Determining the Trade-offs between Thermal Comfort and Cooling Consumption in Indian Office Buildings

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ABSTRACT

The present work is to understand the impact of setpoint temperature and coefficient of performance (COP) of a cooling system on cooling energy consumption, and its effect on thermal comfort of occupants in office spaces for the different climate zones of India. The occupants' thermal comfort sensation is addressed here by the PMV (Predicted Mean Vote) index. The investigation of the mutual relationship between thermal comfort and energy demand is of the foremost importance to define the benchmarks for calibrating the energy use in office buildings. The first approach of this study is associated with the thermal comfort optimization and the second strategy includes energy consumption minimization while maintaining adequate thermal comfort. Results from the parametric energy simulation of a typical open plan office building are presented for different cases in order to evaluate the results with variations in cooling setpoint temperature and COP (an indicator of chiller performance). The results indicate there is a scope to reduce cooling energy consumption without compromising thermal comfort. India has a wide range of climatic conditions, hence this research comes up with a comparative analysis of cooling energy savings per unit increase in the cooling setpoint temperature for different climatic zones based on the system efficiency. Looking at the total energy use, this study suggests, the appropriate modulations in the setpoint temperature with respect to its climate zone.

INTRODUCTION

Any building requires energy for many functions like construction, operation and demolition. The main sector for energy consumption is building operation, of which HVAC systems form the most important end-use (Mathews, Botha, Arndt, & Malan, 2001). Buildings consume 33% of total energy in India and this is growing at the rate of 8% per annum (Rawal et al., 2012). Estimates reveal that, total built-up area will increase rapidly, as nearly 66% of the commercial sector is yet to be built by 2030 (Ramesh & Khan, 2013). Energy efficiency in buildings is a critical issue due to the increase in energy costs, energy consumption and the related environmental impacts, especially those related to global warming.

It is therefore, important to realize the energy consumption while regulating the indoor temperature. In the past, the thermal comfort standards was not analysed to optimize energy efficiency (Indraganti & Rao, 2010).Thermal comfort has a significant impact on the productivity of building occupants and it is also important to consider energy consumption with it. Recently, the idea of comfort and good living has been re-defined completely and the building industry responded to this new comfort expectation with vigor. In the last two decades, there has been exceptional increase in demand for air conditioned buildings as perception of comfort is changing rapidly. A building may be designed or retrofitted with energy efficiency measures resulting in substantial energy bill savings. These savings show great loss with respect to workplace inefficiencies, if the occupants are not comfortable(Mathews et al., 2001).

Most published research work deals with common “quantifiable” factors such as temperature, humidity and air velocity etc. However, the state of comfort depends on a wide range of factors, which are “not quantifiable” such as mental status, habits, education of the people etc. Among these factors, the one that is most studied is “acclimatization” to a particular climate. Various studies confirm that preferences/ acclimatization of people in different locations vary. This may result in people of warmer climate having a tolerance to higher temperatures as compared with people in colder region (Corgnati, Fabrizio, & Filippi, 2008; Indraganti & Rao, 2010; Mallick, 1996). There is a need to define comfort range of setpoint temperature according to the context of region and ambient temperature(Indraganti & Rao, 2010).This study attempts to understand the impact of variation in cooling setpoint temperature and chiller coefficient of performance (COP) on energy consumption as well as thermal comfort of occupants in office spaces.

India is a vast country with a variety of geographical features resulting in a multitude of climatic conditions. These have been simplified and categorized into five climatezones – hot and dry, warm and humid, composite, moderate and cold. Detailed characteristics of these zones are provided in the National Building Code of India (Bureau of Indian Standards, 2005). For this study, one representative city from each of these climate zones was identified: Ahmedabad, Chennai, Delhi, Bangalore and Guwahati.

METHODOLOGY

For the purpose of this study, a typical office building was modeled in Design Builder 3.0.0.104 using input parameters obtained through literature study.Simulations were run for five climatic zones mentioned earlier and the roof and floor were treated as adiabatic representing a typical intermediate floor.

