

High Performance Buildings and Occupant Comfort

Peter Simmonds, Ph.D., FASHRAE, FIBPSA, FFTI B and S Analytics, Marina Del Rey and Hong Kong peter@petersimmonds.com

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



EDUCAT,

ASHRAE is a Registered Provider with The American Institute of Architects Continuing Education Systems. Credit earned on completion of this program will be reported to CES Records for AIA members. Certificates of Completion for non-AIA members are available on request.

This program is registered with the AIA/CES for continuing professional education. As such, it does not include content that may be deemed or construed to be an approval or endorsement by the AIA of any material of construction or any method or manner of handling, using, distributing, or dealing in any material or product. Questions related to specific materials, methods, and services will be addressed at the conclusion of this presentation.





High Performance Buildings and Occupant Comfort

By Peter Simmonds

GBCI cannot guarantee that course sessions will be delivered to you as submitted to GBCI. However, any course found to be in violation of the standards of the program, or otherwise contrary to the mission of GBCI, shall be removed. Your course evaluations will help us uphold these standards.

Course ID: 0090010881

Approved for: X General CE hours BD+C X **LEED-specific hours** ID+C EED

Learning Objectives for this Session

- PPD/PMV analysis can be used for space comfort diagnostics.
- Using comfort analysis provides more information for the design team.
- Not all analysis tools are capable of simulating occupant comfort.
- Multiple use spaces still require to provide occupant comfort.
- To understand the limitations of maintaining comfort
- To understand the possible energy consumption.

ASHRAE is a Registered Provider with The American Institute of Architects Continuing Education Systems. Credit earned on completion of this program will be reported to ASHRAE Records for AIA members. Certificates of Completion for non-AIA members are available on request.

This program is registered with the AIA/ASHRAE for continuing professional education. As such, it does not include content that may be deemed or construed to be an approval or endorsement by the AIA of any material of construction or any method or manner of handling, using, distributing, or dealing in any material or product. Questions related to specific materials, methods, and services will be addressed at the conclusion of this presentation.



The Game

}How do we get to net zero? }How do we provide occupant comfort?





CH-93-10-4

THERMAL COMFORT AND OPTIMAL ENERGY USE

P. Simmonds Member ASHRAE



25 years ago



ASHRAE 90.1, 2013 Appendix G, Exceptions:

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 Section 5.2.3 of ASHRAE Standard 55, "Elevated Air Speed," or Appendix D of Standard 55, "Computer Program for Calculation of PMV-PPD."



Thermal Comfort Standard



ANSI/ASIIRAE Standard 55-2013 (Supersedes ANSI/ASHRAE Standard 55-2010) Includes ANSI/ASHRAE addenda listed in Appendix M

Thermal Environmental Conditions for Human Occupancy

See Appendix M for approval dates by the ASHRAE Standards Committee, the ASHRAE Board of Directory, and the American National Standards Institute.

This standard is under continuous maintenance by a Standard Standard Project Committee (SSFC) for which the Standards Committee has established a downerind program for regular publication of addends or revisions, including procedures for temely, documented, committue, and dealers in any change to any public the standards. The change submittal form, minimum, action on requests for change or any public the standards. The change submittal form, minimum public temestical, and dealers may be obtained in electronic form from the ASHRAE. Web site (www.abrae.org) or in paper from from the Mininger of Standards. The tester election of an ASHRAE Standard multip to purchased from the ASHRAE. Web site (www.abrae.org) or hom ASHRAE Castomer Service, TADT Table Crete, NE, Attanta, GA 2023;20305. Email: orders@abraham.com, Fax. 40–321-5477. Telephone. 40–430–4400 (worldwick), or toll free 1400-527-4723 (be roteen in US and Canada). For reprint permission, go to www.abrae.org) emsource.

