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Assessment of Thermal Comfort in Naturally Ventilated Factory Buildings:
A Case Study in Mumbai, India.

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ABSTRACT: Productivity and Satisfaction of the building occupants is largely influenced by Thermal Comfort. Specifically, in Factory buildings where occupants are constantly exposed to excessive heat produced from machines, it is important to maintain comfortable indoor environment and therefore evaluation of the comfort conditions inside these buildings is necessary. The research aims at assessment of naturally ventilated factory buildings located inside a Factory Premise in Mumbai. Three factory buildings with similar process and architectural features having different orientation and sizes were selected for assessment. The assessment was done based on onsite measurements and thermal comfort survey of the occupants. Key reasons behind discomfort were identified. Based on this assessment and comparison with standards, design guidelines were formulated. There is further scope for validating effect of passive design strategies with the help of Building Simulation.
KEYWORDS: Thermal Comfort, Industrial Buildings, Adaptive Thermal Comfort, Naturally Ventilated Buildings

1. INTRODUCTION
Rising urban temperatures has become one of the major concerns today. Mega cities in India like Mumbai now fall into 'Very Hot category' with average summer heat index increasing at a rate of 0.56°C /decade. (Madaani, 2017) As a result of which the use of energy for cooling and air-conditioning of the indoor environment is by now one of the largest sectors in energy consumption. In Mumbai, it constitutes about 40% of total energy consumption (Cox, 2012). In factory buildings, where occupants are constantly exposed to excessive heat produced from machines, installation of active cooling systems is generally avoided as the energy required for creating thermal comfort could make reasonable impact on manufacturing cost.

Thermal discomfort in factories affects health and productivity of the workers. Therefore, it becomes important to evaluate the thermal comfort conditions inside these buildings.

1.1. Aim & Objectives
The aim of the research was to assess thermal comfort in naturally ventilated factory buildings located in warm and humid climate of Mumbai. The study intended to analyse methods of measuring thermal comfort in factory buildings and to evaluate the existing comfort conditions in these buildings.

2. METHODOLOGY
To assess thermal comfort conditions inside factory building, three buildings located in a large industrial premises at Mumbai were selected as case study. The buildings had common architectural features but were different in terms of size and orientation. The manufacturing processes of metal engineering are carried out inside all three naturally ventilated factory buildings.

The Indian Model of adaptive thermal comfort (IMAC) and ASHRAE 55-2013 - adaptive thermal comfort model was followed to assess thermal comfort conditions.

Thermal comfort survey was conducted where the subjects were permanent workers from first and second shift in the three buildings. The questionnaire was distributed to 400 occupants and the response rate was 44.75%. On-site measurements and survey were conducted on same day in each building.

2.1. Measurements
Key environmental parameters affecting thermal comfort such as Air Temperature, Humidity, Mean Radiant temperature, Air Movement were measured. The measurements were taken in the month of April.

For each building, one weekday and one weekend profile were plotted. Weekday profile was plotted for 12 hrs and weekend profile was plotted for 10 hrs. Architectural data was collected through observations and secondary data collection mainly included architectural drawings and standards.

3. FINDINGS
All three factory buildings were analysed based on design parameters, heat gain calculations and thermal comfort survey of occupants.

All the buildings scored 50% against design criteria given in National Building Code (2016) for naturally ventilated buildings. Buildings lacked mainly in design of opening and partitions. Addition of mezzanine floor, partitions, and ancillary buildings around, were found to hinder smooth air-flow inside the building.

Heat gain calculation showed that heat gain through building envelope is a major cause of heat gain. Ideal opening to floor area ratio which was calculated based on rate of heat gain was found to be sufficient for two buildings out of three. The existing opening to floor area ratio was found to be reduced than designed ratio.

The Indoor operative temperature was calculated as per ASHARE 55-2013 and Neutral temperature was calculated as per IMAC/NBC standard. It was observed that operative as well as neutral temperatures were out of adaptive thermal comfort ranges specified by both the standards. (Refer to table 1)

Higher operative temperatures were observed on weekends when fans and machinery was not operated.

