NIGHT PURGE AS A MEANS TO REDUCE COOLING LOAD OF AN OFFICE IN PUNE, INDIA

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ABSTRACT

In some areas of high air condition adoption there is potential for night purge natural ventilation to reduce the number of hours that the air condition system is operated, leading to a reduction in energy usage and associated carbon dioxide emissions. In this study we examine the potential efficacy of such a strategy implemented in an office building located in Pune, India. Using a dynamic thermal model we have demonstrated that around 10% annual cooling load saving can be achieved. Results from an actual application of this strategy in Pune demonstrate that when conditions are beneficial significant pre-cooling of the office space can be achieved before the occupied period, reducing the cooling load, saving energy, carbon emissions and costs.

INTRODUCTION

The global air conditioning market continues to rise, up 13% in 2011 compared to 2010, driven in part by the socio-economic growth of developing countries with hot climates. It is possible that world consumption of energy for cooling could explode tenfold by 2050 (Cox 2012). In most countries, the bulk of electricity that runs air conditioners is generated from fossil fuels, most prominently coal. The consequence of an increased demand for cooling will therefore be an increase in greenhouse gas emissions from fossil fuel burning which is likely to impact climate change. In addition to placing strains on nations' power grids, air conditioners pose threats to the environment and environmental health, primarily as contributors to global warming (Dahl 2013).

India has been identified as a huge growth market for the air conditioning industry and ways to reduce the cooling load required by such conditioning apparatus will decrease the impact on energy usage. Despite high daytime temperatures there are particular climatic zones within India where night time temperatures fall sufficiently to be able to provide a cooling effect. The principle of utilising cooler night time air to pre cool a building overnight has been utilised since antiquity and was implemented with success by Boswell Reid in the temporary UK House of Commons, during the mid-19th Century, after fire damaged the Palace of Westminster (Reid 1844). Typically implemented in temperate climates, cool night-time air is introduced into a building through windows, vents or louvres using natural ventilation.

A high potential for night-time ventilative cooling over the whole of Northern Europe and significant potential in Central, Eastern and even some regions of Southern Europe has been demonstrated (Artmann et al. 2007; Yun & Steemers 2010). However, night-time ventilation is highly dependent on climatic conditions, as a sufficiently high temperature-difference between ambient air and the building structure is needed during the night to achieve efficient convective cooling of the building mass. Therefore utilising passive night-time cooling methods in warmer climates are likely to be more challenging. It is typical for traditional Indian vernacular houses to use passive ventilation through open windows at night to help cool the space (Singh et al. 2010). Natural ventilation continues to be the *modus operendi* for rail terminals in India and although occupants have been shown to be more comfortable at high temperatures in such buildings, these occupants are generally transient in nature (Deb & Ramachandraiah 2010). It is unlikely that temperatures such as those recorded in the rail terminal building will be deemed acceptable in a prestigious office complex and therefore air conditioning will be required to deliver the required comfort. Nevertheless a mixed mode hybrid system that utilises passive cooling when appropriate has the ability to reduce the building cooling load (Homod et al. 2014). Further energy savings could be idealised by utilising an adaptive comfort strategy to the cooling set points and using ceiling fans to increase air speeds (Indraganti et al. 2014; Mishra & Ramgopal 2015).

Natural ventilative cooling can also be improved by running cool water through the building fabric and cooling the thermal mass but such a strategy is not suitable for retrofit applications (Yu et al. 2014).

The local environment should also be considered when considering passive night cooling strategies as certain urban locations have been shown to reduce the efficacy of night purge strategies due to local micro climate eg canyons that may be significantly warmer than predicted and built up areas (Geros et al. 2005; Ramponi et al. 2014).

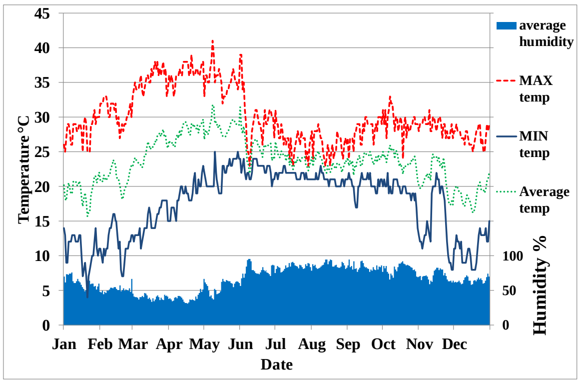

Figure 1 - Annual daily minimum, maximum and average temperature of the ISHRAE Pune weather data file. The average daily humidity is also shown.

