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Experimental Investigation of the indoor environment assessment on conventional and hybrid mixing ventilation system

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ABSTRACT

The conventional air conditioning system has contributed to the spread of airborne contaminants and viruses throughout the space, and it causes occupants health at risk. Many researchers are recently focused on rectifying this problem by implementing the personalized ventilation (PV) system. The PV supplies fresh air directly to the occupant breathing zone, and it can maintain the well-being of occupants, improve indoor air quality and thermal comfort. The present study investigates the indoor air distribution assessment on mixing ventilation (MV) and mixing with personalized ventilation (MV+PV) systems. The experimentation is carried out in the office cabin model with the dimension of 3m×3m ×3m. This study has considered two cases. The performance evaluation is determined in terms of temperature, velocity, carbon dioxide distribution and thermal comfort. Results showed that the average CO_2 concentration in case 2 was 540 ppm, 25% lower than in case 1. Compared to ASHRAE 55 and ISO7730, the temperature distribution and PMV-PPD for both cases were within acceptable limits. The significant outcome of this study is to provide the better understanding of airflow distribution in the experimental room and the enhancement of the breathing zone.

Keywords: Mixing ventilation, personalized ventilation, thermal comfort, indoor environment, CO_2 concentration

1. INTRODUCTION

Nowadays, heating, ventilation and air conditioning (HVAC) systems are widely used in buildings to provide a productive and healthy environment by maintaining thermal comfort. Nearly 50% of building energy is consumed for HVAC operation alone. The fresh and conditioned air is required to maintain an improved indoor air quality (IAQ) and thermal comfort level in the conditioned space, leading to higher energy consumption. Hence, utilizing traditional air conditioning to provide optimal thermal comfort and IAQ with minimal energy consumption is challenging. In office space applications, many employees share the same thermal zone. Still, they may demand different comfort conditions based on various personal characteristics such as age, sex, clothing, metabolic activity, etc. [1]

Mixing ventilation (MV) is one of the traditional air distribution systems for buildings, as shown in figure 1. The low-temperature high-speed air is supplied through the MV at ceiling level to maintain an acceptable temperature level in the room. The inlet supply air is mixed with room air and delivered to the occupants at a suitable temperature and velocity. High-temperature contaminated air settles in upper space due to the buoyancy effect and mixes with the supplied air, resulting in poor air quality [2].

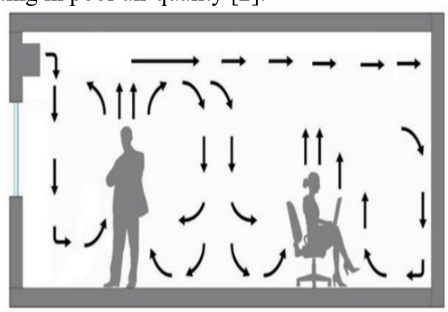

Figure 1: Mixing ventilation in an office [2]

Personalized ventilation (PV) provides fresh air directly into the breathing zone, as shown in figure 2. The possibility of mixing fresh air with existing contaminated air is reduced by PV, resulting in improved inhale air quality and occupant's well-being [3].

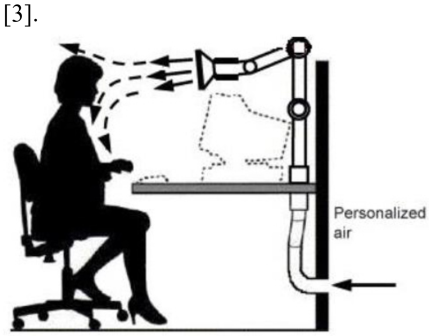

Figure 2: Personalized ventilation in an office cabin[3]

Usually, the PV is kept in/near the desktop. Thus, the occupant can easily control their working environment. The drawback of this system has lesser heat removal capacity at the lower level of the occupant zone. Both types of ventilation

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systems have flaws, and the current study proposes combining an MV system supported by a PV system to solve these issues.

