

Evaluation of Thermal Comfort Status and Design Intervention Inside the Kitchen of Indian Railway Pantry Car

A thesis submitted in partial fulfilment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

by

MD SARFARAZ ALAM



Department of Design

Indian Institute of Technology Guwahati

Guwahati-781039

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MD SARFARAZ ALAM

Roll No. 166105008

Under the supervision of

Dr. Urmi Ravindra Salve



Department of Design

Indian Institute of Technology Guwahati

Guwahati-781039

INDIA

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Department of Design
Indian Institute of Technology Guwahati
Guwahati-781039
INDIA

DECLARATION

This is to certify that the research work in the thesis entitled “**Evaluation of Thermal Comfort Status and Design Intervention Inside the Kitchen of Indian Railway Pantry Car**” is carried out by me at the Department of Design, Indian Institute of Technology Guwahati, under the supervision of Dr. Urmi Ravindra Salve. The results documented in this thesis are achieved by me and it has not been submitted to any other University or Institute for the award of any degree or diploma.

Md Sarfaraz Alam

Md Sarfaraz Alam
Roll No. 166105008
Department of Design
Indian Institute of Technology Guwahati
Guwahati-781039, Assam
INDIA



Department of Design
Indian Institute of Technology Guwahati
Guwahati-781039
INDIA

THESIS CERTIFICATE

This is to certify that the work contained in the thesis entitled “**Evaluation of Thermal Comfort Status and Design Intervention Inside the Kitchen of Indian Railway Pantry Car**” by **Md Sarfaraz Alam**, a student of the Department of Design, Indian Institute of Technology Guwahati, for the award of the degree of **Doctor of Philosophy** has been carried out under my supervision and that this work has not been submitted elsewhere for any degree or diploma.

Urmi Salve

Dr. Urmi Ravindra Salve
Assistant Professor
Department of Design
Indian Institute of Technology Guwahati
Guwahati-781039, Assam
INDIA

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MD SARFARAZ ALAM
IIT Guwahati

ABSTRACT

Thermal comfort refers to the thermal balance between the "human body" and the "environment" and also the appropriate balance between "body heat production and heat dissipation," which have a significant impact on the human body. Numerous research is available on thermal comfort under different environments like buildings, transports, manufacturing industries and allied work sectors in both developed and developing nations. Although fewer studies have also been conducted under different kitchen environment such as rural households, restaurants, and hotels; but research work associated with the kitchen environment of the railway pantry car is almost negligible. Pantry car represents a significant contribution to the catering system in Indian Railways, which provides meals to every onboard passenger. It is an integral part of every long and short distance train. This study presents a field survey and simulation investigation of thermal comfort conditions inside the kitchen of railway pantry car during different cooking periods. Present study aims to evaluate and improve the thermal comfort conditions inside the kitchen of the Indian Railway Pantry Car (IRCTC).

During the field survey, a standard checklist on subjective perception of thermal comfort was carried among 69 chefs working in 14 pantry car kitchens of Indian Railways. The data was collected during two seasons (summer and winter) and in two climatic zones (humid and subtropical climate zone and tropical wet and dry climate zone). Environmental parameters (air temperature, globe temperature, relative humidity, air velocity) of thermal comfort were also measured. Based on the survey outcomes and measured data, this study analyzed the chefs' neutral temperature and comfort temperature range inside the existing kitchen environment of pantry car; with the aid of indices like predicted mean vote (PMV) and predicted percentage dissatisfied (PPD). The results show that the measured indoor thermal parameters do not comply with the international standard. The maximum limit for thermal parameters was observed during lunch and snacks period, while minimum for the breakfast period. The outdoor thermal parameters affect the indoor thermal parameters during the seasonal and climatic variations when cooking inside the pantry car. Between all cooking periods like breakfast, lunch, snacks, and dinner; there was no significant difference found for all parameters (air temperature, globe temperature, relative humidity, air velocity) in the summer season, however significant difference was observed among monitored parameters during the winter season except humidity and air velocity. The PMV-PPD index predicted a very high thermal dissatisfaction rate during cooking inside the pantry car. Simultaneously, the analysis also revealed that this index was not appropriate to evaluate the pantry car kitchen environment's thermal comfort due to high temperature, high metabolic rate, and less air movement. Subjective responses indicated that the chefs were dissatisfied with the current conditions of the pantry car as most of the cooks reported a high dissatisfaction rate. The chef neutral temperature of the pantry car was determined as 23°C and 21.62°C during the summer and winter season, respectively. Simultaneously, the comfort temperature range was determined for summer (18.50-27.80°C) and winter (17.80-25.50°C) season, respectively. These findings help to improve the indoor working environment of the pantry cars kitchen of Indian railways.

During the simulation investigation, a computational fluid dynamics (CFD) approach was incorporated using the standard effective temperature (SET) index to determine thermal comfort status. A baseline CFD model of the pantry car kitchen was validated by comparing it with the measured value of air temperature and air velocity, which found acceptable limits for validation according to the ASHRAE-55 standard.

While performing CFD analysis of non-air-conditioned pantry cars, four different modified case models were considered. The analysis results designate that the existing case model did not follow the recommended range of the SET index. Further, results indicated that “*Case I*” significantly improved the air velocity and reduced indoor temperature; which helps to enhance thermal comfort. Simultaneously, a value of SET was found with a comfortable thermal sensation within all cooking periods, which is better for the pantry car workers. This study suggested a sustainable improvement in the thermal comfort of the non-air-conditioned pantry car kitchen in the Indian Railways, which can be implemented immediately.

Similarly, while performing CFD analysis of air-conditioned pantry cars, three modified cases of pantry cars were executed. The analysis results indicate that the pantry car's existing case model did not follow the recommended range of the SET index. Comparing the existing case model with all the modified cases, it was observed that the indoor temperature dropped in the modified cases. Whereas in all modified pantry case models, the “*Case III*” model showed a better concept where the air velocity increased substantially as the temperature decreased. Simultaneously, the SET was found to have a comfortable thermal sensation between the temperature (26.5–28.6°C) ranges during the entire cooking period. However, in *Case I* and *Case II*, the SET limit's value was comfortable, except for the lunch period. It may be concluded that the supply air from the upper edges of the kitchen's front and back walls would increase thermal comfort and energy savings.

NOMENCLATURE

| | |
|----------------------------------|----------------------------------|
| Clo | Clothing Insulation, clo |
| met | Metabolic Rate, W/m ² |
| T _a or t _a | Air Temperature, °C |
| T _g or t _g | Globe Temperature, °C |
| t _{mrt} | Mean Radiant Temperature, °C |
| T _{op} | Operative Temperature, °C |
| RH | Relative Humidity, % |
| v _a | Air Velocity, m/s |
| T _n | Neutral Temperature, °C |
| T _{cr} | Comfort Temperature Range, °C |
| D | Globe Diameter, m |

Abbreviations

| | |
|--------|---|
| ET | Effective Temperature |
| ET* | New Effective Temperature |
| SET | Standard Effective Temperature |
| PMV | Predicted Mean Vote |
| PPD | Predicted Percentage of Dissatisfied |
| TSV | Thermal Sensation Vote, (-3, +3) |
| TCV | Thermal Comfort Vote, (-3, +3) |
| IRPC | Indian Railway Pantry Car |
| IR | Indian Railway |
| CFD | Computational Fluid Dynamics |
| CBE | Center for the Built Environment |
| IAQ | Indoor Air Quality |
| ASHRAE | American Society of Heating, Refrigerating and Air-Conditioning Engineers |

CONTENTS

| | <i>Title</i> | <i>Page No.</i> |
|-------|--|-----------------|
| | Acknowledgements | i |
| | Abstract | ii |
| | Nomenclature | iv |
| | Contents | v |
| | List of Figures | viii |
| | List of Tables | xi |
| | Chapter 1- Introduction | 1 |
| 1.1 | Back ground of study | 1 |
| 1.2 | Need of study | 4 |
| 1.3 | Structure of the thesis | 4 |
| | Chapter 2- Review of Literature | 6 |
| 2.1 | Thermal comfort | 6 |
| 2.2 | Thermal comfort factors | 7 |
| 2.2.1 | Environmental factors | 10 |
| 2.2.2 | Personal/individual factor | 14 |
| 2.3 | Various indices of thermal comfort | 16 |
| 2.3.1 | PMV/PPD, Predicted mean vote/Predicted percentage of dissatisfaction | 16 |
| 2.3.2 | ET, Effective temperature | 17 |
| 2.3.3 | ET*, New effective temperature | 18 |
| 2.3.4 | SET, Standard effective temperature | 18 |
| 2.3.5 | Operative temperature | 18 |
| 2.4 | Thermal comfort model | 19 |
| 2.4.1 | PMV-PPD model | 19 |
| 2.4.2 | Adaptive model (ASHRAE 55-2017 and EN 16798) | 19 |
| 2.5 | Comfort zone | 21 |
| 2.6 | Thermal comfort standard | 23 |
| 2.6.1 | ASHRAE standard 55 | 23 |
| 2.6.2 | ISO 7730 standard | 23 |
| 2.7 | Thermal comfort approaches | 24 |
| 2.7.1 | Field survey approach | 24 |
| 2.7.2 | Simulation approach | 27 |
| 2.7.3 | Laboratory approach | 30 |
| 2.8 | Globally thermal comfort studies in the kitchen environment | 32 |
| 2.9 | Thermal comfort studies of kitchen environment in India | 37 |
| 2.10 | Closure of literature review | 40 |
| 2.11 | Research question | 41 |

| | | |
|--|---|-----------|
| 2.12 | Aim and objectives | 41 |
| 2.13 | Hypothesis | 42 |
| Chapter 3- Evaluation of Thermal Comfort Inside the Pantry Car | | 43 |
| 3.1 | Details of the location, duration, physical structure of pantry car kitchen and subject description | 43 |
| 3.1.1 | Location | 43 |
| 3.1.2 | Duration | 44 |
| 3.1.3 | Physical structure of pantry car kitchen | 45 |
| 3.1.4 | Subject description | 45 |
| 3.2 | Data collection | 46 |
| 3.2.1 | Objective measurement data: indoor and outdoor thermal parameters | 46 |
| 3.2.2 | Assessing clothing insulations and metabolic activity level | 47 |
| 3.2.3 | PMV-PPD index calculation | 48 |
| 3.2.4 | Subjective assessments | 48 |
| 3.3 | Data analysis | 49 |
| 3.4 | Results and discussion | 50 |
| 3.4.1 | Objective measurement evaluation of indoor and outdoor environments during cooking periods | 50 |
| 3.4.1.1 | Significant difference testing between indoor and outdoor thermal parameters | 58 |
| 3.4.1.2 | Significant difference testing between cooking periods | 59 |
| 3.4.1.3 | Evaluation of PMV-PPD index | 60 |
| 3.4.2 | Subjective measurement evaluation | 62 |
| 3.4.3 | Optimum temperature | 70 |
| 3.4.3.1 | Neutral (comfort) temperature | 70 |
| 3.4.3.2 | Comfort temperature range | 72 |
| 3.4.3.3 | Subjects neutral temperature compared with other studies | 73 |
| 3.5 | Summary | 74 |
| Chapter 4- Improvement of Thermal Comfort Inside the Pantry Car | | 76 |
| 4.1 | Improving thermal comfort inside the kitchen of non-air-conditioned pantry car | 76 |
| 4.1.1 | Details of the non-air-conditioned pantry car kitchen | 76 |
| 4.1.2 | Measurement | 77 |
| 4.1.3 | Standard effective temperature (SET) index estimation | 78 |
| 4.1.4 | CFD modelling and simulation | 78 |
| 4.1.5 | Results and discussion | 84 |
| 4.1.5.1 | Temperature field analysis between all cases | 93 |
| 4.1.5.2 | Air velocity analysis between all cases | 95 |
| 4.1.5.3 | Estimation of thermal comfort between the cases of pantry car | 97 |
| 4.1.6 | Summary | 99 |

| | | |
|---|--|-----|
| 4.2 | Improving thermal comfort inside the kitchen of air-conditioned pantry car | 100 |
| 4.2.1 | Details of the air-conditioned pantry car kitchen | 100 |
| 4.2.2 | Measurement and SET index estimations | 101 |
| 4.2.3 | CFD modelling and simulation | 101 |
| 4.2.4 | Results and discussion | 106 |
| 4.2.4.1 | Temperature field analysis between all cases | 110 |
| 4.2.4.2 | Air velocity analysis between all cases | 111 |
| 4.2.4.3 | Estimation of thermal comfort between cases of pantry car | 113 |
| 4.2.5 | Summary | 115 |
| Chapter 5- Conclusions | | 117 |
| 5.1 | Key contribution | 118 |
| 5.2 | Limitations of the present research | 118 |
| 5.3 | Scope of the future work | 119 |
| References | | 120 |
| List of Publication | | 138 |
| Appendices | | 140 |
| Appendix I- Thermal Comfort Survey Inside the Kitchen of Railway Pantry Car | | 140 |
| Appendix II- Governing Equations | | 145 |