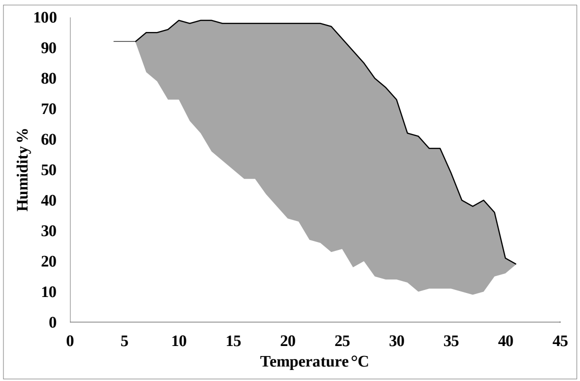

Figure 2 - Climatic corridor of external Pune ISHRAE weather data

There are three main parameters affecting the efficacy of a natural night purge strategy and these are; the temperature difference between inside and outside, the useful air flow rate and the thermal capacity of the building. To get the best cooling effect it is important to ensure efficient coupling of the air flow with the thermal mass of the building. If air flows are short circuited then convective exchanges between the cool fresh air and the building fabric can be poor reducing the ventilation efficiency (Geros et al. 1999). Artmann et al demonstrated that displacement ventilation can be a less efficient night purge strategy at low air flows as hotter air stratifies at the ceiling reducing the heat transfer from the ceiling (Artmann et al. 2010).

In this study we consider a prestigious office located in Pune in the North West of India. The climate in Pune is influenced by the local steppe climate and classified according to Köppen and Geiger as BSh, Arid Steppe Hot (Peel et al. 2007; Kottek et al. 2006). It has a very hot summer period between March and June (average temperature c28°C) and warm and humid winter period November to January (average temperature c20°C). During the winter and mid seasons the external temperature can drop as low as 5°C and using natural ventilation this can provide cooling to a building internal space. However, due to the high humidity that is also experienced, introducing this cool air is not appropriate at all times so as not to introduce high humidity into the office space which could lead to condensation and dampness leading to mould growth and can have detrimental impacts on electrical office equipment. The cooler periods of the year are also the wettest and therefore careful control is required to ensure that natural ventilation only occurs when optimal. Utilising automatically controlled vents, windows or louvres, is one way that night cooling can be implemented effectively and this study investigates the efficacy of such a strategy.

EXPERIMENT

Pune weather analysis

Analysis of the ISHRAE Energy Plus weather file for Pune shows that there are large differences between the minimum and maximum daily temperatures between November and May, suggesting that this diurnal swing can be utilised for effective night purge strategies. Between June and October, when it is relatively cooler, the diurnal swing is much smaller and average daily humidity is also high, suggesting that the effectiveness of a night purge strategy is likely to be low during this period, Figure 1. The Pune annual weather is described in a climatic graph, Figure 2, showing the temperature and humidity extremities that are experienced. Only certain weather conditions are useful for cooling purposes. In this study the useful cooling corridor is when the external temperature is less than or equal to 25°C and the humidity is less than 70%, which is equivalent to 1296 hours, Figure 3, of which, 513 hours occur at night between the hours of 22:00 and 06:00, Figure 4. This represents 14.8% and 5.9% of the annual Pune ISHRAE weather data respectively.

Table 1 - Table showing the number of hours each month that the external temperature is less than or equal to 25°C and humidity is less than 70%

	Number of hours external weather is <=25°C and <70% humidity	
MONTH	**ALL**	**22:00-06:00**
January	213	18
February	243	65
March	300	194
April	219	191
May	27	26
June	0	0
July	0	0
August	0	0
September	0	0
October	7	0
November	82	11
December	205	8

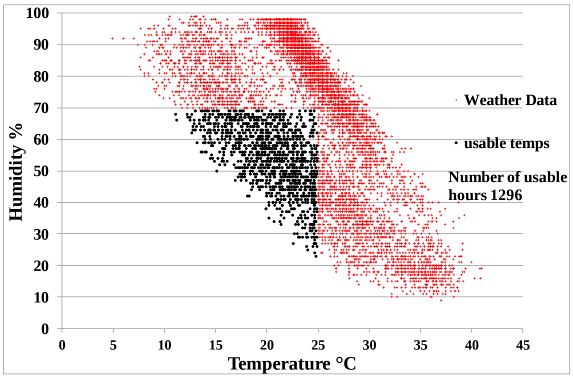

Figure 3 - Hourly ISHRAE weather data for Pune with hours available for cooling, ie temperature <=25°C and humidity < 70% indicated