© 2013 ASHRAE

ISSN 1041-2336



Thermal Comfort Definitions

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



Early work



 \bigcirc

The Groninger Museum, Groningen, the Netherlands











Akron Art Museum





Akron Art Museum



4/27/2018



The original building



Pearl River, China







Thermal Comfort – GZDI Design



Thermal Comfort



Real Time Comfort Control





8 Canada Square, London





Typical Trading Floor



Past Experience

- } No scientific approach to complaints
- } Complaints received regarding draughts, 'too hot', 'too cold'
- } Reactive activity based on individual experience / 'knee jerk
 reaction'
- } Average quantity of daily calls / emails received across all three floors were 3 per day
- Only factor that was measured that influenced thermal comfort was Air Temperature
- } Controls / unit failures that were not identified



Recent Complaints PPD = 5-7%

Complaints

Air Velocities



Profile shows complaints post Christmas Change activity



PPD/PMV Real Time Control

Clothing SPA Selected VAV Box Temperature Selected PMV and PPD Values Cior 0.70 VAV Box 62 PMV: 0.53 PMV: 0.53 PPD Value: 11.0 % VAV Box 61: 23.1 °C PMV Scale VAV Box 61: 23.1 °C VAV Box 61: 23.1 °C PMV Scale Radiant Space Temp: 24.3 °C VAV Box 61: 23.1 °C +3 +4 Name VAV Box 61: 23.1 °C VAV Box 62: 23.3 °C VAV Box 63: 23.9 °C Name VAV Box 62: 23.9 °C VAV Box 63: 23.9 °C VAV Box 63: 23.8 °C Name VAV Box 66: 24.5 °C 1 Slightty Condition VAV Box 66: 24.5 °C 1 Slightty Condition - VAV Box 66: 23.8 °C 3 Cool -	Clothing SPA Selected	VAV Box Temperatur	Selected PMV and PPD Value PMV: 0.53 PD0View M 0.6	
VAV Box 62 PMV: -0.53 VAV Box 62 PMV: -0.53 PPD Value: 11.0 % PMV Scale VAV Box 61: 23.1 °C PMV Scale VAV Box 62: 23.3 °C PMV Scale Radiant Space Temp: 24.3 °C VAV Box 63: 23.9 °C Air Space Temp: 23.3 °C VAV Box 65: 23.8 °C O Space Humidity: 43 % RH VAV Box 66: 24.5 °C 1 VAV Box 66: 23.8 °C - Slightly Co VAV Box 66: 24.5 °C - Slightly Co VAV Box 66: 24.5 °C - Slightly Co VAV Box 68: 23.8 °C - Cool VAV Box 68: 23.8 °C - Cool VAV Box 68: 23.8 °C - Cool	Clo: 0.70	VAV Box 62	PMV:-0.53	
VAV Box Temperatures Used PMV Scale Sensor Values VAV Box 61:23.1 °C +3 - Hot VAV Box 62: 23.3 °C VAV Box 63: 23.9 °C +2 - Warm Radiant Space Temp: 23.3 °C VAV Box 65: 23.8 °C 0 - Slightty Wa VAV Box 65: 23.8 °C 0 - Neutral - Neutral VAV Box 66: 24.5 °C - - Slightty Co - - VAV Box 66: 24.5 °C - - - Slightty Co - VAV Box 66: 24.5 °C - - - Slightty Co - VAV Box 66: 24.5 °C - - - - - VAV Box 66: 24.5 °C - - - - - VAV Box 68: 23.8 °C - - - - -			[PPD value: 11.0 %	
