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Adaptive Approach in Indian Context and Indoor Environment Design Optimization: A Test Methodology Schematic and Critical Overview

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ABSTRACT: Adaptive thermal comfort model was recently included in GRIHA 2015. In the updated version, GRIHA 2015 refers to ASHRAE Standard 55 (2010), NBC 2005 (which refers to SP 41) and Indian Adaptive Comfort Model (as detailed in GRIHA 2015, appendix 1) for buildings to meet thermal comfort requirements.
With the study taken up for demonstration in this article, we intend to test and analyze the exponentially weighted running mean temperature based approach as adopted in European standard, EN15251 with mere running mean temperature based approach as adopted by ASHRAE standard 55 and Indian Adaptive Comfort Model (GRIHA 2015, appendix 1). Thereby highlighting the better of the two for Indian context.
Also, the present article ventures into the possibilities of minor optimization techniques towards relaxing the boundary conditions, presented here is a case coined and analyzed for potential of one such implication, of "Effective Degree Discomfort Hours (DDH)" over regular total hot degree discomfort hours (DDH).

I. INTRODUCTION

Thermal Comfort

Thermal comfort as widely accepted by mass in general is defined as 'the state of mind, which expresses satisfaction with the thermal environment'.

Par with the basics, Predicted Mean Vote (PMV) model is considered to be the best known heat balance model, but many a times, also tagged as more of a static model. Next is the adaptive hypothesis, relating the thermal comfort perception with the outdoor weather conditions. Adaptive hypothesis has led to a number of closely resembling models which based on adaptive opportunities of occupants and are related to the availability of options of personal control of the indoor climate as well as psychology and performance. Adaptive hypothesis assumes that contextual factors partake with thermal history to modify and thus adapt the individual's thermal expectation.

With an expression of "failure" brought in by Nicole [1] for heat balance approach, he favors the adaptive approach to be standing firm on grounds of more robust comfort analysis methodology.

Tolerant to a wider range of temperatures (psychological adaptation), occupants of naturally ventilated buildings are more responsive to thermoregulatory adaptation through changes in activity level and clothing (behavioral adaptation).

With this advent, ANSI/ ASHRAE Standard 55 (2010), in the current standard, i.e., 2010 accommodates and extends the results from 2004 version of standard 55 to cover naturally ventilated buildings. Also, European Standard EN 15251 [2] also presents an adaptive approach to the evaluation of thermal comfort, the basis of which was the EU project Smart Controls and Thermal Comfort (SCAT's). A relationship between indoor comfort and outdoor climate was developed for free-running buildings, which differentiated the same from the method described in ANSI/ ASHRAE Standard 55 (2010).

Both the models are conceptually similar with few differences [3, 9, 10, 11, 12]

A. Database for derivation of the model are different (ASHRAE RP-884 [4] versus SCATs [5, 6].

B. The building classification differs, ASHRAE chart applies only to naturally ventilated buildings, while the EN 15251 chart applies to any building in free running mode.

C. The derivation of the neutral temperature is different, which leads to difference in neutral temperature.

Given the general practice in India to follow ASHRAE Standard 55 (2010) [7], for the indoor environment designing and lack an exhaustive standard operating procedure in existing green building codes for naturally ventilated building, this article present a methodology schematic to compare and propose the most optimal model in Indian context.

II. OBJECTIVES AND METHODOLOGY

a. To study critically the Standard Operating Procedures (SOP's) in existing green building standards in India for naturally ventilated buildings.

b. Propose and test methodology schematics to compare adaptive comfort models for Indian scenario.

c. To analyze the corrective potential of optimizing thermal severity indices over indoor environment design decisions (In the present case, to propose and test the potential of "Effective DDH" over regular practice with "total hot DDH").

For the analysis purpose the methodology thus adopted in the article is as follows:

Methodology of the analysis is split into three parts, namely, test stage 1, 2 and 3, concerning the progress and nature of task involved in decision making in practice, the nature of analysis involved.

Test stage 1:

a. Finalizing upon the base and test comfort model selection.
b. Check for exemplary performance of the test comfort model in the defined scope of study.
c. Comfort temperature (or range) derivation with thus finalized effective test comfort model.

