were observed and recorded by the surveyors in the February revisits to forty classrooms in the FUSD. From these the characteristics of a typical finger plan and a typical pinwheel classroom were described.

Figure 37 describes the distribution in percentages of the various interior wall, ceiling and floor surfaces.

	Finger Plan			***Pin-wheel Plan***		
	Material	Overall %	***%***	***Material***	Overall %	***%***
Walls	Vinyl	32.32%	55%	Vinyl	47.02%	32%
	Paper		25%	Paper		8%
				Plaster on Lath		40%
	Bulletin Board		20%	Bulletin Board		20%
Windows	Glass	9.99%	100%	Glass	0.67%	100%
Doors	Plywood	1.09%	100%	Plywood	0.58%	100%
Ceiling	Acoustic Tiles	26.61%	84%	Acoustic Tiles	26.20%	100%
Luminaires	Acrylic		16%			
Floor	Linoleum	29.89%	100%	Carpet	25.53%	100%
		100%			100%	

Figure 37: Distribution in percent of interior surfaces in finger plan and pinwheel plan classrooms

6.1.3 Sabine's Formula for Reverberation Time

Reverberation time of a room is defined as the time for the sound to die away to a level 60 decibels below its original level after multiple interactions with the surfaces of the room. The reverberation time can be estimated with a simple relationship, which is called the Sabine formula:

$$RT_{60} = (0.049) \times \left(\frac{V}{S_e} \right) \text{ for measurements in ft.} \qquad \text{- Eqn. 1}$$

Where:

RT_{60} is standard reverberation time, defined as the time for the sound to die away to a level 60 decibels below its original level

V is the volume of the space

S_e is the effective absorbing area of all surfaces in the space

$$S_e = \alpha_1 S_1 + \alpha_2 S_2 + \alpha_3 S_3 + \ldots \quad \text{- Eqn. 2}$$

Where:

α is the absorption coefficient of the material

S is the surface area of the material

Higher reverberation time means that it will take longer for the sound to die away and the room is said to be 'live'. In a very absorbent room, the sound will die away quickly and the room will be described as acoustically 'dead'. Typically reverberation times range from 0.2 to 2.6 sec. Higher reverberation times are desirable for spaces such as music halls and lower for lecture halls and classrooms.

The 'ANSI Acoustical Performance Criteria, Design Requirements and Guidelines for Schools' ANSI S12.60-2002, recommends maximum reverberation time for sound pressure levels in octave bands with mid-band frequencies of 500, 1000 and 2000 Hz. Figure 38 gives a list of materials considered for this study and their absorption coefficients at 500, 1000 and 2000 Hz. The coefficients are obtained from 'Architectural Acoustics' by M. David Egan, McGraw-Hill, 1988. The average of the three coefficients was taken as the absorption coefficient (α) for this study.

Material	Sound Absorption Coefficient			Average
	500 Hz	1000 Hz	2000 Hz	
Gypsum board, 1 layer, 5/8 in tk, w/ air spaces filled w/ fiberous insulation)	0.08	0.04	0.12	0.08
Thick fibrous material behind open facing	0.82	0.8	0.6	0.74
Glass, 1/8", 2' x 3' panes	0.04	0.03	0.02	0.03
Plywood, 3/8 in paneling	0.17	0.09	0.1	0.12
* Acoustical Board, Sound Silencer™ 2" on ceiling from Acoustical Surfaces Inc.	0.52	0.72	0.77	0.67
* Acoustical Board, Sound Silencer™ 1" on ceiling from Acoustical Surfaces Inc.	0.42	0.49	0.76	0.56
Acoustical board, 3/4 in tk, in suspension system	0.83	0.99	0.99	0.94
Glass, ordinary window	0.18	0.12	0.07	0.12
Linoleum on concrete	0.03	0.03	0.03	0.03
Plaster on lath	0.06	0.05	0.04	0.05
Carpet, heavey, on concrete	0.14	0.37	0.6	0.37

* http://www.acousticalsurfaces.com/acoust_ceilings/ss_ceiling.htm?d=20

Figure 38: Sound absorption coefficients for the materials used in this study

At 500 Hz, 1000 Hz and 2000 Hz, and the average absorption coefficient

6.1.4 Calculating Reverberation Time for Classrooms

The calculation of reverberation time was done using the Sabine formula discussed above. The calculations are given in Figure 39 and Figure 40 below.