Sensor Values VAV Box 61:23.1 °C +3 - Hot Radiant Space Temp: 24.3 °C VAV Box 63:23.9 °C +2 - Warm Air Space Temp: 23.3 °C VAV Box 65:23.8 °C 0 - Neutral Space Humidity: 43 % RH VAV Box 66:24.5 °C - - Neutral VAV Box 66:24.5 °C - - Cool - VAV Box 66:24.5 °C - - Cool VAV Box 66:24.5 °C - - Cool VAV Box 68:23.8 °C - - Cool		VAV Box Temperat	res Used PMV. Scale	
Sensor Values VaV Box 62: 23.3 °C +3 - Hot Radiant Space Temp: 24.3 °C VAV Box 63: 23.9 °C +1 - Slightty Wa Air Space Temp: 23.3 °C VAV Box 64: 24.0 °C +1 - Slightty Wa Space Humidity: 43 %RH VAV Box 65: 23.8 °C 0 - Neutral VAV Box 66: 24.3 °C - Slightty Co - Neutral VAV Box 66: 24.3 °C - - Cool VAV Box 68: 23.8 °C -2 - Cool VAV Box 68: 23.8 °C -3 - Cold		VAV Box 61: 23.1 °C		
Radiant Space Temp: 24.3 °C +2 - Warm Air Space Temp: 23.3 °C VAV Box 64: 24.0 °C +1 - Slightly War VAV Box 65: 23.6 °C 0 - Neutral VAV Box 66: 24.5 °C 1 - Slightly Correction VAV Box 66: 24.5 °C - - Cool	Sensor Values	VAV Box 62: 23.3 °C	+3 - Hot	
Radiant Space Temp: 24.3 °C VAV Box 64: 24.0 °C +1 - Slightly Wa Air Space Temp: 23.3 °C VAV Box 65: 23.8 °C 0 - Neutral Space Humidity: 43 %RH VAV Box 66: 24.5 °C -1 - Slightly Control VAV Box 66: 24.5 °C -1 - Slightly Control - Cool VAV Box 66: 24.5 °C -3 - Cool - Cool	1	VAV Box 63: 23.9 °C	+2 - Warm	
Air Space Temp: 23.3 °C VAV Box 65: 23.8 °C 0 - Neutral Space Humidity: 43 %RH VAV Box 66: 24.5 °C -1 - Slightly Co VAV Box 66: 24.5 °C -1 - Slightly Co VAV Box 66: 24.5 °C -1 - Cool VAV Box 66: 23.8 °C -2 - Cool VAV Box 68: 23.8 °C -3 - Cold	Radiant Space Temp: 24.3 'C	VAV Box 64: 24.0 °C	+1 - Slight	ty War
Space Humidity: 43 %RH VAV Box 66: 24.5 °C -1 Slightly Co VAV Box 67: 24.3 °C -2 - - Cool VAV Box 68: 23.8 °C -3 - - Cold	Air Space Temp: 23.3 'C	VAV Box 65: 23.8 'C	0 - Neutr	al
VAV Box 67: 24.3.C -2 - Cool VAV Box 68: 23.8.C -3 - Cold	Space Humidity: 43 %RH	VAV Box 66: 24.5 °C	-1 - Slight	ty Coo
VAV Box 68: 23.8 °C -3 - Cold		VAV Box 67: 24.3 °C	-2 Cool	
12022 B 270- 120 8 20		VAV Box 68: 23.8 °C	-3 Cold	
144 B0X 69-23.0 C		VAV Box 69: 23.8 °C		
	Zone Temps 🛛 🔽 Heat Metering	▼ Misc Plant ▼ BMS 5	ystem 🔽 Fire System 🔽 Floor Plan	