ACTIVITY DETAILS	
Occupancy details	0.01 people/m^2or 6.25 m^2/person
Metabolic rate	0.9 (typing)
Other gains: computer	11 W/m^2
Clothing for winter	1.0 Clo
Clothing for Summer	0.5 Clo
Lighting	
Target illuminance	500 lux
Default display lighting	11 W/m^2
CONSTRUCTION DETAILS	
Walls	230mm thick brick wall with 60 mm XPS polystyrene in outer surface
U-Value	0.440 W/m^2.K (as per ECBC)
Roof	Flat roof of 150mm in cast concrete with XPS polystyrene and Asphalt insulation on top surface
U-Value	0.409 W/m^2.K (as per ECBC)
OPENINGS	
WWR	30%
Window details	1500mm window height, 800mm sill height
GLAZING	

Glass	6mm Low E clear glass
U-Value and SHGC	1.65 $W/m^2.K$ and 0.293 respectively
Frames	UPVC frames
HVAC Details	
HVAC Type	PTAC (Packaged terminal air conditioner)
Cooling Setpoint temperature	Varies as per case (ranges between 22˚C to 28˚C)
Cooling system COP Values	Varies as per case (ranges between 2 to 5)

Considerations

Thermal comfort depends on four environmental factors – air temperature, mean radiant temperature, air velocity and relative humidity. For the purpose of this study, only air temperature is being varied for the purpose of simulation study and the other parameters are allowed to float as per the variation in temperature. Although the operative temperature thermostat AC system gives more significant results for PMV values, air temperature thermostat is used for this study so as to match it with the conventional practice carried out in India. PTAC system is considered for air conditioning. As this system specification does not allow the humidty to vary considerably at a given temperature. Also variation is too less to impact the PMV values.

Runchart: To understand the influences of setpoint temperature and COP values on thermal comfort and enegy consumption, a pathway or a methodology was planned to gain the required results:

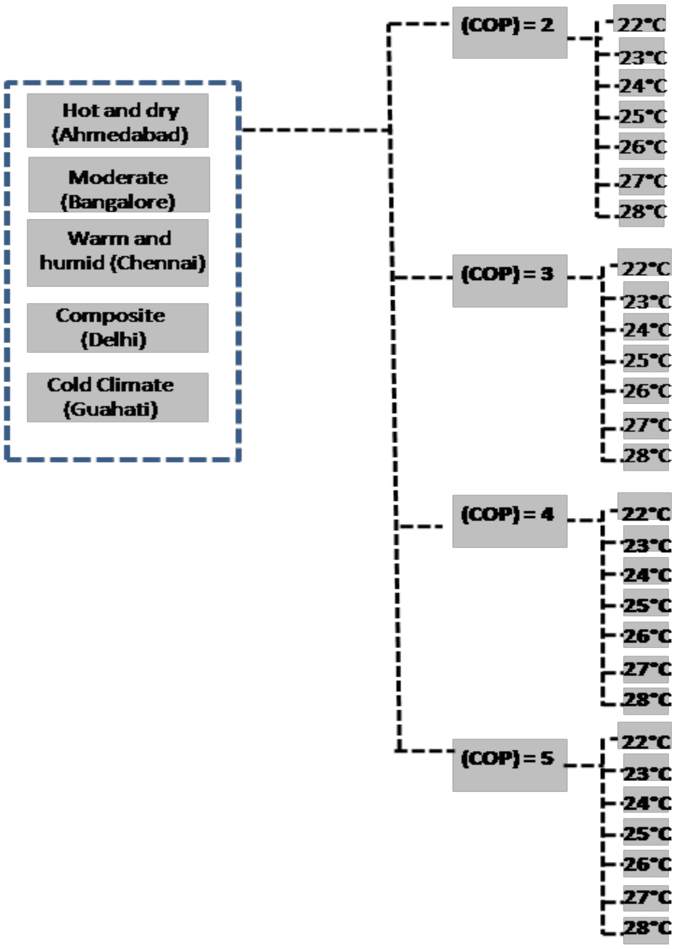

Figure 1 Run chart for simulations

It can be noticed that there are three major and intentional variables (outdoor temperature, COP values and setpoint temperature). For this study, two major outputs: cooling energy consumption and PMV index are analyzed that are obtained from design builder output data sheet.