Test stage 2:

a. Defining the scope of the study, present analysis assumes Warm and Humid climate as the study area. Five cities are selected in warm and humid climatic zone for comparison, namely, Guwahati, Bhubaneshwar, Chennai, Mumbai and Jamnagar.
b. Selecting a parameter for the case dependent analysis, deviance potential and prominence of factors in building envelope for further recommendations. Walling material is considered in the article, thereby commenting upon the order of feasibility of materials across the warm and humid climatic zone of India.
c. Simulations for calculations of output parameters, Tin (indoor temperature) in this case.
d. DDH calculations for thus calculated comfort temperature (range) over selected building envelope parameters across scope of study (warm and humid) climatic zone of India.

Test stage 3:

"EFFECTIVE DDH": It is the DDH over the period of occupancy of the regularly occupied zone and not the total sum over the run of the day, month or year."

a. Calculating the Effective DDH over thus obtained DDH calculations.
b. Comparative analysis of possible differences in total and Effective DDH thus obtained.
c. Order of application feasibility in the given scope of thus considered building envelope parameter. For the present study, it would be feasibility of walling materials over all the cities of Warm and Humid climatic zone of India.

A. Standard Operating Procedures for Naturally Ventilated Buildings in Existing Green Building Standards in India

LEED India. LEED India extensively refers to the ASHRAE Standard 55 (2010) for naturally ventilated cases. ASHRAE Standard 55 (2010) in approach links the thermal responses in naturally ventilated buildings with outdoor climate and two sets for operative temperature limits – one for 80% acceptability and one for 90% acceptability. As included in the diagram as "Acceptable operative temperature ranges for naturally conditioned spaces" (ASHRAE Standard 55 (2010)).

Application of this method requires occupants adjusted operable windows, metabolic rated range from 1.0 met to 1.3 met and adaptive clothing of occupants.

Also, the standard fails to address conditions beyond the boundaries of mean monthly outdoor temperature less than 10°C (50°F) or greater than 33.5°C (92.3°F), which rules out a wide range of temperature un-addressed in India.

GRIHA 2015. In the updated version, GRIHA 2015 has included adaptive thermal comfort model (appendix 1) and refers to ASHRAE Standard 55, NBC 2005 also for the same purpose.

With the aim to achieve thermal comfort, GRIHA 2015 detailed Indoor operative temperature calculation method for three broad categories, namely, Naturally Ventilated buildings, Mixed – mode buildings and Air-conditioned buildings. All of them considering '30 – day outdoor running mean air temperature' as calculation basis.

