UNDERSTANDING THE TRADE-OFFS BETWEEN THERMAL COMFORT AND ENERGY CONSUMPTION IN AIR-CONDITIONED OFFICE SPACES IN INDIA

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ABSTRACT

This study aims to establish a correlation between thermal comfort and energy consumption for typical office buildings in India. Building envelope characteristics are varied to represent local energy code compliant case. Regression analysis is used to derive the aforementioned correlation using energy consumption and thermal comfort indices from the simulation output. The results from this study will assist designers to understand the energy implications of improving thermal comfort, both in terms of comfort hours as well as PMV. This paper is also aimed at supporting some of the field observations from post-occupancy surveys currently being done in India that indicate a preference of temperatures higher than what conventional practice dictates and make the case for more responsible control of indoor environments.

INTRODUCTION

India is a fast developing economy, projected to grow at a rate of 6.1% in 2010 and likely to have a GDP of USD 4 trillion (McKinsey, 2009). This in turn has led to exponential surge in new construction in the country over the last five years. Based on a McKinsey study, India's GDP is expected to grow at a rate of about 7.5% until 2030 (McKinsey, 2009). However, historically, from 1996 until 2012, India GDP growth gate averaged 1.6% reaching an all-time high of 6.1% in March of 2010 and a record low of -1.5% in March of 2004. The key indicators of construction sector, namely, cement and consumption of finished steel registered growth rates of 5.1%and 2.3%, respectively. Between the years of 1971 and 2009 CO_2 emissions in India have increased rapidly with annual average growth rate of 6.6% (Trading Economics). With increased urbanization and growing need for energy, India will play a very critical role at a time when discussions on climate change and environmental sustainability are as intense as they are.

Total floor space in India is currently estimated to be around 12 billion m^2 (1 billion m^2 for commercial and 11 billion m^2 for residential floor space). This is projected to grow to about 41 billion m^2 at a growth rate of 6.6% per year (McKinsey, 2009). ECO-III has also come up with estimates for total commercial floor space for India, based on various sources, its on-going commercial buildings benchmarking exercise and expert insights (USAID ECO-III Project, 2010).

Based on McKinsey projections, however, almost 70% of the floor space (projected till 2030) is yet to be added. In this context energy efficient building design and construction in near future will play important role. The 74th amendment in India's constitution on urban reforms translates into reduction of emissions by nearly 310 MtCO2e by reducing energy consumption in buildings, appliances, lamps and street lights (McKinsey, 2010).

Central Electricity Authority (CEA) estimates that the country is currently facing electricity shortage of 9.9% and peak demand shortage of 16.6% (CEA, 2009).It is estimated that the total national power demand can be reduced by as much as 25% by 2030 by increasing energy efficiency in buildings and other sectors such as agriculture, transportation and appliances (McKinsey, 2010).

In view of this growing demand, discussions on energy security and energy efficiency have gained strength in India over the last few years. Government of India has taken several initiatives in the direction of making energy efficiency a reality in all sectors. The Energy Conservation Act, adopted in 2001(The Energy Conservation (Amendment) Bill, 2010), required all designated consumers to implement specific energy efficiency measures and introduced performance and consumption labelling of appliances. Bureau of Energy Efficiency (BEE), under Ministry of Power, is responsible for implementing this law. BEE also prepared the Energy Conservation Building Code in 2007 for buildings, to be made mandatory across the country in near future. National Missions on Enhanced Energy Efficiency (NMEEE) and Sustainable Habitats (NMSH), under National Action Plan on Climate Change (NAPCC), are two of the eight missions focusing on energy efficiency in buildings. Rating systems such as LEED-India and GRIHA, are setting new trends in 'Green Building' certification. The National Building Code (NBC) of India, that regulates building construction practices in India, is currently in the process of incorporating a new chapter on 'Approach to Sustainability'. On the other hand, India is also partnering with developed economies on various bi-lateral and multi-lateral projects to implement energy efficiency in all sectors, with a very strong focus on buildings and habitat. Policy-makers in India are also realising the urgent need to benchmark building energy use to develop energy baselines, relevant performance indicators and eventually, revision of codes and standards.