RESULTS

To resolve the obtained results for comparission of each case, the cooling energy consumption is convertd into EPI (energy performance Index i.e. the ratio of total electricity used in a building to its total built up area. It is expressed as KWh/m^2/annum).

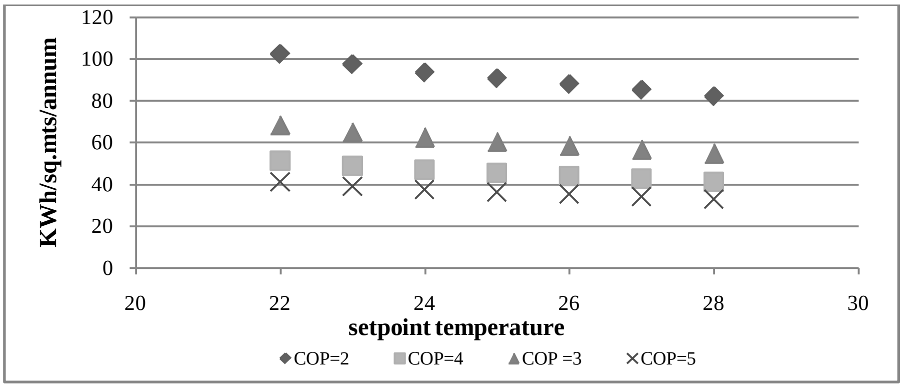

Figure2 *Energy Performance Index for Ahmedabad at particular COP value at Corresponding temperature*

Figure 2 Shows all cases are split into four distinct lines representing cooling energy on 2, 3, 4 and 5 COP value. The case with COP value 2 has the highest cooling enegy consumption and those with COP values 3 and 4 have the lower intermediate values and COP 5 being the lowest. Cooling consumption reduces as the COP value increases, however, this decrement varies drastically. Cooling energy consumption decreases significantly from COP 2 to 3 at particular temerature. The difference of almost 30 units (KWh/m^2/annum) is constant for each setpoint temperature for COP 2 and COP 3. The gradient slope for a single COP value having different setpoint temperature is steep till COP 3, and becomes gentler between COP 4 and the gradient line becomes almost straight for COP 5. This means that cooling consumption becomes nearly constant for higher COP value and there is not much net savings with increase in setpoint temperature. To quantify the same, there is a difference of 21 units of cooling consumption between setpoint 22˚C to 28˚C when COP is 2, however the difference get as low as only 8.0 units for setpoint temperature variations of COP value 5. So it is critical to decide the correct COP value as well for the desired setpoint temperature.

Table 1 EPI at particular Setpoint temperature and COP value for Ahmedabad

SETPOINT/COP	2	3	4	5
22˚C	**103**	68	51	41
23˚C	98	65	49	39
24˚C	94	62	47	37
25˚C	91	61	45	36
26˚C	88	59	44	35
27˚C	85	57	43	34
28˚C	82	55	41	**33**

The values in Table 1 show EPI (KWh/m^2/annum) at respective setpoint temperature and cooling system COP values. It can be seen that the EPI value decreases with increment in the cooling setpoint temperature as well as COP value. Maximum amount of cooling energy consumption per annum takes place at COP 2 and cooling setpoint of 22˚C. And the minimum cooling energy consumed annually for this case is 33 units, for COP 5 and setpoint 28˚C. There is also a reduction in cooling consumption of about 5.0 % annually with 1˚C increment in cooling setpoint. With an increase in COP value at the same setpoint, cooling consumption can be decreased substantially. It decreases by almost 30.0% when COP is changed from 2 to 3. However, chaging COP value from 4 to 5 leads to only 10.0% decrease.