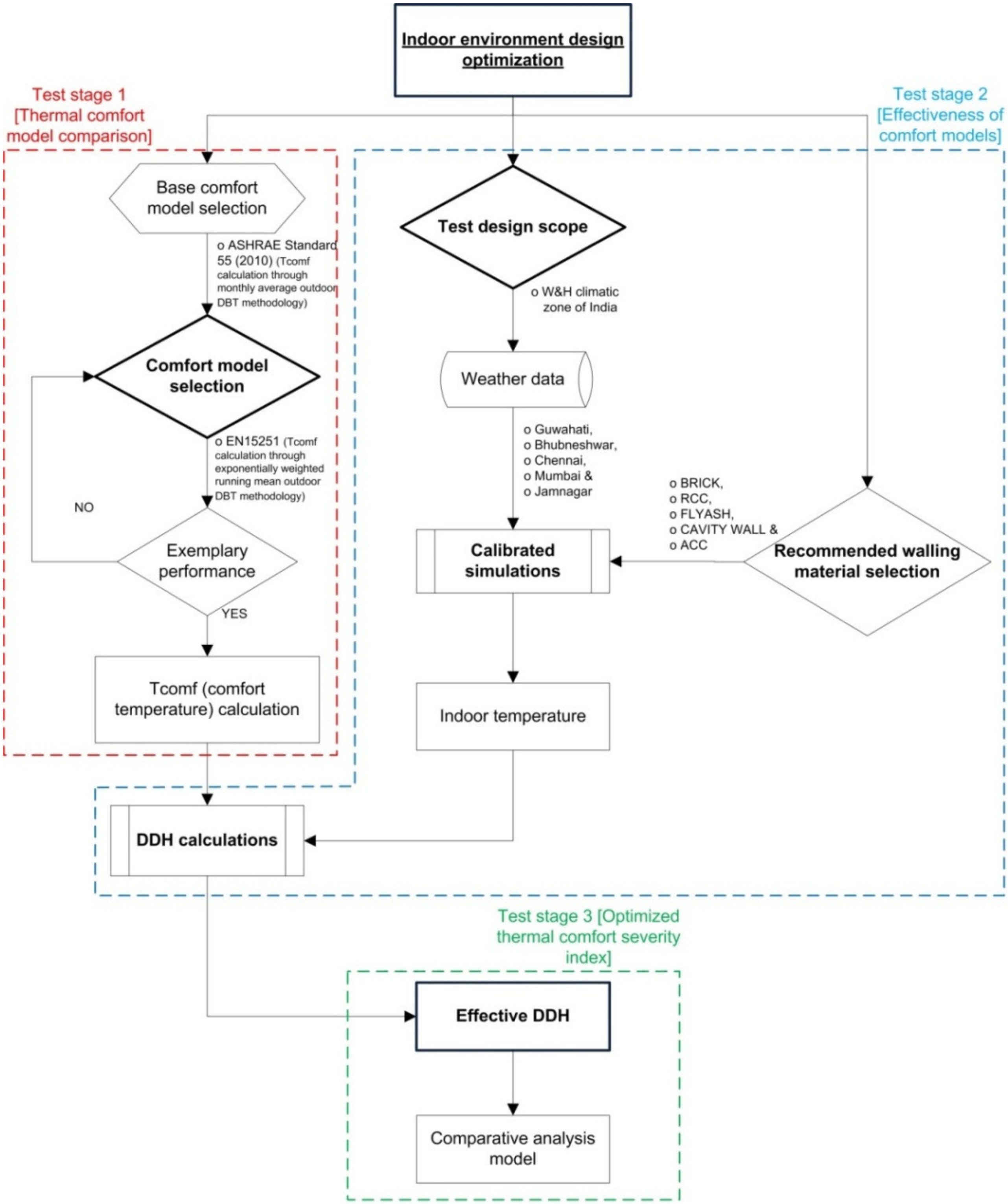


Fig. 1. Methodology Chart.

III. COMFORT MODEL SELECTION AND COMFORT TEMPERATURE (RANGE) (Tcomf) CALCULATIONS

For analysis, study takes under consideration the EN15251 as the test comfort model in comparison with the base model of ASHRAE STD 55. Since EN15251 considers a more robust and dynamic approach towards comfort band estimation, i.e., through considering running mean temperature. Definitions of both the standards thus considered are as follows:

A. ASHRAE STD 55

ASHRAE Standard 55 (2010) derives comfort temperature from a global comfort database, rendering 22°C as T_{comf} (comfort temperature) in winters and

T_{comf} = 17.8 deg.C + 0.31 x T_m

in summers (following in with the general form of comfort temperature equation Tcomf = A*Ta, out + B [8], where T_m is the monthly average of the daily average outdoor dry bulb temperatures. A total of 90% and 80% of people satisfied are assumed to fall at T_{comf} ±2.5 and 3.5°C respectively.