There is no doubt about the fact that sustainability in general and energy efficiency in particular, has finally become a very significant part of the building design process as intent. It has primarily remained an intent and not integrated in the design and operation because of the many gaps that exist related to policy, capacity, skills, and demand, among others. Occupant thermal comfort in buildings represents one such gap because the idea of comfort is limited to maintaining the cooling setpoint based on ASHRAE static comfort model. Furthermore, in spite of the obvious connections, there's been a clear absence of data and studies correlating energy performance and thermal comfort. Building performance must be expressed with a relevant comfort metric/index. This is especially important in view of the current discussions on reducing/optimizing building energy use because there has to be a criterion to judge how much reduction in the energy performance index is possible without compromising on the quality of indoor environment, especially thermal comfort.

India is seeing more focused and productive work and discussions on thermal comfort. It is on the verge of developing a contextual thermal comfort model that could become a part of the existing codes and standards. The authors feel this study is well-timed in that it is trying to link the two hitherto disconnected ends of the aforementioned discussion.

METHODOLOGY

For the purpose of this study, a typical office building of 5 floors and a total area of 2000m^2 was used as the reference building. The dimensions of each floor are 20mx20mx3m, modelled with perimeter and core zones. Window-to-wall ratio was assumed to be 20% equally distributed on all four external walls. Intermediate floors slabs are adiabatic. The model is simulated with business-as-usual envelope and energy code compliant envelope properties (see Table 1 for details). It is important to note here that the code prescribes the same values for wall, roof and window performance, except in the case of moderate climate zone where window performance requirements are less stringent as compared to other zones.

Occupant density was assumed to be 9.3 sqm per person. Equipment power density (EPD) was taken as 12.9 W/sqm and lighting power density (LPD) was 10.8 w/sqm. Infiltration was 0.1 ACH. HVAC system used for simulation was a packaged terminal air conditioner (PTAC) of COP (coefficient of performance) of 2.6, delivering 15 cfm per person of fresh air during occupied hours through the year. Simulations were run for four locations representative of four cooling dominated climate zones in India (Table 1) using EnergyPlus weather data. Building model was simulated as occupied from 0800 to 1800 hours with occupancy varying as given in Table 2. HVAC system follows the occupancy schedule. Clothing insulation value (clo) of 0.5 was used for summer (Mar-Oct) and 1.0 for winter (Nov-Feb).

Table 1 ECBC compliant envelope properties used in the simulation model

Climate Zone	**Wall U-value**	**Roof U-value**	**Window**		
			U-Factor	**SHGC**	**VLT**
Composite (CT)	0.44	0.409	3.3	0.25	0.27
Warm & Humid (WH)	0.44	0.409	3.3	0.25	0.27
Moderate (MD)	0.44	0.409	6.9	0.4	0.27
Hot & Dry (HD)	0.44	0.409	3.3	0.25	0.27

Determination of operative temperature setpoint inputs

According to Fanger's PMV model (Fanger, 1970), comfort is dependent on six variables: air temperature, relative humidity, mean radiant temperature and air velocity are environmental parameters, while clothing and activity are personal parameters. Operative temperature incorporates two of the four environmental parameters: air temperature and mean radiant temperature, which makes it an appropriate metric to use as a control to maintain comfort in the building or simulation model. For the purpose of this study, operative temperature is taken as the average of air temperature and mean radiant temperature.

Three main strategies were adopted to determine the operative temperature setpoints for cooling and heating for code compliant cases for each location:

1. Constant/static setpoint
2. PMV model-based setpoint
3. Adaptive model-based setpoint

In (1), the HVAC was forced to maintain the space at a specific cooling setpoint value ranging from 22 ˚C to 28 ˚C at an increment of 1 ˚C. Heating setpoint for all cases was assumed to be 20 ˚C. The lower values were derived from the industry practice in business-as-usual buildings and the higher values were based on intuitive understanding resulting from experiences of thermal comfort preferences in office buildings.

In (2), operative temperature setpoint values for summer and winter were calculated assuming constant air speed of 0.12m/s, relative humidity of 50%, clo value of 0.5 for summer and 1 for winter, and metabolic activity rate of 1.1 met, to achieve desired PMV values. In case of PMV=0, HVAC is forced to maintain exactly the same operative temperature setpoint without any deadband. Operative temperature setpoint values corresponding to PMV +0.5 and +1 were used as cooling setpoints and those corresponding to PMV -0.5 and -1 were used as heating setpoints.

In (3), the following two adaptive models were used to calculate comfortable or neutral operative temperature for each month using mean monthly outdoor temperature. For the resultant neutral values, HVAC is forced to maintain exactly the same operative temperature setpoint without any deadband. 90% and 80% acceptability ranges were derived using variations of ±1.2˚C and ±2˚C respectively from the neutral values. These values were calculated for each month and used as were used as cooling and heating setpoints for 90% and 80% acceptability cases.

