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Does PMV unnecessarily restrict natural ventilation in buildings?

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Abstract

In this paper, a global map of maximum indoor operational temperatures of buildings is presented. Maximum indoor operational temperatures were evaluated around the world using both PMV and ATC. It is found that utilising ATC to establish a building's design comfort temperatures gives a higher acceptable indoor operative temperature compared to PMV and thus widens the potential temperatures for the use of natural ventilation in buildings while not compromising their ability to provide comfort for adapted populations, suggesting that PMV does unnecessarily restrict the use of natural ventilation for comfort cooling.

It is found that using CIBSE TM52, 100% of Europe can utilise the ATC. If ASHRAE 55-2013 standard is used, 97.1% of global locations can use ATC. It was also found that 89% of global weather files have a temperature difference between ATC and PMV of between 5K and 9K.

Keywords: PMV, Adaptive Thermal Comfort, Natural Ventilation, Comfort comparison, Weather Files

1. Introduction

The measurement of building occupants thermal comfort has, for the last half century, been primarily assessed using two different models: one based on laboratory experiments and steady-state calculations and the other known as the 'Adaptive Method' based on field studies. The Adaptive Thermal Comfort (ATC) model, which is included in such standards as the American ASHRAE 55-2013 standard, the European EN15251 standard and most recently the UK CIBSE TM52, allows warmer indoor operative temperatures of naturally ventilated buildings during summer to be deemed as acceptable and is based on the daily running mean of the local climates. The steady state model, Percentage Mean Vote (PMV), has been the dominant method used by building service engineers over recent decades to predict comfort temperatures in buildings but does not explicitly take into account weather variables.

Thermal comfort standards significantly influence the energy consumed by a building's environmental systems and in turn its carbon emissions and environmental impacts (Yao et al., 2009). Selecting an appropriate thermal comfort model for a building is thus key to lowering this energy consumption. PMV has been typically used as the standard model to access comfort levels. PMV is a steady stated model and does not explicitly take into account the climate in which the building is located.

ATC on the other hand, takes into account the external conditions when assessing comfort.

When modelling a building, a designer will select “input” parameters to achieve a desired “output”, a building design. These model inputs are traditionally insulation levels, air permeability, lighting levels, percentage glazing, glazing type etc. The two key model outputs considered are energy consumption and thermal comfort which are inextricably linked, as are, in turn the input parameters to thermal comfort. All of these input parameters can be changed, apart from one, the local weather. For a building designer, the weather in a particular location is key to understanding the strategies to deliver a sustainable building.

Building designers around the world have a number of weather file databases to access. A freely available source is provided by the U.S. Department of Energy (2013). This paper uses these weather files (2598 locations around the world) to demonstrate the potential savings of adapting a building to its local environment.

2. Methods

PMV and ATC can both determine the indoor operative temperature of a room. Using ATC, a maximum acceptable indoor operative temperature can be calculated using the exponentially weighted running external daily mean temperature. On the other hand, the PMV method focusses on the following parameters:

- Metabolic rate (M [met])
- Thermal resistance of clothing (I_{clo} [clo])
- Air temperature (T [ºC])
- Mean radiant temperature (T_{mrt} [ºC])
- Relative air velocity (v [m/s])
- Relative humidity (RH [%])

To reduce the analytical search space required, the following assumptions are made:

- Metabolic rate is of an office worker (Met = 1.1; Office Typing as outlined in Standard ASHRAE 55 (2013))
- Thermal resistance of clothing is of an office worker (Clo =0.6)
- the air temperature and mean radiant temperature are equal
- the relative air velocity is assumed low (Vel = 0.1 m/s)
- the indoor relative humidity is calculated using the minimum external humidity ratio

In ANSI/ASHRAE Standard 55 (Standard ASHRAE 55, 2013) , comfort is classified by predicted percentage dissatisfied. The <10 bands equates to a PMV of ±0.5. BS EN ISO 7730 (BSI, 2005) buildings are classified as A, B or C on the basis of the range of acceptable internal temperatures as calculated using PMV encountered. For this paper, classification B was selected which allows a PMV range of ±0.5. In European standard BS EN 15251 (Olesen, 2007) the acceptable ranges of PMV are categorised

I, II and III. An ASHRAE ‘90%’ class, BS EN 7730 ‘B’ class and a BS EN15251 ‘II’ class are all equivalent by means of their acceptable PMV range.

In the first step, the exponentially weighted running mean was calculated for all location using the external dry bulb temperature and an alpha value of 0.8 as recommended in TM52 (CIBSE, 2013). Utilising the formula laid out in TM52 (CIBSE, 2013), a category ‘2’ building was selected as equal to that of the PMV class building and thus the maximum indoor operative temperature was calculated by:

Equation 1 - ATCtemp

where T_{rm} is the exponentially weighted running daily mean external temperature.