2. LITERATURE REVIEW AND OBJECTIVES

The literature review explains the recent works associated with PV employed in buildings. It also brings out the various studies to the performance analysis of PV integrated with other ventilation systems. The multi-tuyere apparatus was used to explore the targeted personalized ventilation (TPV) system. The effectiveness of thermal comfort and different tuyeres performance were compared using the computational fluid dynamics (CFD) technique. Moreover, the effects of tuyeres in terms of angle, area and air velocity at the exit were examined using full-scale experimentation. The result shows that the velocity at the controlled area of the occupant was 0.3 m/s and avoids the cold draft. The energy-saving rate was 52.9 % [4]. Zhu et al. [5] investigated the effectiveness of a spot-type personal air conditioner in terms of cooling. The cooling efficiency (CE) means the ratio of sensible heat removal by SPAC and device cooling capacity from the human body. The three rounded nozzles were studied with various airflow rates of 11.8 l/s and 59.0 l/s on the occupant seating and standing positions. Additionally, they investigated the heat loss of the human body through thermal sensation related to a predicted mean vote (PMV). This study concluded better cooling efficiency and control over the cold draft by supplying the airflow rate at higher temperature through the smaller nozzle. A co-flow personalized ventilation system was designed to achieve high air quality in the breathing zone. The tracer gas method was used for analyzing air quality. The suggested system has a ventilation effectiveness of 7, whereas the traditional method has 2. It was accomplished by supplying the same quantity of fresh air at a rate of 2.4 l/s [5]. Amai et al. [6] conducted the experimentation of MV in a full-scale test room. Carbon dioxide (CO_2) tracer gas decay, various ceiling diffusers and internal loads were used to assess air change effectiveness. Different diffuser types, air change and temperature effectiveness were more than or equal one under cooling circumstances. With a decrease in the $T_{0.25}/L$ condition of the evaluated diffuser, the heating conditions of the air change effectiveness reduced considerably. A series of dynamic full-scale tests were performed using ten thermal mass distribution schemes, four air change rates per hour (ACH), and two inlet air temperatures using MV. Results showed that the test room average convective heat transfer coefficient was unaffected by the input air temperature, although it rose in composed with thermal mass level and the ACH [7]. Four common air distribution strategies were tested in winter and summer environments with various occupancy rates. Air dispersion was measured under three different load scenarios. At each location, air temperature and velocity were observed at seven different heights. According to the findings, room heat load conditions considerably impact the MV air distribution method. In addition, all of the air velocities were relatively modest (0.19-0.23 m/s) [2]. Assaad et al. [8] examined the performance of intermediate PV + MV to protect occupants from contaminants using a 3D CFD model and experimental validation. They found that an average flow rate of 7.5 l/s and a frequency of 0.86 Hz provide appropriate intake fractions in the breathing zone, as well as acceptable deposition rates in the surrounding microclimate. The majority of the work focuses on PV integrated with other systems. Very few studies are available to quantify the interaction of personalized ventilation supply air with breathing zone. The present study focuses on improving the air quality by reducing the mixing of the contaminant with PV supply air. This study aims to examine indoor air distribution and thermal comfort on MV and MV+PV systems.

- The experimentation is conducted with the office cabin room model and measured at three locations around the occupant.
- To compare temperature and velocity distribution at different heights (0.1m, 0.6m and 1.1m).
- Furthermore, relate thermal comfort analysis in two cases using CBE thermal comfort tool.
- The CO_2 concentration is analyzed at the breathing zone level (1.1m above the floor)

3. MATERIALS AND METHODS

3.1 Description of the experimental set-up

The experimentation set-up is located in the Fluid mechanics' laboratory, NIT Calicut. It represents an office cabin model with the actual dimension of 3 m (length) × 3 m (width) × 3 m (height). An experiment is carried out to investigate the performance of the MV and MV+PV systems. The experimentation is considered into two cases: case 1 is MV, and case 2 is the MV+PV.