Humphrey's model for centralized HVAC buildings (Brager et al., 1998):

$$T_n = 23.9 + 0.295(T_m - 22) \times \exp(-((T_m-22)/(24*\sqrt{2}))^2)$$

Richard de dear's model for centrally controlled HVAC buildings (de Dear et al., 1997):

$$T_c = 22.6+0.04 \times \text{outdoor ET*}$$

Chart 1 shows the average monthly operative temperature cooling setpoint inputs for PMV and Adaptive-model based strategies for the hot & dry location. The chart clearly indicates that the setpoint values calculated using Humphreys adaptive model are higher than those calculated using de Dear's model. The former set also shows more variation through the year. As suggested by de Dear (de Dear et al., 1997), adaptive model of comfort temperature depends on outdoor effective temperature (ET*). In alignment with RP884, outdoor radiation is not taken into consideration while calculating outdoor ET*. Hourly outdoor ET* was calculated using ASHRAE thermal comfort tool. In peak summer month of May, the operative temperature setpoint value corresponding to neutral temperature from Humphreys model is 3˚C higher than the corresponding valued from de Dear's model. One can trace similar pattern for higher (+1.2˚C) and lower (+2˚C) for summer months where the difference ranges from 2-3˚C. In winter months, however, difference in operative temperature cooling setpoint values from both models reduces to between 0-1˚C. Setpoints calculated using PMV model have a constant value for summer months and another one for winter. This is because the only change from summer to winter is in the clo values. It important to note here that in summer months, PMV model-based setpoint values are almost 1-1.5 ˚C higher than de Dear's model and 0.5-2 ˚C lower than Humphreys. For operating temperature setpoint corresponding to PMV=1 and 80% acceptability limits for the adaptive models, PMV model-based setpoint values are 2-2.5 ˚C higher than de Dear's model and almost 1 ˚C lower than Humphreys. It goes higher than Humpherys when the outdoor conditions are mild (Aug-Mar). For PMV model, the difference in operative temperature cooling setpoint for winter and summer is 2.5 ˚C for PMV=0 and reduces to 0.5 for PMV=+1. This indicates that the change in clo value is not significant factor at higher operative temperature setpoint values.

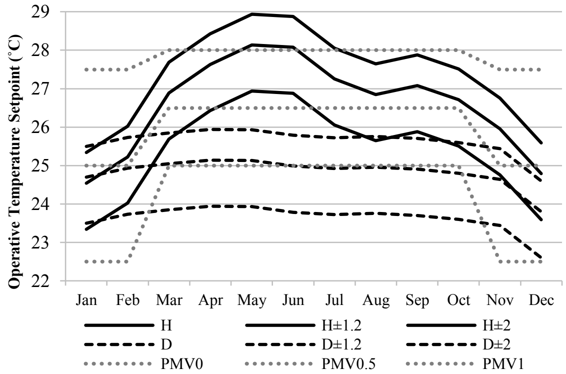

Chart 1 Monthly Average Cooling Operative Temperature Setpoints for Hot & Dry Location

RESULTS

Energy Performance

Percentage savings in Energy Performance Index - EPI ($kWh.m^{-2}.yr^{-1}$) results of the simulation are plotted in Chart 2. This includes cooling and heating EPI. Results are plotted for all three strategies and all cases within each strategy for four climate zones. Percentage savings have been calculated using the constant cooling setpoint of 22 ˚C as the base case.

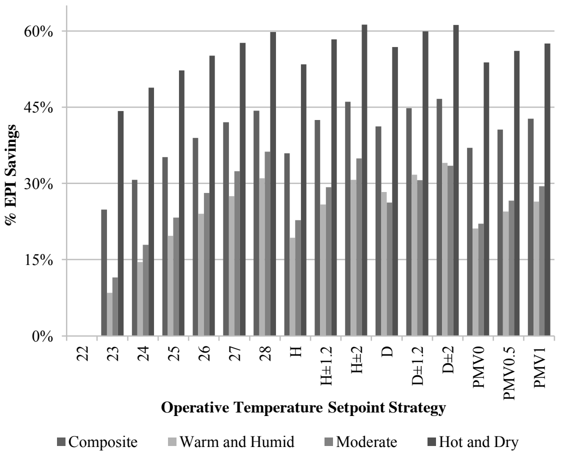

Chart 2 EPI Savings for Operative Temperature Setpoint Strategies

The chart shows maximum EPI savings occur in the hot & dry climate zone for all strategies. These savings range from 45-60% because this climate zone experiences very high mean monthly outdoor temperatures in summers. Maintaining a constant setpoint of 22 ˚C, therefore, means high energy consumption. However, for adaptive models, high mean monthly outdoor temperatures for a hot & dry location also translate into high indoor operative temperature cooling setpoints resulting in lower cooling energy consumption as compared to other climate zones.

