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Thermal Comfort Analysis for Office Room Using Computational Fluid Dynamics: A Review

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Abstract: **Thermal comfort in the room is achieved by maintaining temperatures between 20 °C to 25 °C, as a result of air temperature. The main objective of the present work to study the thermal comfort in office room by changing the design of inlet and outlet duct position using computational fluid dynamics analysis. The present review includes various factors related with thermal comfort of office room, like temperature and air flow inside the office room, that affect the thermal comfort for the occupants. Areas in which additional information is required are identified and comments are made regarding future research directions. From the above literature study, it has been observed that in the field of thermal comfort for the office room lot of work have been seen in worldwide and still going on so there is a scope to work on this field.**

Keywords: heat transfer, thermal comfort, air conditioning system, office room etc.

I. INTRODUCTION

Thermal comfort is the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation. Thermal neutrality is maintained when the heat generated by human metabolism is allowed to dissipate, thus maintaining thermal equilibrium with the surroundings. The main factors that influence thermal comfort are those that determine heat gain and loss, namely metabolic rate, clothing insulation, air temperature, mean radiant temperature, air speed and relative humidity. Psychological parameters, such as individual expectations, also affect thermal comfort.

There are two models of thermal comfort being used in international standards (ASHRAE standard 55-2017); heat balance model (laboratory based) developed by Fanger in 1970 also called as PMV/PPD model and Adaptive thermal comfort model. The first model is best suitable for airconditioned buildings in which the occupants have no control over their immediate surroundings whereas in the later one, the interaction between the occupant and immediate naturally ventilated surroundings is dynamic and the occupant's behavioral, physiological and psychological adaptations are wider compared to conditioned buildings. Fanger's PPD/PMV model ignores the outside temperature (*Tout*), an important factor in defining thermal comfort.

The adaptive model of thermal comfort is a linear regression equation that relates indoor comfort temperature directly to outdoor air temperature in below equation.

$$T_c = 0.31T_{out} + 17.8$$

Where T_c is indoor comfort temperature

T_{out} is outdoor temperature.

II. LITERATURE REVIEW

Jéssica Kuntz Maykot at el.[1] This article aims to assess the effects of gender on requirements for thermal comfort in office buildings. Data were obtained from 83 field studies conducted over 2014 in three office buildings located in Flori-anópolis, southern Brazil. In contrast to what some previous studies have found this work indicates the existence

of significant differences in the thermal comfort responses of male and female subjects.

Jindal A [2] A field study was carried out during monsoon and winter seasons of 2015-16 to investigate the thermal environment and thermal comfort in naturally ventilated (NV) indoor environment of classrooms of a Government residential school located in composite climatic zone of Ambala, India. A total of 640 responses from 130 students in the age group between 10-18 years belonging to rural background were collected. An indoor operative temperature of 27.1°C was recorded as neutral temperature.

Földváry V at el.[3 The ASHRAE Global Thermal Comfort Database II now an online, open-source database, includes approximately 81,846 complete sets of objective indoor climatic observations with accompanying "right-here-right now" subjective evaluations by the building occupants who were exposed to them. A simple webbased interface to the database enables filtering on multiple criteria, including building typology, occupancy type, subjects' demographic variables, subjective thermal comfort states, indoor thermal environmental criteria, calculated comfort indices, environmental control criteria and outdoor meteorological information.

M.T.H. Derks at el. [4] In indoor comfort research, thermal comfort of care-professionals in hospital environment is a little explored topic. To address this gap, a mixed methods study, with the nursing staff in hospital wards acting as participants, was undertaken. The results indicated that the optimal thermal sensation for the nurses — suiting their thermal comfort requirements and work performance — would be closer to 'slightly cool' than neutral.

Ricardo Forgiarini Rupp, Richard de Dear & Enedir Ghisi [5] Studies about thermal comfort in mixed-mode buildings have been performed in order to better under-stand this type of building and its influence on occupants' thermal perception. This work is a first step towards building an adaptive model of thermal comfort forBrazilian subtropical climate.

