High Performance Buildings and Occupant Comfort

Peter Simmonds, Ph.D. ASHRAE Fellow
IBE Consulting Engineers
Sherman Oaks, CA

This ASHRAE Distinguished Lecturer is brought to you by the Society Chapter Technology Transfer Committee

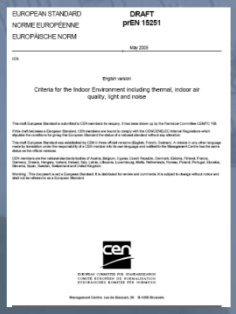
Hypothesis

Engineering problems are under defined, there are many solutions, good, bad and indifferent. The art is to arrive at a good solution. This is a creative activity, involving imagination, intuition and deliberate choice.

- Ove Arup

Thermal Comfort Standards

Thermal Comfort Standards

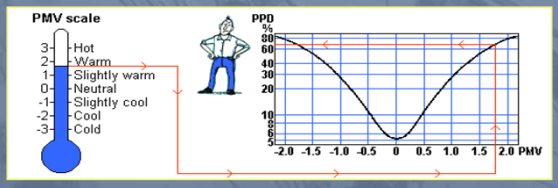


Thermal Comfort Standards

Definitions

- *percent dissatisfied (PD):* percentage of people predicted to be dissatisfied due to local discomfort.
- *predicted mean vote (PMV):* an index that predicts the mean value of the votes of a large group of persons on the seven-point thermal sensation scale.
- *predicted percentage of dissatisfied (PPD):* an index that establishes a quantitative prediction of the percentage of thermally dissatisfied people determined from PMV.

Thermal Comfort



- 1) Metabolic rate.
- 2) Clothing insulation.
- 3) Air temperature.
- 4) Radiant temperature
- 5) Air speed.
- 6) Humidity

Thermal Comfort Calculations

The PMV is given by the following equations:

$$PMV = \left(0{,}303e^{-0{,}036M} + 0{,}028\right)$$

$$\begin{bmatrix} (M-W) - 3{,}05\cdot 10^{-3}\{5733 - 6{,}99(M-W) - p_a\} - 0{,}42\{(M-W) - 58{,}15\} \\ -1{,}7\cdot 10^{-5} M(5867 - p_a) - 0{,}0014M(34 - t_a) \\ -3{,}96\cdot 10^{-8} f_{cl}\left\{(t_{cl}+273)^4 - (\bar{t}_r+273)^4\right\} - f_{cl} h_c (t_{cl} - t_a) \end{bmatrix}$$

where

$$t_{cl} = 35{,}7 - 0{,}028(M-W) - I_{cl}\left\{3{,}96\cdot 10^{-8} f_{cl}\left[(t_{cl}+273)^4 - (\bar{t}_r+273)^4\right] + f_{cl} h_{cl}(t_{cl} - t_a)\right\}$$

$h_c = 2{,}38(t_{cl} - t_a)^{0{,}25}$ for $2{,}38(t_{cl} - t_a)^{0{,}25} > 12{,}1\sqrt{v_{ar}}$

$= 12{,}1\sqrt{v_{ar}}$ for $2{,}38(t_{cl} - t_a)^{0{,}25} < 12{,}1\sqrt{v_{ar}}$

$f_{cl} = 1{,}00 + 1{,}290 I_{cl}$ ... for $I_{cl} < 0{,}078 m^2 \cdot K W^{-1}$

$= 1{,}05 + 0{,}545 I_{cl}$ for $I_{cl} > 0{,}078 m^2 \cdot K W^{-1}$

18 years ago

CH-93-10-4

THERMAL COMFORT AND OPTIMAL ENERGY USE

P. Simmonds
Member ASHRAE

PMV Optimization

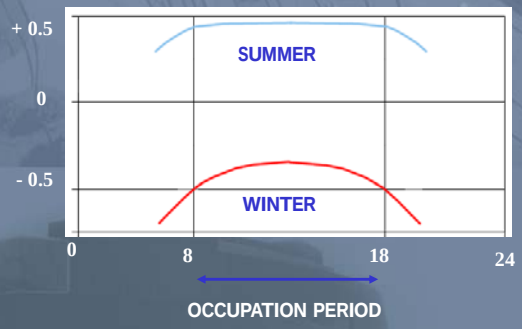
Mathematically, the optimization problem is stated as follows:

$$J = \sum_{k=1}^{k} \left(R(k) + P^{*}\left(\mathrm{PMV}_z(k), f(k)\right)\right)$$

for all (k) with respect to $\mathrm{PMV}_z(k)$ ($k = 1, K$) subject to

$$\mathrm{PMV}_{z\,min}(K) \le \mathrm{PMV}_z(K) \le \mathrm{PMV}_{z\,max}(K).$$

PMV OPTIMISATION



Many engineers are involved in LEED submissions;

EQ Credit 6.2: Controllability of Systems: Thermal Comfort

Requirements

- Provide individual comfort controls for 50% (minimum) of the building occupants to enable adjustments to suit individual task needs and preferences.

Operable windows can be used in lieu of comfort controls for occupants of areas that are 20 feet inside of and 10 feet to either side of the operable part of the window. The areas of operable window must meet the requirements of ASHRAE 62.1-2010 paragraph 5.1 Natural Ventilation.

EQ Credit 6.2: Controllability of Systems: Thermal Comfort

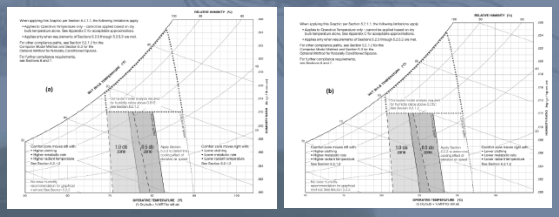
AND

- Provide comfort system controls for all shared multi-occupant spaces to enable adjustments to suit group needs and preferences.

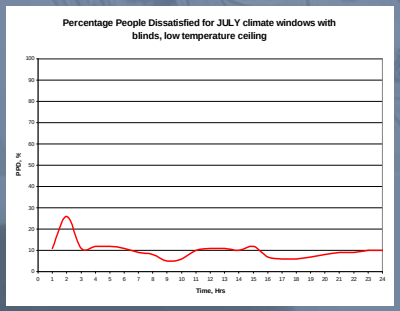
- Conditions for thermal comfort are described in ASHRAE Standard 55-2010 to include the primary factors of air temperature, radiant temperature, air speed and humidity. Comfort system control for the purposes of this credit is defined as the provision of control over at least one of these primary factors in the occupant's local environment.

EQ Credit 7.1: Thermal Comfort Design

Figure 5.2.1.1 The Graphic Comfort Zone Method: Acceptable range of operative temperature and humidity for spaces that meet the criteria specified in Section 5.2.1.1 (1.1 met; 0.5 and 1.0 clo)—(a) I-P and (b) SI.



EQ Credit 7.1: Thermal Comfort Design



EQ Credit 7.1: Thermal Comfort: Design

Requirements

- Design HVAC systems and the building envelope to meet the requirements of ASHRAE Standard 55-2010, Thermal Comfort Conditions for Human Occupancy. Demonstrate design compliance in accordance with the Section 6.1.1 Documentation.

EQ Credit 7.1: Thermal Comfort: Design

system	Temperature control	Humidity control	Air velocity Control	MRT Compensation	PPD control	PMV Control
heating only - baseboard	Y	N	N	N	N	N
Heating + Natural Ventilation	Y	N	N	N	N	N
Heating + Mechanical Ventilation	Y	Y	Y	N	N	N
Heating + Mechanical Ventilation + Top Cooling	Y	Y	Y	N	N	N
VAV with terminal re-heat	Y	Y	Y	N	N	N
VAV with Baseboard Heating	Y	Y	Y	N	N	N
Air - Water Induction Unit	Y	Y	Y	N	N	N
Fan Coils	Y	Y	Y	N	N	N
Radiant Panel Heating	Y	N	N	Y	Y	Y
Radiant Panel Cooling	Y	N	N	Y	Y	Y
Radiant Floor Heating	Y	N	N	Y	Y	Y
Radiant Floor Cooling	Y	N	N	Y	Y	Y
mechanical ventilation with radiant panels						
heating	Y	Y	Y	Y	Y	Y
cooling	Y	Y	Y	Y	Y	Y
mechanical ventilation with radiant floor						
heating	Y	Y	Y	Y	Y	Y
cooling	Y	Y	Y	Y	Y	Y

EQ Credit 7.2: Thermal Comfort: Verification

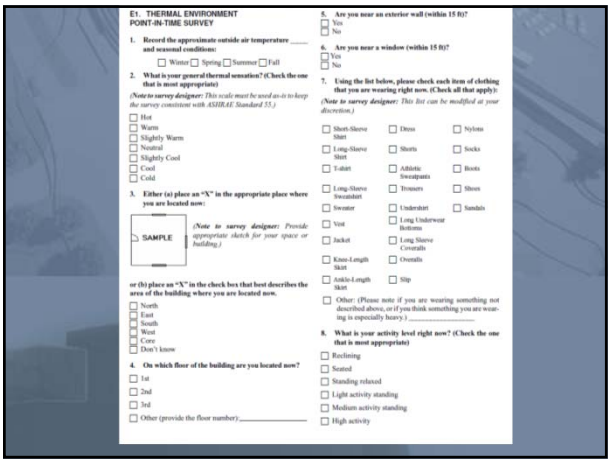
Requirements

- Agree to implement a thermal comfort survey of building occupants within a period of six to 18 months after occupancy. This survey should collect anonymous responses about thermal comfort in the building including an assessment of overall satisfaction with thermal performance and identification of thermal comfort-related problems. Agree to develop a plan for corrective action if the survey results indicate that more than 20% of occupants are dissatisfied with thermal comfort in the building. This plan should include measurement of relevant environmental variables in problem areas in accordance with ASHRAE Standard 55-2010.