EPI savings in composite climate zone range from 25-47%. In this zone, heating becomes a significant part of the total energy consumption and results in high EPI (as compared to warm and humid and moderate climates) at lower setpoints and, consequently, high EPI savings. Savings are least in warm & humid zone (8-34%), except in the case of de Dear's model, because the EPI is high even for higher operative temperature setpoints. This indicates that apart from providing cooling, the system is also using energy to remove the humidity which increases with increase in the outdoor mean monthly temperature. Savings in moderate climate range from 12-36%.

If one compares the setpoint determination strategies, all climate zones show similar trends – savings increase as constant setpoint is increased from 22 to 28˚C, PMV value is changed from 0 to 1 and neutral temperature is increased by 1.2 and 2˚C. Maximum savings occur in hot and dry climate, followed by composite, moderate and least in warm and humid. The only case where this trend shows a slight departure is in de Dear's model where EPI percentage savings are higher in warm and humid and least in moderate. This happens because cooling setpoints from de Dear's model are lower, especially for summer months, as compared to Humphreys and PMV models for moderate climate.

Generally, EPI savings are highest for cases where operative temperatures derived using de Dear's adaptive model. Savings from Humphreys model are slightly lower than de Dear's, the difference ranging from 0-9%. EPI savings from PMV model-based setpoints are lower than those from Adaptive models-based setpoints. Operative temperature setpoint of 28˚C is comparable to 80% acceptability (+2˚C) setpoints for both adaptive models in terms of EPI savings. Similarly, performance of 27 ˚C is very close to that of 90% acceptability (+1.2 ˚C) case.

Comfort

Annual mean PMV values were calculated from hourly PMV results and plotted in Chart 3 for all strategies and four locations. Cases with constant cooling operative temperature setpoint of 22, 23 and 24 ˚C show negative PMV values ranging from 0 to -0.75, though falling within the ASHRAE comfort limits. de Dear's neutral operative temperature setpoint and the one corresponding to PMV=0 also show negative PMV values while Humphreys neutral setpoint case shows positive values of PMV. This clearly indicates that the latter predicts comfort on the warmer side as compared to PMV and de Dear models. de Dear model-based setpoints maintain the PMV values within a narrow range of -0.3 to +0.4 whereas the warmer comfort limit goes up to +1 for other models.

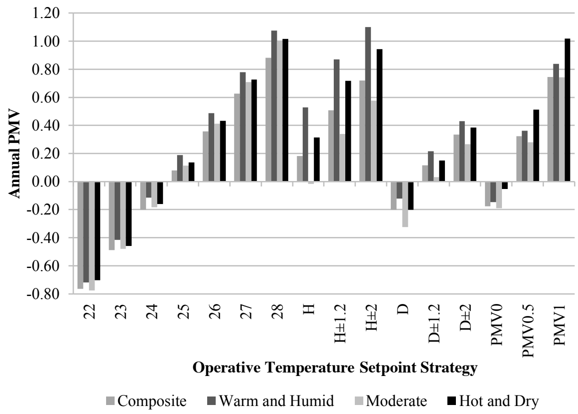

Chart 3 Mean Annual PMV

Annual PMV minimum, maximum, mean and median values have been plotted in Chart 4 for hot and dry location. The range decreases from constant operative temperature setpoint of 22 ˚C to 25 ˚C and shifts towards higher PMV values. It then increases till 28 ˚C. At 28 ˚C the range of annual PMV is 1.5 to -0.25. Also, at lower setpoints, the difference between mean and median is higher which indicates the presence of outliers. For operative temperature setpoints derived from Humphreys model, the range increases with increase in the acceptability limits – it is highest for 80% acceptability and lowest for neutral temperature setpoint. It does not however, shift. PMV model-based operative temperature setpoints follow the same trend but towards the lower end of the PMV scale. de Dear model shows a departure from the trend. The range remains almost the same at neutral, 90% acceptability and 80% acceptability, though it shifts towards higher annual values of PMV. Difference between mean and median decreases with increase in acceptability range.