Finger Plan

	Area sq.ft	Material	%	Surface area sq.ft	Sound Absorbtion Coeffecient (alpha)	Se (sabins)
Total Walls	1035.00	Vinyl	0.55	569.25	0.08	45.54
		Paper	0.25	258.75	0.08	20.70
		Bulletin board	0.20	207.00	0.74	153.18
Window	320.00	Glass	1.00	320.00	0.03	9.60
Door	35.00	Plywood	1.00	35.00	0.12	4.20
Ceiling	851.92	Acoustic Tiles	1.00	851.92	0.56	477.08
Luminaires	160.00	Acrylic	1.00	160.00	0.12	19.73
Floor	960.00	Vinyl	1.00	960.00	0.03	28.80
					Sigma Se >>	758.83
					Reverberation Time >>	**0.77**

Figure 39: Calculation of Reverberation Time for Finger Plan Classrooms

Pin-Wheel

	Area sq.ft	Material	%	Surface area sq.ft	Sound Absorbtion Coeffecient (alpha)	Se (sabins)
Total Walls	1412.89	Vinyl	0.32	452.12	0.08	36.17
		Plaster on lath	0.08	113.03	0.05	5.65
		Paper	0.40	565.16	0.08	45.21
		Bulletin board	0.20	282.58	0.74	209.11
Window	20.00	Glass	1.00	20.00	0.12	2.47
Door	17.50	Plywood	1.00	17.50	0.12	2.10
Ceiling	787.30	Acoustic Tiles	1.00	787.30	0.56	440.89
Floor	767.14	Carpet	1.00	767.14	0.37	283.84
					Sigma Se >>	1025.44
					Reverberation Time >>	**0.48**

Figure 40: Calculation of Reverberation Time for Pinwheel Plan Classrooms

A third case was made of a Finger Plan classroom with improved acoustic design. Two changes were made to the classroom: the floor was changed from vinyl to carpet, and the 2” acoustical board with higher absorption coefficient was used instead of the 1” board used earlier. The calculations are given in Figure 41.

Finger Plan (Modified)

	Area sq.ft	*Material*	*%*	*Surface area sq.ft*	*Sound Absorbtion Coeffecient (alpha)*	*Se (sabins)*
Total Walls	1035.00	Vinyl	0.55	569.25	0.08	45.54
		Paper	0.25	258.75	0.08	20.70
		Bulletin board	0.20	207.00	0.74	153.18
Window	320.00	Glass	1.00	320.00	0.03	9.60
Door	35.00	Plywood	1.00	35.00	0.12	4.20
Ceiling	851.92	***Acoustic Tiles***	1.00	851.92	***0.67***	570.79
Luminaires	160.00	Acrylic	1.00	160.00	0.12	19.73
Floor	960.00	***Carpet***	1.00	960.00	***0.37***	355.20

Sigma Se >> 1178.94

Reverberation Time >> 0.50

Figure 41: Calculation of Reverberation Time for a modified Finger Plan Classroom

6.1.5 Conclusion

The 'ANSI Acoustical Performance Criteria, Design Requirements and Guidelines for Schools' ANSI S12.60-2002, recommends maximum reverberation time for three sizes of classrooms as given in Figure 42. For the finger plan classroom, the volume is 12,000 sf, hence maximum reverberation time requirement is 0.7 sec. For pinwheel plan classroom, the volume is 9972.4 sf, hence maximum reverberation time requirement is 0.6 sec.

Learning space[a)]	Maximum one-hour -average A-weighted steady background noise level[b,c)] dB	Maximum reverberation time for sound pressure levels in octave bands with midband frequencies of 500, 1000, and 2000 Hz s
Core learning space with enclosed volume $< 283\ m^3$ ($< 10\ 000\ ft^3$)	35	0.6
Core learning space with enclosed volume $> 283\ m^3$ and $\leqslant 566\ m^3$ ($> 10\ 000\ ft^3$ and $\leqslant 20\ 000\ ft^3$)	35	0.7
Core learning spaces with enclosed volumes $> 566\ m^3$ ($20\ 000\ ft^3$) and all ancillary learning spaces	40[d)]	[e)]

Figure 42:Table from 'ANSI Acoustical Performance Criteria

Design Requirements and Guidelines for Schools' ANSI S12.60-2002, showing requirements for maximum reverberation time for three classroom sizes.

From the calculations described in, it was found that the reverberation time for finger plan classrooms is **0.77 sec** (from Figure 39) and for pin-wheel plan classrooms is **0.48 sec** (from Figure 40). The finger plan classroom fails to meet its requirement for reverberation time (10% higher than the requirement). The pinwheel plan classroom meets these requirements (lower than the requirement). Hence the finger plan classroom is a more reverberant space than the pin-wheel plan classroom.

With the modified finger plan classroom, it was found that by changing only the acoustical tiles on the ceiling to a better absorbing type, the reverberation time reduced to **0.69 sec**. This is barely under the maximum reverberation time requirement of 0.7 sec. By changing only the flooring from vinyl to a carpet, the reverberation time reduced to **0.54 sec**. By changing both acoustic tiles and adding carpet, it was reduced to **0.50 sec**, which made it very close to reverberation time of the pinwheel classroom. Both these cases, falls within the range of the reverberation time requirement.