ASHRAE 55-2004 7.6.2.1 Survey Occupants

(for comparison, not required for LEED survey)

- 80% of occupants comfortable
- Every operating mode (heating, cooling, etc.)
- Every design condition (hottest day, coldest day, partial loading conditions, etc.)
- Occupant Data:
  - ❑ Occupant 's name, date, and time
  - ❑ Approximate outside air temperature
  - ❑ Clear sky/overcast (if applicable)
  - ❑ Seasonal conditions
  - ❑ Occupant's clothing
  - ❑ Occupant's activity level
  - ❑ Applicable equipment
  - ❑ General thermal comfort level
  - ❑ Occupant's location



E1. THERMAL ENVIRONMENT POINT-IN-TIME SURVEY

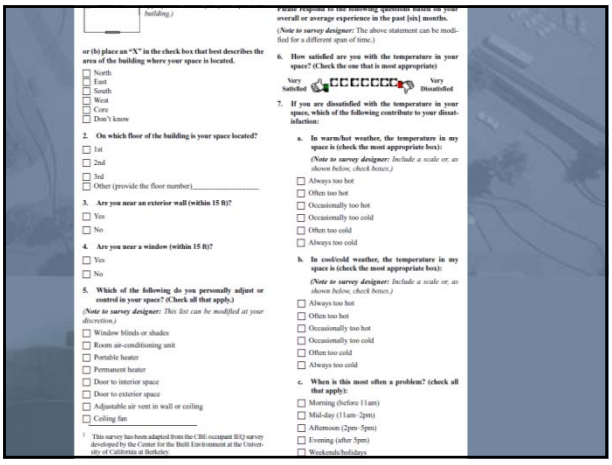
1. **Record the approximate outside air temperature _____ and seasonal conditions:**
   ☐ Winter ☐ Spring ☐ Summer ☐ Fall
2. **What is your general thermal sensation? (Check the one that is most appropriate)**
   (Note to survey designer: This scale must be used as-is to keep the survey consistent with ASHRAE Standard 55.)
   ☐ Hot
   ☐ Warm
   ☐ Slightly Warm
   ☐ Neutral
   ☐ Slightly Cool
   ☐ Cool
   ☐ Cold
3. **Either (a) place an "X" in the appropriate place where you located now:**
   SAMPLE
   (Note to survey designer: Provide appropriate sketch for your space or building.)

   or (b) place an "X" in the check box that best describes the area of the building where you are located now.
   ☐ North
   ☐ East
   ☐ South
   ☐ West
   ☐ Core
   ☐ Don't know
4. **On which floor of the building are you located now?**
   ☐ 1st
   ☐ 2nd
   ☐ 3rd
   ☐ Other (provide the floor number):_____
5. **Are you near an exterior wall (within 15 ft)?**
   ☐ Yes
   ☐ No
6. **Are you near a window (within 15 ft)?**
   ☐ Yes
   ☐ No
7. **Using the list below, please check each item of clothing that you are wearing right now. (Check all that apply):**
   (Note to survey designer: This list can be modified at your discretion.)

☐ Short-Sleeve Shirt	☐ Dress	☐ Nylons
☐ Long-Sleeve Shirt	☐ Shorts	☐ Socks
☐ T-shirt	☐ Athletic Sweatpants	☐ Boots
☐ Long-Sleeve Sweatshirt	☐ Trousers	☐ Shoes
☐ Sweater	☐ Undershirt	☐ Sandals
☐ Vest	☐ Long Underwear Bottoms	
☐ Jacket	☐ Long Sleeve Coveralls	
☐ Knee-Length Skirt	☐ Overalls	
☐ Ankle-Length Skirt	☐ Slip	

☐ Other: (Please note if you are wearing something not described above, or if you think something you are wearing is especially heavy.) _____

8. **What is your activity level right now? (Check the one that is most appropriate)**
   ☐ Reclining
   ☐ Seated
   ☐ Standing relaxed
   ☐ Light activity standing
   ☐ Medium activity standing
   ☐ High activity



building.)

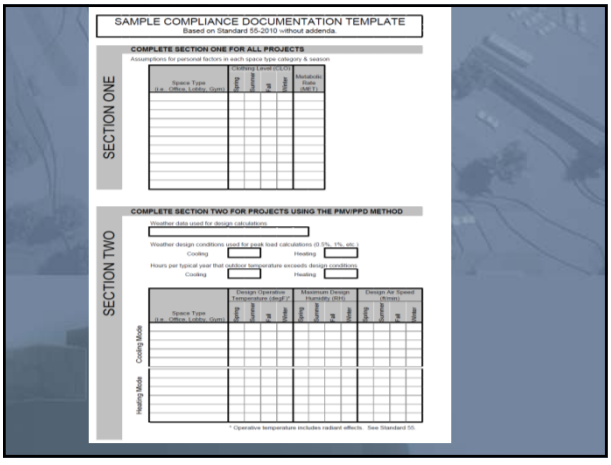
or (b) place an "X" in the check box that best describes the area of the building where your space is located.
☐ North
☐ East
☐ South
☐ West
☐ Core
☐ Don't know

2. **On which floor of the building is your space located?**
   ☐ 1st
   ☐ 2nd
   ☐ 3rd
   ☐ Other (provide the floor number):_____
3. **Are you near an exterior wall (within 15 ft)?**
   ☐ Yes
   ☐ No
4. **Are you near a window (within 15 ft)?**
   ☐ Yes
   ☐ No
5. **Which of the following do you personally adjust or control in your space? (Check all that apply.)**
   (Note to survey designer: This list can be modified at your discretion.)
   ☐ Window blinds or shades
   ☐ Room air-conditioning unit
   ☐ Portable heater
   ☐ Permanent heater
   ☐ Door to interior space
   ☐ Door to exterior space
   ☐ Adjustable air vent in wall or ceiling
   ☐ Ceiling fan

[1] This survey has been adapted from the CBE occupant IEQ survey developed by the Center for the Built Environment at the University of California at Berkeley.

Please respond to the following questions based on your overall or average experience in the past [six] months.
(Note to survey designer: The above statement can be modified for a different span of time.)

6. **How satisfied are you with the temperature in your space? (Check the one that is most appropriate)**
   Very Satisfied ☐☐☐☐☐☐☐ Very Dissatisfied
7. **If you are dissatisfied with the temperature in your space, which of the following contribute to your dissatisfaction:**
   a. **In warm/hot weather, the temperature in my space is (check the most appropriate box):**
      (Note to survey designer: Include a scale or, as shown below, check boxes.)
      ☐ Always too hot
      ☐ Often too hot
      ☐ Occasionally too hot
      ☐ Occasionally too cold
      ☐ Often too cold
      ☐ Always too cold
   b. **In cool/cold weather, the temperature in my space is (check the most appropriate box):**
      (Note to survey designer: Include a scale or, as shown below, check boxes.)
      ☐ Always too hot
      ☐ Often too hot
      ☐ Occasionally too hot
      ☐ Occasionally too cold
      ☐ Often too cold
      ☐ Always too cold
   c. **When is this most often a problem? (check all that apply):**
      ☐ Morning (before 11am)
      ☐ Mid-day (11am–2pm)
      ☐ Afternoon (2pm–5pm)
      ☐ Evening (after 5pm)
      ☐ Weekends/holidays



SAMPLE COMPLIANCE DOCUMENTATION TEMPLATE
Based on Standard 55-2010 without addenda.