In the second step, to remove the building variable from the study, the same, above, uniform building assumptions were applied at each location. Utilising a PMV index of +0.5, the highest possible operative temperature would occur when the internal relative humidity would be at its minimum. As the internal relative humidity could not be known as no actual building is presented in this study, it is assumed that the minimum internal relative humidity possible is that of the minimum external humidity ratio at the internal temperature. Though this may never be the case, due to latent heat from internal gains such as people, it would result in the theoretical maximum operative temperature for any space. Using these assumptions the calculation was run to find the indoor operative temperature which satisfied a PMV index of +0.5.

The temperature difference between the two operative temperatures was then calculated for all locations around the world.

3. Results

Due to the large number of locations, results for only a sample of the locations are shown in Table 1.

Table 1. Sample of Results

Country	State	City	PMV	ATC Temp	PMV Temp	Delta T
				(Deg C)	(Deg C)	(K)
KWT	-	Kuwait Intl Airport	0.5	38.9	27.71	11.19
IND	-	NAGPUR	0.5	38.3	27.41	10.89
USA	CA	Needles Airport	0.5	38.38	27.77	10.61
PLW	-	Koror Island	0.5	35.07	25.76	9.31
CHN	Sichuan	Yibin	0.5	35.6	27.41	8.19
CUB	-	Punta de Maisi	0.5	35.45	27.26	8.19
MDV	-	GAN_ISLAND	0.5	35.45	27.31	8.14
ESP	-	VALENCIA	0.5	34.58	27.72	6.86
USA	MI	Howell	0.5	34.58	27.72	6.86
USA	MD	BALTIMORE	0.5	34.57	27.71	6.86
RUS	-	MOSCOW	0.5	33.15	27.7	5.45

FRA	-	NANTES	0.5	33.12	27.67	5.45
AUS	WA	Albany Airport	0.5	32.8	27.35	5.45
CHN	Qinghai	Tuotuohe	0.5	28.88	27.85	1.03
CHN	-	PAGRI	0.5	28.75	27.85	0.9
USA	AK	BARROW	0.5	27.71	27.51	0.2
CAN	NU	Resolute	0.5	27.37	27.52	-0.15

It can be seen in Table 1 that a difference in operative temperatures ranges from negative 0.15 K in Resolute, Canada (the only negative temperature difference) to positive 11.19 K in Kuwait International Airport, State of Kuwait.

Once all results were tabulated, they were incorporated into google maps for ease of viewing. It can be seen in Figure 1 that there are a number of weather files for Europe, North America, China and Australia, but the rest of the world is sparsely populated.

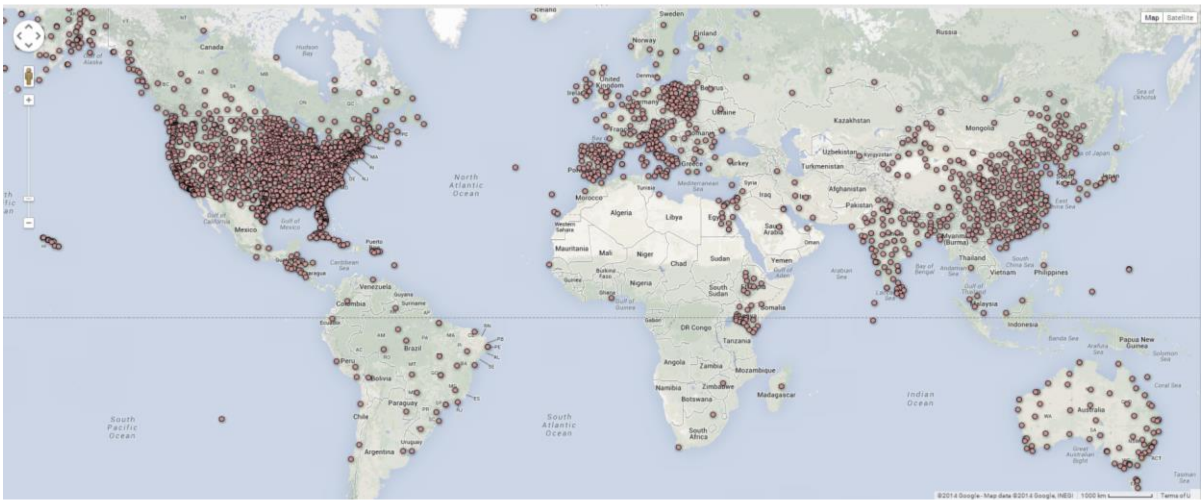

Figure 1. Interactive Map of the World

As seen in Figure 2, by clicking on any marker, the maximum ATC temperature, maximum PMV temperature and the temperature difference (Delta T) are displayed. Information such as the weather file used is also displayed. Additional information (longitude, latitude, ASHRAE climate zone, Koppen Climate Zone, Atmospheric pressure, Humitiy Ratio, TM52 Compliance, ASHRAE 55 Compliance, Exponentially Running Mean Outdoor Temperature) can be added to the displayed window easily.