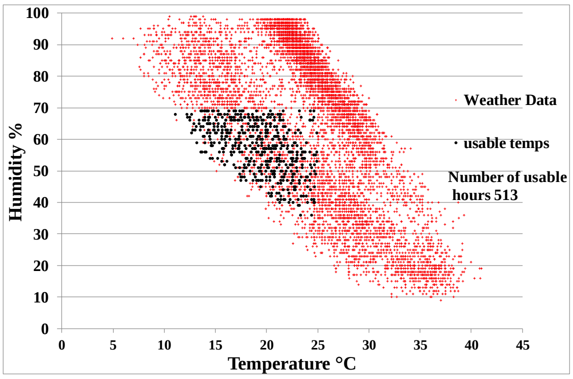

Figure 4 - Hourly ISHRAE weather data for Pune with night time hours available for cooling, ie temperature <=25°C and humidity < 70% indicated

Table 1 shows that as predicted the months with the greatest capacity for natural cooling are between November and May, with March having the greatest capacity at 253 night time hours. In general the majority of the available cooling hours occur during the night time except during December and January where there does appear to be capacity for using natural ventilation cooling during the day.

Modelled office

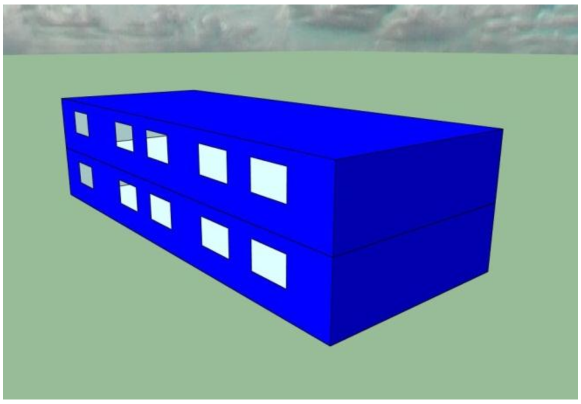

Figure 5- Image of modelled office in IES-VE

An existing first floor office in Pune has been modelled using the dynamic thermal modelling software IES-VE. The office measures 20m wide by 8m deep and is 2.6m high. There are 5 number south facing windows, single glazed, measuring 1.7m wide and 1.1m high. Each of the windows is top hung and opens outward, fitted with a 350mm chain actuator which delivers 0.98m^2 of geometric free open area (calculated as the area of the rectangle and triangles – figure ***Figure 6***). The office is a concrete frame structure with rendered blockwork walls containing insulation. Without detailed construction information we are assuming that the walls meet the Indian Energy Conservation Building Code as it is a relatively new build (Bureau of Energy Efficiency 2006). The assumed construction build-up is detailed in ***Table 2***.

Internal gains

Modelled internal gains include 12 occupants with typical lighting gain of 12W/m^2 and typical equipment gains of 15 W/m^2 as per CIBSE guide A table 6.1 (CIBSE 2006). Standard NCM office occupation profiles are used.

Cooling

The office in Pune is cooled by air conditioning to maintain a maximum temperature of 26°C during the occupied period. The IES-VE model reflects this scenario. To investigate the efficacy of night purge the office windows have been fitted with automatically controlled window actuators.

Night purge strategy

The window actuators of the office in Pune are controlled to open when the external temperature is less than the internal temperature between the hours of 22:00hr and 06:00hr. They are also connected to an external weather station that ensures the windows remain closed during rain events or when the external humidity exceeds 70%.

We have modelled the night purge strategy in IES on the basis that the windows are top hung open out on a 350mm actuator providing a geometric free area of 0.98m^2. We have modelled this opening as a sharp edged orifice such that the equivalent area is 0.98m^2, MacroFlo in IES applies the orifice coefficient of discharge of 0.62 resulting in an effective free area of 0.61m^2 (IES-VE n.d.).