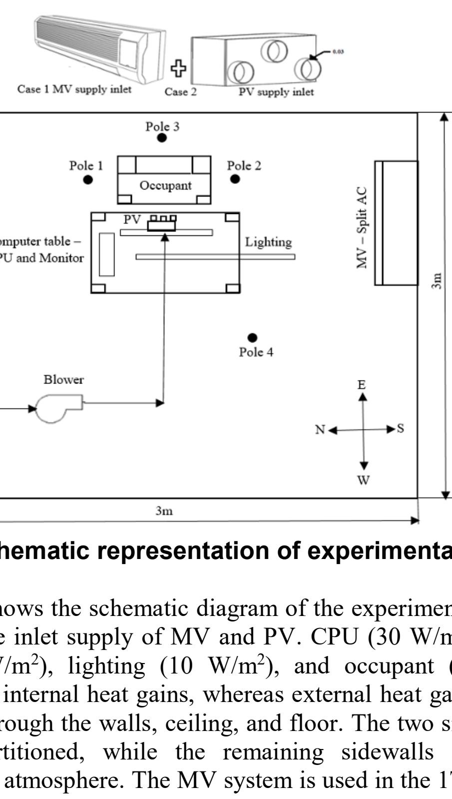


Figure 3: Schematic representation of experimental set-up

Figure 3 shows the schematic diagram of the experimental set-up with the inlet supply of MV and PV. CPU (30 W/m^2), monitor (5 W/m^2), lighting (10 W/m^2), and occupant (65 W/m^2) are the internal heat gains, whereas external heat gains are realized through the walls, ceiling, and floor. The two side walls are partitioned, while the remaining sidewalls are exposed to the atmosphere. The MV system is used in the 1TR split air conditioning (SAC) and supply unit on the occupant's left sidewall. The PV system supply unit had three holes with a diameter of 0.03m and it is connected with another air conditioning system. A duct and blower are used to supply the fresh air directly to the occupant breathing zone through the PV supply inlet.

3.2 Instrumentation and measurement methods

Table 1 shows the instrument details used in this study. The experimentation and measurement methods are followed by ISHRAE, ASHRAE 55, 62.1 and ISO 7730 standards [9] [10].

Table 1: Instrument description

Instruments	Range	Accuracy
IAQ probe	0 to 5000 ppm	± 5%
	0 to 100%	± 3%
Hotwire anemometer probe	0 to 50°C	± 0.5°C
	0 to 20 m/s	± 0.03 m/s
Globe thermometer	0 to 120 °C	± 0.5°C

The variables of velocity and temperature are measured in three different locations (poles 1, 2 and 3) around the occupants at the heights of 0.1m, 0.6m and 1.1 m.

Figure 4: Instrument details and measurement methods

The CO_2 concentration is measured in the position of 1.1m height around the occupants. The indoor environment conditions are noted in pole 4 at the height of 1.1m. Table 1 provides the specification of the instrument used in the experimentation. In the experiment, two Testo 480 comfort measurement devices were employed, as illustrated in figure 4. One to measure the area surrounding the occupants (pole 1 or 2 or 3) and the other to analyse the room's conditions (pole 4).

3.3 Experimental procedure

For case 1, switch on the SAC system alone, then set the supply temperature and flow rate at 19°C and 85 l/s. The temperature and velocity around the occupant are monitored once it has reached a steady-state condition. CO_2 level was also noted near the breathing and surrounding space of the occupant. For test case 2, the SAC supply flow rate is reduced to 80 l/s. Afterwards, the blower is switched on to activate the PV system. The flow rate is set to 5 l/s by adjusting the blower supply voltage. After 15 minutes, the temperature, velocity and CO_2 values are recorded through the data logger.

3.4 Evaluation of thermal comfort

Fanger devised a comfort equation that includes both environmental and human factors. Air temperature, velocity, mean radiant temperature and relative humidity are the environmental factors, whereas the activity level and clothing insulation are the human factors. The level of activity governs the rate of metabolism [10]. The predicted mean vote (PMV) and percentage of people dissatisfied (PPD) indices of the thermal comfort model are depicted in figure 5.

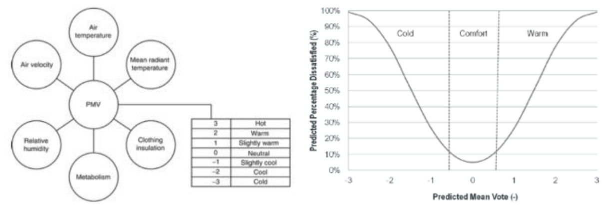


Figure 5: Description of PMV and PPD model [11]

In this study, 1.1 met (65 W/m^2) was used to represent office occupants' typing, reading, and writing activities, while 0.59 *clo* was used to characterize clothing factors (trousers and long sleeve shirts). Furthermore, the PMV-PPD of two cases were evaluated and compared using the center for the built environment (CBE) thermal comfort tool [12].