PPD Thermal Comfort Index





PPD at Room design of 24 °C

12 14

Reference: PPD Thermal Comfort Toolkit http://smap.cbe.berkeley.edu/comforttool

ASHRAD-SC

2.63

114

Payerrownellers mant (42-terranetaure)

18 48 30 22 34 29 25

Div-bub Temperature (*c)

INCOME to these and the second in a second s The main registry expension is interviewing consistent to the many sector and both at the one has the case were which derives the constraints would be at any possible of the careful to the the thermal control. The case which are constraints provide the balance and the point will not the assist when.

NOIST

25.90

Gregory Ranges

28

20 1

15 8

10 T

30 50 124

Current Experience

} Installed Predicted Percentage of Dissatisfied (PPD) system

- } Now measure the 6 factors that influence thermal comfort Air Temperature, Relative Humidity, Air Velocity, Radiant Temperature, Clothing, Metabolic Rate
- } Average daily complaints now reduced to around 1 per day
- } Smaller zones giving more accurate control
- } Thermal comfort conditions are logged





The efficiency of the façade-midseason





The Living Skin



SL-08-053

Modeling the Heat Gain of a Window with an Interior Shade— How Much Energy Really Gets In?

Douglas C. Hittle, PhD Fellow ASHRAE Peter Simmonds, PhD Fellow ASHRAE













Cooper Union- Results

} The resulting utility costs are \$400,770 compared to \$602,672 for the budget case.

} The total energy cost savings is 34% and is therefore eligible for 7 LEED points.

} The proposed case is predicted at consuming 1,170,365 kWh of electricity per year and the budget case is predicted at consuming 2,184,932 kWh of electricity per year.

} This is a 46% reduction below the budget case.





Space Control System



Harbin Bank, Beijing


The Climate Facade





Copyright Building and Systems Analytics 2018

Analysis Plane



Summer Comparison

Percentage People Dissatisfied -Summer



Winter Comparison

Percentage People Dissatisfied -Winter



CO2 Emissions



Louis Vuitton Museum, Paris



LVMH- Paris



The Forum



Forum Conditioning system



Radiant ceiling for heating and cooling

Radiant floor for heating and cooling

The Forum



CFD for Comfort analysis



CFD for Comfort analysis



CFD for Comfort analysis



Claremont McKenna College



Typical Office



Meeting room





Claremont McKenna College

Energy consumption 48% lower than code required building.





Terminal 2 – 680,000m2



Environmental Responsibility





Breathing Skin Concept



Radiation Exchange Concept



Radiant floor and displacement ventilation

Radiant Floor & Displacement Ventilation

· A vertical closed-loop ground heat exchanger is used for radiant floor heating and cooling systems.

- A displacement ventilation system is connected to a cool tube system installed in a underground pathway.
- The radiant floor systems and the displacement ventilation system are designed to maintain a constant level of thermal comfort in the occupied zone.



Roof Performance- Summer

Temperatures of Roof - Summer



Occupant Comfort - Summer



Roof Performance- Winter

Temperatures of Roof - Winter



Occupant Comfort - Winter



Two Tabor Tower, Denver







0 р g h B u C n g а

Two Tabor Tower, Denver



- Final The new 30 to 33-story Two Tabor Center has been designed with a focus on providing tenants a productive and healthy work environment that is employee-centric and provides easy access to the many amenities of Tabor Center and the 16th Street Mall.
- Figure 1 Two Tabor Center will add approximately 637,000 to 692,000 rentable square feet of class AA office space to Tabor Center, creating one of the largest office complexes in Denver with over 1,217,000 rentable square feet of office space. Retail space occupies the ground level of Two Tabor Center along 17 St. and Larimer Street. Entrances to a 1,700-space underground parking garage.

Comparison of glass types

	Cavity	floor area	Solar Radiation (btu/h)	Transmission (btu/h)	total	Envelope load per SF floor area (Btuh/sf)
VUE1-30 (40%)	Air(10%)/Argon (90%)	765,272	1,133,853	629,567	1,763,420	2.30
VNE4-53 (40%)	Air(10%)/Argon (90%)	765,272	1,496,149	623,118	2,119,268	2.77
VRE1-38 (40%)	Air(10%)/Argon (90%)	765,272	1,516,277	648,914	2,165,191	2.83
VP1-13 (40%)	Air(10%)/Argon (90%)	765,272	1,328,420	1,059,492	2,387,911	3.12
VNE1-63 (40%)	Air(10%)/Argon (90%)	765,272	1,905,410	640,315	2,545,725	3.33
VUE1-30 (65%)	Air(10%)/Argon (90%)	765,272	1,842,511	824,042	2,666,553	3.48
VNE1-53 (65%)	Air(10%)/Argon (90%)	765,272	2,431,243	788,959	3,220,201	4.21
VNE4-53 (65%)	Air(10%)/Argon (90%)	765,272	2,431,243	813,563	3,244,805	4.24
VRE1-38 (65%)	Air(10%)/Argon (90%)	765,272	2,463,950	855,480	3,319,430	4.34
VP1-13 (65%)	Air(10%)/Argon (90%)	765,272	2,158,682	1,522,669	3,681,351	4.81
ASHRAE 90.1 (40%)	Air(10%)/Argon (90%)	765,272	2,683,676	1,093,886	3,777,561	4.94
VNE1-63 (65%)	Air(10%)/Argon (90%)	765,272	3,096,291	841,508	3,937,799	5.15
ASHRAE 90.1 (65%)		765,272	4,360,973	1,578,560	5,939,533	7.76
VNE1-53 Air (65%)	Air (100%)	765,272	2,507,560	995,206	3,502,765	4.58