Shilei Lu, Bo Pang, Yunfang Qi & Kun Fang[6] The unique geographical location of Hainan makes its climate characteristics different from inland areas in China. A thermal environment test for different types of buildings in Hainan and a thermal comfort field investigation of 1944 subjects were conducted over a period of about two months. The results of the survey data show that a high humidity environment did not have a significant impact on human comfort. **Elena Barbadilla Martat el.[7]** The study of the thermal comfort of the occupants of a building represents an important challenge, due to its close relation with energy efficiency. The percentage of thermal sensation votes in comfort evolved from 94% (prior to implementing the comfort algorithm) to 87.5% (once implemented) for the summer season and from 79.5% to 81.6% for the winter season. The results demonstrate that the adaptive model is effective for the optimization of HVAC systems, and that it is possible to achieve energy savings without impairing the comfort of its occupants for the type of climate and buildings considered.

Vitor E.M. Cardoso at el. [8] The aim of this article is to present a comparison between thermal comfort evaluation methods applied in a free running bus terminal located in a mild climate country. Data was collected in field measurements and surveys were performed on 240 passengers, focusing warm season operation conditions. An alternative approach based on the correlation between SET* and dissatisfied voters established through the thermal preference method provided a wider comfort range that appears, in this case, to be adequate.

Hye-Jin Cho & Jae-Weon Jeong [9] This research presents a method for evaluating the thermal environment via a series of energy simulations using the TRNSYS 17 program, integrated with an engineering equation-solver (EES) program. In this paper, the indoor-air conditions and PMV values for each LDIDECOAS operation mode are represented. A detailed analysis of the impact of the indoor-air conditions on the PMV is provided in this paper. Furthermore, the simulation results for LDIDECOAS were compared with those for a conventional variable-air-volume (VAV) system

Andrei Claudiu Cosma & Rahul Simha [10] This work evaluated the use of thermographic cameras as a non-invasive method to automatically model human thermal comfort in transient conditions, using data from 30 healthy subjects tested in an office setup with ambient temperatures between 21.11 °C and 27.78 °C. The results suggest that non-invasive thermographic cameras that combine visual and thermal modes are sufficiently accurate in real-world settings to drive control of HVAC systems.

Jaewan Joe at el. [11]This paper introduces a new multi-agent system approach to optimal control of high performance buildings and presents algorithms for both distributed system identification and distributed model predictive control (DMPC). For the system identification, each thermal zone is divided into sub-systems, and a parameter set for each sub-system is first estimated individually, and then integrated into an inverse model for the whole thermal zone using the dual decomposition algorithm.

Aleksandra Lipczynska, Stefano Schiavon & Lindsay T. Graham[12] The experiment was performed in three environmental conditions (one with a set-point of 23 °C—a typical set-point used in Singapore—and two elevated (up to 28 °C) room temperature conditions). The results show that the most comfortable thermal condition, with thermal sensation closest to neutral, is achieved at a room temperature of 26 °C with operating fans.

Luo M, Wang Z, Brager G, Cao B & Zhu Y [13] In this paper, we studied the mutually dependent relationship between indoor climate experience and occupants' comfort expectation. An intriguing experiment was conducted in China where wintertime indoor thermal environments in northern cities are much warmer than in southern region. It is much quicker for occupants to accept neutral indoor climate than to lower their expectation and adapt to under-conditioned environments. These two phenomena can be well described by the index "demand factor", which can serve as a reference for future thermal comfort study.

Pazhoohesh M & Zhang C [14] A personal comfort assessment model predicts occupants' thermal comfort responses, specific to each individual, as an alternative to the mean response of a large population. The implementation of the proposed method shows the mean margin error of 12.95 percent for the prediction of preference temperatures of nine occupants in a shared space. The result shows that the proposed approach has a significant potential of maintaining most of the occupants in a reasonable thermal comfort range.

Rupp RF, Kim J & de Dear R. Ghisi E [15] The objective of this work is to investigate the relationship between various contextual factors and the perception of thermal comfort in workplaces, by examining the gap between the current thermal comfort criteria and the actual requirements observed for different groups of occupants. The analysis indicates that different groups of occupants require different comfort zones, suggesting that group differences should be considered when designing/operating spaces for diverse groups of occupants.