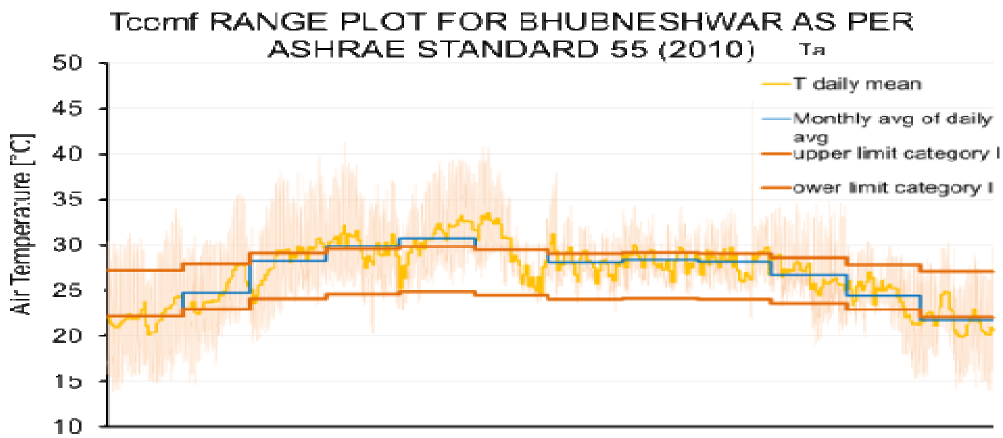


Fig. 2. T_{comf} range plot for Bhubaneshwar as per ASHRAE Standard 55 (2010).

B. EN15251

Derived from a European comfort database,

T_{comf} = 18.8°C + 0.33 × T_{rm}

in summer, where T_{rm} is the exponentially weighted running mean of the daily outdoor temperature, approximated using the previous week's temperatures as:

$T_{rm} = (T_{-1} + 0.8T_{-2} + 0.6T_{-3} + 0.5T_{-4} + 0.4T_{-5} + 0.3T_{-6} + 0.2T_{-7})/3.8$,

where T_{-n} is the average outdoor temperature 'n' days before the day in question. A total of 90% and 80% of people satisfied are assumed to fall at T_{comf} ± 2.0 and 3.0°C, respectively.

Considerate point to ponder in this case is leveraging of the comfort temperature band, especially towards higher temperature ranges in this case. For what falls under uncomfortable temperature now falls to a considerate extent in to the comfort temperature band due adaptation accounting of past seven day's thermal history by exponential weighted average mean.

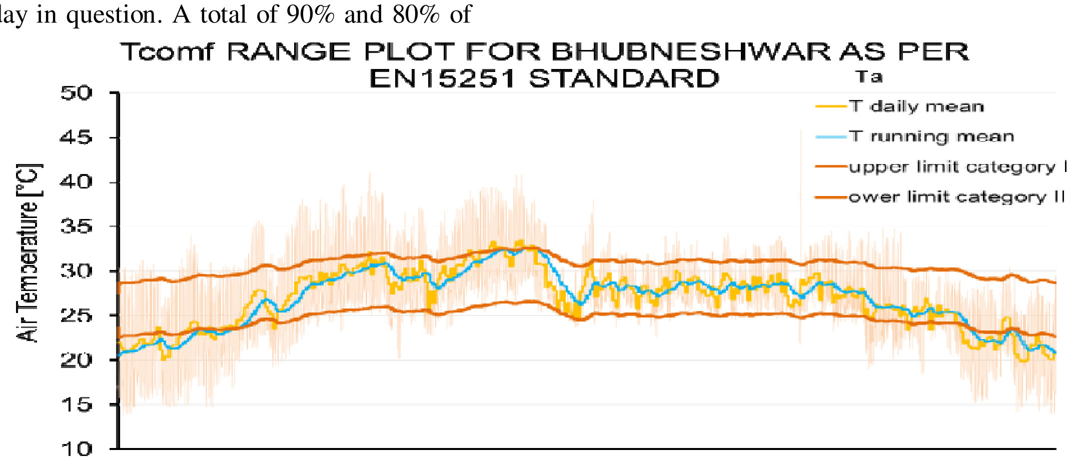


Fig. 3. T_{comf} Range plot for Bhubaneshwar as per EN15251 standard.

Comfort temperature range were thus calculated with ASHRAE Standard 55 (2010) considering the monthly average outdoor temperature and European Standard, EN15251, considering exponentially weighted running mean of outdoor DBT for calculation of comfort temperature. Corresponding plot of comfort temperature ranges with outdoor DBT is shown in Fig. 4.