SECTION ONE

COMPLETE SECTION ONE FOR ALL PROJECTS
Assumptions for personal factors in each space type category & season

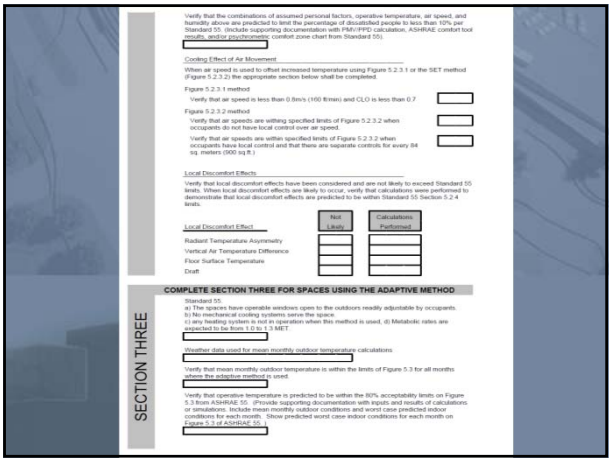
Space Type (i.e., Office, Lobby, Gym)	Clothing Level (CLO) Spring	Summer	Fall	Winter	Metabolic Rate (MET)

SECTION TWO

COMPLETE SECTION TWO FOR PROJECTS USING THE PMV/PPD METHOD
Weather data used for design calculations: _____
Weather design conditions used for peak load calculations (0.5%, 1%, etc.)
Cooling _____ Heating _____
Hours per typical year that outdoor temperature exceeds design conditions
Cooling _____ Heating _____

	Space Type (i.e., Office, Lobby, Gym)	Design Operative Temperature (deg F)[1] Spring	Summer	Fall	Winter	Maximum Design Humidity (RH) Spring	Summer	Fall	Winter	Design Air Speed (ft/min) Spring	Summer	Fall	Winter
Cooling Mode													
Heating Mode													

[1] Operative temperature includes radiant effects. See Standard 55.



Verify that the combinations of assumed personal factors, operative temperature, air speed, and humidity above are predicted to limit the percentage of dissatisfied people to less than 10% per Standard 55. (Include supporting documentation with PMV/PPD calculation, ASHRAE comfort tool results, and/or psychrometric comfort zone chart from Standard 55).

Cooling Effect of Air Movement

When air speed is used to offset increased temperature using Figure 5.2.3.1 or the SET method (Figure 5.2.3.2) the appropriate section below shall be completed.

Figure 5.2.3.1 method:
Verify that air speed is less than 0.8m/s (160 ft/min) and CLO is less than 0.7 ☐

Figure 5.2.3.2 method:
Verify that air speeds are withing specified limits of Figure 5.2.3.2 when occupants do not have local control over air speed. ☐
Verify that air speeds are within specified limits of Figure 5.2.3.2 when occupants have local control and that there are separate controls for every 84 sq. meters (900 sq ft.) ☐

Local Discomfort Effects

Verify that local discomfort effects have been considered and are not likely to exceed Standard 55 limits. Where local discomfort effects are likely to occur, verify that calculations were performed to demonstrate that local discomfort effects are predicted to be within Standard 55 Section 5.2.4 limits.

Local Discomfort Effect	Not Likely	Calculations Performed
Radiant Temperature Asymmetry		
Vertical Air Temperature Difference		
Floor Surface Temperature		
Draft		

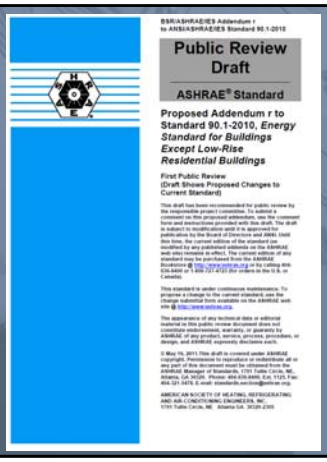
SECTION THREE

COMPLETE SECTION THREE FOR SPACES USING THE ADAPTIVE METHOD
Standard 55:
a) The spaces have operable windows open to the outdoors readily adjustable by occupants.
b) No mechanical cooling systems serve the space.
c) any heating system is not in operation when this method is used, d) Metabolic rates are expected to be from 1.0 to 1.3 MET ☐

Weather data used for mean monthly outdoor temperature calculations _____

Verify that mean monthly outdoor temperature is within the limits of Figure 5.3 for all months where the adaptive method is used. ☐

Verify that operative temperature is predicted to be within the 80% acceptability limits on Figure 5.3 from ASHRAE 55. (Provide supporting documentation with inputs and results of calculations or simulations. Include mean monthly outdoor conditions and worst case predicted indoor conditions for each month. Show predicted worst case indoor conditions for each month on Figure 5.3 of ASHRAE 55.) ☐



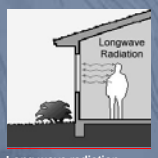
ASHRAE 90.1 addendum R

- **Temperature and Humidity Schedules.** Temperature and humidity control setpoints and schedules as well as *temperature control throttling range* shall be the same for *proposed* and *baseline building designs.*
- **HVAC Fan Schedules**. Schedules for HVAC fans that provide outdoor air for ventilation shall run continuously whenever spaces are occupied and shall be cycled on and off to meet heating and cooling loads during unoccupied hours.
- **Baseline Design**
- Same as Proposed Design
- **Exceptions:**
- 1. Setpoints and schedules for HVAC systems that automatically provide occupant thermal comfort via means other than directly controlling the air dry bulb and wet bulb temperature may be allowed to differ provided that equivalent levels of occupant thermal comfort are demonstrated via the methodology in Appendix D-Computer Program for Calculation of PMV-PPD of Standard 55.
- **2.** Schedules may be allowed to differ between *proposed design* and *baseline building design* when necessary to model nonstandard *efficiency* measures, provided that the revised schedules have the approval of the *rating authority*. Measures that may warrant use of different schedules include, but are not limited to, *automatic* lighting controls, *automatic* natural
- ventilation controls, *automatic* demand control ventilation controls, and *automatic* controls that reduce service water heating loads. In no case shall schedules differ where the controls are manual (e.g., manual operation of light switches or manual operation of windows).

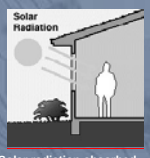
Strange Facts

- When glass breaks, the cracks move faster than 3,000 miles per hour. To photograph the event, a camera must shoot at a millionth of a second!

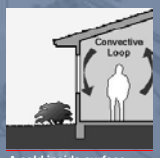
How windows influence comfort



Long wave radiation exchange is the dominant mechanism by which windows influence thermal comfort.



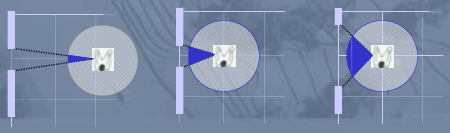
Solar radiation absorbed by the window influences thermal comfort by increasing the interior window surface temperature. Transmitted solar radiation that reaches the body will have a significant impact on comfort.



A cold inside surface temperature can induce a convective draft in a room..

View factor

The view factor is a function of window size, room geometry, and occupant location



View factor is used to quantify the amount of radiation energy leaving the body that reaches the window.

View factor is increased by moving closer to the window.

View factor is increased with a larger window.

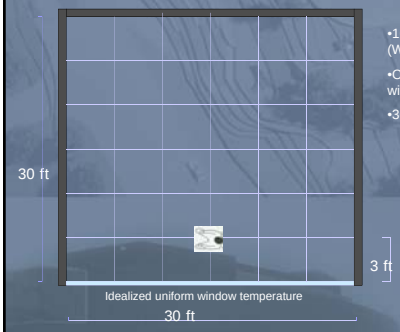
Window to wall ratio (WWR)

WWR 20%

WWR 40%

WWR 100%

Example Simulation Geometry

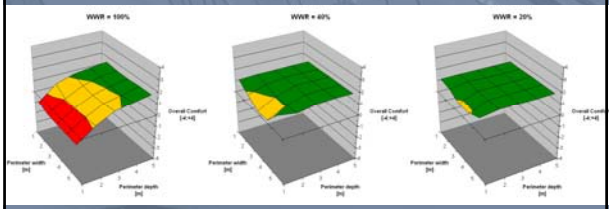


- 100% Window to wall ratio (WWR)
- Occupant sitting 1 meter from the window
- 30 ft x 30 ft x 10 ft room

Spatial distribution of comfort

75°F inside air temperature

104°F inside window surface temperature, single tinted glass, ASHRAE summer condition