Figure 2. Interactive Map, Viewing Information

Figure 3 shows a frequency distribution of the temperature difference between the ATC and PMV maximum operative temperature. It can be seen that 70% of all global locations fall into the bins between 6 K and 8 K, 81% between bins of 6 K and 9K, and 89% between 5 K and 9 K.

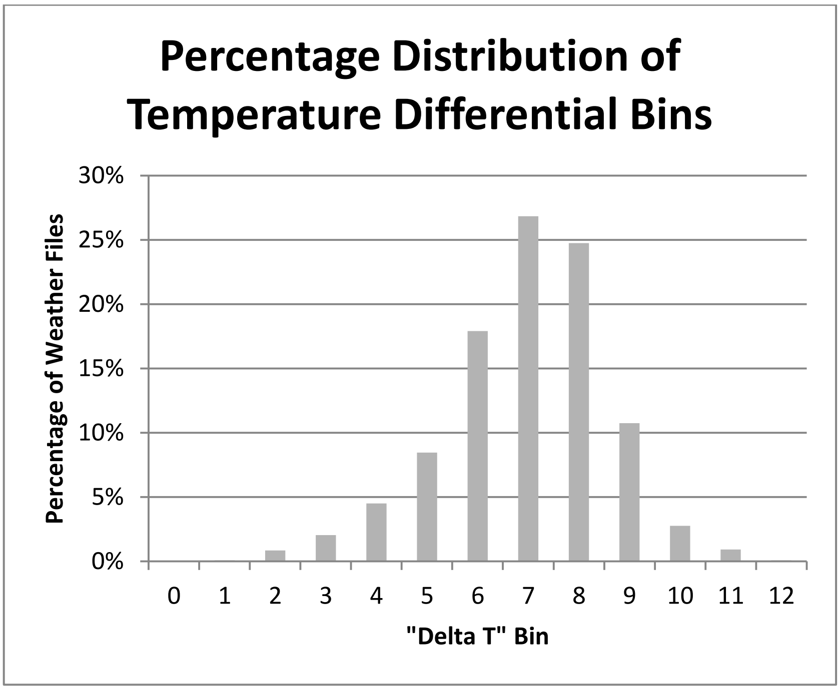

Figure 3. Percentage Distribution of Temperature Differential Bins

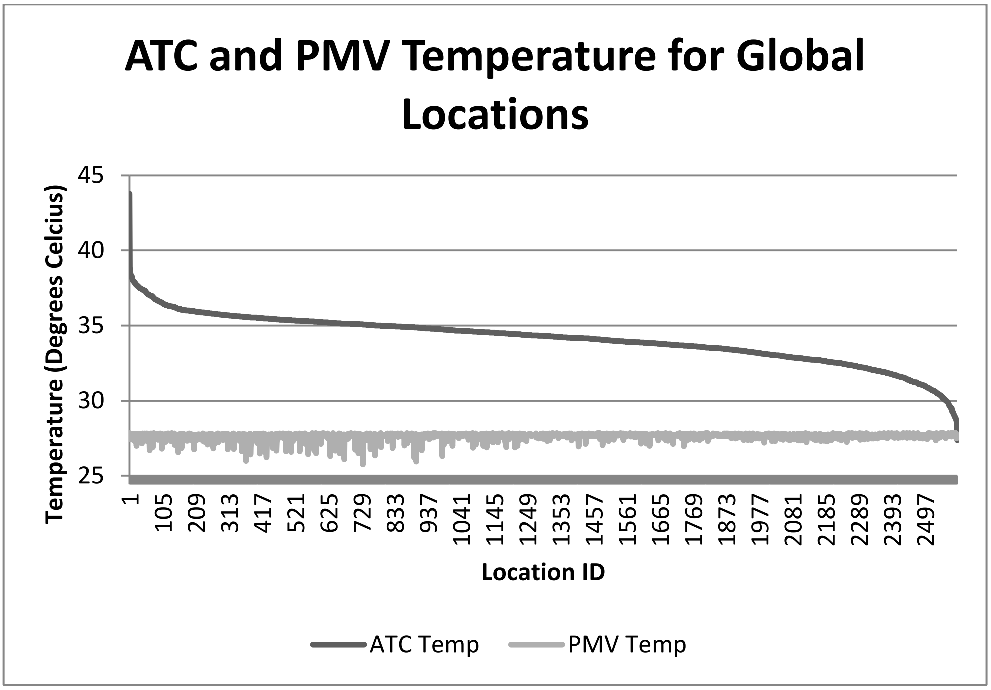

Figure 4. ATC and PMV Temperature for Global Locations

In Figure 4, it can be seen that some location reach an ATC_{temp} of near 44°C.