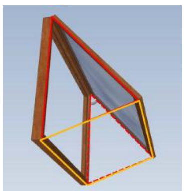

Figure 6 - Calculation of the openable area of a top hung open out window, showing the rectangle and triangular areas that are summed

Table 2 – Table showing the construction build up of the modelled office in Pune

CONSTRUCTION	CONSTURCTION BUILD UP	U-VALUE (W/m^2K)	THERMAL MASS kJ/m^2K
External Wall	External render 10mm Polyurethane board 60mm Concrete block 150mm Plaster 15mm	0.34	134.06
Internal floor / ceiling	Cast concrete 300mm	2.41	176.4
Flat roof	Stone chippings 10mm Felt 5mm Polyurethane board 55mm Cast concrete 150mm	0.40	200
Floor	Clay 750mm Brick 250mm Cast concrete 100mm Insulation 30mm Screed 50mm	0.41	50.4
Glazing	Single glaze float glass, g-value 0.46	3.05	

As well as modelling a night purge strategy that is the same as that which is applied to the in situ office, we also modelled four other scenarios so that we could compare the predicted cooling energy savings that could be expected. The modelled scenarios are listed in ***Table 3***.

Table 3- Night purge strategies modelled in IES-VE. Ta = indoor air temperature, To = Outside air temperature and Rho = outside relative humidity

SCENARIO	NIGHTPURGE STRATEGY
A	No night purge, windows remain closed
B	To<Ta and Rho <70% 22:00hr to 06:00hr
C	To<Ta and Rho <70% 18:00hr to 06:00hr
D	To<Ta and Rho <80% 22:00hr to 06:00hr
E	To<Ta and Rho <80% 18:00hr to 06:00hr

DISCUSSION AND RESULT ANALYSIS

The results from the dynamic thermal modelling suggest that a night purge strategy is effective at reducing the cooling load required to limit internal temperatures to a maximum of 26°C, ***Table 4***. Using Scenario A as the base case, with no openable vents or night purge strategy, allows effective comparison. If night purge is enabled between the hours of 22:00hr and 06:00hr when the external temperature is less than the internal temperature and the external humidity is less than 70% (Scenario B) there is a predicted annual energy saving of 7.5%. If the same night purge strategy is extended to between the hours of 18:00hr and 06:00hr the energy saving can be increased to 9.9% (Scenario C). Further energy savings can be made if the allowable external humidity conditions are altered such that night purge is enabled when the external humidity is less than 80%, delivering 13.1% and 15.7% savings for Scenario D and Scenario E respectively.

Table 4 - Annual cooling plant sensible load predicted by dynamic thermal modelling under various night purge scenarios

SCENARIO	ANNUAL COOLING PLANT SENSIBLE LOAD MWh	SAVING COMPARED TO BASE CASE
A	18.58	
B	17.18	7.5%
C	16.74	9.9%
D	16.14	13.1%
E	15.65	15.7%

The predicted energy savings are not distributed evenly throughout the year due to the external climate. Throughout much of May to October little energy savings are predicted due to the high humidity, precipitation and temperatures that occur during this period, ***Figure 1***.

The monthly cooling loads savings, compared to the base case, are shown in Figure 7 and Figure 8 respectively. The largest predicted savings are during the month of February where between 26.5% and 48.9% savings are predicted dependent upon the night purge strategy used. Increasing the length of night purge from 8 hours (22:00hr to 06:00hr) to 12 hours (18:00hr to 06:00hr) makes little difference for most of the year with the exception of December and January where much greater energy savings are

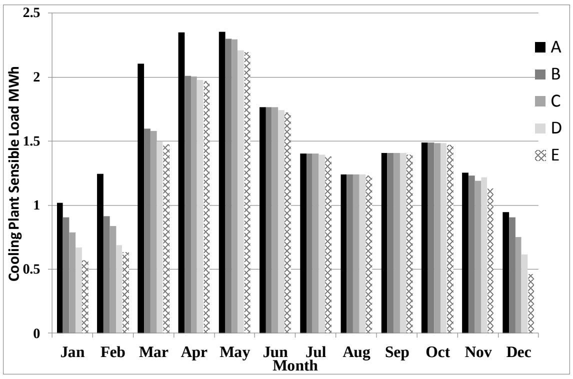

Figure 7- Monthly cooling plant sensible loads for the modelled scenarios

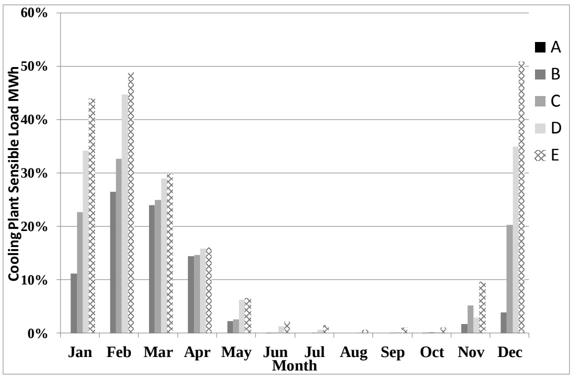

Figure 8 - Monthly cooling plant sensible load savings in comparison to base case Scenario A