Ģ 0 р y r g h t В u d n g а n

External Load (btu/h)









y

r

g

t

g

а

n

EUI (kBtu/ft2)

Ģ

0

р

y

r

g

h

t

В

u

d

n

g

а

n





4/27/2018

0

р

y

g

h

t

В

u

d

n

g

а

n

Comparison of Building Loads – Design Results


Wilshire/Gayley Residential





Acceptable Operative Temperature (to) Ranges for Naturally Conditioned Spaces



Exponentially weighted running mean temperature

$$T_{rm} = (1-a).\{T_{od-1} + a.T_{od-2} + a^2T_{od-3}....\}$$

 $F_{rm}{}^n = (1-a).T_{od}{}^{n-1} + a.T_{rm}{}^{n-1}$
a is a constant (a < 1),
 T_{rm} Running mean temperature
 Trm^n is Trm on day n
In this database TrmX = Trm for a = X/100
 T_{od} Daily mean temperature



-

-

ASHRAE 55 Adaptive Comfort Comparison of Indoor Operative Temperature to Flat Mean and Prevailing Mean Criteria: Wilshire-Gayley, November, alpha = 0.7 for prevailing mean



comparison of maximum air velocities



comparison of maximum air velocities

- For operative temperatures (t_o) above 25.5°C (77.9°F), the upper limit to average air speed (V_a) should be 0.8 m/s (160 fpm).
- For operative temperatures (t_o) below 22.5°C (72.5°F), the limit to average air speed (V_a) should be 0.15 m/s (30 fpm).
- For operative temperatures (t_o) between 22.5°C and 25.5°C (72.5°F and 77.9°F), the upper limit to average air speed (V_a) it is acceptable to approximate the curve in I-P and SI units by the following equation:

$$V_a = 50.49 - 4.4047 t_o + 0.096425(t_o)^2 (m/s, °C)$$

 $V_a = 31375.7 - 857.295 t_o + 5.86288(t_o)^2$ (fpm, °F)





GuoXing Avenue Mixed Use Haikou, Hainan, Chir



% shading through fins





Comparison of EUI (kWh/m2)



4/27/2018

CO2 Emissions

















Stratified Conditions for 22nd JULY



Energy Use Intensity (EUI) kBtu/h.ft2



PPD for a summers day in the Concourse



PPD for 1st to the 31st JULY -Concourse



1766-RP Development of a Unified Tool for Analysis of Room Loads and Conditions

Principal Investigators: Chip Barnaby Peter Simmonds

> January 27, 2017 Las Vegas





Goal

To integrate software previously developed by several ASHRAE research projects to create a single application that includes all of the necessary algorithms for calculating space heat balance and radiant energy exchange.

This application is provisionally named RPEHB and will be created by combining RPE (from 1383-RP) and the heat balance room model (originating in 987-RP and enhanced by 1199-RP and 1311-RP).



The Process in Practice

SketchUp

|--|--|

SketchUp takes the geometry and converts this into a building model that can be read by OpenStudio

OpenStudio builds the simulation model with constructions, schedules, design weather, ...