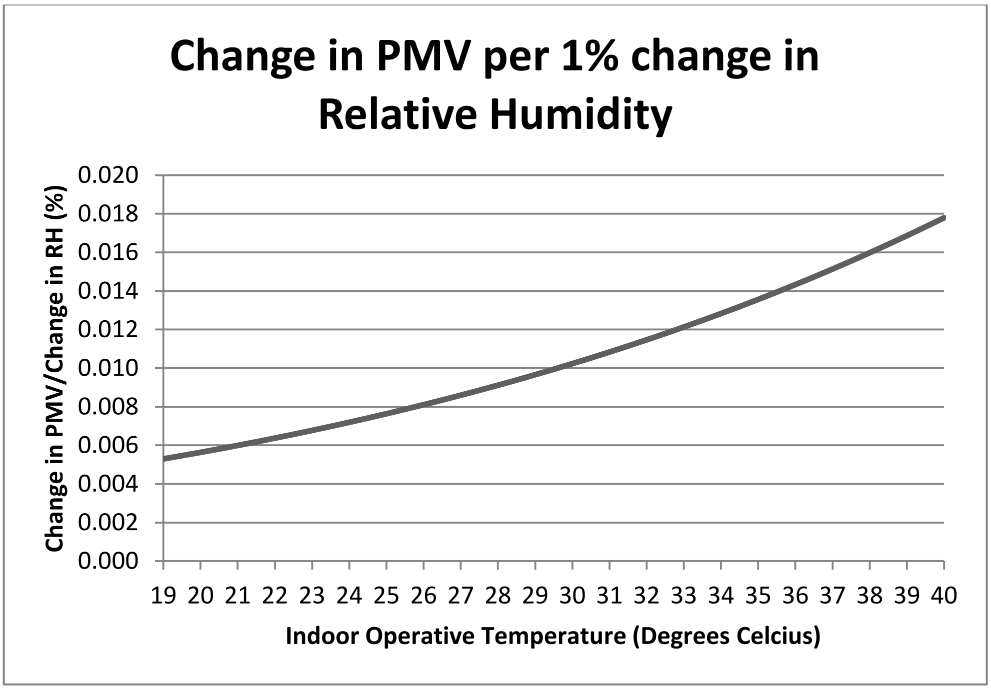

Figure 5. Change in PMV per 1% change in Relative Humidity at varying Indoor Operative Temperature

Figure 5 shows the change in PMV for a one percent change in relative humidity at different indoor operative temperatures. This calculation used the following assumptions:

- Metabolic rate is of an office worker (Met = 1.1)
- Thermal resistance of clothing is of an office worker (Clo =0.6)
- the air temperature and mean radiant temperature are equal
- the relative air velocity is assumed low (Vel = 0.1 m/s)

However this graph is valid for any static value of metabolic rate and thermal resistance of clothing. This shows that the higher the operative temperature, the higher the variation in PMV index per unit change in relative humidity.

To compare MET values between different standards, the calculations were rerun using a MET value of 1.2. This decreased the PMV maximum indoor operative temperature by between 0.5K and 0.6K, with the average change being 0.56K.

Table **2** shows the global weather files which fail the ASHRAE 55 criteria of the maximum allowable T_{rm} (33.5°C). Some of these weather files are for duplicate locations. For example, Las Vegas has three weather files that fail this criteria.