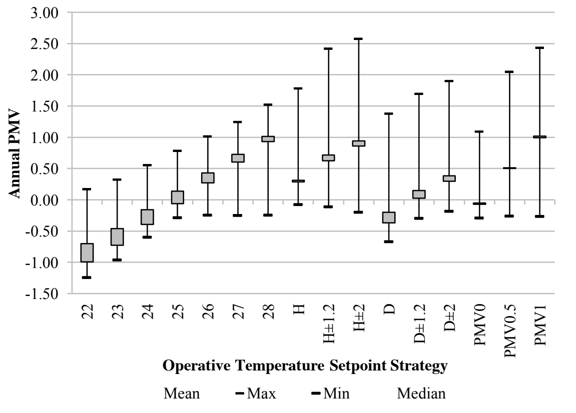

Chart 4 Annual PMV for hot and dry location

Energy and comfort

Energy performance index was plotted for hot and dry climate zone with the percentage of comfortable hours for 90% acceptability and 80% acceptability in Chart 5. This chart makes it possible to isolate cases that have the more comfortable hours with lower EPI. For 80% acceptability, wherein less than 20% people would be dissatisfied with the thermal environment, scenarios with constant operative temperature setpoints 23-26 ˚C perform well. All Humphrey's model-based setpoint scenarios, de Dear's neutral temperature setpoint and scenarios where operative temperature is solved for PMV=0 and +0.5, perform well too. Of these, Humphreys 80% acceptability scenario has the lowest EPI of 94 kWh/m^2 and the constant setpoint of 23 ˚C has the highest EPI of 134 kWh/m^2. For the narrower range of 90% acceptability, scenario with constant setpoint of 24˚C and PMV=0 perform well with EPI values 123 and 112 kWh/m^2 respectively. It is important to note here that 24 ˚C gives a PMV of -0.16 while for PMV=0 scenario, the mean annual PMV value is -0.05.

Similar charts were prepared for other locations (Charts 6-8). For 80% acceptability in composite zone location (Chart 6), scenarios with constant operative temperature setpoints 23-26 ˚C, all Humphrey's model-based setpoint scenarios, de Dear's neutral temperature setpoint and 90% acceptability scenarios all PMV scenarios perform well in terms of comfort. Of these Humphrey's 80% acceptability scenario has the lowest EPI of 84 kWh/m^2 and the constant setpoint of 23 ˚C has the highest EPI of 118 kWh/m^2. For the narrower range of 90% acceptability, scenario with operataive temperature setpoint calculated for PMV=0, 90% acceptability scenario in de Dear's adaptive model, perform well thermally and have EPI values of 101 and 93 kWh/m^2 respectively. Annual mean PMV for PMV=0 case is 0.18 and for de Dear model 90% acceptability is 0.18.

For warm and humid location (Chart 7), scenarios with constant operative temperature setpoints 23-26˚C perform well. All Humphrey's model-based setpoint scenarios, de Dear's neutral temperature setpoint and scenarios where operative temperature is solved for PMV=0 and +0.5, perform well too, following the same trend as hot and dry location. Of these, Humphreys 80% acceptability scenario has the lowest EPI of 99 kWh/m^2 and the constant setpoint of 23˚C has the highest EPI of 137 kWh/m^2. For the narrower range of 90% acceptability, scenario with constant setpoint of 24˚C and PMV=0 perform well with EPI values 128 and 121 kWh/m^2 and annual mean PMV values of -0.11 and -0.15 respectively.

Trends for moderate location are slightly different. According to Chart 8, all PMV and adaptive comfort scenarios perform well for 80% acceptability, as well as constant setpoints scenarios from 23 to 26 ˚C. Scenarios of 80% acceptability according to Humphreys adaptive and PMV models have lowest EPI (84-86 kWh/m^2) and 23 ˚C constant setpoint has the highest EPI of 114 kWh/m^2.

Humphreys neutral setpoint and scenarios for PMV=0, 0.5 perform well with 96-100% of hours falling in the comfortable range according to 90% acceptability limits. Of these, PMV=0.5 has the lowest EPI of 91 kWh/m^2 and PMV=0 has the highest EPI of 100 kWh/m^2. EPI for Humphreys neutral setpoint scenario is 95 kWh/m^2 and the corresponding mean annual PMV is -0.02.