4. RESULTS AND DISCUSSION

The temperature and velocity distribution profiles have been explored in detail concerning heights above the floor of cases 1 and 2. Furthermore, the CO_2 concentration and thermal comfort indices have been compared with both cases.

4.1 Variation of temperature and velocity

Figure 6 describes the temperature variation along with different heights. In case 1, the inlet air supplies into the space from ceiling to floor direction.

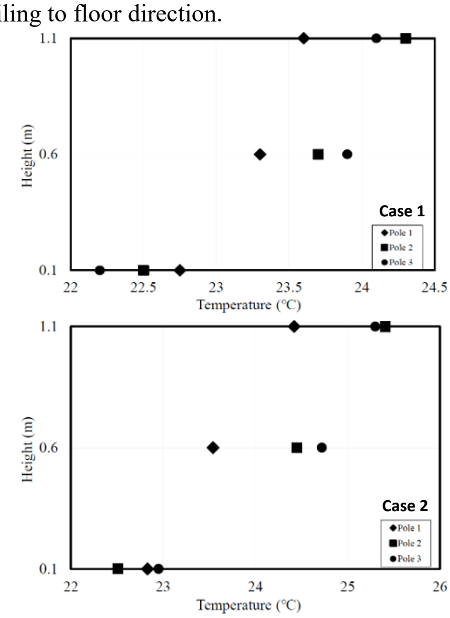


Figure 6: Variation of temperature profile with heights above the floor for cases 1 and 2

There was no outlet or exhaust, and the airflow circulation was confined inside the room. The cold supply air was passing over the equipment and occupant. Afterwards, the absorbed heat was distributed throughout the space, resulting in the dilution of the room air. The entire conditioned space was maintained at a lower temperature difference. For the three poles, the temperature surrounding the occupant was about 22°C-24.5°C. The mean room air temperature was kept at 23.8°C. In addition, the temperature difference between 1.1m (head level) and 0.1m (ankle level) of the three poles was found to be 0.85°C, 1.8°C and 1.9°C, respectively. The location of pole 2 and 3 was directly contacted with the supply air, whereas pole 1 was placed after the occupant. As a result, the temperature difference between poles 2 and 3 was identical, whilst pole 1 was slightly increased than others. In case 2, the total flow rate was divided into two pathways. The MV system supplies 80 l/s, and the airflow circulation was similar to case 1. The remaining five l/s flow rate was provided directly to the breathing zone using the PV system. Both MV and PV systems were working parallel, so it was called a hybrid MV system. The PV supply air temperature was higher than the MV system. It has interacted mainly in the breathing zone area. Thus the case 2 room air temperature was increased at the height of 0.6m to 1.1m around the occupants. The observed mean temperature was 24.8°C. The attained temperature from ankle to head level was between 22.5°C-25.5°C. The temperature difference between 0.1m and 1.1m was higher than in case 1 because the PV had a higher supply air temperature. Poles 1, 2, and 3 had a temperature difference of 1.59°C, 2.9°C, and 2.3°C, respectively.

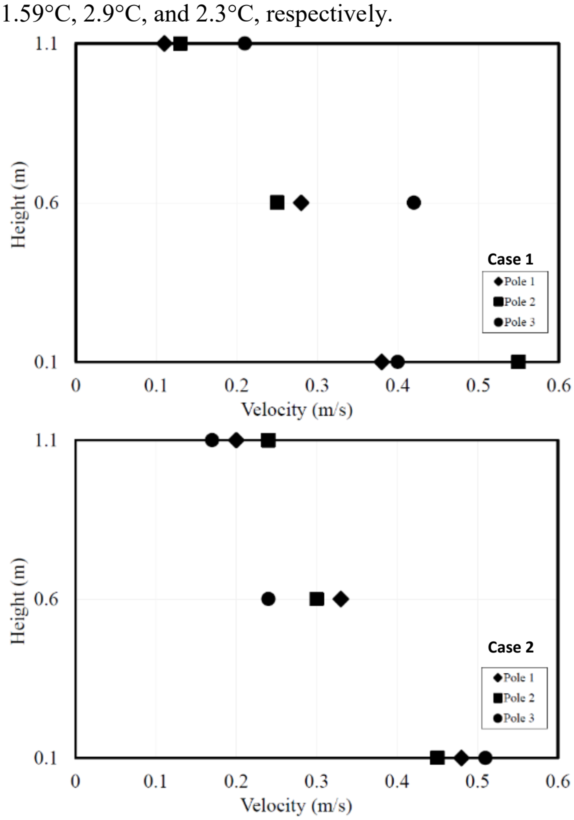


Figure 7: Variation of velocity profile with heights above the floor for cases 1 and 2