Comfortable

Just comfortable

Uncomfortable

Window geometry impacts

Window on one side,
Local comfort = -1.3*

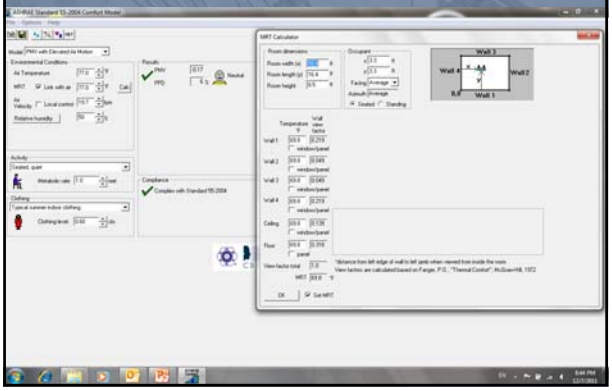
Windows on two sides,
Local comfort = -2.5*

*-4 (very uncomfortable) to +4 (very comfortable) scale

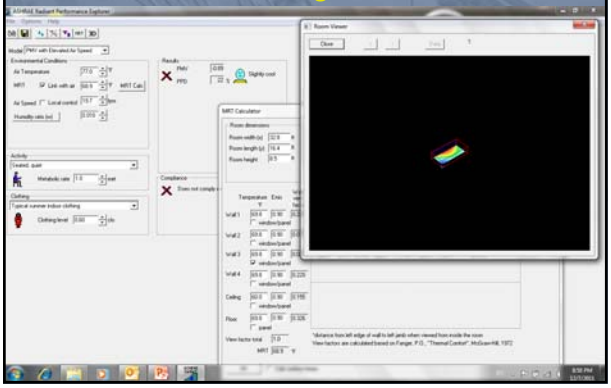
2000mm x 1800mm
Single-glazed, aluminum frame
NFRC winter condition
1m away from the window

These two examples show that two rooms with the same window area and window types, but with a different geometry, can have significantly different comfort.

ASHRAE Thermal Comfort Tool



RPE Design Tool



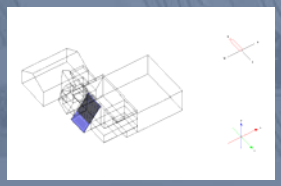
Strange Facts

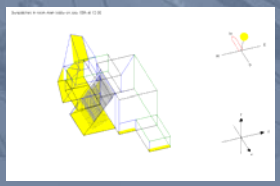
- The longest recorded flight of a chicken is 13 seconds!

What applications are suitable for Occupant Comfort?

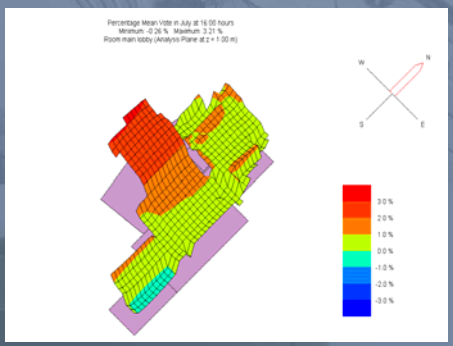
Akron Art Museum

Akron Art Museum

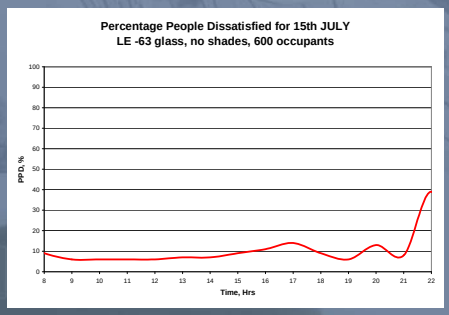




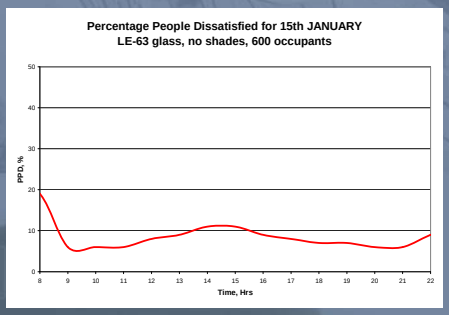
Akron Art Museum



Akron Art Museum



Akron Art Museum



Akron Art Museum

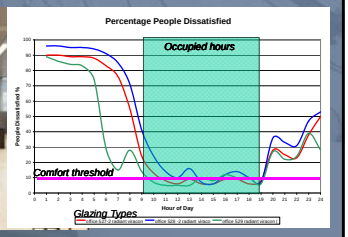
Strange Facts

- A Boeing 747 airliner holds 57,285 gallons of fuel

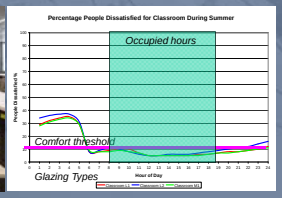
Will it work?

The Cooper Union – A Living Skin

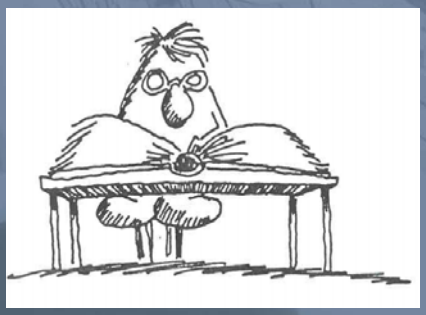
PPD Results – Different Rooms



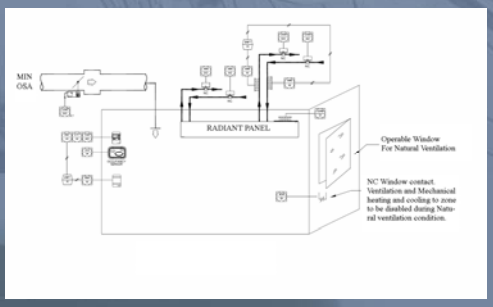
PPD Results: Classrooms (summer)



Overall Control strategies?



Space Control System

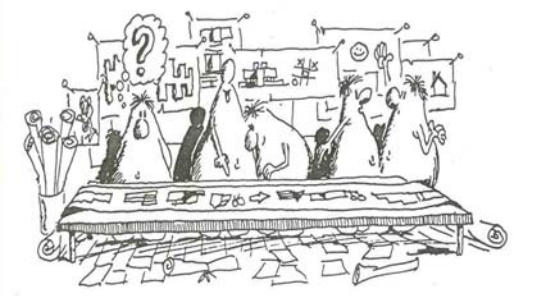


Cooper Union

Strange Facts

- It's illegal to drink beer out of a bucket while you're sitting on a curb in St. Louis!

Lessons Learned

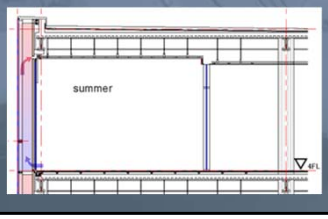


The Building

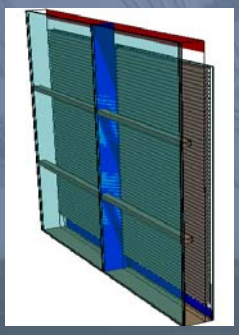
The tower is Class A complex office building,
below grade 6 levels,
above grade 71 levels,
building elevation 309.4m,
above grade building area is 169,243m2,
below grade building area is 45,112m2.

DOUBLE SKIN FAÇADE

- Determine suitability of glazing
- Evaluate optimal blind strategy
- Identify ventilation strategy
- Quantify cavity flow rates
- Underfloor Air Distribution
- Radiant Cooling
- Assess impact on offices

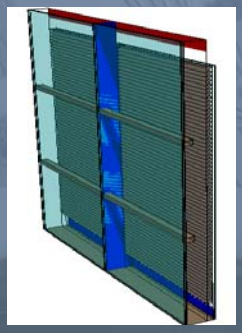


The Problem, Part 1



- The glazing elements were calculated as independent units, i.e. free hanging in a space and not associated the building.

The Problem, Part 2



- The convective and radiant heat gains through the glazing system were 'lumped' together to provide a maximum load to the space of 160 W/m2

The Problem solved, part 1

- The local design institute proposed to install perimeter fan coil units to compensate for the 'high' perimeter load from the glazing system

The Problem solved, part 2

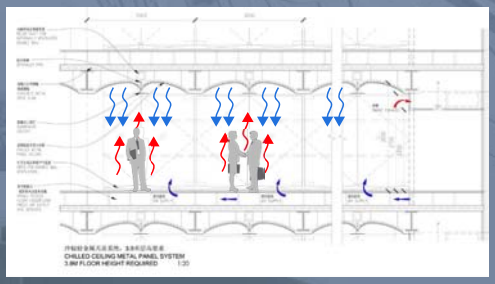
The fan coil unit would be operated by a temperatures sensor located on the glazing.