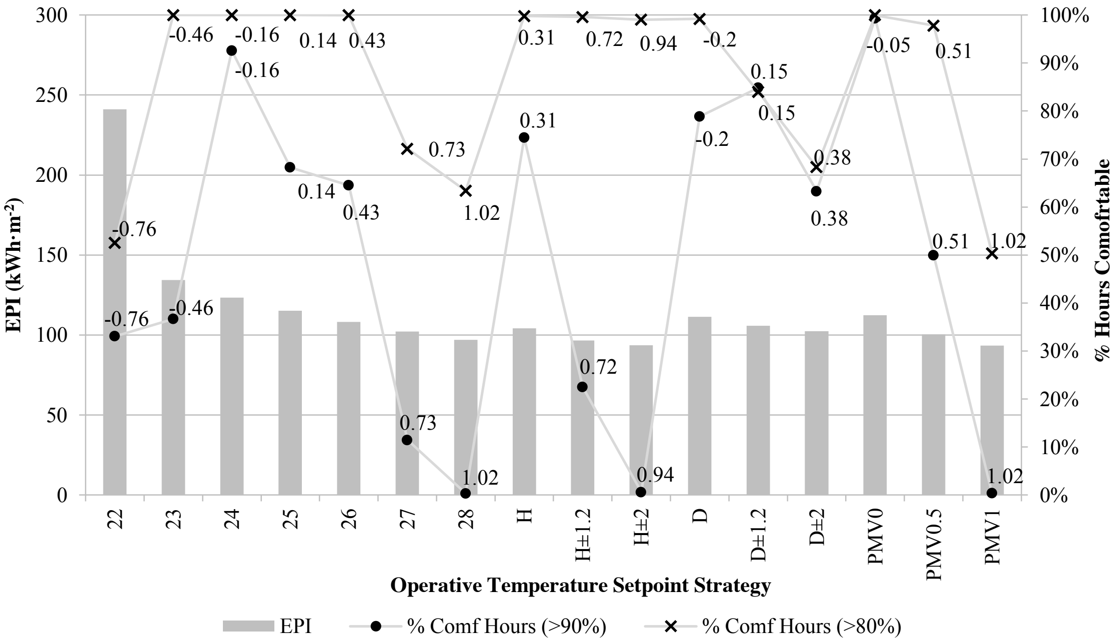

Chart 5 EPI savings and % comfort hours for hot and dry location

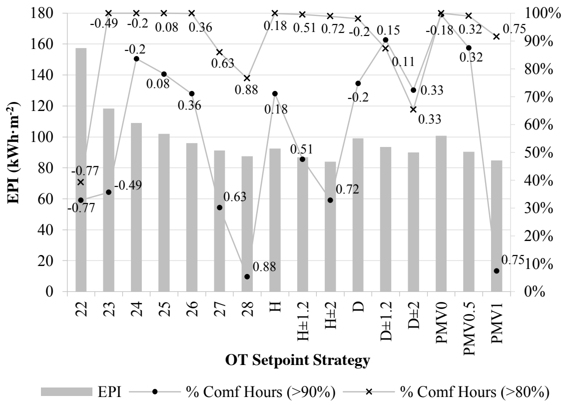

Chart 6 EPI Savings and % Comfort hours for Location in Composite Climate Zone

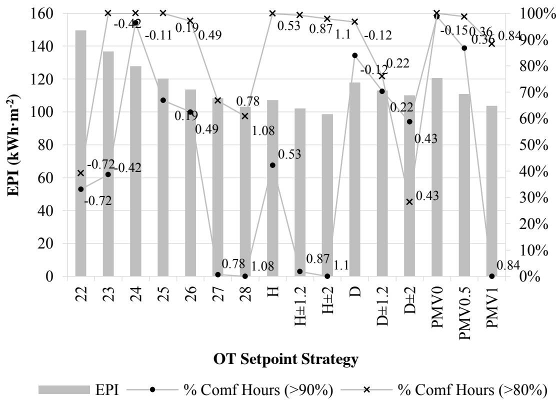

Chart 7 EPI Savings and % Comfort hours for Location in Warm and Humid Climate Zone

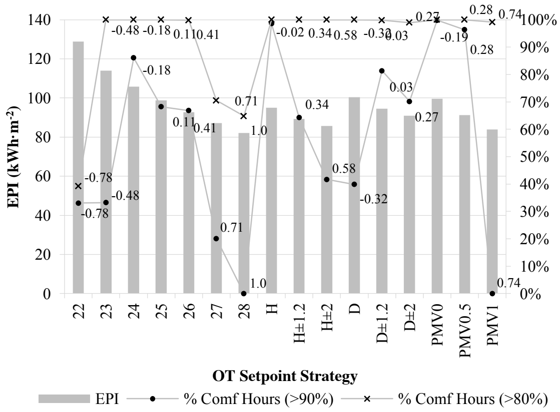

Chart 8 EPI Savings and % Comfort hours for Location in Moderate Climate Zone

Regression analysis was performed to assess predictability of energy consumption and occupant comfort in the building. EPI and mean annual PMV value have been selected as the key outputs of the regression analysis. Similarly, cooling setpoint was identified as key input variable for the regression equation as majority of energy consumption is expected from the cooling system in the building.