List of Figures

| <i>Figure</i> | <i>Page No.</i> |
|--|-----------------|
| Figure 2.1. Present research state of art | 6 |
| Figure 2.2. Environmental and individual factors for predicting thermal comfort inside pantry car kitchens | 7 |
| Figure 2.3. PPD and PMV relationship graphs | 17 |
| Figure 2.4. Seven point PMV thermal sensation scale | 17 |
| Figure 2.5. The ASHRAE adaptive comfort model (adopted from ASHRAE standard 55-2017) | 20 |
| Figure 2.6. The EN 16798 adaptive comfort model | 20 |
| Figure 2.7. Various thermal comfort approach | 24 |
| Figure 2.8. Schematic diagram showing the research gap | 41 |
| Figure 3.1. Climatic zones in India, based on the Koppen classification system | 44 |
| Figure 3.2. CBE thermal comfort tool | 48 |
| Figure 3.3. Indoor and outdoor air temperature variation graph based on (a) season, and (b) climatic zone | 53 |
| Figure 3.4. Indoor and outdoor globe temperature variation graph based on (a) season, and (b) climatic zone | 54 |
| Figure 3.5. Indoor and outdoor relative humidity variation graph based on (a) season, and (b) climatic zone | 56 |
| Figure 3.6. Indoor and outdoor air velocity graph based on (a) season, and (b) climatic zone | 58 |
| Figure 3.7. Distribution of PMV value at the cooking time | 61 |
| Figure 3.8. Dispensation percentage of subjective response to thermal comfort | 64 |
| Figure 3.9 Dispensation percentage of subjective response to thermal sensation | 65 |
| Figure 3.10. Dispensation percentage of subjective response to thermal acceptability | 66 |
| Figure 3.11. Dispensation percentage of subjective response to thermal preference | 67 |
| Figure 3.12. Dispensation percentage of subjective response to feel air-flow movement | 67 |
| Figure 3.13. Dispensation percentage of subjective response to feel humidity | 68 |
| Figure 3.14. Dispensation percentage of subjective response to feel temperature | 69 |
| Figure 3.15. Dispensation percentage of subjective votes about the air quality | 70 |
| Figure 3.16. The regression analyses between the TSV and Ta during (a) summer and (b) winter, season inside the pantry car | 71 |
| Figure 3.17. Comfort temperature range during summer | 73 |
| Figure 3.18. Comfort temperature range during winter | 73 |
| Figure 4.1. Study design of CFD simulation analysis | 76 |
| Figure 4.2. Existing model of non-air-conditioned pantry car kitchen | 76 |

| | |
|---|-----|
| Figure 4.3. Description of the non-air-conditioned pantry car | 77 |
| Figure 4.4. Location of field measurement data collection point | 77 |
| Figure 4.5. 3D-model of the railway pantry car kitchen | 78 |
| Figure 4.6. Mesh model of the railway pantry car kitchen | 79 |
| Figure 4.7. Various modification cases – (a) Case I, (b) Case II, (c) Case III, and (d) Case IV | 83 |
| Figure 4.8. Case I, summer season (i) air temperature and (ii) velocity, distribution profile of CFD at various cooking period; (a) breakfast, (b) lunch, (c) snacks, and (d) dinner | 86 |
| Figure 4.9. Case I, winter season (i) air temperature and (ii) velocity, distribution profile of CFD at various cooking period; (a) breakfast, (b) lunch, (c) snacks, and (d) dinner | 87 |
| Figure 4.10. Case II, summer season (i) air temperature and (ii) velocity, distribution profile of CFD at various cooking period; (a) breakfast, (b) lunch, (c) snacks, and (d) dinner | 88 |
| Figure 4.11. Case II, winter season (i) air temperature and (ii) velocity, distribution profile of CFD at various cooking period; (a) breakfast, (b) lunch, (c) snacks, and (d) dinner | 89 |
| Figure 4.12. Case III, summer season (i) air temperature and (ii) velocity, distribution profile of CFD at various cooking period; (a) breakfast, (b) lunch, (c) snacks, and (d) dinner | 90 |
| Figure 4.13. Case III, winter season (i) air temperature and (ii) velocity, distribution profile of CFD at various cooking period; (a) breakfast, (b) lunch, (c) snacks, and (d) dinner | 91 |
| Figure 4.14. Case IV, summer season (i) air temperature and (ii) velocity, distribution profile of CFD at various cooking period; (a) breakfast, (b) lunch, (c) snacks, and (d) dinner | 92 |
| Figure 4.15. Case IV, winter season (i) air temperature and (ii) velocity, distribution profile of CFD at various cooking period; (a) breakfast, (b) lunch, (c) snacks, and (d) dinner | 93 |
| Figure 4.16. Temperature field of various cases model of pantry car kitchens during the different cooking periods a) summer, and (b) winter season | 95 |
| Figure 4.17. Air velocity movement of various cases model of pantry car kitchens during the different cooking periods at (a) summer, and (b) winter season | 96 |
| Figure 4.18. SET thermal sensation comparison of the existing case with all modified cases during (a) summer, and (b) winter season | 99 |
| Figure 4.19. Existing condition of the air-conditioned pantry car kitchen | 100 |
| Figure 4.20. Details of the air-conditioned pantry car kitchen | 100 |
| Figure 4.21. Measuring point of thermal parameters inside the pantry car | 101 |
| Figure 4.22. Air-conditioned railway pantry car 3D-model | 101 |
| Figure 4.23. Air-conditioned pantry car mesh model | 102 |
| Figure 4.24. Comparison of measured and simulated air temperature data at | 104 |

| | |
|---|-----|
| different cooking periods inside the kitchen of pantry car | |
| Figure 4.25. Comparison of measured and simulated air velocity data at different cooking periods inside the kitchen of pantry car | 104 |
| Figure 4.26. Different modified cases – (a) Case I, (b) Case II, (c) Case III | 106 |
| Figure 4.27. Case I, (i) temperature and (ii) velocity, distribution profile of CFD at various cooking period; (a) breakfast, (b) lunch, (c) snacks, and (d) dinner | 108 |
| Figure 4.28. Case II, (i) temperature and (ii) velocity, distribution profile of CFD at various cooking period; (a) breakfast, (b) lunch, (c) snacks, and (d) dinner | 109 |
| Figure 4.29. Case III, (i) temperature and (ii) velocity, distribution profile of CFD at various cooking period; (a) breakfast, (b) lunch, (c) snacks, and (d) dinner | 110 |
| Figure 4.30. Temperature field of various cases model of pantry car kitchens during the different cooking periods | 111 |
| Figure 4.31. Air velocity movement of various cases model of pantry car kitchens during the different cooking periods | 112 |
| Figure 4.32. Comparison between existing case with modified cases based on the SET index during various cooking periods | 114 |

List of Tables

| <i>Table</i> | <i>Page No.</i> |
|---|-----------------|
| Table 2.1. Acceptable limit of RH percentage | 12 |
| Table 2.2. Acceptable limit based on the operative temperature | 13 |
| Table 2.3. Acceptable limit based on the air velocity | 14 |
| Table 2.4. Various types of work activity and metabolic rate | 15 |
| Table 2.5. Different types of garments clothing insulation values | 16 |
| Table 2.6. Regression equation used to identified for comfort temperature | 22 |
| Table 3.1. Details of instruments used during the field study | 46 |
| Table 3.2. Insulating value of clothing elements | 47 |
| Table 3.3. Thermal comfort survey checklist of sensation and preferences for indoor parameters | 49 |
| Table 3.4. Thermal comfort survey checklist of sensation and preferences for indoor parameters | 49 |
| Table 3.5. Indoor and outdoor environmental factors based on the seasonal variation and climate zone | 51 |
| Table 3.6. Mann Whitney test ranks for both indoor and outdoor thermal parameters | 59 |
| Table 3.7. Mann Whitney test statistics for thermal parameters | 59 |
| Table 3.8. Kruskal-Wallis test - summer and winter season | 60 |
| Table 3.9. Average data of field measurements and thermal comfort indices during cooking period based on season and climatic zone | 62 |
| Table 3.10. Demographic details of railway pantry car chefs (n = 69) | 63 |
| Table 3.11. Job characteristics of railway pantry car chefs (n = 69) | 63 |
| Table 3.12. Summer and winter season T_n and T_{cr} for chefs inside the pantry car | 72 |
| Table 3.13. A summary of subjects neutral temperature some previous thermal comfort studies | 74 |
| Table 4.1. Boundary conditions of the entire cooking period in the pantry car | 80 |
| Table 4.2. Comparison of measured and simulated air temperature (in °C) | 80 |
| Table 4.3. Comparison of measured and simulated air velocity (in m/s) | 81 |
| Table 4.4. Modification of the cases of pantry car kitchen | 81 |
| Table 4.5. Boundary conditions of the entire cooking period in the pantry car | 103 |
| Table 4.6. Modified cases of pantry car kitchen | 105 |
| Table 4.7. Various thermal comfort studies using supply air concept in CFD analysis | 115 |

1.1 Background of the study

Indian Railways (IR) is the largest rail networks in Asia and the world's second-largest "under a single management", transporting 21 million passengers and more than 2 million tonnes of freight daily "during 2010-11" (Alam et al., 2017; Neeraj, 2012; Ramani, 1998). However, during the financial year 2019-2020, it carried "8,086 million passengers and 1,208.41 million tonnes of freight" (Ministry of Railways, 2020). With 67,956 km of route lengths, Indian Railways is one of the world's largest railway networks with more than 12,000 passenger trains such as; "Express/Mails, Superfast Express/Mail, Sampark Kranti Express, Yuva Express, Kavi Guru Express, Vivek Express, Rajya Rani Express, Jan Sadharan, Express, Suburban trains, Shatabdi Express, Rajdhani Express, Humsafar Express, AC Express, Duronto Express, Tejas Express, others too" running across the nation every day (Ministry of Railways, 2020; Alam et al., 2017; Neeraj, 2012; Deb & Ramachandraiah, 2010). The railway transportation sector is performing a significant role in the twenty-first century in India and other countries (Alam et al., 2017; Neeraj, 2012). Catering is an essential feature of the Indian railways, serving its on-board passengers with the relishing food to satiate their hunger during the travel (Alam et al., 2017; Patil et al., 2012). On-board catering needs to be multi-varied as India being a multi-cultural country across its dimensions (Patil et al., 2012). Therefore, Indian Railways serves the food need of almost every passenger belonging to different states through it existing 11,237 "static catering units" and have 338 pairs of pantry cars in its fleet (Alam et al., 2017; Patil et al., 2012; Yadav, 2015). Pantry car, contributing as an effective catering service, an integral part of every long and medium distance train, serves travelers' food requirement on-board (Veer et al., 2017; Vidhale et al., 2014). The single pantry car coach consists of 3-5 chefs, 40-50 waiters and two railway pantry car employees (Pethkar et al., 2015; Alam et al., 2019a). In the present scenario, there are two types of railway pantry coach models available, namely (i) ICF "Integral Coach Factory" and (ii) LHB "Linke Hofmann Busch."

LHB pantry car coach model has air conditioning facility (Alam et al., 2017). In contrast, ICF pantry car coach models are non-air-conditioned (Pethkar et al., 2015; Alam et al., 2017). Models of air-conditioned pantry car coaches are currently very few compared to non-air-conditioned pantry cars (Pethkar et al., 2015). Air-conditioned pantry car coaches have a

better aesthetic design and passenger comfort. The previous research studies reveals that while cooking, there is no significant difference in thermal environment between both these two types of pantry car coaches (Alam et al., 2017; 2019a; 2020). Chefs use the same kind of appliances for cooking in both pantry car coaches like “gas stove,” “heater,” “oven,” “kettle,” “deep fryers,” “soup warmer,” etc. These kinds of appliances lead to generation of heat and humidity during the period of food preparation (Matsuzuki et al., 2011). The existing hot and humid conditions cause excessive sweating and non conducive working environments for chefs (Matsuzuki et al., 2011). This uncomfortable work environment adversely affects the chef’s physical and mental health, which is associated with human thermal comfort.

Thermal comfort refers to the thermal balance between the “human body” and “the environment” and also the appropriate balance between “body heat production and heat dissipation,” which have a significant impact on the human body (Song, 2009; Rahmillah et al., 2017). According to ASHRAE 55, thermal comfort is the mind's condition that the people report contentment with the surrounding environment (Aryal et al., 2021; Ebenezer et al., 2019; Simion et al., 2016). Six significant factors (environmental and personal) which influence human thermal comfort includes “air temperature, globe temperature, relative humidity, air velocity, clothing level and metabolic rate” (Simion et al., 2016; de Melo Pinto et al., 2015). Numerous indoor thermal comfort studies have been established in developed and developing countries in various sectors based on the field survey, simulation, and laboratory experiment. Most of the available research has concentrated on building environment, hospital, school (Rasli et al., 2019; Carvalhais et al., 2016; Hamzah et al., 2018; Zhou et al., 2019a), and passengers comfortness in the vehicles, viz., car, bus, train, and aeroplane (Teli et al., 2013; Spentzou et al., 2018; Neacsu et al., 2017). In these studies, thermal comfort parameters were analysed, compared with the comfort range of the ASHRAE standards and also evaluated the perception rate of workers regarding the thermal environment. However, few thermal comfort research studies have also been done in various kitchens environment like; restaurant, household, and domestic that analysed the thermal environmental conditions and comfort temperature using field survey and simulation approach (Liu et al., 2020; Debnath et al., 2016; Saha et al., 2012).

Ravindra et al. (2019) conducted thermal comfort research on the rural household kitchen in India during the summer, pre-summer, and winter seasons and estimated the indoor "air temperature" and "relative humidity" at cooking time. Also, the authors predicted the "Predicted Mean Vote-PMV" index vote range between -0.85 to 1.25 based on the ASHRAE 55-2017 standards. Similarly, PMV and "Predicted Percentage Dissatisfied-PPD" votes range

found were 1.73 to 2.36 and 63% to 90%, respectively, during the working hours inside the home kitchens in Indonesia (Rahmillah et al., 2017). While in Finland, Pekkinen (1998) established thermal comfort research in the commercial kitchen based on the laboratory test using a variety of cooling methods using PMV and PPD methods. Simone & Olesen (2012) conducted thermal comfort research on commercial kitchens that used data collection techniques based on the physical and subjective parameters and identified the most effective cooking zones. Correspondingly, the same types of research conducted by Simone & Olesen (2013a) in the United States commercial kitchen environment based on the assessment of the PMV and PPD index method. The result of the study indicated that PMV and PPD index methods not directly applicable for thermal comfort application of the commercial kitchen environment due to high air temperature, high globe temperature, and high metabolic rate. Again, the same thermal comfort research established by Simone et al. (2013) in the commercial kitchens based on the physical measurements and examine the applicability of thermal comfort standards in the commercial kitchen. The authors also indicated PMV is not directly suitable for the commercial kitchen environment.

The research of Zhou et al. (2016) in China explains that reduced air-temperature by implementing a "push-pull ventilation system" that could improve the thermal comfort of workers living inside the kitchen. Another study in China conducted by Chen et al. (2020) on commercial kitchen with "Computational Fluid Dynamics-CFD" simulation that indicates the discharge rate of $14 \text{ m}^3 \cdot \text{min}^{-1}$, can remove fumes outdoors and suggested that increase of exhaust fan volume will reduce the dissatisfactory rate of human thermal sensation. Similarly, in Malaysia, research conducted by Mansoor et al. (2014a) on thermal comfort in a commercial kitchen environment improves the "ventilation system." This study's outcomes examine that if supply air increases, then the temperature will decrease at the cooking zone, so recommended 0.28 m/s air-velocity supply inside the kitchen for thermal comfort. In Bangladesh, Hamidur Rahman & Sadrul Islam (2016) carried out a study on the urban residential kitchen using the CFD simulation identified the effect of the different positions of hood suction for improving thermal comfort. In this study, both the front and bottom hood outlet concepts were found to be superior for thermal comfort.

Li et al. (2014) conducted a study in China on air-conditioned commercial kitchens using CFD analysis. Three supply air temperature cases for different airflow rates were tested and compared with field measurement data. It was indicated that proper capture and containment efficiency could be achieved with an airflow rate of $12600 \text{ m}^3/\text{h}$ with an air supply temperature of 28°C . Another study conducted by Ren et al. (2012) in the kitchen

environment of Chinese restaurants identified flow field characteristics (FFC) of the exhaust hood (EH) using CFD. This study suggested that if the exhaust increases' airflow rate, the indoor temperature will decrease, so the height of the exhaust should not be higher. In Indonesia, Sabtalistia et al. (2014) carried out an experiment on thermal comfort studies in apartment kitchen environments, which examined different positions of air-conditioning (AC) supplies. This study's outcomes indicated that AC's supply from the wall near the kitchen would increase thermal comfort as it would be a short distance from the work area and reduce draft discomfort. Also Shetty et al. (2016) observed the hot and humid environment in Singapur using the standard effective temperature (SET) index and CFD simulation to predict thermal comfort. This study compared experimental data with measured data based on the ASHRAE standards. Many researchers have used the same SET index to predict the occupant's thermal comfort in hot and humid indoor environments when performing simulations (Nazarian et al., 2017; Malek et al., 2015; Han et al., 2007). However, no researcher has focused on evaluating and enhancing chefs' thermal comfort status in Indian pantry car kitchens.