Figure 7 represents the variation of air velocity with different cases. The air velocity was 0.28 m/s – 0.11 m/s in case 1 from 0.6m to 1.1m height. The measured mean velocity was 0.23 m/s. The case 2 air velocity around the occupants was slightly higher than case 1. The case 2 air velocity ranges between 0.33 m/s-0.17 m/s. The air velocity in case 1 was within acceptable limits, whereas case 2 was somewhat higher. The acceptable air velocity is less than 0.25 m/s [10].

4.2 CO_2 Concentration of MV and MV+PV system

In both cases, the average CO_2 concentration was depicted in figure 8. In case 1, the air was constantly recirculated due to improper infiltration. The average CO_2 concentration level of case 1 and case 2 were 715 ppm and 540 ppm. Even though roughly 6% of fresh air was provided in each cycle in case 2, the heat load and overall supply flow rates were equal in both cases. As a result, case 2 was maintained a lesser CO_2 concentration level in the room. Moreover, it was compared to the ISHRAE standard for both the cases within the class B level [9].

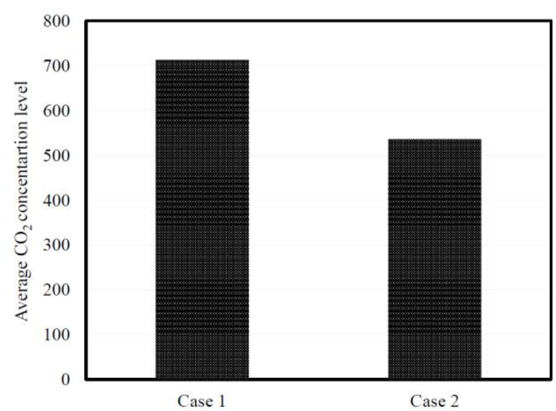
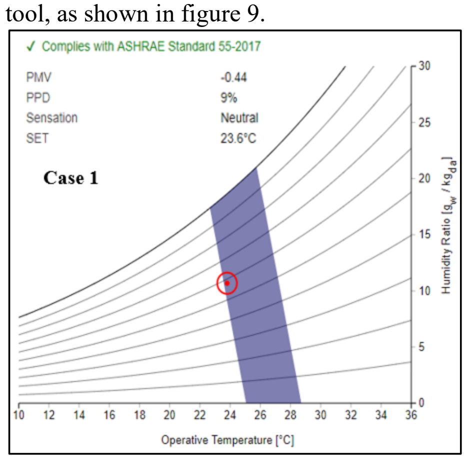


Figure 8: Average concentration of CO_2 level in cases 1 and 2

4.3 Thermal comfort analysis

Thermal comfort indices were predicted using CBE thermal comfort tool, as shown in figure 9.



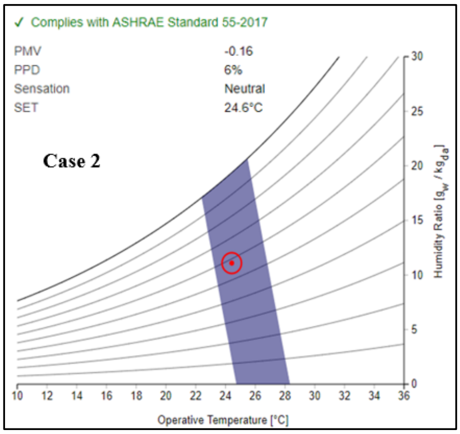


Figure 9: Prediction of PMV-PPD on cases 1 and 2

The PMV-PPD achieved in case 1 were -0.44 and 9% of the "neutral" sensation. Case 2 had PMV-PPD levels of -0.16 and 6%, comparable to case 1 in a similar sense. The air velocity and temperature play a role in both cases and it significantly affects PMV-PPD. Moreover, case 2 are more comfortable in the observed breathing zone air velocity and temperature. It feels occupant more comfortable. Nonetheless, the PMV-PPD was acceptable in both cases. According to the ASHRAE 55 guidelines [10], if the PPD is greater than 20%, it is considered an uncomfortable indoor environment.