Charts in the previous analyses clearly indicate the difference in trend between annual kWh consumption in constant annual setpoint strategy and monthly varying setpoint strategies. Hence, the regression analysis was further split in these two series to achieve better analysis results. Charts 9 and 10 demonstrate EPI and PMV regression analysis results for hot and dry location. The primary axis on the charts denotes annual EPI while the secondary axis denotes mean annual PMV vote achieved through the strategy. The horizontal axis denotes cooling setpoint for the building.

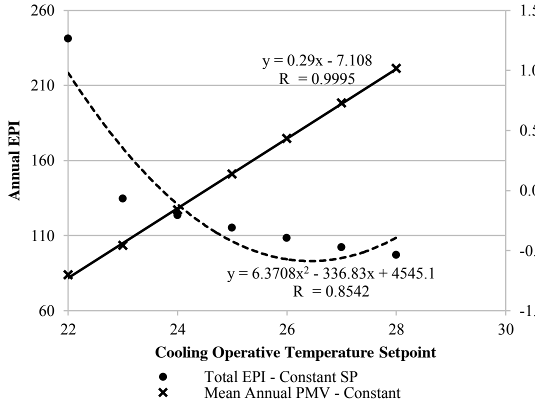

Chart 9 Regression analysis of EPI and mean PMV for constant setpoints for hot and dry location

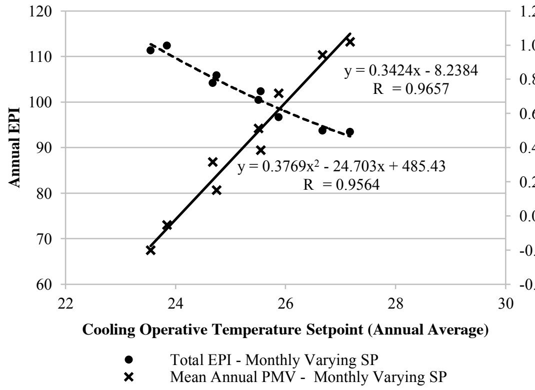

Chart 10 Regression analysis of EPI and mean PMV for monthly varying setpoints for hot and dry location

At first, the linear regression was conducted for EPI using cooling setpoint as input variable but the derived equation could not capture the rapid increase in energy consumption yielding poor curve fit (R^2 = 0.647). After several iterations of regression analysis, second order polynomial was selected as the appropriate strategy to yield suitable fit for analysis. While fourth-order polynomial yielded better results (R^2=0.94) for hot and dry location, it yielded similar results for other location while providing indications of curve overfit. Linear regression was used for mean annual PMV using cooling setpoint as input variable which yielded very encouraging results (R^2=0.99).

The regression approach was conducted for EPI and mean annual PMV using annual cooling setpoint as input variable. The annual average of cooling setpoint was derived by calculating mean setpoint for the occupied period throughout the year.

The similar analysis was performed on the rest of the cities to derived regression equations for each climate file. The following table lists derived regression equations and associated R-square for the individual curves:

Table 4 EPI and PMV Regression Equations

PMV	R^2	EQUATION
Constant setpoint		
Composite	0.9403	2.3968x2-129.71x+1843.9
Warm and Humid	0.9983	0.6971x2-42.357x+743.29
Moderate	0.9941	0.7669x2-45.74x+762.5
Hot and Dry	0.8542	6.3708x2-336.83x+4545.1
Monthly varying setpoint		
Composite	0.9365	0.3924x2-24.236x+454.44
Warm and Humid	0.7415	0.8023x2-45.789x+752.66
Moderate	0.8191	0.0085x2+0.6523x-10.962
Hot and Dry	0.9564	0.3769x2-24.703x+485.43