1.2 Need of the present work

Although a lot of literature is available dealing with thermal comfort and associated environmental conditions in context of buildings and vehicles, but rare studies are available in the context of kitchens. Furthermore, literature related to the thermal comfort of railway pantry car workers is almost negligible. Railway pantry car kitchens are similar to commercial kitchens such as hotels and restaurants. Still, there are many differences, such as context (pantry cars are moving in nature), workflow, job demands, indoor architecture, etc. A pilot study was carried out at the beginning of this study, whose consequences showed that the railway pantry car kitchen's working environment gets hot and humid during cooking simultaneously, no difference was found between non-air conditioned and air-conditioned pantry car based on the objective and subjective assessment. Therefore, a need was generated to evaluate the thermal comfort and its improvement in the Indian railway pantry car kitchen during the cooking time.

1.3 Structure of the thesis

The present thesis is organized into five chapters, and the details included in each chapter are highlighted below:

Chapter 1 briefly introduces the railway pantry car, the pantry car model's work scenario, thermal comfort and factors, and thermal comfort work in the kitchen environment.

Chapter 2 presented a detailed literature review on thermal comfort, various factors of thermal comfort, thermal comfort indices, predicting models of thermal comfort, comfort zones, the international standard of thermal comfort, and various approaches to estimate the thermal comfort, and correspondingly reviewed numerous thermal comfort investigations carried on the kitchen and its related work environment in globally and Indian scenarios. Identification of research gaps based on the extensive literature survey and prepared the current study's research questions, simultaneously aim and objectives of recent work presented, and the study's hypothesis.

Chapter 3 presented the thermal comfort evaluation methods and results based on the objective and subjective measurements with the PMV-PPD index. Simultaneously illustrated the determination of the chefs' optimal temperatures while working inside the pantry car.

Chapter 4 presents the analysis of CFD simulation and modelling of railway pantry car kitchens as well as shows the improvement of thermal comfort. The baseline model has been validated by comparison with field measurement data and determined the thermal comfort based on the SET index results using numerical simulation analysis.

Chapter 5 delivers the overall work outcomes, conclusions obtained based on the present work, and limitations of the present study with future scope in this domain.

This chapter reviewed literature related to several concepts of thermal comfort like factors, indices, predicting models, comfort zones for occupants, and different standards with estimating approaches. Simultaneously, thermal comfort and its related works performed on global and Indian kitchen environments have been discussed, as shown in Figure 2.1.

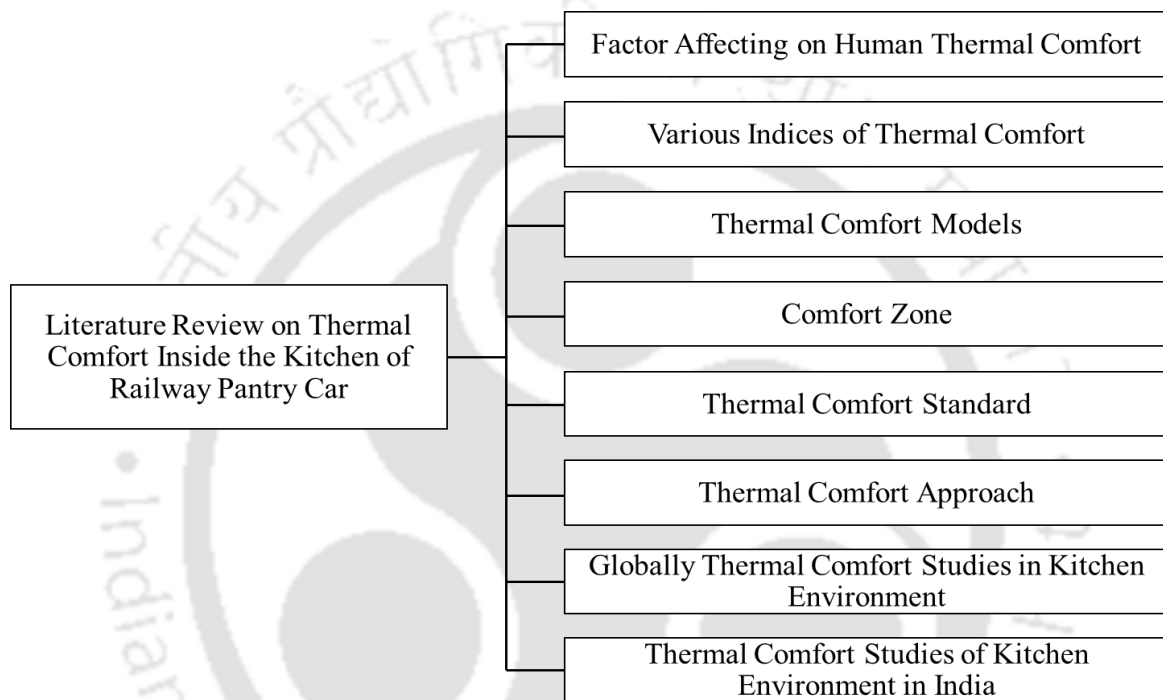


Figure 2.1. Present research state of art

2.1 Thermal comfort

According to the standard of the “ISO-7730”, thermal comfort may be defined as "condition of mind, which expresses satisfaction with the thermal environment" (Aryal et al. 2021; Hussein et al., 2009; Rasli et al., 2019). Thermal comfort is related to the perception of a subject living in any thermal environment, which is related to a lot of factors, therefore it is a bit complicated to guess and defined correctly (Simion et al., 2016). Because in the same thermal environment the perception rate of workers is varied due to the different acclimatization of the body. It means in the similar thermal atmosphere, the comfort condition differs from person to person. The factors of thermal comfort depend on the "heat exchange between the human body and the ambient environment" in any working condition (Simion et al., 2016).

As per the "American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)" in psychometric charts, the comfort zone depends on the satisfaction of occupants in any "thermal environment", it must be at least 80% (Simion et al., 2016; ASHRAE, 2004; Kumar et al., 2016).

2.2 Thermal comfort factors

According to the literature, the assessment of thermal comfort of the "occupants" inside a "hot and humid" built environment like the kitchen of a railway pantry car is related to "environmental factors" and "personal factors" that affect the worker's body and organs which they perceive while working (Aryal et al. 2021; Alam et al., 2019a; 2019b; Humphreys et al., 2013; Humphreys et al., 2007; Humphreys, 1978; Nicol et al., 2020). All these factors are the major contributing factors that need to be considered in order to achieve the "thermal satisfaction of workers" over the period of work.

The environmental factors are correspondingly related to these parameters such as; "air temperature", "mean radiant temperature (assessing with globe temperature)", "relative humidity", and "air velocity". Similarly, personal or individual factors are related to these parameters like; "clothing insulation", and "metabolic rate/activity level" (Aryal et al. 2021; Alam et al., 2019b; Humphreys et al., 2013; Humphreys et al., 2007; Nicol et al., 2020). Environmental and individual factors of the human thermal comfort are demonstrating in Figure 2.2.

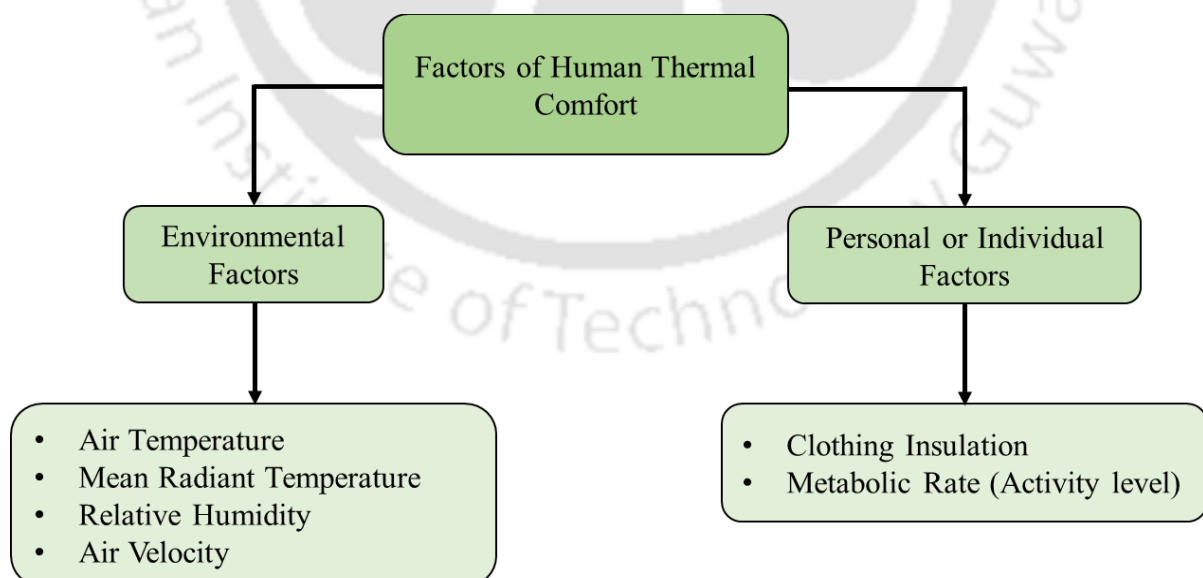


Figure 2.2. Environmental and individual factors for predicting thermal comfort inside pantry car kitchens

Other factors that affects human organism related to thermal comfort are; age, gender, weight, health, drinking, working conditions, season, climate others too (Simion et al., 2016; Del Ferraro et al., 2015; Kruger & Drach, 2017). These factors have a significant effect on the occupants while working time inside the kitchen of the railway pantry car. This would be a considerable factor for achieving thermal comfort and improving the indoor built environment. All these factors are strongly related to the comfort zone in any work environment and should be compared with the recommended standard value of “thermal comfort” (Aryal et. al. 2021; Simion et al., 2016).

As per the previous research directed inside the commercial kitchen environment heating and cooking appliances such as; electric heater, pressure cooker, stove, oven, kettle others too, create heat and moisture inside the kitchen at the time of meal preparation period (Haruyama et al., 2010; Matsuzuki et al., 2011). Due to this, the inner environment of the kitchen like a pantry car becomes too “hot and humid”. There are several studies which describe the various factors of thermal comfort affecting “indoor and outdoor” thermal environment (Kumar et al., 2016; Kumar et al., 2020; Singh et al., 2019).

Wei et al. (2017) investigated a study on “thermal comfort in commercial kitchen environments” in China, in which they found that the dominant contributing factor is the outdoor temperature. When the outside “temperature is low”, there is a lot of change in the “inside temperature”. Similarly, in the United States, Simone & Olesen (2013a) researched commercial kitchen environments in which air temperature and metabolic rate were found to be very high, because of which the PMV index was not applicable for predicting thermal comfort. Logeswari & Mrunalini (2017) conducted a heat stress study on large kitchen workers in the hostel environment in India, concluded the body temperature of the workers to be very high, exceeded recommendation limit as prescribed by “World Health Organization (WHO)”. Similarly, in India, Ramesh & Manikandan (2015) studied the hotel kitchen environment, focusing on solar radiation to improve thermal comfort. Ogulata (2007) demonstrated that clothing value, climatic condition, and physical activity are key parameters that influence human thermal comfort. Heinonen (1998) investigated thermal comfort studies in Finnish commercial kitchen environments, in which they found that the supply air temperature or airflow has a significant effect on indoor temperature. Lin et al. (2011) directed the seasonal effect on the outdoor thermal parameters, strong correlation among “thermal perception”, “air temperature” and “mean radiant temperature” was found. However, there was no significant relation to airflow and humidity. Consequently, Karjalainen (2007) states that in an indoor environment there is a gender difference based on

thermal perception, the sensitivity is higher in women as compared to male subjects. Similarly, in a laboratory study based on the perception rate of “thermal comfort”, there is a small significant difference found between genders (Parsons, 2002). However, Fanger (1970) stated in his research that he did not find any “significant differences between genders” in climate chamber research. There is a significant difference among “air temperature”, “mean radiant temperature”, and “air velocity”, although there is no significant difference in terms of “humidity” as indicated in the study (Hwang, 2006). While Liu et al. (2012) analysed three category weight groups (physiological adaptation, behavioural adaptation, psychological adaptation) have significant impact on the “adaptive thermal comfort of occupants”. Few studies mentioned that drinking consumption impact the thermal comfort of the workers. Baker & Standeven (1997) demonstrated experimental research on behavioral factors such as the effect of drinking on “human thermal comfort”. Haldi & Robinson (2011) also discussed the hot and cold drinks consumption “influence on the thermal comfort” of workers. Similarly, drinking beverages significantly impact human thermal comfort during work hours as reported by Mustapa et al. (2016), which would equally affect the work performance in the pantry car.

Heart rate is a very important parameter of physiological factors, which demonstrates the thermal perception of an individual living in any environment (Zhu et al., 2018).

Liu et al. (2008) evaluated the physiological parameters like heart rate which affects three groups of workers and analysed thermal comfort. Same way Liu et al. (2011) examined mean skin temperature and heart rate variables to predict the perception of the workers for assessment of thermal comfort. However, changes in heart rate are much greater with a high metabolic rate in a warm environment, greatly affecting the thermal satisfaction of the occupants (Choi et al., 2012). Besides, Xiong et al. (2015) described that physiological parameters have a very significant effect on air temperature, which will greatly affect thermal comfort. Similarly, Zhu et al. (2018) experimented research on “thermal comfort based on the heart rate variability” under the different types of environmental scenarios. A study conducted by Matsuzuki et al. (2011) analysed the impact of commercial kitchen environmental conditions on the occupants during the work period. In that, they used the heart rate variable for the estimation of thermal strain. Similarly, working hours, working time, time-shifting, and others too affect heat stains in the kitchen environment (Haruyama et al., 2010).