When the surface temperature of the glass reached 36C the fan coil would be operated!

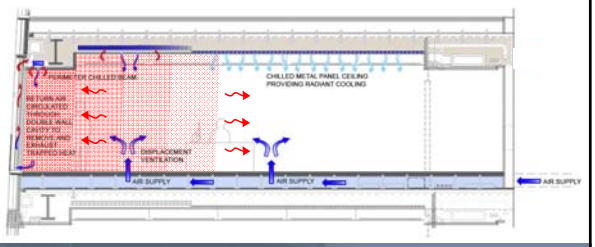
Pearl River-Typical floor

Pearl River-Typical floor

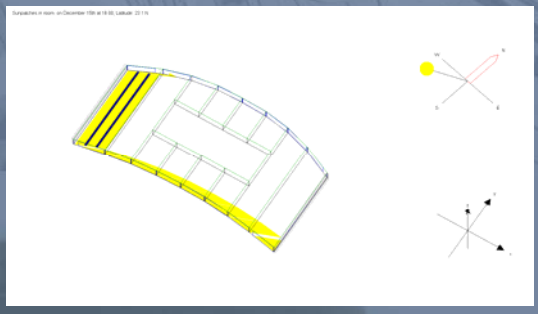
RADIANT CEILING WITH UFAD



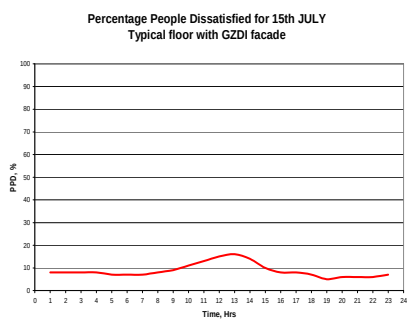
"INSIDE - OUT" RETURN AIR PATHS



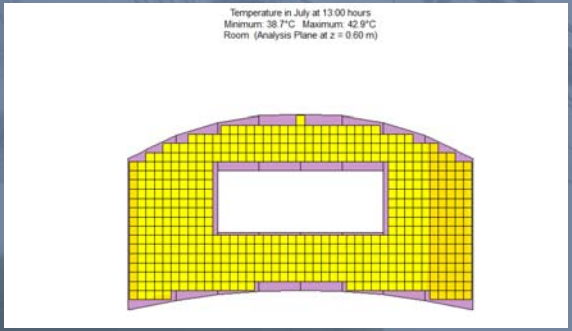
Solar Radiation



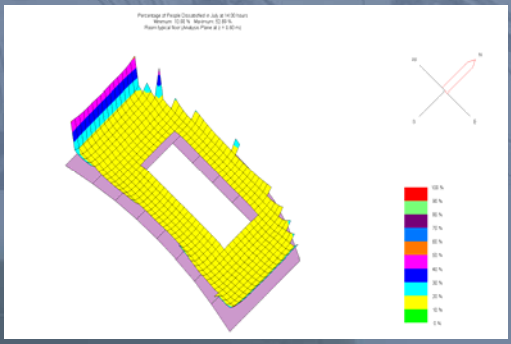
Thermal Comfort



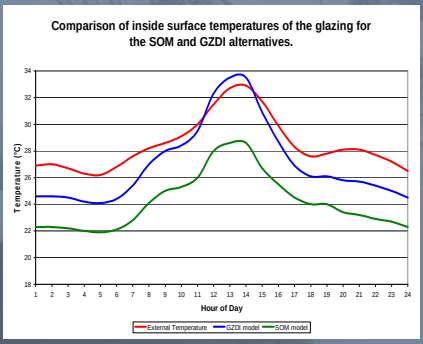
Typical floor plan



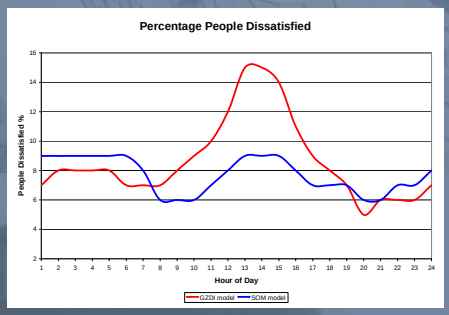
Thermal Comfort - GZDI Design



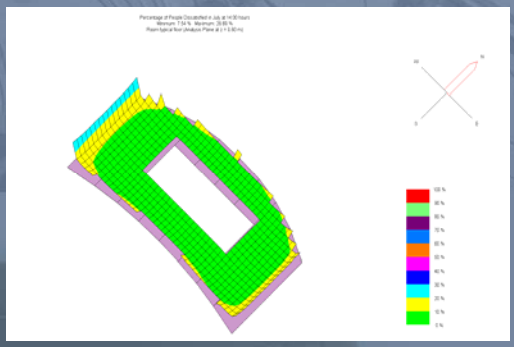
The source of the problem



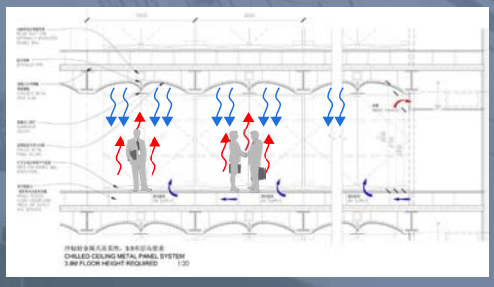
Thermal Comfort



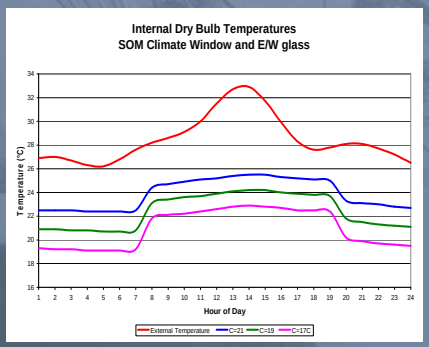
Thermal Comfort - SOM Design



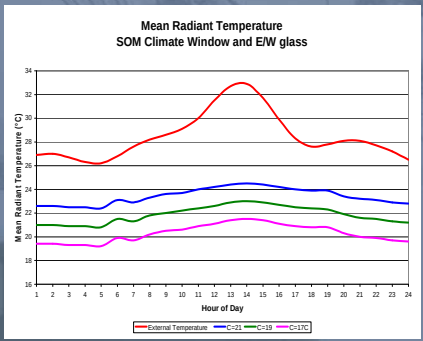
RADIANT HEAT EXCHANGE



ENERGY OPTIMIZATION



ENERGY OPTIMIZATION



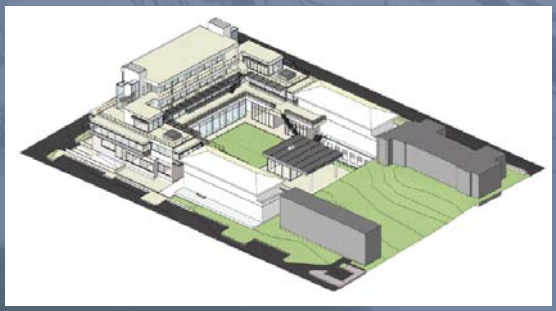
Electrical Use

Electrical End-use Totals (kWh)									
Alternative	Lights	Equip.	Cooling	Tower	Pumps	Fans	Ext. Lights	Total	difference
Energy code model	11,018,820	7,669,796	7,442,374	3,149,994	668,473	4,159,840	424,998	34,534,300	
SOM model	5,705,439	7,701,318	2,954,554	460,101	54,892	633,896	424,998	17,935,200	48.07%
GZDI model	6,797,416	7,673,057	3,716,758	496,234	64,093	1,107,307	424,998	20,279,860	41.28%

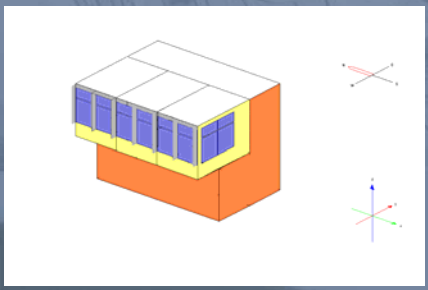
Strange Facts

- Windmills always turn counter-clockwise. Except for the windmills in Ireland!