Sally Shahzad at el. [16] The aim of this research is to investigate the application and performance of an advanced personal comfort system, a thermal chair, using Computational Fluid Dynamics (CFD), Building Energy Simulation (BES) and field test analysis. a model of a threestory office building with thermal chairs were created and simulated in the commercial BES software, IES Virtual Environment. the results of the field study revealed 20% higher comfort and 35% higher satisfaction level, due to the use of thermal chair.

Sun C, Zhang R, Sharples S, Han Y & Zhang H [17] This paper presents the results from a longitudinal study during a summer season of ten mixed-mode offices located in Harbin, a city in northern China, which experiences severe winters and warm summers. The results showed a high probability of window opening for both day and night, and a high frequency of the use of a mix of cooling options, including fans and air conditioning, accompanied by natural ventilation in the summer season.

Samar Thapa, Ajay Kr.Bansal, Goutam Kr.Panda [18] In this paper the results of adaptive thermal comfort based field studies conducted in 3 naturally ventilated office buildings of cold and cloudy climate in north east India are presented. The result were found to be comfortable in cooler temperature than that prescribed in the standard, and thereby a modification in the comfort zone, which reflects the adaptive action of the subjects for the region is proposed.

Wang Z at el. [19] This paper aims to list and examine the magnitude and significance of individual difference in the preferred/neutral/comfort temperature through reviewing previous climate chamber and field studies. first, collecting individual physiological and psychological response; second, predict individual comfort with machine learning algorithms; and third, accommodating individual difference with Personalized Comfort Systems.

Tongling Wu , Bin Cao & Yingxin Zhu [20] A long term field study was conducted in an office building in Guangzhou, which is located in the Hot Summer and Warm Winter climate zone of China. The study covered three seasons - summer, autumn,

and winter. the temperature of air-conditioning in office buildings in hot climates could be set to a higher level than it usually was, so that air conditioning energy could be saved while occupants‟ comfort won‟t be sacrificed. In autumn and winter, no heating or cooling was provided to the investigated rooms, and the occupants‟ neutral temperatures in the two seasons were 25.8oC and 23.3oC respectively. **Chengcheng Xu, Shuhong Li Xiaosong Zhang & Suola Shao [21]** they conducted a field study of thermal comfort and thermal adaptive behaviours of residents in a traditional residential settlement in Nanjing in summer and winter. The results show that traditional dwellers are more tolerant to harsh environments, and their thermal neutral temperature and thermal sensitivity are lower in winter and higher in summer, than those of the people that reside in modern dwellings. Residents of traditional homes employ a series of thermal adaptive behaviours to expand their thermal comfort zone.

Huan Zhang at el. [22] The Corrected Predicted Mean Vote (CPMV) index is proposed in this paper to evaluate the indoor thermal comfort in solar conditions. To validate the accuracy of CPMV, experimental studies have been conducted in three different types of transparent envelope buildings in Tianjin, North China. CPMV is validated to be applicable in evaluating the indoor thermal comfort in buildings with solar radiation.

Serghides Despina at el. [23] This paper examines the thermal comfort conditions during summer and winter in an existing office building in an urban context. The Cyprus case study focuses on the impact of the thermal comfort Standards on the energy performance evaluation of the buildings and it promotes the sustainable and energy efficient design by selecting the most appropriate Standard to assess the thermal comfort for occupants.

Jouvan Chandra & Pratama Putra [24] This paper presents an investigation regarding the effect of indoor thermal to building's occupant satisfaction which is equipped by mechanically ventilated. this study found that the relationship amongst indoor environmental quality to produce occupant satisfaction is a complex system that need to be assessed comprehensively. Besides, it is invaluable to advance our understanding of the relationship amongst ventilation system, occupant behaviour, and building energy in tropical climate in assessment of occupant satisfaction.

Laura Pomfret & Arman Hashemi [25] This paper evaluates thermal comfort in domestic zero energy buildings. Dynamic simulations are used to assess a variation of scenarios including: construction types, natural ventilation strategies, solar shading, and occupancy periods in a low energy case study dwelling, within the United Kingdom. Increasing the effective openable glazing area to facilitate natural ventilation in zero energy buildings and further improve the indoor thermal comfort.