However, some of the researchers have described in their studies the effect of ventilation systems such as exhaust hoods, air channel supply on indoor thermal comfort (Lin et al., 2005a; Chen et al., 2013; Hua et al., 2012). A proper installation position of ventilation systems is essential for keeping a good indoor environment for the people which increases their work performance and helps to maintain thermal comfort. Kitagawa et al. (1999) through subjective evaluation have investigated the “effect of humidity and air movement on thermal comfort by the radiant cooling method”. In a review by Cheng et al. (2012) two different types of ventilation systems were mentioned as (i) “mixing ventilation” and (ii) “displacement ventilation”, shows its effects on thermal comfort and performance of the system. As per Lin et al. (2005b) displacement ventilation is better for the thermal environment and proposed this to the building environment. A similar study was carried out by Novoselac & Srebric (2002) which also stated that displacement ventilation is better for performance. Shan et al. (2016) conducted a study on the comparison between “mixing ventilation and displacement ventilation” in a classroom-based on the air supply. The authors concluded that mixing ventilation “leads to higher overall draft sensation” while displacement ventilation “leads to cold feet sensation”. Cho et al. (2002) tested four different types of “ventilation systems” and they proposed a “new ventilation system” installation for enhancement of thermal comfort. All the researchers have put forward their rationale for a favourable air supply, showing that the “displacement ventilation system” is more appropriate for the indoor built environment which will control the thermal comfort factors like “air temperature” and “air velocity” inside the pantry car.

2.2.1 Environmental factors

a). Air temperature

Air temperature is a vital environmental factor that directly impacts on “human thermal comfort”. It is described as the “average temperature of air surrounding the body, with respect of location and time” (Simion et al., 2016). Inside the pantry car kitchen the air temperature depends on the seasons and climatic zone at the working period.

There are various studies illustrated the recommended range of the comfort air temperature for summer and winter seasons. The “National Building Code” of India recommended the comfort temperature range for the occupant's during the season; “summer (23-26°C)” and “winter (21-23°C)” (Manu et al., 2016). The standard comfort range of air temperature according to ASHRAE is “24.5-27.0°C (summer season)”, and “19.5-22.5°C (winter season)”

(Alam et al., 2019b). These comfort temperatures have been determined based on the national and international standard data set, which is not validated or suitable for every context (Alam et al., 2019b). Therefore, numerous researchers have used an adaptive strategy to achieve the optimum temperature for occupants as per the working environment.

Deb & Ramachandraiah (2010) proposed a comfort (neutral) temperature (31.93°C) for railway waiting hall passengers during the summer season based on subjective survey. Correspondingly, Ye et al. (2005) suggested comfort temperature (23.3°C) for Chinese railway passengers. While comfort temperature for the school buildings in Malaysia were air-conditioned (24.4°C) and non-air-conditioned (28.4°C) (Hussein et al., 2009). Ravindra et al. (2019) have used an adaptive strategy for a better work environment in the kitchen environment to achieve the optimum temperature of household workers at Punjab in the Indian context.

The previous study guided to the measurement of air temperature inside the kitchen of the pantry car environment should be "1 ft. (0.3 m) near the workstation and 43 in. (1.1 m) above the workstation floor" as per the recommended by ASHRAE standard (Alam et al., 2019a). The chest and facial area of workers are a major body part that is affected due to temperature variation inside the commercial kitchen environment (Livchak et al., 2005; Simone et al., 2013).

b). Mean radiant temperature

Mean radiant temperature (MRT) also plays a very significant contribution to “predict the thermal comfort of occupants”, which can be described as a “uniform temperature in an imaginary atmosphere”, where the radiant heat emanating from the “human body equal to the heat transfer” from the actual atmosphere (ISO, 1998). It is quite difficult to estimate and is not measured directly. There are many methods or techniques to determine this, which has been shown by many researchers. It can be determined by globe temperature, which has been described in several studies. It depends on the “diameter of the globe”, generally taking the diameter of the globe to 0.15 meters (5.9 in) (ISO, 1998). The recommended formula of the "MRT" using with globe temperature has been incorporated below in equation (2.1) (Alam et al., 2019a; 2019b).

$$t_{mrt} = \left[(t_g + 273)^4 + \frac{1.1 \times 10^8 v_a^{0.6}}{\varepsilon D^{0.4}} \times (t_g - t_a) \right]^{1/4} - 273 \quad (2.1)$$

Where, Mean radiant temperature- t_{mrt}

- Air temperature- t_a
- Globe temperature- t_g
- Velocity of air- v_a
- Globe diameter- D
- Emissivity of the globe surface- ϵ

The measuring distance and height of the MRT are assumed to be similar to the “air temperature” in commercial kitchen environments (Alam et al., 2019a; Simone et al., 2013; Simone & Olesen, 2012). Air movement has an important impact on the variation of “MRT and air temperature”. The comfortable range of MRT for official occupants was 18°C-27°C, which varies on the person's clothing and activity level (Choudhury et al., 2011). Some researchers while calculating thermal comfort indices have used MRT as mean dry-bulb air temperature in the buildings, kitchen environments, and others too because of the difficulty in predicting MRT (Hussin et al., 2014; Chaudhuri et al., 2016; Toudert, 2005). This will be considered keeping in mind the above-described conditions of MRT for the estimation of thermal comfort indices of occupants while working in the pantry car.

c). Relative humidity

As per the “ASHRAE standard 55”, the explanation of relative humidity (RH) is "the ratio of the partial pressure of water vapor to the equilibrium vapor pressure of water at a given temperature" (ASHRAE, 2013). There are various studies suggested the acceptable limit of the RH percentage based on the condition and scenario. Such as air-conditioned building environments the acceptable limit of RH percentage should be normally between 30 to 60% (Wolkoff & Kjergaard, 2007; ASHRAE, 2016). However, the percentage of indoor RH has been directed to be more than 30% to reduce the drying nasal passage for occupants. If it is less than 30%, it will increase the dry sensation, which directly affects the worker's health and efficiency (Arundel et al., 1986). When the RH percentage will increase beyond acceptable limit, the “heat loss by evaporation will be much greater”. According to the “ASHRAE 55 standard”, the acceptable limit of RH has been illustrated in Table 2.1 (Alam et al., 2019b).

Table 2.1. Acceptable limit of RH percentage (Alam et al., 2019b)

| RH percentage range | Sensation |
|---------------------|-------------|
| 30% to 60% | Comfortable |
| 40% to 60% | Optimum |
| 50% | Ideal |

If the temperature is within the "comfort range: 19–23°C", then RH has a lower impact on the comfort, for which the RH is in the 40–70% range (Chandel & Aggarwal, 2012). The authors also found that higher percentage of RH gives to workers a warm sensation during work, when the wind velocity is low. According to ASHRAE, (2004) during the summer and winter season, an acceptable limit based on the operative temperature is illustrated in Table 2.2. Inside the pantry car kitchen environment, the RH data should be "1 ft (0.3 m) near the workstation and 43 in. (1.1 m) above the workstation floor" which has validated and tested based on the international standard Simone et al. (2013).

Table 2.2. Acceptable limit based on the operative temperature (Chandel and Aggarwal, 2012)

| Season | Operative temperature ranges |
|--|------------------------------|
| "Summer (clothing insulation = 0.5 clo)" | |
| RH 30% | 24.5–28°C |
| RH 60% | 23–25.5°C |
| "Winter (clothing insulation = 1.0 clo)" | |
| RH 30% | 20.5–25.5°C |
| RH 60% | 20–24°C |

d). Air velocity

According to the statement by Simion et al. (2016) air velocity is the "mean or average speed of the air to which the body is exposed, concerning the location and time". The human body, specifically the neck, head, and legs, is a very sensitive part that greatly senses the flow of air movement and these entirely depends on the perception rate of the workers. In the kitchen of the railway pantry car, many workers feel the movement of the air differently as shown in the previous study (Alam et al., 2019b). Therefore, it is important to control the movement of air and its direction to sustain a "comfortable indoor environment". As per the (Chandel & Aggarwal, 2012) several circumstances of air velocity for the thermal comfort of workers are illustrated in Table 2.3.

The acceptable limit of air velocity in the indoor built environment for the summer season is (<0.25m/s), and for the winter season is (<0.15m/s) (Alam et al., 2019b). Manshoor et al. (2014b) experimented on the commercial kitchen environment and found that air velocity (0.05m/s) is most appropriate to prevent the heat. Another similar type of study directed by Mansoor et al. (2014a) in the commercial kitchen environment in Malaysia. The authors analysed that that if the supply of air increases than temperature will decrease at the cooking zone. They recommended "0.28m/s-air velocity" for thermal comfort because "high air

velocity” is not applicable for commercial kitchen. While as per Chen et al. (2020) the discharge rate ($14 \text{ m}^3 \cdot \text{min}^{-1}$) is sufficient to remove fume outdoors in the commercial kitchen environment. The result also states that increasing the volume of the exhaust hood will reduce the dissatisfaction rate of the occupants. Keeping all these conditions in mind, ventilation can be designed for adequate movement of air in the kitchen environment of a railway pantry car, so as to enhance “thermal comfort” of the labourers.

Table 2.3. Acceptable limit based on the air velocity (Chandel and Aggarwal, 2012)

| Specific individual living assessment | Ranges of air velocity |
|--|------------------------|
| Grievances about stagnant air | 0 to 0.5m/s |
| Usually favorable “manufactures of air outlet devices, e.g., base performance on 50 fpm air velocity in the occupied zone” | 0.5 to 2.5m/s |
| “Awareness of air motion, but can be comfortable (e.g. some retail shops and stores) when the temperature of moving air is above room air temperature” | 2.5 to 5m/s |
| “Constant awareness of air motion, but can be acceptable (e.g. some factories) if air supply is intermittent and above room air temperature” | 5 to 10m/s |
| “Increasingly draft conditions with complaints about (wind) in disrupting a task, activity and so forth” | 10m/s |

2.2.2 Personal/individual factor

a). *Metabolic rate*

In a thermal comfort study, metabolic rate or activity level is the vital individual factor which affects working conditions or scenarios of occupants in both indoor and outdoor environments. If the metabolic rate is high than the workers feel more heat, and the more sweat comes out from the workers' body, due to which the thermal discomfort of workers will increase (Simion et al., 2016). When the value of the metabolic rate decreases, the occupants feel a cold thermal sensation because the temperature of the skin decreased drastically due to which the discomfort increases (Simion et al., 2016; Appah-Dankyi & Koranteng, 2012). It has a “significant effect” on the human body over thermal sensation, temperature interference, and workers' comfort (Simion et al., 2016; Kumar et al., 2010). Table 2.4 demonstrated the various types of work activity and metabolic rates.

Few authors have considered the metabolic rate (2.0 met) for cooking activities in the kitchen environment due to standing and medium activity level (Alam et al., 2019a; 2019b). The metabolic rate also significantly influences the “prediction of thermal comfort indices”. Such as Simone et al. (2013) have demonstrated in their research due to the high metabolic rate, the PMV index does not apply to the prediction of thermal comfort. Similarly, Rahmillah et al.

(2017) also state the PMV method is not appropriate for the estimate of thermal comfort inside the kitchen atmosphere due to high metabolic rate and temperature. The metabolic rate can be measured either by “telling human subjects to perform certain activities or assumed” from recommended Table 2.4 (Simion et al., 2016; Timplalexis et al., 2019).

Table 2.4. Various types of work activity and metabolic rate (Simion et al., 2016)

| Work Movement | Metabolic Rate, <i>met</i> (W/m^2) |
|---------------------|--|
| “Sleeping” | 0.7 (40) |
| “Reclining” | 0.8 (45) |
| “Seated, quiet” | 1.0 (60) |
| “Standing, relaxed” | 1.2 (70) |
| “Light work” | 1.6 (93) |
| “Medium work” | 2.0 (117) |
| “Heavy work” | 3.0 (175) |

b). Clothing

Clothing comfort is “one of the most important attributes of textile materials” (Das & Alagirusamy, 2010). The basic “understanding of comfort aspects of textile materials would be extremely useful for fiber, yarn and fabric manufacturer, researcher, garment designer, processing industries, garment houses, users of the fabrics for specialty applications and all others related with textile and garment industries” (Das & Alagirusamy, 2010). Clothing helps workers to keep their body temperature balanced in the hazard or hot and humid environment, which acts as a balancing medium of the environment and the skin of the workers (Li, 2001). Clothing insulation is the “thermal insulation provided by clothing” (ASHRAE, 2004; Indraganti, 2010; Rijal et al., 2010). The unit of the clothing insulation is "Clo" and 1 “Clo” equal to the $0.155 \text{ K}\cdot\text{m}^2\cdot\text{W}^{-1}$ (ASHRAE, 2004; Das & Alagirusamy, 2010).

It can be measured from “human subjects or mannequins, or an initial assumption is made using ASHRAE recommended standard” (Timplalexis et al., 2019; Awang, 2019). The clothing values of different garments are demonstrated in Table 2.5 (Alam et al., 2019b; Timplalexis et al., 2019). As reported by the Chandel & Aggarwal (2012) people in India during winter season normally wearing “sweater, jacket, inner garment, socks, cap” equals to 0.9 clo value as recommended by ASHRAE. However, pantry car chef’s generally wearing clothes according to Indian style outfits while performing the cooking period inside the kitchen of the railway pantry car. Present study clothing value can be estimated for “summer” and “winter” season as per the recommended Table 2.5.

Table 2.5. Different types of garments clothing insulation values (Chapter, 2005)

| Cloth statement | "Clo" | Cloth statement | "Clo" |
|---|--------|--|--------|
| <i>Underwear</i> | | <i>Dresses and skirts</i> | |
| "Bra" | "0.01" | "Skirt (thin)" | "0.14" |
| "Panties" | "0.03" | "Skirt (thick)" | "0.23" |
| "Men's briefs" | "0.04" | "Sleeveless, scoop neck (thin)" | "0.23" |
| "T-shirt" | "0.08" | "Sleeveless, scoop neck (thick), i.e., jumper" | "0.27" |
| "Half-slip" | "0.14" | "Short-sleeve shirtdress (thin)" | "0.29" |
| "Long underwear bottoms" | "0.15" | "Long-sleeve shirtdress (thin)" | "0.33" |
| "Full slip" | "0.16" | "Long-sleeve shirtdress (thick)" | "0.47" |
| "Long underwear top" | "0.20" | | |
| <i>Footwear</i> | | <i>Sweaters</i> | |
| "Ankle-length athletic socks or stockings" | "0.02" | "Sleeveless vest (thin)" | "0.13" |
| "Sandals/thongs or Shoes" | "0.02" | "Sleeveless vest (thick)" | "0.22" |
| "Slippers (quilted, pile lined) or Calf-length socks" | "0.03" | "Long-sleeve (thin)" | "0.25" |
| "Knee socks (thick)" | "0.06" | "Long-sleeve (thick)" | "0.36" |
| "Boots" | "0.10" | | |
| <i>Shirts and blouses</i> | | <i>Suit jackets and waist coats</i> | |
| "Sleeveless/scoop-neck blouse" | "0.12" | "Sleeveless vest (thin)" | "0.10" |
| "Short-sleeve knit sport shirt" | "0.17" | "Sleeveless vest (thick)" | "0.17" |
| "Short-sleeve dress shirt" | "0.19" | "Single-breasted (thin)" | "0.36" |
| "Long-sleeve dress shirt" | "0.25" | "Single-breasted (thick)" | "0.44" |
| "Long-sleeve flannel shirt" | "0.34" | "Double-breasted (thin)" | "0.42" |
| "Long-sleeve sweatshirt" | "0.34" | "Double-breasted (thick)" | "0.48" |
| <i>Trousers and coveralls</i> | | <i>Sleepwear and Robes</i> | |
| "Short shorts" | "0.06" | "Sleeveless short gown (thin)" | "0.18" |
| "Walking shorts" | "0.08" | "Sleeveless long gown (thin)" | "0.20" |
| "Straight trousers (thin)" | "0.15" | "Short-sleeve hospital gown" | "0.31" |
| "Straight trousers (thick)" | "0.24" | "Short-sleeve short robe (thin)" | "0.34" |
| "Sweatpants" | "0.28" | "Short-sleeve pajamas (thin)" | "0.42" |
| "Overalls" | "0.30" | "Long-sleeve long gown (thick)" | "0.46" |
| "Coveralls" | "0.49" | "Long-sleeve short wrap robe (thick)" | "0.48" |
| | | "Long-sleeve pajamas (thick)" | "0.57" |
| | | "Long-sleeve long wrap robe (thick)" | "0.69" |

2.3 Various indices of thermal comfort

There are many thermal comfort indices available to estimate the working thermal environmental conditions, whether it is thermal comfort or not (Auliciems & Szokolay, 1997; Epstein & Moran, 2006; Fanger, 1970).