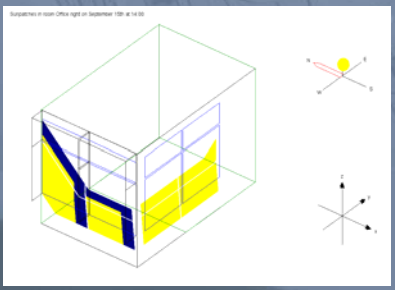
Claremont McKenna College



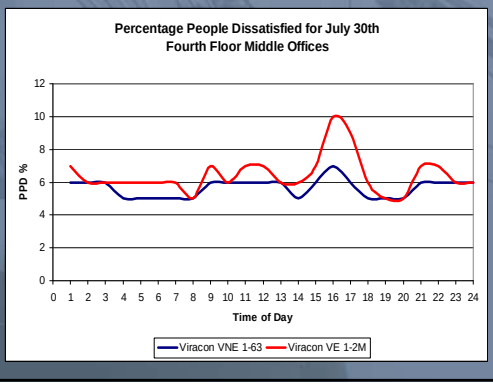
Shading devices



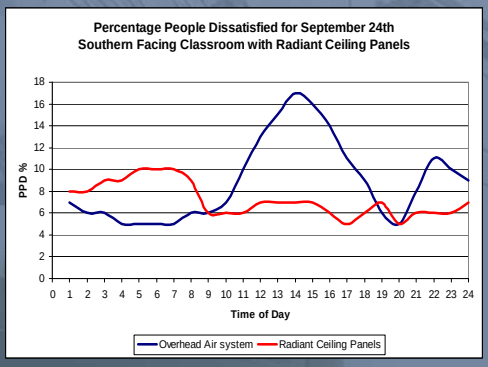
Shading



Thermal Comfort



Thermal Comfort



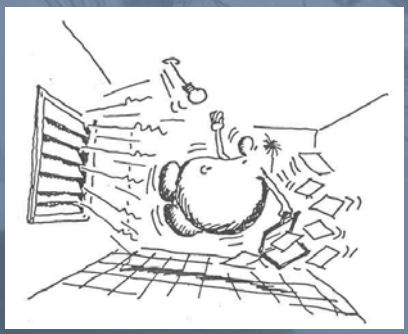
Typical Office

Typical Classroom

Previous Designs: New Los Angeles Federal Courthouse

Activity Level:	1	Activity Level:	2	Activity Level:	1	Activity Level:	2
Clothing Level:	1	Clothing Level:	1	Clothing Level:	2	Clothing Level:	2
Air Velocity:	0.20m/s	Air Velocity:	0.20m/s	Air Velocity:	0.20m/s	Air Velocity:	0.20m/s
PMV Comfort Distribution		PMV Comfort Distribution		PMV Comfort Distribution		PMV Comfort Distribution	
between 8:00 and 18:00		between 8:00 and 18:00		between 8:00 and 18:00		between 8:00 and 18:00	
BAND	Frequency	BAND	Frequency	BAND	Frequency	BAND	Frequency
PMV < -3.0	1	PMV < -3.0	0	PMV < -3.0	0	PMV < -3.0	0
-3.0 =< PMV < -2.5	86	-3.0 =< PMV < -2.5	0	-3.0 =< PMV < -2.5	0	-3.0 =< PMV < -2.5	0
-2.5 =< PMV < -2.0	84	-2.5 =< PMV < -2.0	1	-2.5 =< PMV < -2.0	0	-2.5 =< PMV < -2.0	0
-2.0 =< PMV < -1.5	61	-2.0 =< PMV < -1.5	108	-2.0 =< PMV < -1.5	17	-2.0 =< PMV < -1.5	0
-1.5 =< PMV < -1.0	82	-1.5 =< PMV < -1.0	88	-1.5 =< PMV < -1.0	141	-1.5 =< PMV < -1.0	0
-1.0 =< PMV < -0.5	12	-1.0 =< PMV < -0.5	106	-1.0 =< PMV < -0.5	105	-1.0 =< PMV < -0.5	133
-0.5 =< PMV < 0.0	2	-0.5 =< PMV < 0.0	23	-0.5 =< PMV < 0.0	61	-0.5 =< PMV < 0.0	137
0.0 =< PMV < 0.5	2	0.0 =< PMV < 0.5	3	0.0 =< PMV < 0.5	3	0.0 =< PMV < 0.5	56
0.5 =< PMV < 1.0	0	0.5 =< PMV < 1.0	1	0.5 =< PMV < 1.0	3	0.5 =< PMV < 1.0	3
1.0 =< PMV < 1.5	0	1.0 =< PMV < 1.5	0	1.0 =< PMV < 1.5	0	1.0 =< PMV < 1.5	1
1.5 =< PMV < 2.0	0	1.5 =< PMV < 2.0	0	1.5 =< PMV < 2.0	0	1.5 =< PMV < 2.0	0
2.0 =< PMV < 2.5	0	2.0 =< PMV < 2.5	0	2.0 =< PMV < 2.5	0	2.0 =< PMV < 2.5	0
2.5 =< PMV < 3.0	0	2.5 =< PMV < 3.0	0	2.5 =< PMV < 3.0	0	2.5 =< PMV < 3.0	0
PMV >= 3.0	0	PMV >= 3.0	0	PMV >= 3.0	0	PMV >= 3.0	0

Natural Ventilation, Adaptive Comfort



5.3 Optional Method for Determining Acceptable Thermal Conditions in Naturally Conditioned Spaces

For the purposes of this standard, occupant-controlled naturally conditioned spaces are those spaces where the thermal conditions of the space are regulated primarily by the occupants through opening and closing of windows. Field experiments have shown that occupants' thermal responses in such spaces depend in part on the outdoor climate and may differ from thermal responses in buildings with centralized HVAC systems primarily because of the different thermal experiences, changes in clothing, availability of control, and shifts in occupant expectations. This optional method is intended for such spaces.

5.3 Optional Method for Determining Acceptable Thermal Conditions in Naturally Conditioned Spaces

In order for this optional method to apply, the space in question must be equipped with operable windows that open to the outdoors and can be readily opened and adjusted by the occupants of the space. There must be no mechanical cooling system for the space (e.g., refrigerated air conditioning, radiant cooling, or desiccant cooling). Mechanical ventilation with unconditioned air may be utilized, but opening and closing of windows must be the primary means of regulating the thermal conditions in the space. The space may be provided with a heating system, but this optional method does not apply when the heating system is in operation. It applies only to spaces where the occupants are engaged in near-sedentary physical activities, with metabolic rates ranging from 1.0 to 1.3 met. See Normative Appendix A for estimation of metabolic rates. This optional method applies only to spaces where the occupants may freely adapt their clothing to the indoor and/or outdoor thermal conditions.

5.3 Optional Method for Determining Acceptable Thermal Conditions in Naturally Conditioned Spaces

Figure 5.3 accounts for local thermal discomfort effects in typical buildings, so it is not necessary to address these factors when using this option. If there is reason to believe that local thermal comfort is a problem, it is acceptable to apply the criteria in Section 5.2.4.

Figure 5.3 also accounts for people's clothing adaptation in naturally conditioned spaces by relating the acceptable range of indoor temperatures to the outdoor climate, so it is not necessary to estimate the clothing values for the space.

No humidity or air-speed limits are required when this option is used.

ASHRAE Std 62.1-2007

- "Naturally ventilated spaces shall be permanently open to and within 8m (25ft) of operable wall or roof openings to the outdoors, the operable area of which is a minimum of 4% of the net occupiable floor area……."
- "The means to open required operable openings shall be readily accessible to the building occupants whenever the space is occupied."

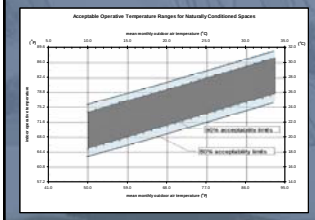
The Development of Adaptive Comfort

- Meta-analysis (Humphreys 1975,1976)
- Auliciems (1981,1989)
- The ASHRAE model from Research Project 884 by De Dear and colleagues (1997,1998). This study had 21,000 observations from 160 buildings in 9 countries

Summary of weighted linear regression of bin-mean thermal sensation on operative temperature (after de Dear et al 1997)

	HVAC	NV	MM
Number of buildings	109 2 missing	44 1 missing	4 None missing
Number of buildings included in the analysis	63	36	3
Mean (+/- stdev) model gradient	0.52 +/-0.248	0.27 +/-0.134	0.39 +/-0.105

NATURAL VENTILATION THERMAL COMFORT



- According to ASHRAE Standard 55, an optional method can be used when determining acceptable thermal conditions in naturally conditioned spaces. The optional method uses a graph to show the criteria for allowable indoor operative temperatures for spaces.
- The natural ventilation comfort graph has the mean monthly outdoor temperature on the x-axis and the operative temperature on the y-axis.