Table 2. Locations that Fail ASHRAE 55 Maximum Trm

Country	State	City	Max T_{rm}
KWT	-	Kuwait Intl Airport	39.69
KWT	-	KISR Coastal Weather Station	38.90
IND	Rajasthan	Kota	38.46
USA	CA	Needles Airport	38.13
IND	-	NAGPUR	37.89

USA	CA	Blythe Riverside Co Arpt	37.87
SAU	-	RIYADH	37.72
USA	NV	Nellis Afb	37.69
IND	Rajasthan	Bikaner	37.20
USA	AZ	Luke Afb	37.12
USA	AZ	Yuma Mcas	36.94
IND	Madhya Pradesh	Gwalior	36.92
USA	AZ	Scottsdale Muni	36.89
EGY	Aswan	Aswan	36.67
IND	Chhattisgarh	Raipur	36.64
USA	AZ	Phoenix Sky Harbor Intl Ap	36.62
IND	Rajasthan	Barmer	36.61
ARE	-	ABU DHABI	36.36
USA	AZ	Yuma Intl Arpt	36.18
USA	AZ	Phoenix/Int'l Airport	36.17
IND	Maharashtra	Nagpur	36.15
USA	CA	Palm Springs Intl	36.04
IND	Andhra Pradesh	Ramagundam	36.04
IND	Haryana	Hissar	36.01
USA	AZ	Deer Valley Phoenix	35.86
USA	AZ	Casa Granda Awos	35.82
IND	Delhi	New Delhi	35.78
IND	Maharashtra	Akola	35.65
IND	Punjab	Amritsar	35.65
IND	Rajasthan	Jaisalmer	35.59
USA	AZ	PHOENIX	35.49
IND	Rajasthan	Jodhpur	35.47
EGY	-	ASWAN	35.41
IND	Rajasthan	Jaipur	35.40
AUS	WA	Newman Airport	35.37
CHN	-	TURPAN	35.29
IRN	-	Bandar Abass	35.29
IND	Uttar Pradesh	Allahabad	35.23
IND	Uttar Pradesh	Gorakhpur	35.17
IND	Gujarat	Ahmedabad	35.16
USA	AZ	Yuma	35.10
IND	-	AHMEDABAD	35.06
USA	UT	Saint George Awos	35.05
EGY	Al Wadi al Jadid	Kharga	35.04
IND	Madhya Pradesh	Bhopal	35.04
USA	CA	Imperial	35.00
AUS	WA	Meekatharra Airport	34.95
IND	-	NEW DELHI	34.94
USA	CA	Daggett Barstow Daggett Ap	34.92

USA	NV	Las Vegas Mccarran Intl Ap	34.81
USA	CA	Palm Springs Thermal Ap	34.64
USA	CA	China Lake	34.61
IND	Andhra Pradesh	Kurnool	34.49
AUS	WA	Giles	34.47
USA	NV	LAS_VEGAS	34.34
IND	Uttar Pradesh	Lucknow	34.27
CHN	Xinjiang Uygur	Turpan	34.23
IND	Maharashtra	Sholapur	34.18
IND	Madhya Pradesh	Jabalpur	34.16
IND	Andhra Pradesh	Hyderabad	34.15
USA	NV	Las Vegas/Int'l Airpor	34.12
EGY	Qina	Luxor	33.99
USA	CA	Twentynine Palms	33.97
IND	Andhra Pradesh	Nellore	33.96
IND	Bihar	Bhagalpur	33.94
ISR	-	Eilat	33.91
IND	Bihar	Patna	33.90
AUS	SA	Oodnadatta Airport	33.89
USA	CA	Barstow/Daggett	33.87
USA	CA	DAGGETT	33.86
AUS	WA	Wyndham	33.72
USA	TX	Del Rio Laughlin Afb	33.71
IND	-	CHENNAI	33.62
USA	OK	Altus Afb	33.62
CHN	Hubei	Wuhan	33.52

4. Discussion

As seen in Figure 4, the PMV maximum operative temperature varies minimally around the world. This small change is due to the fact that PMV is totally based on indoor criteria and the only input parameter that is varied for each location is relative humidity. It could be seen that clothing levels and metabolic rate would also change dependent to the local environment (weather, culture, gender, activity and authorities figures to name but a few). It can also be seen that by adopting ASHRAE Standard 55 ATC for buildings around the world, 97.1% of locations could potentially adopt more no-energy consumption strategies, by reverting to the use of naturally ventilated buildings.

5. Conclusion

For all but one location around the world, ATC calculation allows for higher internal operative temperatures. This means a designer has a greater possibility to incorporate natural ventilation once the daily climate allows for heat purging from the building at night. 76 locations had a maximum exponentially running mean that was higher than 33.5°C and thus are prohibited from using the ASHRAE Standard 55 ATC criteria.

6. Further Studies

More work is needed to determine the impact of design comfort criteria in relation to future weather predictions and the resulting energy needs to keep buildings adequately warm or cool in a changing climate. In which regions of the world can we adapt to future climate with free-running buildings? The growing challenge of providing comfort in more extreme climates also begs the question of can we better utilise thermal mass storage to reduce or increase the indoor operative temperatures of spaces during prolonged high or low air temperatures using ambient energy, be it wind or sun.

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