2.3.1 PMV/PPD, Predicted mean vote/Predicted percentage of dissatisfaction

In the current scenario, PMV "Predicted Mean Vote" and PPD "Predicted Percentage of Dissatisfied" index are very popular to predict the thermal comfort for both the indoor and

outdoor environment (Fang et al., 2019; Papadopoulos et al., 2020). It was established by Fanger (1970) “based on the heat balance equation” concept. For thermal comfort conditions, the value of PMV should be within slightly cool to slightly warm thermal sensation, and PPD should be less than 10% (Cheung et al., 2019; ISO, 2005). In a parametric calculation, all “four environmental factors” and “two personal factors” are required for the estimation of the “PMV and PPD index” (Chai et al., 2020). Two international standard models of PMV "ASHRAE Standard 55-2017 and EN-16798" are available. The CBE Thermal Comfort tool is very popular nowadays for calculating the PMV-PPD index (Ravindra et al., 2019; Rahmillah et al., 2017). Figure 2.3 shows the PPD as a function of PMV and Figure 2.4 shows the seven point thermal sensation scale.

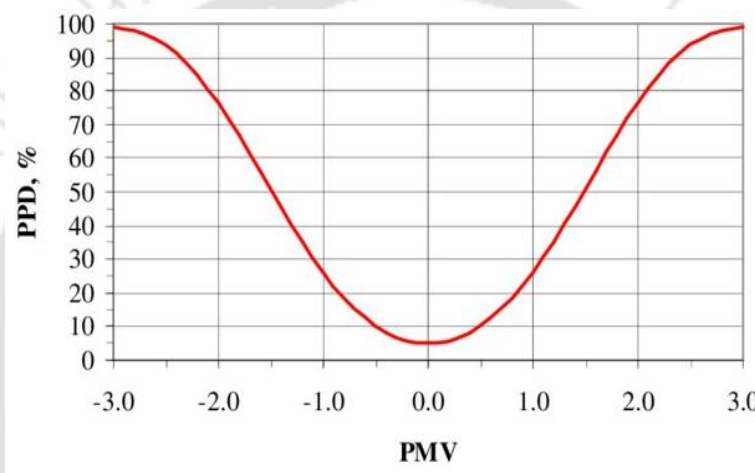


Figure 2.3. PPD and PMV relationship graphs

| |
|--------------------|
| Cold (-3) |
| Very cool (-2) |
| Slightly cool (-1) |
| Neutral (0) |
| Slightly warm (+1) |
| Warm (+2) |
| Hot (+3) |

Figure 2.4. Seven point PMV thermal sensation scale

2.3.2 ET, Effective temperature

Effective temperature (ET) was introduced in 1923 by the Houghten and Yagloglou at the Pittsburgh Research Laboratories, which "represented by a set of equal comfort lines drawn

on the psychometric chart" (Auliciems & Szokolay, 1997; Blazejczyk et al., 2012). ET was described as "the temperature of a still, saturated atmosphere, which would, in the absence of radiation, produce the same effect as the atmosphere in question" (Blazejczyk et al., 2012). This index was basically produced to sort out the relative influences of air temperature and humidity on thermal comfort (Blazejczyk et al., 2012). This index was used for about 50 years but is not currently in use, as it was suspended in the 1970s (Auliciems & Szokolay, 1997).

2.3.3 ET*, New effective temperature

New effective temperature (ET*) was determined by Gagge (1971). ET* was established utilising the two-node model, which includes the "heat transfer from the body core to the skin", then "from the skin to the environment" (Auliciems & Szokolay, 2007). It was specified as "the temperature (dry bulb temperature) of a uniform enclosure at 50% relative humidity, which would produce the same net heat exchange by radiation, convection and evaporation as the environment in question" (Auliciems & Szokolay, 2007). However, in contrast to ET, radiant temperatures are considered in ET* (Auliciems & Szokolay, 2007).

2.3.4 SET, Standard effective temperature

Another popular thermal comfort index is the SET "Standard effective temperature", an index based on rational physiology developed by ASHRAE. Prediction of this thermal comfort index also requires six factors and the calculations of this are similar to the PMV index (Gagge et al., 1986; Doherty & Arens, 1988). Thermal sensation range of SET in this index (in °C) is "<17 cool", "17-30 comfortable", "30-34 warm", "34-37 hot", ">37 very hot" (ASHRAE, 2017; Zare et al., 2018; Enescu, 2017). ASHRAE 55-2010, describes SET as "the temperature of an imaginary environment at 50% relative-humidity, <0.1m/s [0.33ft/s] average air speed, and mean radiant temperature equal to average air temperature, in which total heat loss from the skin of an imaginary occupant with an activity level of 1.0 met and a clothing level of 0.6 clo is the same as that from a person in the actual environment, with actual clothing and activity level" (ASHRAE, 2017). If the worker is involved in a sedentary activity with light clothes, ET* will be equal to SET (Nilsson, 2004). Currently, there is a lot of software available for calculating this index, one of which is the CBE Thermal Comfort tool (Ravindra et al., 2019; Rahmillah et al., 2017).

2.3.5 Operative temperature

Operative temperature (T_{op}) is defined as a “uniform temperature of an imaginary black enclosure in which an occupant would exchange the same amount of heat by radiation plus convection as in the actual non-uniform environment” (ISO, 1998; 2005; ASHRAE, 2013). A. F. Dufton developed this important index in 1929. It can be estimated as the “average of the mean radiant and ambient air temperatures, weighted by their respective heat transfer coefficients” (Han et al., 2007). There are certain conditions specified according to international standard while calculating, such as; “occupant’s metabolic rates must be between 1.0met and 1.3met”, “not in direct sunlight”, “not exposed to air velocities greater than 0.10m/s (20 fpm)” and “difference between average air temperature and mean radiant temperature is less than 4°C” (ASHRAE, 2013; Kazkaz & Pavelek, 2013). Whereas in some studies, it has been suggested that the operative temperature can be assessed as equal to the air temperature for thermal comfort evolution, if it is found in the criterion, like; "no radiant panel cooling or radiant panel heating system in place", and "the coefficients of the window solar heat gain are less than 0.48" (ASHRAE, 2013; Myhren & Holmberg, 2006; Kazkaz & Pavelek, 2013).

2.4 Thermal comfort model

2.4.1 PMV-PPD model

The details of PMV/PPD are shown in section (2.3.1). As stated above, according to PMV/PPD index standard for an ideal thermal environment, the PMV values must be within the range of slightly cool and slightly warm, with only 10% occupants dissatisfied with their thermal environment. Six parameters, such as air temperature, mean radiant temperature, relative humidity, air velocity, clothing insulation, and metabolic rate, are needed to calculate this as reported in numerous studies (Simion et al., 2016; Ravindra et al., 2019; Rahmillah et al., 2017; Chandel & Aggarwal, 2012; Hussin et al., 2014).

2.4.2 Adaptive model (ASHRAE 55-2017 and EN 16798)

The adaptive model associates to the indoor comfort temperature to the prevailing mean outdoor temperature (de Dear & Brager, 1998), as illustrated in Figure 2.5 and Figure 2.6.

Both ASHRAE 55-2017 and EN 16798 adaptive model is applicable only "for buildings without mechanical cooling systems and where there is easy access to operable windows and occupants who may freely adapt their clothing to the indoor and/or outdoor thermal conditions" (ASHRAE, 2017; EN, 2019).

✔ Complies with ASHRAE Standard 55-2017

80% acceptability limits = Operative temperature: 22.1 to 29.1 °C
Comfortable

90% acceptability limits = Operative temperature: 23.1 to 28.1 °C
Comfortable

Adaptive chart

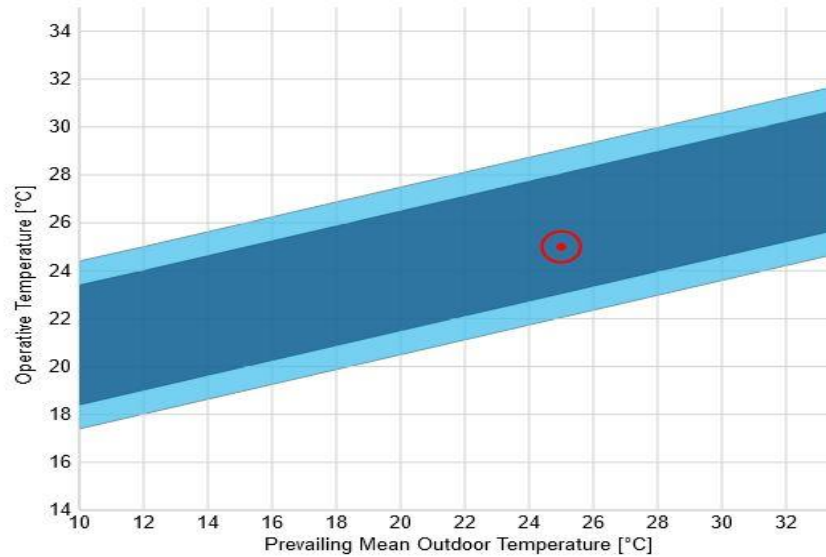


Figure 2.5. The ASHRAE adaptive comfort model (adopted from ASHRAE standard 55-2017)

✔ Complies with EN-16798

Class III acceptability limits = Operative temperature: 21.7 to 30.7 °C
Comfortable

Class II acceptability limits = Operative temperature: 22.7 to 29.7 °C
Comfortable

Class I acceptability limits = Operative temperature: 23.7 to 28.7 °C
Comfortable

Adaptive chart

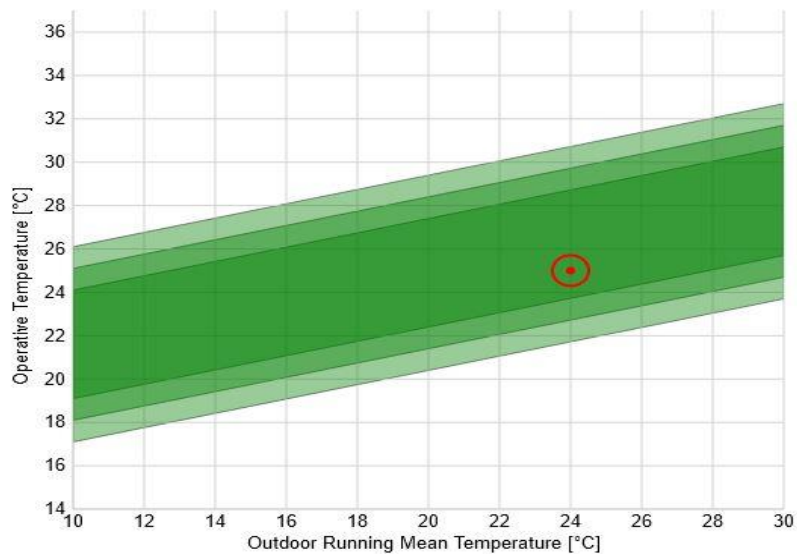


Figure 2.6. The EN 16798 adaptive comfort model

The criteria for the spaces are such as; "there is no mechanical cooling or heating system in operation, metabolic rates varies from 1.0 to 1.3 met, occupants are allowed to freely adapt their clothing insulation" (ASHRAE, 2017). In rural kitchen environments, thermal comfort was assessed by applying ASHRAE 55-2017 and EN 16798 adaptive thermal comfort (ATC) models, which concluded that ATC is not suitable for assessing kitchen environments due to the specific limitation (Ravindra et al., 2019).

2.5 Comfort zone

ASHRAE standard expresses the thermal comfort zone as "the range of operative temperatures that provide acceptable thermal environmental conditions or in terms of the combinations of air temperature and mean radiant temperature that occupants find thermally acceptable" (ASHRAE, 2004). Comfort is a subjective judgment; therefore, "not all occupants are likely to agree on the optimal comfort temperature" (ASHRAE, 2004). The de Dear and Brager (2002) stated that "satisfaction is associated with slightly warm, neutral, and slightly cool, thermal sensations", which are expressed in the central portion of the thermal sensation scale (TSV). The code employed in ASHRAE standard 55 is that "comfort temperature is the operative temperature at which either the average person will be thermally neutral or at which the largest proportion of a group of people will be comfortable" (ASHRAE, 2004).

According to ASHRAE 55 standard, equation (2.2) states the "relationship between TSVs and operative temperature through regression analysis". In comfort investigations, the regression model's gradient is "typically interpreted as being inversely related to occupant's thermal adaptability" (ASHRAE, 2004). In different terms, the "steeper regression line signifies more sensitiveness (or the less tolerant) of the occupants to temperature variations" (de Dear et al., 2018).

$$TSV = A \cdot T_{op} + B \quad (2.2)$$

Where, TSV= thermal sensation vote, T_{op} = operative temperature, A= regression coefficient, and B= constant.

From this regression equation ($TSV \sim T_{op}$), "comfort zones could be calculate based on points of T_{op} where $TSV = \pm 1$ " (Mishra & Ramgopal, 2013). It is based on "the idea that occupants are within slightly warm (+1), neutral (0), and slightly cool (-1) with the existing indoors" (Mishra & Ramgopal, 2013). Many thermal comfort studies have used this regression model analysis to achieve comfort zones in a different work environment, as illustrated in Table 2.6.