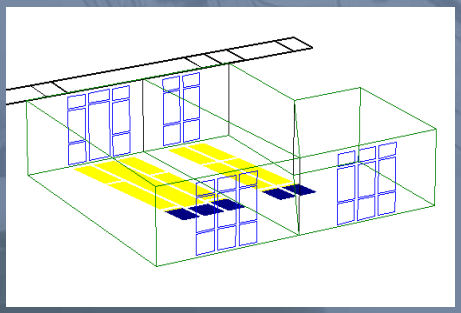
Outdoor Design Criteria

The following parameters show the coordinates for the Student Housing. The dry bulb and wet bulb temperatures are also stated for the annual cooling and heating design conditions.

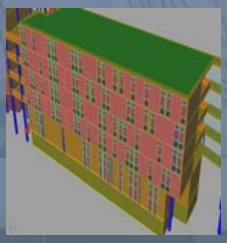
Climate Data	
Location	San Diego, CA
Latitude	32.72° N
Longitude	117.17° W
Elevation	30 ft
Outside Design Dry Bulb Temperature / Coincident Wet Bulb Temperature	84.7°F / 67.7°F
Winter Design Dry Bulb Temperature	44.8°F

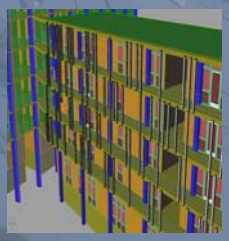
The above data are based on the 0.4% summer design temperatures and winter minimum design temperatures as found in the CEC – Title 24 Appendix X.

Based on the following sun path diagrams, the solar load is more significant for the 5-story housing building than the high-rise building due to orientation and shading.



UCSD Revelle Housing



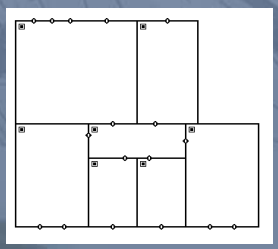


Airflow modeling

- The layout of the simulation model was constructed in CONTAM to determine the airflow results from the outside conditions.

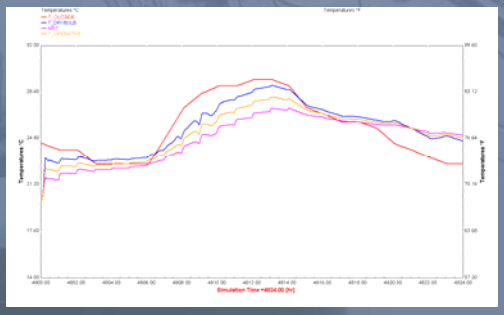
Assumptions

- The ventilation airflow was determined for Aug 5th (design day) and was then used as the fixed ventilation flow in the simulation model for all days of the design month using the hourly outdoor dry bulb temperature for each day.

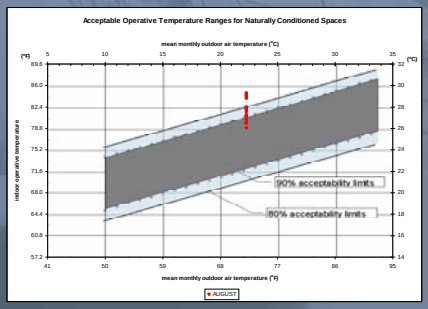


Infiltration air changes for each room. A zero infiltration means air is supplied to the room from connecting zones (doorways)

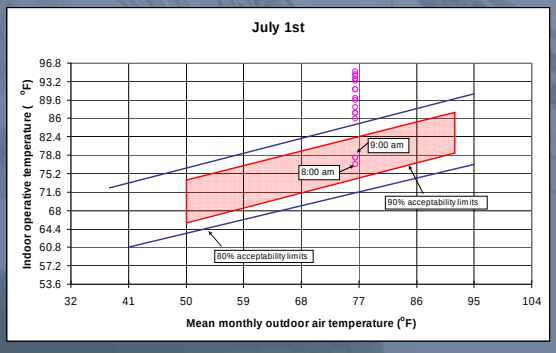
Fully Mixed Air Conditions for space - Commons



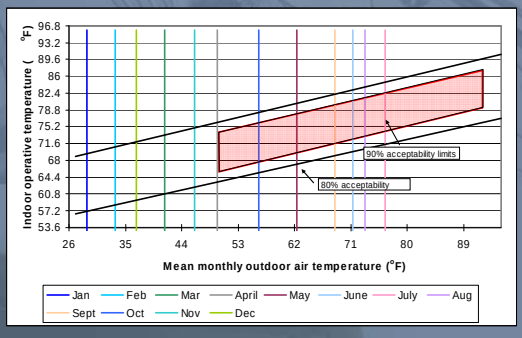
Acceptable Operative Temperature Ranges for the design day, August 5th. The mean monthly outdoor temperature is 72.2oF.

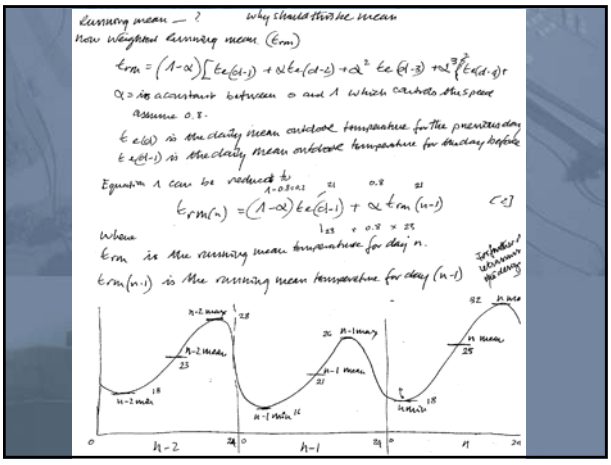


Adaptive comfort

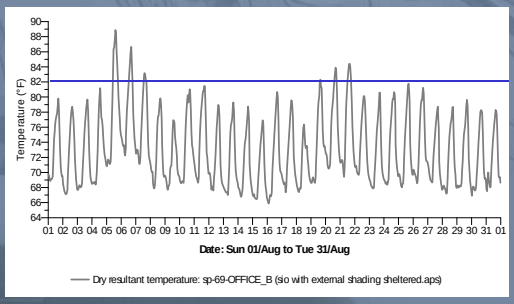


Adaptive comfort





Exceedance

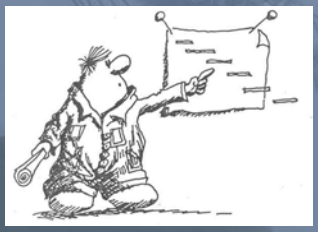


Discussion

- There also follows another interesting discussion on how the natural ventilation in a space is calculated. Is this wind driven or buoyancy driven?

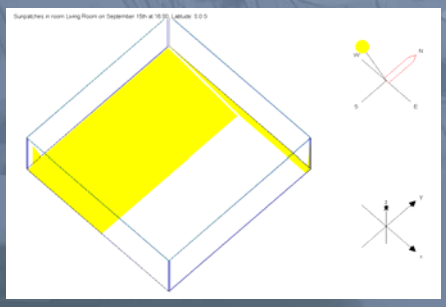
Just when you think you are finished

Established technology tends to persist in spite of new technology.

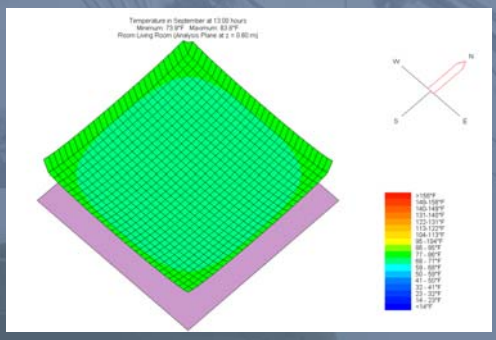


The Living Room

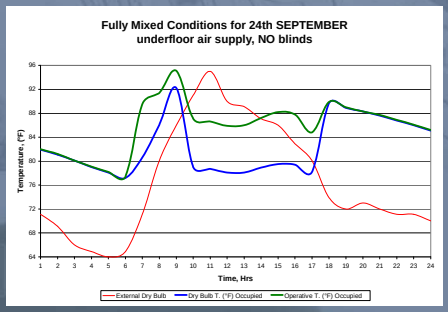
Living Room



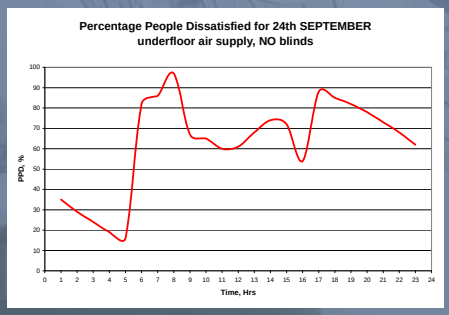
Living Room



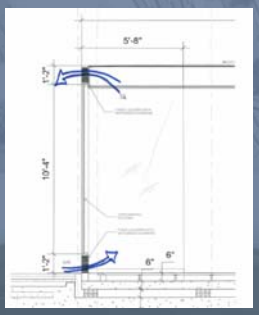
Living Room



Living Room



Natural Ventilation

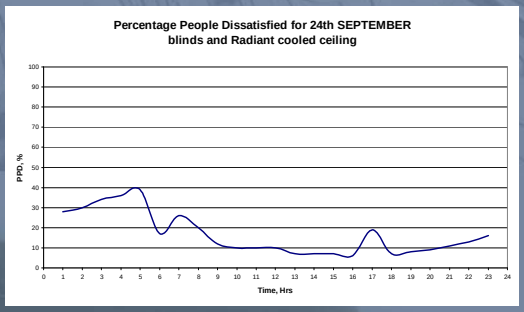


Cooler air enters at low level and the warmer air escapes through the openings.