Table 2 Percentage of hours falling under a given range of PMV value

SETPOINT/COP	-2.5	-1.5	-0.5	0.5	1.5	2.5	3
	-3	**-2.5**	**-1.5**	**-0.5**	**0.5**	**1.5**	**2.5**
22˚C	0%	0%	31%	62%	7%	0%	0%
23˚C	0%	0%	0%	70%	30%	0%	0%
24˚C	0%	0%	0%	45%	55%	0%	0%
25˚C	0%	0%	0%	44%	56%	0%	0%
26˚C	0%	0%	0%	1%	99%	0%	0%
27˚C	0%	0%	0%	0%	100%	0%	0%
28˚C	0%	0%	0%	0%	72%	28%	0%
	-3	**-2**	**-1**	**0**	**1**	**2**	**3**

Table 2 gives the percentage of hours out of occupied hours falling under particular bin of PMV value at a given setpoint temperature. It shows that at 22˚C and 23˚C setpoint temperature gives more than 60 % hours having PMV value in a range of 0.5 to -0.5. i.e., more than 60% of the occupied hours are comfortable for the occupants. The percentage gets reduced to 45% at 24˚C. It can be noticed that no matter 26˚C or 27˚C is maintained as indoor temperature 100% of the occupied hours fall under PMV value 0.5 to 1.5 i.e. uncomfortable thermal conditions. Table 3 shows a comparative analysis of different climatic zones of India on how much one can save on each degree rise of setpoint temperature. The table can be used by the occupant to interpret at what temperature it will make sense to reduce or modulate the indoor temperature and how much one can save against it with respect to the climatic zone.

Table 3 Shows percentage of reduction in cooling energy consumption at corresponding temperature in particular cities

Ahmedabad	Bangalore	Chennai	Delhi	Guwahati
-	-	-	-	-
7%	7%	6%	7%	6%
7%	8%	6%	7%	6%
6%	7%	7%	7%	6%
8%	8%	8%	8%	8%
9%	9%	9%	8%	9%
10%	9%	10%	9%	10%

Figure3 gives an idea of percentage of people dissatisfied with their thermal environment at each setpoint temperature considered in each particular city, representing respective climatic zone.