Table 2.6. Regression equation used to identified for comfort temperature

| Author | Location/area | Regression model | R ² |
|-----------------------|--|---|----------------|
| de Dear, 1985 | Australia | $TSV=0.522 T_{op} - 12.67$ | 0.98 |
| Cena, 1999 | Australia, hot-humid office | $TSV=0.21 T_{op} - 4.28$ (summer) | 0.84 |
| | | $TSV=0.27 T_{op} - 6.29$ (winter) | 0.88 |
| Hwang et al., 2006 | Taiwan, classrooms | $TSV=0.1413 ET^{*-} - 3.762$ | 0.88 |
| Lin et al., 2010 | Taiwan, short-haul and long-haul, buses and trains | $TSV=0.15 T_{op} - 3.82$ (short-haul) | 0.83 |
| | | $TSV=0.09 T_{op} - 2.58$ (long-haul) | 0.85 |
| Deb, 2010 | India, railway | $TSV= 0.62T_a - 19.80$ | 0.64 |
| Nguyen et al., 2012 | Belgium, hot & humid, building, South-East Asia | $TSV=0.41 T_{op} - 11.44$ | 0.96 |
| | | $TSV=0.216 ET^{*-} - 5.86$ | 0.85 |
| | | $TSV=0.195 SET - 4.97$ | 0.97 |
| Azizpour et al., 2013 | Malaysia, hospitals | $TSV=0.487 T_{op} - 12.96$ | 0.96 |
| Sarkar, 2015 | India, house-kitchen | $TSV=0.573 T_{op} - 9.574$ (winter) | 0.89 |
| Liu et al., 2016 | China, high-speed railway stations, passengers | $TSV=0.38 T_{op} - 9.76$ (late spring) | 0.91 |
| | | $TSV=0.17 T_{op} - 3.58$ (late fall) | 0.96 |
| Ioannou, 2017 | Netherland, kitchen | $T_{op}=0.754 TSV + 20.406$ | 0.17 |
| Ryu et al., 2017 | South Korea, apartment; kitchen | $TSV=0.668T_{in} + 17.879$ | 0.49 |
| de Dear et al., 2018 | Australia, humid-subtropical climate, residential; kitchen | $TSV= 0.13T_a - 2.80$ | 0.86 |
| Liu et al., 2018 | China, ship, passenger cabins | $TSV = 0.288T_{op} - 6.020$ | 0.60 |
| Gautam et al., 2019 | Nepal, building; kitchen | $TSV=0.194T_a + 0.3$ (wintry) | 0.24 |
| Gautam et al., 2020 | Nepal, sub-tropical climate building; kitchen, room | $TSV=0.20T_g - 0.87$ (Local people) | 0.22 |
| | | $TSV=0.05T_g - 0.40$ (Migrant people) | 0.007 |
| Jia et al., 2021 | China, Airport terminal; passengers | $TSV= 0.279T_{op} - 7.153$ (summer) | 0.04 |
| | | $TSV= 0.211T_{op} - 5.000$ (transition) | 0.02 |
| | | $TSV= 0.158T_{op} - 2.795$ (winter) | 0.03 |

T_a = air temperature, T_{in} = indoor air temperature, T_g = globe temperature

2.6 Thermal comfort standard

Currently, two popular international standards of thermal comfort exist which are quite used, such as; ASHRAE Standard 55, ISO 7730 (Nicol et al, 2012). Both these standards are used to estimate PMV/PPD index which represents thermal comfort or temperature control (Nicol et al, 2012).

2.6.1 ASHRAE standard 55

ASHRAE Standard 55, is “*thermal environmental conditions for human occupancy*” (ASHRAE, 2004; 2013). This standard is sponsored by the American National Standards Institute (ANSI). However, this standard nomenclature is introduced by America, but it used globally (ASHRAE, 2013). The ASHRAE 55 standard's goal is to “specify the various combinations of indoor thermal environmental factors and personal factors that will produce thermal environmental conditions acceptable to a majority of the occupants within a space” (ASHRAE, 2013). The utmost renowned and most recent versions of the standard are the “2004, 2010 and 2017 updated versions” (ASHRAE, 2004; 2013; 2017).

ASHRAE 55 is the first international standard to incorporate an adaptive thermal model in 2004 that has been periodically modified based on the applicability (ASHRAE, 2004). The adaptive comfort model of ASHRAE applies to naturally controlled spaces when all of the following criteria are met, such as “there is no mechanical cooling system installed, and no heating system is in operation, the occupants of the spaces should be engaged in near-sedentary physical activities (metabolic rate should be between 1.0 to 1.3 met), occupants are free to adapt their clothing to the indoor and/or outdoor thermal conditions (clothing insulation should range between 0.5 to 1.0 clo)” (ASHRAE, 2004; Nicol et al, 2012).

2.6.2 ISO 7730 standard

The ISO 7730 standard - “*Ergonomics of the thermal environment—Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria*” was established in parallel with “ASHRAE 55 standard” (ISO, 2005). “It enables the analytical determination and interpretation of thermal comfort using calculation of PMV, PPD and local thermal comfort criteria, given the acceptable environmental conditions for general thermal comfort. It applies to healthy men and women exposed to indoor environments where thermal comfort is desirable” (ISO, 2005). The determination of thermal comfort in this standard is similar to the ASHRAE standard, e.g., environmental factors and individual factors are also taken into consideration (ISO, 2005).

This standard is mostly used to evaluate the building environment in Europe, as it is considered more appropriate than the ASHARE standard due to environmental conditions and geographical locations. During the prediction of thermal comfort, "the criterion for compliance is not outlined in ISO 7730" (ISO, 2005).

2.7 Thermal comfort approaches

Numerous researchers in diverse countries developed a strategy to achieve thermal comfort in hot and humid environments based on environmental conditions (Del Ferraro et al., 2015; Hwang et al., 2006; Jia et al., 2021; Logeswari & Mrunalini, 2017; Rasli et al., 2019;). Therefore, according to the literature, three major approaches have been described to evaluate thermal comfort and its improvement, as shown in Figure 2.7.

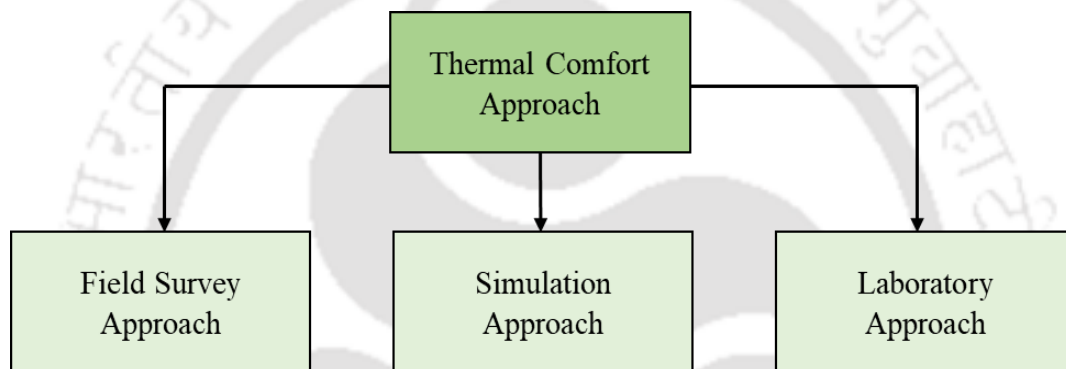


Figure 2.7. Various thermal comfort approach

2.7.1 Field survey approach

Han et al. (2007) conducted a thermal comfort study "inside residences of three cities in the hot-humid climate of central southern China". In this study, objective and subjective techniques were performed during the summer season. This study shows that only 48.2% of the measured values followed the ASHARE comfort standards, while 87.3% of occupants accepted the thermal environment, reflecting thermal adaptability. Based on the thermal adaptation, 90% of occupants were satisfied with the comfort temperature range of 22.0–25.91°C. The outcomes of this investigation can be utilized to design a low energy consumption system for thermal comfort.

Wijewardane & Jayasinghe (2008) conducted thermal comfort research on factory workers in "warm, humid tropical climates" in Sri Lanka. Comfort temperature was determined based on the perception responses. This study designated that "workers acclimatized to warm, humid climatic conditions could tolerate up to 30°C without much ventilation when engaged in light

factory work". Whereas it was shown that if the indoor air velocity is maintained up to 0.6m/s, the comfort temperature range could be increased to 34°C. These results were validated by examining various studies of adaptive models for hot and humid environments.

Deb & Ramachandraiah (2010) conducted a field survey on passenger's thermal comfort at the railway station of Indian railways. This study was accompanied by field measurements and questionnaire responses of 402 passengers during the summer season for a period of fifteen days. The outcomes showed that the people living in the railway station's current environmental condition were uncomfortable.

De Giuli et al. (2014) conducted a field survey in Italian schools using subjective and objective assessment with the PMV-PPD index. The study results indicated that the subjective response to thermal sensation was different from PPD values. However, based on pupil-sensation ranking, there was no significant difference found between subjective and objective approaches.

Accordingly, Del Ferraro et al. (2015) conveyed a "field study on thermal comfort in an Italian hospital considering differences in gender and age". This study compared the adaptive model with the PMV model based on ISO 7730. In this study, statistical investigation reveals that the "PMV model finds the best correlation with Actual Mean Vote (AMV) values in a sample of male medical staff under 65 years of age". Simultaneously, very weak correlations between "AMV and PMV values have been found between gender and age," which may be an essential factor in assessing thermal comfort in the hospital.

Assimakopoulos & Katavoutas (2017) carried a thermal comfort survey at the Athens Metro platforms using environmental parameters evaluation, including the PMV/PPD index. In this study, operative temperature, air temperature, globe temperature, air velocity, and relative humidity were monitored during the summer season in the two platforms. The results showed that both stations' operative temperature values were far from the "traditional still-air comfort zone". Simultaneously, the PMV values at both stations were outside the recommended indoor thermal comfort zone.

Qi et al. (2017) investigated the "thermal comfort inside the car passenger compartment in China". This research basically carried the "influence of car passenger compartment's temperature variation on thermal comfort by conducting a field experiment". Correspondingly, two separate illustrations were examined during the stage of "parking and

driving". The outcome showed a "clear temperature reduction of the air conditioning systems when the car moved forward".

Lu et al. (2018) in China conducted a field study on "non-air-conditioned buildings in a tropical island climate" to investigate thermal comfort. In this study, field survey data were collected using physical measurements and a standard questionnaire. The survey data results show that a "high humidity environment did not significantly impact human comfort". In this study, a neutral temperature was proposed as 26.1°C with the comfort temperature range 23.1°C to 29.1°C for tropical residents.

Wang et al. (2018) accompanied a field study on rubber factory workers in China throughout the summer season. In this study, the indoor and outdoor environment factor of thermal comfort was measured. During the survey, it was found that 75% of the occupants voted for the indoor temperature within the range of 28-32°C. The Indore temperature adaptability showed that the factory workers preferred the TSV model over the PMV model. Simultaneously, compared to other studies, the occupants accommodated themselves to the indoor temperature as the outdoor temperature rises.

Hossain et al. (2019) carried out thermal comfort research on three garment factories in Bangladesh during the "cool-dry, hot-dry, and warm-humid" seasons. This study field survey was accomplished using objective and subjective assessment. The analysis of this study revealed that the range of comfort temperature of occupants was during the seasons "cool-dry (22.7–29.1°C), hot-dry (22.3–30.4°C), and warm-humid (28.7–30.9°C)". Correspondingly, they have suggested a preferred average air velocity of 0.3m/s for occupants inside the factory.

In Italy, Ulpiani et al. (2019) researched to "improve the comfort and liveability of urban open spaces during the hottest months of the summer by implementing an overhead water mist cooling system". The objective and subjective measurement carried out in "two diverse Italian urban spaces (Ancona and Rome, representative of Cfa and Csa climates)". Thermal comfort orientation was defined as "optimized design criteria, the system proved to work best with a dominant and steady light breeze (1–2m/s) in highly irradiated sites and suspended at 1.2–1.5m above the average height of users".

Atmaca & Gedik (2020) performed thermal comfort studies on religious buildings in Turkey, applying "objective measurement and survey methods: examples of mosques in a temperate-humid climate". In this study, the mosque's indoor and outdoor thermal comfort conditions

were measured according to the recommended standard. Also, thermal comfort was assessed based on the thermal perception of the person living there. Its findings indicated that the combined effect of measured and subjective perception was within an acceptable range.

Kumar et al. (2020) conducted a field survey in India during the autumn and winter seasons on "occupant's thermal comfort expectations in naturally ventilated engineering workshop". In this study also objective and subjective measurements were done during the field survey. This study's consequences were compared to the international standards; as well the comfort level was assessed. The study showed "a maximum of 70% of subjects were found comfortable when indoor temperature varied from 28°C to 32°C". The average comfort temperature was found 5°C higher than the autumn season compared to the winter season.

2.7.2 Simulation approach

El-Bialy & Khalil (2011) performed a thermal comfort study on passengers at a subway station in Egypt using a "computational fluid dynamics-CFD" simulation. In this study, κ - ϵ turbulence model was incorporated in "Fluent 6.3 software" while performing simulations. In design modification, various cases/models of air-conditioning systems were simulated to improve thermal comfort inside the railway station, in which essential parameters such as air temperature, air velocity, and humidity were controlled.

Yuan et al. (2013) established a thermal comfort study on commercial kitchen environments in China using the CFD simulation approach. The research used Airpak software for CFD simulation. Two traditional ventilation systems, viz.; mixing and displacement, were analysed in a commercial kitchen atmosphere during the working period. The effects demonstrate that displacement ventilation "can maintain a thermally comfortable environment with a low air velocity, a small temperature difference between the head and ankle level, and a low percentage of dissatisfied people in the occupied zone".

Konstantinov & Wagner (2016) performed a simulation study in Germany on "double-decker train cabins with passengers" to identify the condition of thermal comfort. In this study, "coupling flow simulations was conducted with the CFD code OpenFOAM with finite-element simulations of the heat transport within the passengers using the code THESEUS-FE". Two cases of cooling and heating were analysed during design modification. The estimation reveals that "temperature distribution in the cabin was inhomogeneous and different between the upper and lower deck". This study determines that in investigations

concentrating on “different ventilation techniques performance”, the complete cabin must be considered.

Noman et al. (2016) studied thermal comfort in a warm and moist mosque environment in Malaysia during prayer. In this study, the CFD approach was utilized to "carry out flow simulations to identify a suitable strategy to improve the mosque's thermal comfort". Simultaneously, PMV/PPD indices were used to evaluate the thermal comfort of residents. The CFD simulation results in this study revealed that "installing four exhaust fans above the windows on the mosque's west wall" would increase thermal comfort inside the mosque and save energy.

Khatoon & Kim (2017) accompanied human thermal comfort research on passenger's car in Korea. In this research, various ventilation systems have been introduced to enhance thermal comfort inside the car using the FLUENT 16.0 software for CFD application. The consequences of the standard Fanger's model and the revised Fanger's model were discussed and analysed.