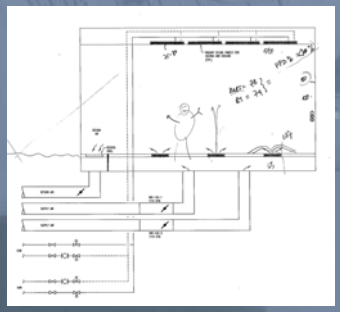
A control sequence will open and close the dampers to modulate the inside temperatures

And maintain comfort conditions.

Living Room



Intelligent Building Control



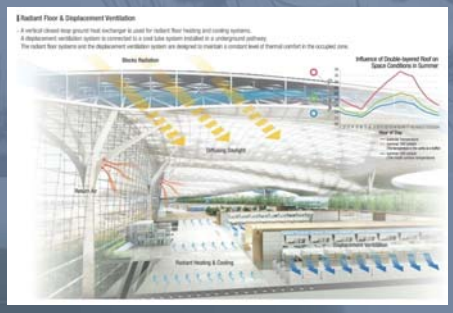
The Living Room

The Living Room

Living Room

Incheon Airport, Terminal II, Korea

Incheon Airport, Terminal II, Korea



The ultimate comfort clothing

High Performance Buildings and Occupant Comfort

- If you have to ask, you're not entitled to know
- If you don't like the answer, you shouldn't have asked the question.

On this day

- 2003 Former Iraqi dictator Saddam Hussein is arrested in a farmhouse near his hometown of Tikrit. Hussein had been in hiding since the Allied liberation began the previous March 20.
- 2003 Opera singer Luciano Pavarotti marries his producer Nicoletta Mantovani in the singer's hometown of Modena, Italy.
- 1999 Brazil's second effort to launch an earth satellite fails when the second stage of the rocket booster doesn't ignite; the rocket is destroyed three minutes after launch.
- 1978 Production of the Susan B. Anthony US dollar coin begins.
- 1961 American primitive artist Grandma Moses dies at age 101.
- 1947 The Maine Turnpike officially opens to traffic.
- 1941 Great Britain declares war on Bulgaria, during WWII.

On this day

- 1928 The George Gershwin musical, An American in Paris, premieres at Carnegie Hall in New York.
- 1924 Actor Clark Gable marries his acting coach, Josephine Dillon.
- 1918 Woodrow Wilson becomes the first US president to visit France while in office.
- 1819 The town of Tuscaloosa, Alabama, is incorporated.
- 1769 New Hampshire's Dartmouth College receives its charter from King George III of England.
- 1642 Dutch explorer Abel Tasman discovers New Zealand.
- 1557 Explorer Sir Francis Drake leaves England to sail around the world.

Born on this day

- 1967 Jamie Foxx - comedian, actor
- 1954 John Anderson - country singer
- 1950 Wendie Malick - actress (Just Shoot Me)
- 1949 Tom Verlaine - guitarist, singer (Television)
- 1949 Randy Owen - guitarist, singer (Alabama)
- 1948 Ted Nugent - guitarist, singer (Damn Yankees, Amboy Dukes)
- 1948 Jeff 'Skunk' Baxter - guitarist (The Doobie Brothers, Steely Dan)

Born on this day

- 1941 John Davidson - singer, actor
- 1929 Christopher Plummer - actor
- 1925 Dick Van Dyke - actor
- 1920 George Shultz - US Secretary of State (1982-88)
- 1910 Van Heflin - actor (Oscar® winner, 1942)
- 1903 Carlos Montoya - flamenco guitarist
- 1818 Mary Todd Lincoln - wife of 16th US president Abraham Lincoln

Primary factors influencing window comfort

- Window geometry
- Room geometry
- Occupant location

View factors

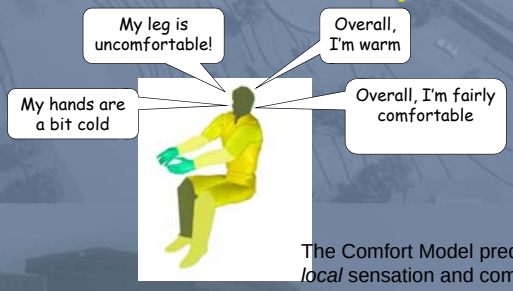
- Glazing system
- Frame type
- Exterior conditions (T_{db}, wind, solar)
- Interior conditions (T_{air}, surface temperatures, RH, air velocity)
- Human factors (clothing, metabolic rate, location)

Window inside surface temperatures

Local discomfort

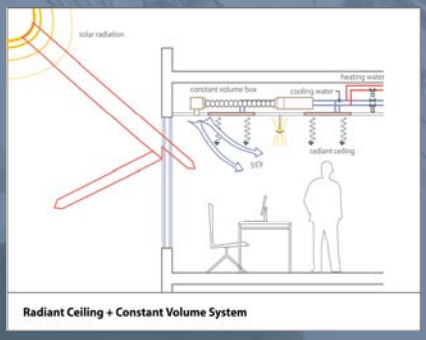
- Most thermal comfort complaints are a result of *local* discomfort rather than overall comfort
- Windows often cause local discomfort because the longwave radiation is stronger on one side of the body
- PMV predicts overall comfort but is not able to assess local discomfort

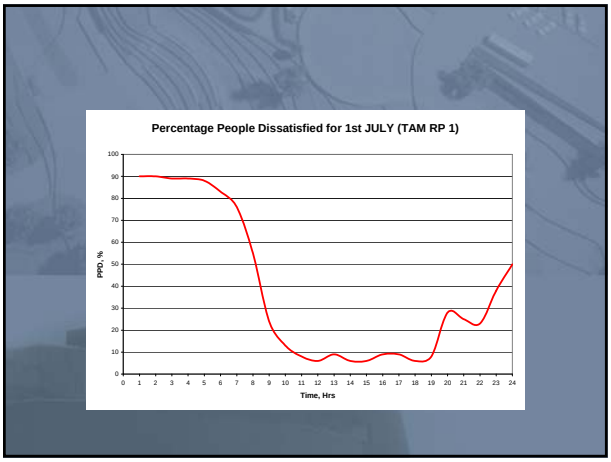
Comfort Model output



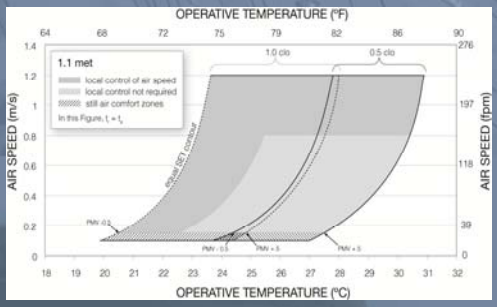
The Comfort Model predicts *local* sensation and comfort as well as overall sensation and comfort.

System

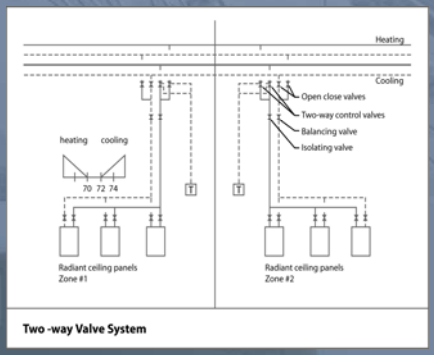




Acceptable range of operative temperature and air speeds for the comfort zone



Individual Space Control Options



Two -way Valve System