5. CONCLUSIONS

The experimental investigation was evaluated in two cases on an office cabin model. The velocity and temperature variation with heights above the floor has been examined from the measured data of two cases. Thermal comfort and CO_2 concentration have been assessed and compared with the different system operating cases.

- For the three poles, the temperature around the occupant was about 22°C-24.5°C in case 1. The mean room air temperature was maintained at 23.8°C and 24.8°C for cases 1 and 2, respectively. The air velocity in case 1 was within acceptable limits, whereas case 2 was somewhat higher due to the additional PV system.
- ISHARE IEQ standard 2016 states that the CO_2 concentration should be at or below class B. The results of the experiment showed that this was accomplished. Compared to both the cases, the case 2 average CO_2 was 540 ppm, which was 25% lesser than the case 1. Furthermore, the MV+PV system can maintain the improved breathing zone level.
- The case 2 PMV-PPD level was -0.16 and 6%, and the sensation was similar to case 1. Also, in both cases, thermal comfort indices are in acceptable comfort conditions.

Further, a detailed numerical analysis will be carried out and validated with similar model experimental results. Also, to assess the aerosol and respiratory droplets in the breathing zone under various operating conditions of a conventional and hybrid mixing ventilation system.

REFERENCES

[1] ASHRAE, Handbook Fundamentals, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA, 2001.

[2] D. Müller, C. Kandzia, R. Kosonen, A. K. Melikov, and P. V. Nielsen, Mixing Ventilation - Guide on Mixing Air Distribution Design, REHVA Federation of European Heating, Ventilation and Air Conditioning Associations (19), 2013.

[3] B. Yang, A. K. Melikov, A. Kabanshi, C. Zhang, F. S. Bauman, G. Cao, H. Awbi, H. Wigö, J. Niu, K. W. D. Cheong, K. W. Tham, M. Sandberg, P. V. Nielsen, R. Kosonen, R. Yao, S. Kato, S. C. Sekhar, S. Schiavon, T. Karimipanah, X. Li, and Z. Lin, A review of advanced air distribution methods - theory, practice, limitations and solutions, Energy and Building, 202, 2019, pp.109359

[4] R. Gao, C. Wang, A. Li, S. Yu, and B. Deng, A novel targeted personalized ventilation system based on the shooting concept, Building and Environment 135, 2018, pp. 269–279

[5] H. Ezzat Khalifa, M. I. Janos, and J. F. Dannenhoffer, Experimental investigation of reduced-mixing personal ventilation jets, Building and Environment 44, 2009, pp. 1551–1558

[6] H. Amai and A. Novoselac, Experimental study on air change effectiveness in mixing ventilation, Building and Environment 109, 2016, pp. 101-111.

[7] R. Guo, P. Heiselberg, Y. Hu, H. Johra, R. Lund Jensen, K. T. Jønsson, and P. Peng, Experimental investigation of convective heat transfer for night ventilation in case of mixing ventilation, Building and Environment 193, 2021, pp. 107670.

[8] D. Al Assaad, K. Ghali, N. Ghaddar, and C. Habchi, "Mixing ventilation coupled with personalized sinusoidal ventilation: Optimal frequency and flow rate for acceptable air quality," Energy and Building 154, 2017, 569–580.

[9] ISHRAE, Indoor Environmental Quality Standard- 10001: 2016, 2016-2017.

[10] American Society of Heating, Refrigerating, Air-Conditioning Engineers, and American National Standards Institute, Thermal environmental conditions for human occupancy, American Society of Heating, Refrigerating and Air-Conditioning Engineers, 11, 2004.

[11] Van Hoof, Joost, George Demiris, and Eveline JM Wouters, Handbook of smart homes, health care and well-being. Springer International Publishing, 2017.

[12] Tyler, Hoyt, Schiavon Stefano, Piccioli Alberto, Moon Dustin, and Steinfeld Kyle. CBE thermal comfort tool, Center for the Built Environment, University of California Berkeley, 2013.