Zhang & Lu (2017) conducted the thermal comfort study on "high-speed train compartment with underfloor air supply" in China. In this study, an underfloor air supply mode was presented and compared with the traditional sidewall supply and bottom return mode to increase thermal comfort in a high-speed train compartment. Simultaneously, air temperature, air velocity was controlled while performing CFD simulation and also introduced PMV-PPD index. The study outcomes determined that the "underfloor air supply mode significantly improved the air quality and thermal comfort".

Ibrahim & Mehta (2018) in India conducted a thermal comfort study among the car driver inside the car cabin using CFD simulation analysis. This study also analysed various air conditioning positions during design modification in the “Ansys Fluent 18.0” software. A turbulence model was included at different points inside the car cabin for flow analysis during the simulation. The extraction of this study made a design modification taking into account the temperature and velocity of the air, which increases air-conditioning capacity as well as thermal comfort of the passenger car cabin.

Demir et al. (2019) investigated a thermal comfort study on the "tram car passenger cabin" in Turkey. In this study, "heating, ventilation, and air conditioning (HVAC) vents of a tram car passenger cabin were designed" by employing the CFD approach. The main thermal comfort

factor, such as air temperature and velocity, was controlled in a modified design, which helped increase thermal comfort to a limited range.

Iranzo et al. (2019) conducted a CFD simulation study in Spain on "air ventilation and comfort in railway vehicles operating in ventilation mode". In this study, the CFD model has been established with features of "the wagon geometry in detail, including air diffusers geometry, passengers, and luminaires". The outcomes reveal an apparent effect of the "air supply system and design geometry on comfort", because "local velocities well above 1m/s were obtained for the original design". This study noted that thermal comfort does not become suitable when "air inlet temperature was conditioned to 19°C, particularly for the original diffuser design" concept.

Sugiono et al. (2019) researched Indonesia on "improving the thermal comfort of workers in the finished good warehouse based on PMV-PPD using CFD analysis". In this study, indoor and outdoor side, thermal comfort parameters viz.; "air temperature, air velocity, mean radiant temperature, and relative humidity and activity type, clothing" were collected at the existing warehouse. The simulation analysis proved that "temperature and air velocity" were the critical factors for enhancing thermal comfort. Therefore, it concluded that "installing 33 exhaust fans with a capacity type of 3610 m³/h" will improve thermal comfort at the factory.

Chen et al. (2020) carried a thermal comfort study on the Chinese kitchen environment using CFD simulation and experimental calibration. This article introduces the "theoretical formulas with experimental calibration and establishes an improved CFD model based on Fluent V19.04". The standard "k-e turbulence model combined with a wall function was utilized to analyse particulate matter's violent, turbulent movement". Based on the "improved CFD model, the movement of particulate matter under the effect of the range hood with air curtain was simulated"; also, this model was evaluated by PMV and PPD indexes. This study's outcomes directed that the "increasing the exhaust volume would reduce the dissatisfaction rate of human thermal sensation to some extent".

Liu et al. (2020) demonstrated the "improving indoor air quality and thermal comfort in residential kitchens with a new ventilation system" in Changsha, China. The study was performed on sixteen cooking workers during the peak time of cooking using field measurements and CFD simulation analysis. This study's "steady-state RNG k- ϵ model was performed to optimize the integrated system design for both summer and winter conditions". The outcomes determine that "the kitchen's thermal environment was highly non-uniform and

too hot in summer," and "the air temperature in the kitchen could increase by 5.3°C during cooking". The new ventilation system, "upward air curtains around the gas stove and conditioned air from the cabinet under the stove," concept was proposed to enhance thermal comfort inside the kitchen.

2.7.3 Laboratory approach

Bartels (2003) conducted a thermal comfort laboratory approach on aeroplane seats in Germany. This study was examined by the "physiological laboratory test methods like skin model and seat comfort tester". Simultaneously "seat trials with subjects were examined in a climatic chamber". The consequences of this investigation indicated that a "fabric cover" carried significantly more sweat than "leather".

In Taiwan, Lin et al. (2013) inspected a "laboratory validation study of comfort and limit temperatures of four sleeping bags configured according to EN 13537 (2002)". In this study participants, individual judgments and physiological responses were recorded and investigated. During the analysis, it was determined that the comfort temperature and limit temperature were underestimated for sleeping bags MA0, MA3, HAG, and MAM. This study suggested that traditionally sleeping bags need to be re-designed for whole-body thermal comfort, which helps customers' health and well-being.

Hintea et al. (2014) conveyed a study in the UK on the "applicability of thermal comfort models to car cabin environments". In this study, four thermal comfort models like "PMV, Taniguchi's model, Zhang's model, and Nilsson's" have been examined during driving. The consequences of this study indicated that "PMV and Nilsson's model could be applied to the atmosphere of a car's cabin when a small air temperature rate change (of under 1.5°C per minute)". In contrast, "Taniguchi's and Zhang's models" were found not applicable. However, based on the subjective responses, Nilsson's model has been most recommended by the researchers.

Fang et al. (2015) performed a laboratory experiment on "individual air supply nozzles inside the aircraft cabins" in China. In this study, questionnaire responses were received concentrated on "opening the nozzle, adjusting the level of airflow, and changing the direction of the airflow". The outcomes indicated that the "human thermal and draft sensations change over time in an aircraft cabin". Also, it was found that when the passengers enter the cabin, the thermal comfort is good, but after staying there for some time,

the discomfort increases. This study concluded that the "design of more efficient air distribution systems within passenger aircraft cabins" enhances thermal comfort.

Pala & Oz (2015) performed thermal comfort research "inside a bus during the heating period within a climatic chamber" in Turkey. In this study, the thermal comfort parameters were investigated with different bus concept designs based on HVAC, accompanied by a "combined theoretical and experimental work". The bus was moved inside the climate chamber at 20°C for over 7 hrs while performing laboratory analysis. For the entire assessment, "Transient Energy Balance Model and Gagge Model" was used for accurate measurement and indoor environment assessment, respectively.

Dahlan & Gital (2016) conducted thermal comfort and sensation study in Malaysia on tropical offices and people's transient conditions. This study recognized the "affective and sensory responses" obeyed due to "hysteresis effects in transient thermal conditions consisting of warm-neutral and neutral-warm which was performed in a quasi-experiment" perspective. The results of this study revealed that "PMV is an acceptable alternative to predict thermal sensation immediately after a down-step thermal transition (≤ 1 min exposure duration) for people living in a hot-humid climate nation".

Similarly, Velt & Daanen (2017) experimented to determine the "optimal bus temperature for thermal comfort during a cool day" in the Netherlands. This study was carried out with objective and subjective evaluation, where 28 male and 72 female subjects participated while performing laboratory tests. During analysis, the estimated values inside the bus found to be "temperature ($22.5 \pm 1.1^\circ\text{C}$) and RH ($59.9 \pm 5.8\%$) corresponded to a slightly warm feeling (TS = 0.85 ± 1.06) and TC of 0.39 ± 0.65 ". Based on the linear regression evaluation, the bus temperature was $20.9^\circ\text{C} \pm 0.6^\circ\text{C}$, corresponding to TC = 0 and TS = 0. Finally concluded that a "1.6°C lower bus temperature during the cool day would have led to less thermal discomfort and energy savings".

In Korea, Shin et al. (2019) experimented on "thermal comfort using driver's bio-signals which depend on vehicle cabin and vent exit air temperature". The investigation was accomplished using the "brain and pulse waves" examination of the subjects who came from "an uncomfortable range to a comfortable temperature in the cabin temperature". Additionally, standard thermal comfort questionnaires were used to examine subjective responses with stress index. Results of this study directed that during the cooling states, "the stress index and ratio between low frequency and high frequency (LF/HF) did not clearly

indicate an uncomfortable condition, except when the cabin and vent exit temperatures were 30°C and 16.5°C, respectively". It was also noticed that when the temperature of the vents was low, the occupants felt less thermal sensation.

Zhou et al. (2019a) experimented thermal comfort study in Tianjin, China, on "passenger cars under driving conditions" during the summer season. The investigation was carried "under outdoor driving conditions, measuring the outside weather conditions, the air and surface-temperatures inside a car, and the skin-temperatures and thermal sensation votes of the driver under summer conditions". This study outcome directed that the "air and surface temperatures in the car were non-uniform" and "decreased rapidly in the first 15 minutes after the air-conditioning system was switched on".

Babis-Morejón et al. (2020) carried out the experimental thermal comfort study on "university campus building in tropical climate" in Colombia. In this study, thermal comfort environmental parameters were recorded in both indoor and outdoor conditions in the classroom. Total 584 scholars participated in this investigation; simultaneously, PMV-PPD indices were calculated using "Fanger's methodology", "thermal sensation vote -TSV" and the "actual percentage dissatisfied-APD". The consequences of this research illustrated that "PMV values may vary with clothing insulation, which does not affect TSV" inside the classroom. Moreover, a comfort temperature was estimated at 23°C and 24°C based on thermal acceptability with a 90% satisfaction rate.

Wang et al. (2020) established the laboratory test approach on "thermal comfort and virtual reality headsets" in China. This experiment tested the "thermal properties and subjective thermal discomfort of five virtual reality headsets" and their connections. A total of 27 college scholars practiced "each of the five headsets for 45 minutes," miniature data loggers measured microclimate temperature and relative humidity. However, infrared thermography was used to record the temperature distribution during the trial. During the trial, mean values of "microclimate temperature and relative humidity increased by 7.8°C and 3.5% respectively". It was concluded that "thermal discomfort was negatively correlated with total coverage area and microclimate temperature".

2.8 Globally thermal comfort studies in the kitchen environment

In this section, crucial thermal comfort studies conducted in kitchen environments outside India are discussed.

In Glasgow, Pekkinen & Takki-Halttunen (1992) performed a laboratory experiment on the kitchen environment to identify the thermal comfort and ventilation efficiency. Various concepts of ventilation design were analysed based on the air supply system while executing the experiment. Also, thermal conditions were measured with the help of an indoor climate analyser. The study outcomes exhibited that the "ventilation effectiveness and contamination removal effectiveness were highest by the cooking appliances when the supply units were located on the floor". Simultaneously, the most suitable "thermal conditions were found when the supply air unit was placed in the ceiling next to the exhaust hood system".

Again Pekkinen(1998) conducted a thermal comfort study on the kitchen environment in Finland. This study laboratory test was performed to recognize the better "air supply and personal nozzle system," followed by the PMV-PPD index. The experiment's consequences confirmed the "thermal satisfaction was greatly improved with the help of supply air through the hood with low velocity, especially when directed downwards, and using personal nozzles for local cooling," which the user can adjust.

Mak and Yik (2002) presented a thermal comfort study based on the CFD simulation approach inside the kitchen atmosphere in Hong Kong. FLUENT version 4.4 software was taken in this study, in which the k-e turbulence model was used when performing the CFD analysis. A total of 42 cases of the different air ventilation system's window dimensions were assessed during the kitchen zone simulation. Results indicated that the "minimum ventilation rate for achieving reasonable cooling as well as thermal comfort in the kitchen was $7.30 \times 10^{-1} \text{ m}^3/\text{s}$ and the minimum window area was 23.33% of the floor area of the kitchen, which was higher than the prescribed minimum window area stated in Building Regulation". This study suggested that on-field measurements should be measured for validation of CFD simulation results.

Another CFD simulation study was conducted by Livchak et al. (2005) on the kitchen environment in America, which investigated the "supply air systems" performance to increase thermal comfort. In this study, a "theoretical equation was developed to account for temperature rise in a kitchen when hoods are not capturing air, or untempered hot outside air supplied into a kitchen" area. Simultaneously, two ventilation systems, "mixing and thermal displacement," were tested while performing the simulation. The indoor temperature was found 10°F (5.5°C) higher in the summer season, which reduces workers' production rate by 30% during the hood performance analysis. The test outcomes were demonstrated that

thermal displacement ventilation was more efficient than mixing ventilation, which reduces air temperature up to 10°F (5.5°C) inside the restaurant kitchen.

Similarly, Nugroho et al. (2007) conducted thermal comfort research on terraced house kitchens in Malaysia. This study mainly focused on validating the model based on CFD simulation and field measurement data; together, it explored the kitchen's environmental condition. This study showed a decent agreement between CFD simulation and field measurement for validation of the model. And the assessment of the results revealed that the terraced houses built environment is not in conformity with the kitchen's thermal comfort due to low air velocity. This study recommended installing solar-chimneys could help to enhance thermal comfort in the kitchen atmosphere.

Simone & Olesen (2013b) conducted a thermal comfort study on the commercial kitchen environment in Denmark. This paper has described standard procedure for data collection techniques during field experiments like; thermal comfort factors measuring point, location, and subjective evaluation criteria. More than 100 commercial indoor kitchen environments were analyzed to validate the process. During the analysis, the PMV index values were over-estimated the thermal comfort outcomes according to the ISO-EN 7730 standard due to high temperature and metabolic rate. However, with an 11% dissatisfaction rate, the comfort temperature of 20–25°C has been found for occupants. Moreover, a "strong quadratic relation was estimated between the TSV and percentage dissatisfaction" during the data analysis.

Similarly, in the United States, Simone & Olesen (2013a) researched the commercial kitchen environment during the summer and winter seasons. In this study also, data were collected in more than 100 commercial kitchen environments according to the standard method. Simultaneously, effects of variation of season and climate were determined throughout the cooking process. This research also intimated that the PMV index does not apply to kitchen environments because some predicted value was higher than the recommended (± 2) limit, which was due to high temperature and metabolic rate. This study suggested some different methods for further studies, such as subjective and objective evaluation.

Simone et al. (2013) conducted another study on commercial kitchen environments in the United States. The study was carried out on different kitchen areas, "cooking, food preparation, and dishwashing," in the 100 commercial kitchen environments during the summer and winter seasons. In this investigation, physical parameters such as T_{op} , T_a , T_{mrt} , RH, V_a were measured and simultaneously illustrated a data collection technique and

procedure. The study results showed that the kitchen's measured physical parameters pointed towards the warm to the hot environment. According to the "ASHRAE 55 and ISO EN 7730" most of the measured parameter values exceeds beyond the recommended range. It also showed that, due to high temperatures and high activity levels, the PMV-PPD index was not directly applied to evaluate the commercial kitchen environment's thermal comfort.

Rahmillah et al. 2017 conducted a thermal comfort field investigation on the residential kitchen environment during cooking activities in Indonesia. Field measurement data like temperature, humidity, air velocity, clothing insulation, and metabolic rate were obtained during the cooking period [morning, afternoon, evening] in two residential kitchens, where a conventional gas stove was used the cooking process. And using the CBE Thermal Comfort Tool, the PMV-PPD index was calculated based on the ASHRAE-55 standard. During the analysis, the PMV and PPD value range was found between 1.73 to 2.36 and 63% to 90%, respectively, with warm thermal sensation. In contrast, 71% of the occupants stated the morning cooking period to be more comfortable than other periods. Finally, this study also revealed that the PMV-PPD index has some limitations. It does not directly apply to the estimation of thermal comfort in the kitchen environment, as shown in further studies.