OpenStudio

Visualization of simulation results that evaluate space conditions with and without radiant systems

RPEHB



SketchUp



OpenStudio - constructions



OpenStudio – room loads

una Tem							N THERE BOARD EAL
Drop]	General Londo Mea	ure Cuton			Î	Default Construction Sets
Soare rype	1					1	Default Schedule Sets
Filter: Load 7/pe Show al loads		:					Design Specification Outdo
Space Type Name	Al	Lottere	Nulpher	Sefinition	SJedde	AblySteam	People Definitions
	r		Above to Solutions		Apply to Selected	(Propie Only)	Lights Definitions
	г	🕴 🖡 FeakBoom - CZ1-3 People	1.000000	Room - CZ1-3 People Definition	Office Mac Occ	Office Activity	Luminaire Definitions
19 - Office - BreakRoom - C21-3	r	Ireaklaan -C21-3Light	L.00000	Room - C21-3 Lights Definition	Office Bidg Light		Electric Equipment Definitio
	Г	€		C0000	Office 2x8 Quarter On		Gas Equipment Definitions
	r	🛊 FeakSoon -C2+&People	1.000000	Room - CZ+8 People Definition	Office Mac Occ	(Office Admity)	Water Use Equipment Definitions
19 - Office - BreakRoom - CZ4-0	r	V C244 Decrc Ealpret	L-000000	All Dectric Toupnent Definition	Office Bidg Light		Hot Water Equipment Definitions
	Г	Hoon - C2+8 Infitration		·····	Office Infi Quarter On		Stram Equipment Definitio
	г	juedOffice -C21-3People	1.000000	Diffice + C21-3 People Definition	Office Nork Occ	Office Adulty	• Other Equipment Definition
😌 😂 😂						0	Internal Hass Definitions

RPEHB – Import and Display

Room Viewer - Building 1 THERMAL ZONE 1



Explore Results ...





Refer to set				
1.8.78.76				
e Options Help				
				Display Nameab IF MRR INI 0.6
				20:00 20:00 20:00 20:00 20:00 F 20:00 F Room Conditions F T respond (C) [20:0] T respond (C) [20:0]
				f maple (*C) (500 (130 F w (*C) 240 System output (w)
ale	Sufaces		Contot Paraseters	Ar 40106 6168 Px 6913 °C Pavel 0
sularg 1 IEUNG at-2010/ N long-116.47° E	Suface 1 + Suface 2 Suface 3	Loreng 10 [Const	A Sealed C Standing	Total 40106
Autor conditions BELING Are Clin 41 Contro DRooMuß	Sub Surface 10 Sub Surface 11	National (O) [[Final	Chathana International (0.50 -	Whole constructs
Room CFA 329.6 st Panel 0.0 st	Sid Surface 5	Ditter Gardali	Relation transfer (2) 51 +	PM 0.05 (P)
Themal Zone 1	Sub Surface 6 Sub Surface 7	Flux Wilef W Conv		PEDIAL 5
Date/free Juli21 16:00 IP Solar i → Toux 34.0 °C Eb 737 Ed 182 Worf	Sub Suface 5 Sub Suface 9 Suface 4	Rad Total	Direct sun in contart P	Nedtal

Can Current Zone Selections Provide Occupant Comfort?

BY PETER SIMMONDS, FELLOW ASHRAE: TOM HARTMAN, LIFE MEMBER ASHRAE

For HVAC system design, office buildings are typically divided into local thermal zones made up of multiple occupied spaces (*Figure 1*). Thermal zones are areas of the occupied building selected by the designer in which it is believed uniform thermal conditions can be maintained throughout with the means of local thermal distribution and control employed. The number and size of zones are based on several criteria, but designers typically employ rules of thumb in selecting and laying out thermal zones.

In an office building with similar internal loads throughout, such rules usually require a minimum of ane zone for each of the perimeter exponences on each floor, a maximum number of separate spaces ceiling or radiant floor that is individually controlled for that area."

Determining whether a zone configuration can achieve acceptable comfort for its occupants requires



Thank you

Building and Systems Analytics LLC 4209 Via Marina, #408 Marina Del Rey, CA 90292, USA Unit 1202, 12/F, Malaysia Building 50 Gloucester Road Wanchai, Hong Kong www.petersimmonds.com peter@petersimmonds.com