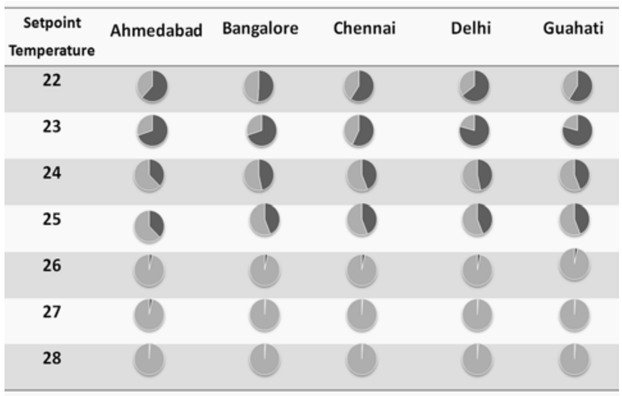

Figure 3 *Showing % of Comfortable Hours in black*

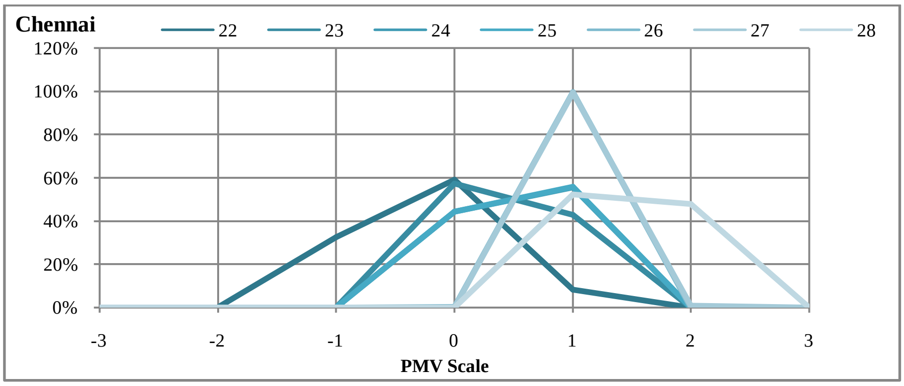

Figure 4 *Comfort conditions for Chennai at given setpoint temperatures*

Table 4 EPI at particular Setpoint temperature and COP value for Chennai

SETPOINT/COP	2	3	4	5
22˚C	**97**	65	49	39
23˚C	91	61	46	36
24˚C	85	57	43	34
25˚C	80	53	40	32
26˚C	74	49	37	29
27˚C	67	44	33	27
28˚C	60	40	30	**24**

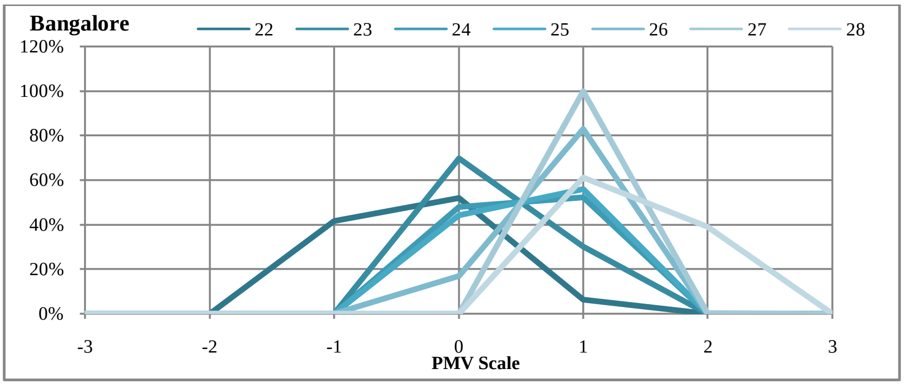

Figure 5 *Comfort conditions for Bangalore at given setpoint temperatures*

Table 5 EPI at particular Setpoint temperature and COP value for Bangalore

SETPOINT/COP	2	3	4	5
22˚C	**84**	56	42	34
23˚C	78	52	39	31
24˚C	72	48	36	29
25˚C	67	44	33	27
26˚C	61	41	31	24
27˚C	56	37	28	22
28˚C	50	34	25	**20**

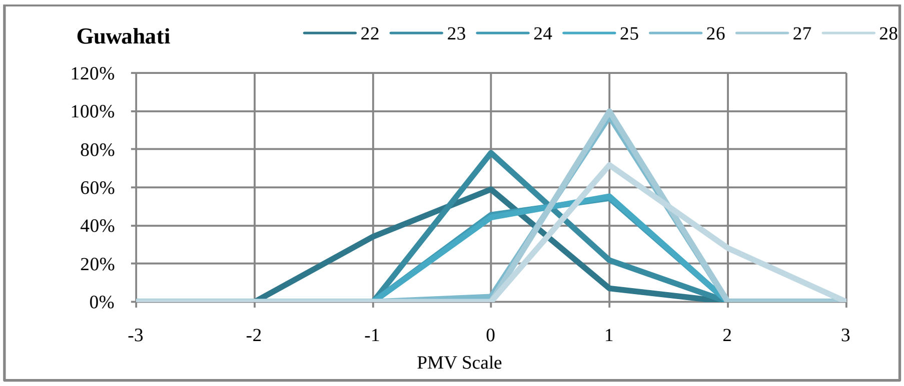

Figure 6 *Comfort conditions for Guwahati at given setpoint temperatures*

Table 6. EPI at particular Setpoint temperature and COP value for Guwahati

SETPOINT/COP	2	3	4	5
22˚C	**86**	57	37	30
23˚C	81	54	35	28
24˚C	76	51	33	27
25˚C	72	48	32	25
26˚C	66	44	29	24
27˚C	60	40	27	22
28˚C	54	36	25	**20**