Marina Laskari at el.[26] This paper presents a methodology for the simultaneous subjective and objective evaluation of thermal comfort in commercial buildings. The methodology is based on the intermediate protocol level for the evaluation of thermal comfort as suggested by ASHRAE's Performance Measurement Protocols for Commercial Buildings. The study is utilized for the identification of serious thermal comfort issues but also for the determination of the preferred comfort conditions in the Leaf Lab office spaces.

Diego S. Caetano at el.[27] Energy-efficient buildings of the public and commercial sector challenge significantly future infrastructure projects in Brazil. This paper presents how real occupants in office buildings perceive and assess the higrothermal comfort. Results of the field study are compared towards the requirements in the Brazilian (NBR 16401) and European Standards (EN 15251) in office buildings in hot and humid climate regions.

Sally Shahzad at el[28] In this study, the application of the thermal chair was analysed using Computational Fluid Dynamics (CFD) and field-test analysis in an open plan office in Leeds, UK during winter. The results of the CFD model indicated an improvement in the local thermal comfort of the user. The CFD analysis provided detailed analysis of the thermal distribution around a siting manikin and was used to design and construct the thermal chair. The results of the field data survey indicated a great improvement in users' comfort (20%) and satisfaction (35%).

Xiang Deng at el.[29] This study uses field monitoring and post occupancy evaluation (POE) surveys to investigate the indoor thermal comfort of an office building that is located in subtropical zone. For the case study building, the static thermal comfort model gives outputs that matched well with the responses of the occupants during the POE survey in winter while the dynamic model is more

representative of the sensation of the occupants in summer,

Zhidan Zhao at el.[30] In this study, the application of the PMV model in Qatar with dry, subtropical desert climate is evaluated. An experiment was conducted in an office building in Doha, Qatar to reveal the occupant perception of indoor thermal comfort. The corresponding occupants' satisfaction level with the indoor thermal comfort and their adaptive behavior were also assessed.

Emanuele Naboni at el.[31] The research discusses how thermal comfort maps, which are prepared with the use of Computational Fluid Dynamic simulation method, could integrate energy simulation outputs to uphold qualitative architectural design decisions. The applicability of the thermal maps within an architectural design process is discussed adopting standard energy simulation comfort outputs as a reference. The capabilities and the limitations of the method are appraised.

John Kaiser Calautit at el. [32] The aim of this work was to investigate the performance of a roof-mounted cooling windcatcher integrated with heat pipes using Computational Fluid Dynamics (CFD) and field test analysis. The windcatcher model was incorporated to a 5m x 5m x3 m test room model. Numerical model was validated using experimental data and good agreement was observed between both methods of analysis.

Yangrui Song at el.[33] This paper investigates air-conditioning (AC) usage patterns and adaptive comfort behaviors in a Chinese residential context. Field measurements were conducted in 43 homes in Tianjin from May 14th to November 20th in 2016. The indoor temperatures corresponding to 80% thermal acceptability ranged from 21.0℃ to 27.3℃. We also derived statistical models to predict the likelihood of adaptive behaviors (i.e. turning on AC, turning on fans and opening windows or doors) with regard to outdoor air temperatures.

Oluleke Bamodu, Liang Xia & Llewellyn Tang [34] the work in this paper involves the investigation of an office room in cooling mode ventilated by a 4way cassette air conditioner, which is increasingly being installed in eastern china. The results in this paper, which are carried out by computational fluid dynamics simulation, indicate that a superior sir distribution performance is achieved by the 4-way cassette AC when compared to the wall mounted system. The results also show potentials for energy saving using 4-way cassette AC.

Conclusion:

The present review includes various factors related with thermal comfort of office room, like temperature and air flow inside the office room, that affect the thermal comfort for the occupants. Also included various experiential and computational models for investigate physiological response and the sensation of thermal comfort in the non-uniform transient environment of a room. Areas in which additional information is required are identified and comments are made regarding future research directions. From the above literature study it has been observed that in the field of thermal comfort for the office room lot of work have been seen in worldwide and still going on so there is a scope to work on this field.

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