As evident from the plot, EN15251 renders a higher comfortable range for the same temperature range offering a considerate lower temperature range through ASHRAE Standard 55 (2010). EN15251 being considering the adaptive thermal history for past seven days increases the adaptive comfort range and thus renders a towards the higher range of average DBT.

This is considered as the base reason for assuming a probable minimization in over designing in comparison with AHSRAE standard 55 (2010). To analyze a potential visible difference, degree discomfort hours are been attempted with calibrated simulation in the later part of the article.

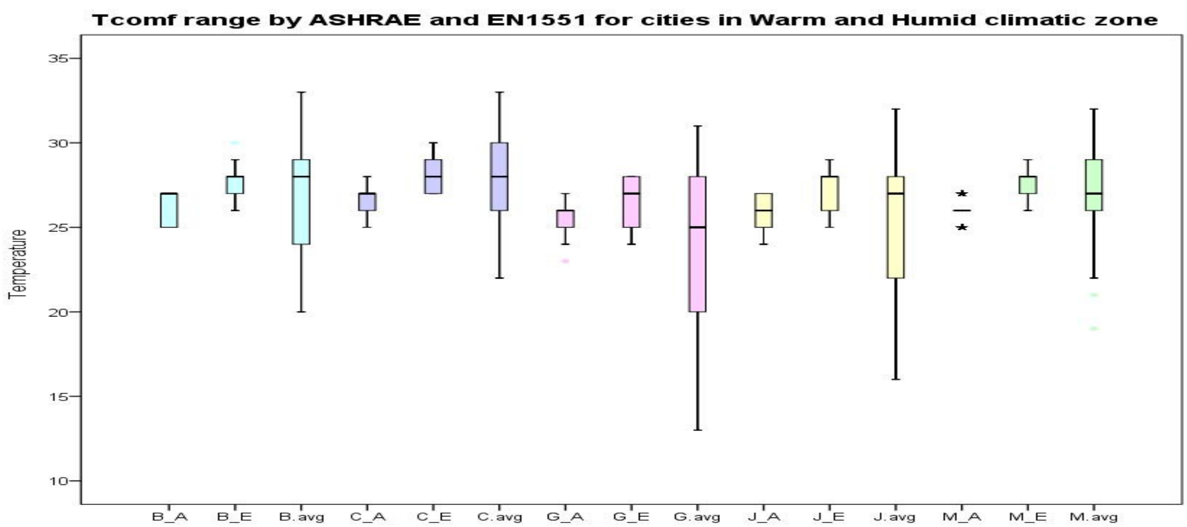


Fig. 4. Outdoor DBT plot with T_{comf} by ASHRAE Standard 55 (2010) and EN15251 for cities across W&H climate
B_A: ASHRAE Standard 55 (2010) based comfort temperature range for Bhubaneshwar;
B_E: EN15251 based comfort range for Bhubaneshwar;
B_{avg}: Outdoor temperature range for Bhubaneshwar, likewise, C: Chennai, G: Guwahati, J: Jamnagar and M: Mumbai.

IV. WALL MATERIAL SELECTION AND CALIBRATED SIMULATIONS

With base case of Brick wall, four more walling materials as building envelope parameter for analysis are being considered, namely, ACC, Cavity Wall, Fly Ash and RCC. To calculate the degree discomfort hours, test model was simulated with each walling material for all the five cities across W&H climatic zone of India.

Indoor temperature results thus obtained from simulations were plotted against the comfort temperature range obtained from both ASHRAE Standard 55 (2010) and EN15251.

Analysis clearly depicts a considerate minimization of overdesign subjected with ASHRAE Standard 55 (2010) in comparison with EN15251. The comfort temperature rage for EN15251 showed two major benefits over the ASHRAE Standard 55 (2010) model:

a. Data sprawl: The comfort temperature range obtained from EN15251 is bigger in comparison with ASHRAE Standard 55 (2010) mode, thus demanding corresponding lesser conditioned damping of the indoor air temperature to fall under comfortable range.

b. Skewedness towards higher temperatures: The range of comfort temperature obtained from EN15251 is skewed more towards the higher temperature range. Given the study scope falling in W&H climatic zone, the subjective surveys studies recommend higher temperature ranges to be the issue demanding critical concern. Since conditioning is most prominent in higher temperature ranges, it directly affects the load.