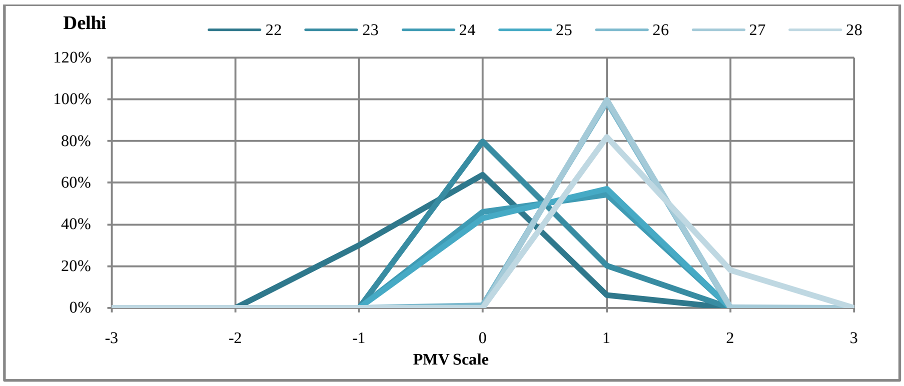

Figure 7 *Comfort conditions for Delhi at given setpoint temperatures*

Table 7EPIat particular Setpoint temperature and COP value for Delhi

SETPOINT/COP	2	3	4	5
22˚C	**90**	60	45	36
23˚C	84	56	42	34
24˚C	78	52	39	31
25˚C	73	48	36	29
26˚C	67	45	34	27
27˚C	61	41	31	25
28˚C	56	37	28	**22**

Comparison:

At the very first observation, comparing the case of Bangalore (Table 5) to Ahmedabad (Table 1), the highest annual cooling energy consumption at setpoint 22˚C for COP 2 is 103 units for Ahmedabad where as it is as low as 84 units for the case of Bangalore. By changing the COP value from 2 to 3, the reduction in cooling energy consumption is 29 units for Bangalore whereas the reduction is more significant (35 units) in case of Ahmedabad. For COP 3, there is a reduction of on an average 4 units per degree setpoint temperature in Bangalore. In case of Ahmedabad the difference is of 2 units. Bangalore and Guwahati (Table 6) shows a very similar consumption pattern for all temperatures and COP values with a difference of 3 to 4 units, Bangalore being the lowest. Likewise, Chennai and Ahmedabad shows similar trend of consumption, Ahmedabad being the highest of all the cities (Table 4).

CONCLUSION

The most important observation of this study is that, low cooling setpoint temperature does not contribute significantly in lowering the cooling energy consumption at higher COP value of the PTAC cooling system. This is, however, true only for systems with average or low efficiency. The study proves through quantification the importance of using appropriate COP for achieving cooling energy savings while maintaining thermal comfort.

The outdoor environment also plays an important role in determining the trade-offs between comfort and cooling energy consumption. For instance, it was observed that Ahmedabad and Chennai had the highest cooling energy consumption of 103 and 97 units at COP of 2 and setpoint 22˚C, whereas Bangalore, Guwahati and Delhi show almost 8 to 10 units less cooling energy consumption for the same cooling setpoint and COP values.

Another important observation for each city is that the comfort levels at 24˚C and 25˚C are more or less the same (more than 50% of the occupants feel neutral on PMV scale). 24˚C setpoint consumes almost 6 % higher cooling energy annually than 25˚C (Table 3) so one can make a decision of maintaining one degree higher and contribute in saving cooling energy consumption.

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