BUILDING - 3					
Summary for Weekday Temperature Profiles:					
Outdoor Temperature Range (Max – Min) (°C)	Indoor Temperature Range (Max – Min) (°C)	Indoor Operative Temperature range (Max-Min) (°C)	Neutral Temperature calculated as per IMAC (°C)	IMAC /NBC Comfort Range (Max – Min) (°C)	ASHRAE adaptive thermal comfort range (Max – Min) (°C)
35.5-25.20	41.53- 28.00	36.50-28.93	28.0	30.14 -25.38	29.18-22.18
Summary for Weekend Temperature Profiles:					
33.00-28.00	35.70-27.00	35.29-27.50	28.4	30.14 -25.38	30.26-23.26

Table 1: Table showing temperature ranges for building 3

The measurements were plotted against thermal comfort survey and observed that even after 70% of reduction in occupancy and activity in second shift, in one of the building; operative as well as indoor ambient temperatures were constantly high. This further validates insufficient natural ventilation and trapping of heat and envelope heat gain. (Shown in Figure 1)

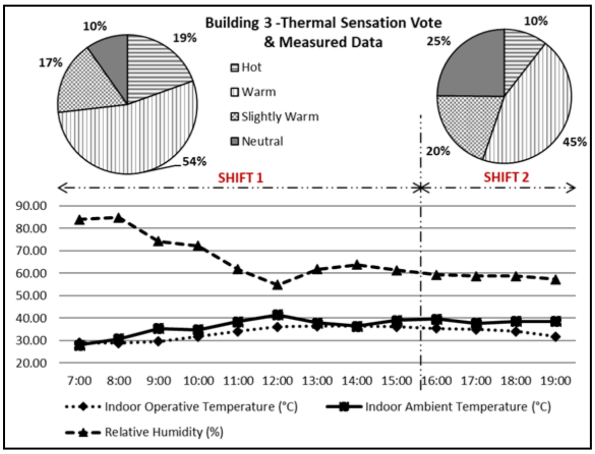

Figure 1: Survey Results compared with measured data

It was also observed that 70%,35%,27% of occupants in building 1,2&3 respectively voted as neutral or slightly warm.

4. CONCLUSION

All the buildings were thermally uncomfortable for most of day. It can be said that due to addition/alteration in structures, original building design intent has been lost. This has in turn reduced opening to floor area ratio and resulted in trapping of heat inside building. The building with lesser opening to floor area ratio was found to be highly uncomfortable. It was also observed that building occupants showed acceptance towards temperatures beyond adaptive thermal comfort range.

For existing buildings, effect of passive design strategies for improving thermal comfort can be explored with the help of building simulation.

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REFERENCES

1. ASHRAE55. (2013). *ANSI/ASHRAE 55-2013,Thermal Environmental Conditions for Human Occupancy.* Atlanta,GA.
2. Cox, S. (2012, July 10). *Cooling a Warming Planet: A Global Air Conditioning Surge.* Retrieved July 08, 2017, from Yale Enviornment 360:
3. De dear, R., & Brager, G. S. (2001). Climate, Comfort, & Natural Ventilation. *Moving Thermal Comfort Standards into the 21st Century.* Oxford.
4. GRIHA. (2016). *GRIHA V5.* Griha Council.
5. NBC. (2016). *National Building Code of India.* Bureau of Indian Standards.
6. Neha Madaani. (2017, Feb 26). Heat index increasing significantly per decade. *The Times of India*.
7. Nicol, F. (2004). Adaptive thermal comfort standards in the hot-humid tropics. *Energy and Buildings*, 628-638.
8. The Times of India. (2017, Feb 26). Heat index increasing significantly per decade. *The Times of India*.
9. Wijewardanea, S., & Jayasingheb, M. (2008). Thermal comfort temperature range for factory workers in warm-humid tropical climates. *Renewable Energy 33*, 2057–2063.