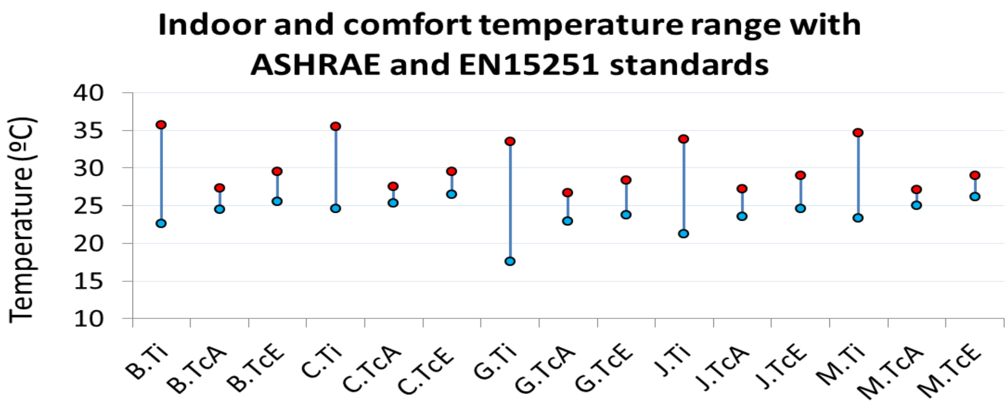
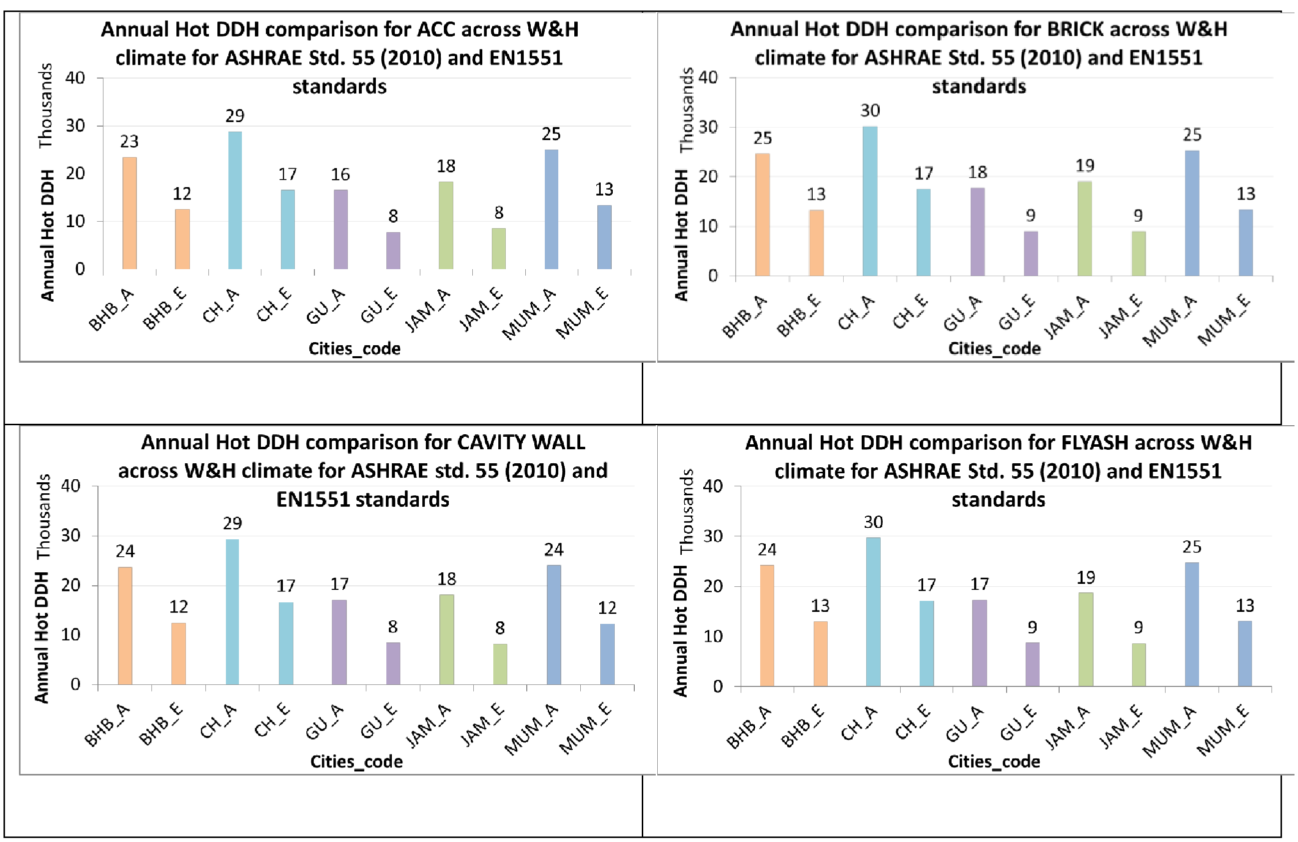