EPI	R^2	EQUATION
Constant setpoint		
Composite	0.9997	0.2761x-6.8319
Warm and Humid	1	0.2992x-7.2964
Moderate	1	0.2965x-7.2994
Hot and Dry	0.9995	0.29x-7.108
Monthly varying setpoint		
Composite	0.9784	0.2415x-5.9292
Warm and Humid	0.7839	0.3298x-7.851
Moderate	0.8707	183.1596
Hot and Dry	0.9657	0.3424x-8.2384

As seen in the table above, very good curve fit was achieved for EPI with constant setpoint strategy. For monthly variable setpoint strategy, reasonable curve fit was also achieved for EPI with least accurate results for warm and humid climate (R^2 = 0.7839). Similarly, very good curve fit was achieved for PMV with least accurate results for warm and humid climate for monthly variable setpoints (R^2 = 0.7415). This slight reduction prediction in warm and humid climate was due to impact of humid climate on EPI and mean annual PMV since humidity has not been included in the input variable. However, the simple approach which only considers operative temperature (mean radiant and air temperature) yield fairly accurate regression results for annual curves.

CONCLUSION

Simulations were used to understand the impact of varying cooling temperature setpoints based on prevalent industry practice and various static and adaptive thermal comfort models on energy consumption of a typical office building typology for four locations, each representative of a cooling dominated climate zone of India.

First, the target indoor comfort conditions were set using static cooling setpoints that remained constant through the year disregarding any influence of seasons or geographical location. In the second scenario, PMV model was used to derive setpoints corresponding to the PMV values of 0, 0.5 and 1. Finally, de Dear and Humphreys adaptive thermal comfort models were used to calculate the setpoints corresponding to conditions of neutrality and 90 and 80% acceptability. For each of these scenarios, operative temperature was used as the setpoint control. Thermal comfort performance for each of these strategies was expressed in terms of PMV and number of occupied hours deemed comfortable by 90 and 80% ranges of acceptability. PPD was used to calculate the latter. Energy performance was expressed in terms of EPI (kWh/m^2).

The setpoint control strategy that best optimizes thermal comfort and energy consumption for 80% acceptability is the one that uses Humphreys adaptive model 80% acceptability operative temperature setpoint. This, however, is true for all climate zones except moderate, where PMV = 1 scenario is the optimal scenario. In case of 90% acceptability, the operative temperature setpoint corresponding to PMV = 0.5 optimizes energy consumption and comfort best, except in the hot and dry climate where de Dear's adaptive model solved for 90% acceptability is the optimal scenario.

This study clearly shows that the thermal environment in buildings should not be controlled using a static setpoint. More importantly, it also shows that even higher setpoints that are not varied seasonally or monthly may cost more in terms of occupant discomfort. Therefore, not only is it important to look at a wider range of comfort conditions for indoor environment, it is very critical to look at a more varied one. This indicates the need for a radical shift in the way buildings design and operated.

It also initiates a way into looking at control strategies that are a mix of adaptive and static models of thermal comfort for air-conditioned buildings in India. Simulation results show that for a hot and dry location, a constant operative temperature setpoint of 24 ˚C can keep 80% of occupants comfortable for all occupied hours throughout the year. Operative temperature setpoint derived from Humphreys adaptive model for 80% acceptability can do the same with 24% less EPI.

Regression equations developed as part of this study can be used by designer/architects in selecting the suitable operative temperature cooling setpoint input for the building to achieve desired comfort in the building (mean annual PMV) while balancing that with the energy consumption (EPI). For example for hot and dry location, selecting 25 ˚C operative temperature setpoint will yield lowest percentage of uncomfortable people (0.08 mean PMV) in constant setpoint strategy but would require EPI of 102 kWh/m^2 to achieve that comfort. Designer can then opt to shift the 26 ˚C operative temperature setpoint which will yield higher percentage of uncomfortable people (0.36 mean PMV) but would also save energy by reducing building EPI to 96 kWh/m^2. It is important to state here that the optimal solutions may vary with building typology, envelope characteristics, HVAC system configuration and other features. There's a need for more research and studies to develop more generic expressions to connect comfort and energy consumption.

With the growing commercial floor space area, rising expectations and ever-increasing spending capacity, air conditioning has become a necessity in work places and is here to stay. Through this paper, the authors have tried to understand the possibility of using adaptive control strategies even for air conditioned buildings. This premise is stems from the fact that the PMV models meant to be used to determine comfort conditions in controlled buildings is not an entirely static model as it accounts for adaptation by change in clothing. For this same reason, other adaptive models may be used as control strategies for such buildings.

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