predicted utilising the 12 hour night purge, indeed it may well be possible to extend natural ventilation cooling during much of the daytime as external conditions are favourable. For example in December the predicted energy savings are 3.9% and 34.9% when humidity is less than 70% and 80% respectively utilising the 8 hour night purge (Scenario B and D) and this increases to an energy saving of 20.4% and 51% when the night purge is extended to 12 hours (Scenario C and E). These results suggest that a 12 hour night purge would be beneficial during December and January, but would deliver little savings in comparison to an 8 hour purge for the rest of the year.

The dynamic thermal model used in this study is based on an actual office in Pune where an automated night purge strategy based on Scenario B has been implemented. Data regarding internal room temperature, external room temperature and window vent position where recorded using an NVlogiQ Room Controller and Data Logger and was collected between April and late September 2014, more recent data has yet to be collected due to difficulty accessing the site. Although the collected data is from sub optimal months for an effective night purge strategy due to the external conditions at this time of year, there is evidence of the strategy in use on a number of days when conditions were favourable. The data reveals that, when conditions are right for night purge, significant cooling can be delivered.

Figure 9 shows recorded data over a three day period during mid-September. The internal temperature is indicated by the unbroken red line, which shows that the maximum internal temperature is maintained at just over 25°C (14/09 c15:00 to 21:00hr), suggesting an effective air conditioning system. At 22:00 when the night purge is implemented and the vents open the internal temperature drops over 2°C, pre-cooling the office prior to the start of the day. Once the vents close at 06:00hr there is an immediate increase in temperature, this will be a result of heat from the thermal mass of the room convecting and radiating into the space, and with reduced air flow, this heat will build up. Nevertheless, the room temperature remains well below the cooling setpoint throughout much of the day on 15/09. An effective night purge strategy is implemented during the night of the 15/09 such that the room is sufficiently cooled that the mechanical air conditioning is not operational for the duration of the whole of the day on the 16/09, despite the external temperature (blue dashed line) exceeding 26°C for the majority of the day.

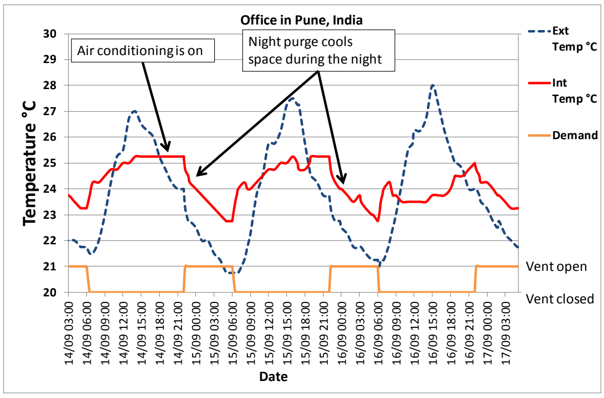

Figure 9 - Recorded data from a monitored office in Pune implementing a night purge strategy during a few days in September 2014. This strategy is shown to be effective at decreasing the internal temperature (red) resulting in reduced air conditioning us

CONCLUSION

Utilising night purge ventilation to reduce overheating has been used as an effective strategy in temperate climates for many years. In this study we have investigated the efficacy of such a strategy in reducing building cooling loads in much hotter climates. Despite high daytime temperatures, there are large diurnal swings in a number of months in the

BSh (Arid Steppe Hot) climate at Pune that can be exploited to provide free cooling during the night when the external temperature is less than the internal temperature. The models in this study have identified typical annual sensible cooling load savings of between 7.5% (Scenario B) and 15.7% (Scenario E) dependent upon the night purge strategy used. The greatest savings are made during the months of December through to March when the external temperature and humidity is lower. During December cooling load reductions of over 50% can be delivered. Data collected from an office in Pune suggests that such a night purge strategy is indeed effective at reducing internal temperatures during the night to an extent that removes the need for daytime cooling requirements. The study suggests that such night purge strategies should be considered in climates other than temperate climates as an effective strategy to mitigate the use of mechanical cooling systems, thus reducing energy usage and associated greenhouse gas emissions.

NOMENCLATURE

BSh	=	Arid Steppe Hot
Ta	=	Indoor air temperature
To	=	Outside air temperature
Rho	=	Outside relative humidity

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