Fig. 5. Indoor and comfort temperature range with ASHRAE Standard 55 (2010) and EN15251 standards.
* B.Ti: Indoor temperature of Bhubaneshwar;
B.Tca: Comfort temperature as per ASHRAE Standard 55 (2010);
B.TcE: Comfort temperature as per EN15251, likewise, C: Chennai, G: Guwahati, J: Jamnagar and M: Mumbai

V. DDH ESTIMATION

Degree Discomfort Hour is thus calculated with the derived comfort temperature and the trend is been studied for variations occurring across cities, standards and materials. A comprehensive comparison graph is as follows:



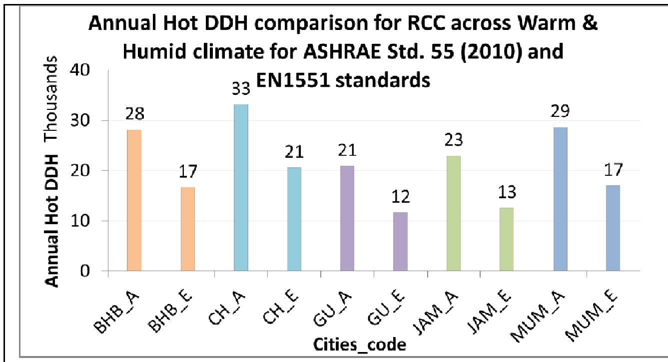


Fig. 6. Annual Hot DDH comparison for walling materials across W&H climate for ASHRAE Standard 55 (2010) and EN15251 standards.
* BHB_A: ASHRAE Standard 55 (2010) based DDH of Bhubaneshwar;
BHB_E: EN15251 based DDH of Bhubaneshwar, likewise, CH: Chennai, GU: Guwahati, JAM: Jamnagar, MUM: Mumbai.

Analysis rendered following observations:
a. Independent of the influence of walling materials and cities, EN15251 yields approximately 50% less degree discomfort hours in comparison with ASHRAE Standard 55 (2010), thereby curtailing to almost half, the design criteria for conditioned indoor environment.

b. Order of favorable walling material cases fall almost in the following order of preference:
ACC > CAVITY WALL > FLY ASH > BRICK > RCC, beyond the order of preference based on achieving minimal degree discomfort hours another major factor governing the same, cost alters the order to a considerable extent.

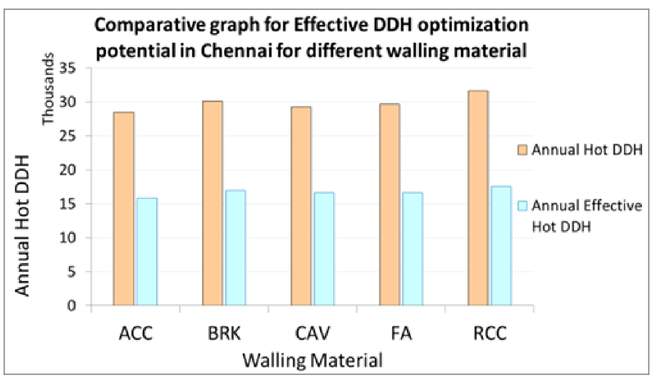


Fig. 7. Comparative graph for effective DDH optimization potential in Chennai for different walling material.

Beyond analysis based on total hot DDH, this article presents the potential of savings through optimal indoor environment designing and minimizing the over design condition by adopting a more responsive mode of degree discomfort hours calculation method to be considered, namely "Effective DDH", described as follows:

EFFECTIVE DDH. Effective DDH as the case will be presented is defined as:
"Degree Discomfort Hours only accounting the hours of actual discomfort, in other words accounting only the occupied hours of regularly occupied spaces of the study scope."
The Fig. 7 Shows a clear minimization of 43% reduction in degree discomfort hours by adopting effective DDH methodology, which when used in lieu with the European overdesigning of the indoor environment as shown in Fig. 8.

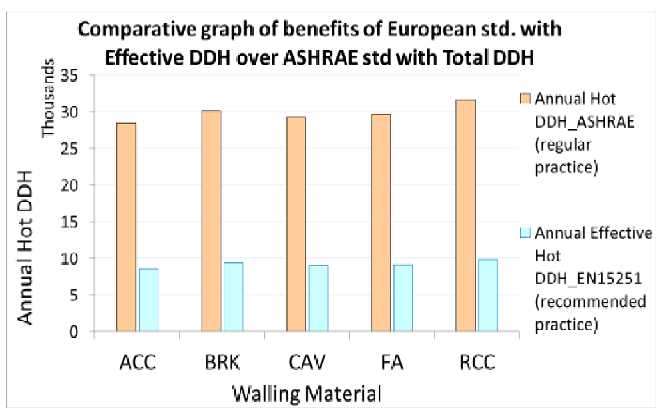


Fig. 8. Comparative graph of benefits of European standard with Effective DDH over ASHRAE Standard 55 (2010) with Total Hot DDH.

VI. OBSERVATIONS

a. With the recent addition of adaptive thermal comfort model in GRIHA, the current study highlights that EN15251 provides a more exhaustive and realistic running mean temperature to be considered for neutral temperature calculation. Methodology detailed in EN15251 proves to be more effective and better in comparison with both ASHRAE Standard 55 and Indian adaptive comfort model, both of which assumes 'running mean temperature' only, whereas EN15251 uses 'exponentially weighted running mean temperature.

b. Mathematically, exponentially weighted running mean outdoor DBT provides with a more exhaustive comfort temperature, considering past seven day's thermal history and thus rendering daily adapted comfort temperature in comparison with ASHRAE Standard 55 (2010) which renders a single comfort temperature value for a month.

c. Comfort temperature range rendered with EN15251 resulted in more skewed results towards higher temperature range.

d. Due shift in the domain of comfort temperature towards higher temperature range with EN15251, the load design scope corresponding to damping the higher temperature ranges is reduced which in W&H climate is of major concern, unlike lower temperature range in winters.

e. EN15251 results approximately 50% reduction in Degree

Discomfort Hours in comparison with ASHRAE Standard 55 (2010) comfort model.

f. Further, application of Effective hot DDH technique renders yet again 50% reduction in comparison with the total hot DDH.

g. When compared with the regular practice of adopting ASHRAE Standard 55 (2010) model with total hot DDH, EN15251 renders a gross total of 70% reduction when adopted with Effective hot DDH method.

VII. CONCLUSION

Given the indicative yet exhaustive in terms of recommendation, guidelines for naturally ventilated buildings referred by GRIHA can yet be extended to a more robust and dynamic methodology. Having tested with two adaptive comfort models and learning the benefits of exponentially weighted running mean average methodology for comfort temperature estimation can further be detailed and tested to the best of applicability in five climatic zones of India. Also the basic thermal comfort severity indices can further be revisited for possibilities of checking with the minimization in overdesign cases. This paper presents schematics towards a more descriptive trial and error test with existing or new comfort models to suit best in interest of Indian climatic scenario.

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