Wei et al. (2017) researched thermal comfort in the Chinese "domestic kitchens under a non-uniform thermal environmental" situation. In this study, experimental consequences indicated that "when the outdoor air temperature is low, there is a large temperature fluctuation in the kitchen, especially near the side of the outer window area ". Because of this, the "non-uniform thermal environment in the domestic kitchen" could not be neglected in the winter season. Correspondingly during analysis, the "vertical temperature difference" was found to be more than 6°C. The study suggested that the kitchen window must be closed while preparing food and a new push-pull ventilation design approach to the kitchen environment should be used.

Accordingly, Hyun-Cheol et al. (2019) administered a "field survey on the thermal environments and worker satisfaction of South Korean commercial kitchens" in the summer. In this research, objective and subjective measurements were made on the ten kitchen environments from five Korean catering sectors. A total of 46 occupants participated throughout the field measurement, which responded to thermal satisfaction responses on thermal sensation and thermal comfort rating scale. Consequences of this paper showed that

"South Korean commercial kitchens were relatively low in humidity control and workers discomfort was shown to be 58.8% on average".

Similarly, Liu et al. (2019) conducted a thermal comfort study to assess the "thermal environment in a kitchen with a new ventilation system" in China. The study was completed using subjective and objective procedures throughout the cooking period inside the kitchen with and without a ventilation system during the summer season. A total of 32 cooks participated for personal judgment based on the thermal sensation rating scale. The outcomes determined that the "thermal environment in the kitchen was non-uniform and local thermal sensation had a great influence on the whole body sensation. Without the new ventilation system, the cooks complained that the hottest parts were thorax, head, and face" regions. Correspondingly thermal sensation votes of cooks were improved with the establishment of the new ventilation system.

Zhou et al. (2019b) carried out the investigation on "capture efficiency and thermal comfort in Chinese residential kitchen with a push-pull ventilation system in the winter" period. In this study, the test was segregated into two separate divisions. The first section was to "test the push-pull ventilation system's capture efficiency under different functioning situations". While the second section was to "investigate the thermal comfort of the human body during the cooking process with and without air curtain in winter stage". The results revealed that the "push-pull ventilation system can effectively improve the capture efficiency of the range hood". The low-momentum make-up air and the reasonable air distribution around the stove were found to be important to achieve great appearance.

Zhou et al. (2019c) appraised "four models for predicting thermal sensation in residential kitchen environments" in China. A total of 20 culinary workers were participated in assessing the thermal comfort experiment. Also, objective and subjective measurements were performed at the time of food preparation inside the kitchen. This research compared the actual thermal sensation to "four predicted thermal comfort models like; predicted mean vote (PMV), dynamic thermal sensation (DTS), the University of California at Berkeley (UCB), and the transient outdoor thermal comfort from (Lai's)" models. The outcomes determined that "all the models could predict the trend of the thermal sensations but with errors," Therefore, this study suggested an appropriate thermal comfort model, which predicts the Chinese commercial kitchen environment.

Chen et al. (2020) carried out a study on "air quality and thermal comfort analysis of kitchen environment with CFD simulation and experimental calibration" in China. In this study, Fluent V19.04 software was used for CFD simulation, while experimental analysis was carried using analytical formulas. Although, the k-ε turbulence model was incorporated when performing flow analysis in CFD. Additionally, the baseline CFD model was validated to compare experimental and simulated data throughout the cooking process. The outcomes of the "calibrated CFD model was found to be consistent with the experimental data in terms of the fume concentration". The mean "errors at two gauging points was reduced to 10% with the new model from 40% with the original CFD model" nearly. The indoor air quality and thermal comfort were assessed based on this CFD model. The study advised that exhaust volume 11-14 m³ min⁻¹ can improve thermal comfort and air quality.

Liu et al. (2020) performed similar studies on "improving indoor air quality and thermal comfort in residential kitchens with a new ventilation system" in China. A total of 16 cooking workers participated while performing similar varieties of meals inside the kitchen. Also, field measurement and questionnaire surveys were done while operating the task. In this paper, the "RNG k-ε turbulence" model was used for CFD simulation analysis during the summer and winter seasons. This study outcome reported that the indoor kitchen environment was very "hot and non-uniform" during the summer season throughout the cooking process. The value of air temperature was more than 5°C, which was very high; simultaneously, "TVOCs and PM_{2.5} concentrations exceeded the limits as prescribed by Chinese standards" in the kitchen environment.

Vorosne-Leitner et al. (2020) researched "indoor environmental assessment method in the residential kitchen" in Hungary. This study proposed a "new design and monitoring method of residential kitchens with gas stoves". Initial outcomes of "laboratory examinations indicated that the largest stovetop burner with the power of 2.8 kW" has a crucial contribution in reducing emissions. Also, the amount of gas measured in the indoor environment was outside the Hungarian standards. Simultaneously, the PMV model was predictable for thermal comfort when cooking with a gas stove in the Hungarian residential kitchen environment. The range was -0.3 to +2.0, which showed the warm atmosphere.

2.9 Thermal comfort studies of kitchen environment in India

In this section, critical thermal comfort and its associated studies conducted on the kitchen environments in India are discussed.

Pal & Rehman (2008) investigated "efficient cookstove technology for improving the kitchen environment and livelihood for women" in rural India. This study involves "18 local women's user groups and 2 self-help groups" participated with the 189 individuals. In this study, 1021 "improved cookstoves" were established in 20 villages of 10 districts in Haryana state. Implementation results saved fuel consumption of about "378 tonnes per year" during work. Correspondingly, the intervention used in this study increased the income at the local group level.

Saha et al. (2012) performed an "experimental and computational investigation of indoor air quality inside several community kitchens in a large campus" at the university. In this study, a survey was conducted on four kitchens during cooking, in which air temperature, CO₂, and CO gases were measured with the help of the *indoor air quality-IAQ Calc7545* instrument. Simultaneously, fluent software was incorporated for numerical simulation analysis, in which the "mixture model for the multiphase flow" was taken for the flow region. The study results found a good agreement between the experimental data with the CFD simulated data based on the ASHRAE standard, which validates the models' boundary and grid conditions.

Praseeda et al. (2014) performed a study to assess "the impact of material transition and thermal comfort models on embodied and operational energy in vernacular dwellings" in India. This study survey was accomplished on three kitchens, four bedrooms. In this survey, environmental factors of thermal comfort like air temperature, relative humidity, and air velocity were measured using a standard instrument at 1.8 meters above the ground. Simultaneously, a dynamic simulation model was created using DesignBuilder (v 2.2.5) software, and for CFD analysis, Energy-Plus software was used. The CFD model was validated by comparing it to measured data. For predicting the thermal comfort inside the building, two significant thermal comfort models were utilized, like TSI and ASHRAE standards. The outcome reveals that "replacing rubble stone masonry with burnt clay brick masonry and stabilized soil block masonry would increase the embodied energy of the dwelling by 9.7 times (870%) and 2.8 times (182%)" respectively.

Sarkar & Bose (2015) researched "thermal performance design criteria for bio-climatic architecture in Himachal Pradesh," India. This study carried the layout design plan of the residential building environment of kitchen area. The study was performed based on qualitative and quantitative procedures. During the survey, environmental parameters such as temperature, humidity, velocity were recorded, while a standard checklist was used for

subjective evaluation. However, based on field survey outcomes, the occupants' comfort temperature was predicted using simple regression analysis, such as Humphreys suggested.

Debnath et al. (2016) determined the study on "the age of air in rural Indian kitchens for sustainable built-environment design". In this study, building parameters were measured during a field survey in a kitchen where the "chimneys/improved cookstoves" were not introduced. Simultaneously, inner air-velocity and "age of air" were measured during the field visit and simulation analysis was performed. A virtual indoor environment of the naturally ventilated kitchen using the RANS software was created. The study results indicated that the "critical building parameters that can enable sustainable design strategies without introducing clean fuel or improved cookstoves might be unaffordable," traditionally undesirable, or inaccessible.

Anand et al. (2017) performed research on a "simplified tool for building layout design based on thermal comfort simulations". In this study, the kitchen environment's indoor space was simulated using "ECOTECH version-11.0" software to predict the PMV index for thermal comfort estimation. The simulations were completed in three different climatic zones in India, validated by field experiment data. This study showed that building spaces like kitchen, bedroom, and living room were different based on the working period.

Kittur & Jaiswal (2019) reviewed the "design and development of a smart kitchen chimney for energy-saving" in India. This review paper discussed problems regarding "grease, smoke, and odour" inside the kitchen caused by inadequate ventilation design systems. This study showed that the exhaust hood and filtering system are commonly used as a mechanism in kitchen ventilation systems. Also, a fan in the kitchen area was also found to be a significant factor in the proper ventilation system. This review helps to design a suitable "smart kitchen chimney," which can be effectively used to increase thermal comfort and reduce indoor air quality.

Ravindra et al. (2019) conducted thermal comfort research on rural household kitchen environment in Punjab, India. In this study, field measurement was carried out using "IAQ monitor and real-time Q-TRAK (TSI Model Q-Trak 7565, Shoreview, MN)", through which air quality, air temperature and humidity were measured respectively. Data were recorded in three seasons like winter, pre-winter, and summer. According to European and ASHRAE thermal standards, the kitchen's thermal comfort was evaluated based on the "PMV-PPD and adaptive thermal comfort (ATC)" models. The inside "air temperature and relative humidity

in rural households during winter were varied from 11.9–25.2°C and 63.4–90.5%", while "during pre-summer, it ranged between 21.3 to 27.4°C and 48.4–78.4%", similarly "during summer it ranged between 28.4 to 37.8°C and 13.7–63.8%". The PMV values of the "households ranged between –0.85 to 0.69 (winter), –0.32 to 0.4 (pre-summer) and 0.53 to 1.25 (summer) for ASHRAE 55-2017," and "–0.56 to 1.11 (winter), 0.04 to 0.99 (pre-summer) and 1.21–2.36 (summer) for EN15251" guidelines. Whereas the "PPD ranged between 5 and 20% (winter), 5–8% (pre-summer) and 11–38% (summer) for ASHRAE 55-2017 and 5–31% (winter), 5–26% (pre-summer) and 36–90% (summer) for EN15251" guidelines.

2.10 Closure of literature review

The following conclusions are made based on the literature review.

- In developed and developing countries, numerous thermal comfort studies have been conducted using field surveys, simulation, and laboratory approaches on building environments such as; schools, hospitals, and factories. Simultaneously few studies focused on the passenger's thermal comfort like; cars, buses, trains, and aeroplanes. Many of these studies used regression models for thermal comfort prediction, excluding other standard models due to workers' adaptability and climatic conditions.
- However, few researches have been done in commercial kitchen environments based on objective and subjective evaluation in developed and developing countries, which used field surveys, CFD simulations, and experimental approaches. These studies investigated the applicability of various thermal comfort indices and the proposed comfort temperature for workers. They suggested a new ventilation system or exhaust system that would help to increase the kitchen's thermal comfort. But no research was found on the kitchen environment of the railway pantry car.
- In India, some literature has been found in kitchen environments that have shown thermal comfort estimation. However, most of this research discussed the building's architectural and air quality point of view. In contrast, no studies have been found in the kitchen environment of railway pantry cars that have evaluated the working chefs' thermal comfort in pantry cars or improved indoor environments.

The research gap identified for the current research has been schematically presented in Figure 2.8.

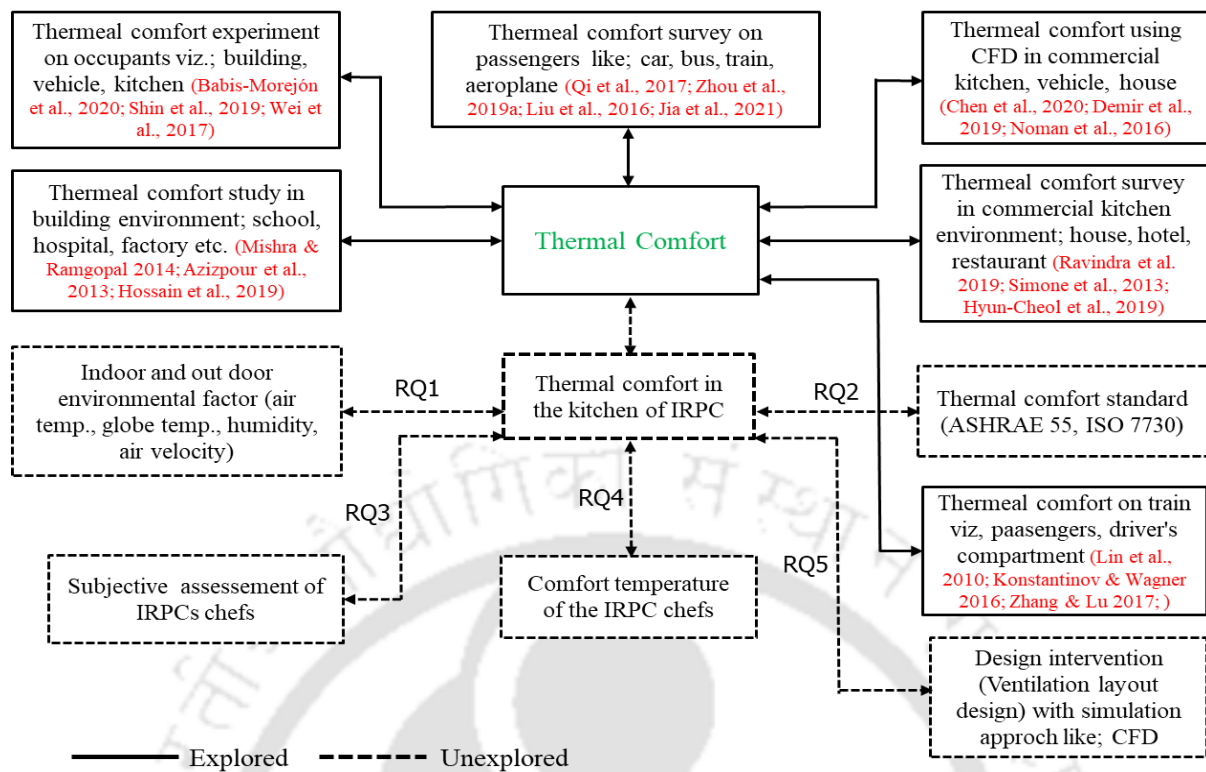


Figure 2.8. Schematic diagram showing the research gap

2.11 Research question

The following research questions are formed based on the research gap.

- Is there any significant difference between indoor and outdoor thermal parameters of pantry car?
- Do the measured indoor thermal comfort parameters of Indian railway pantry cars comply with the standards?
- What are the subjective responses regarding the thermal environment inside the pantry car?
- What is the neutral temperature, comfort temperature range inside the pantry car for chefs?
- Which is the best proposed design for enhancing the thermal comfort inside the IR pantry car?

2.12 Aim and objectives

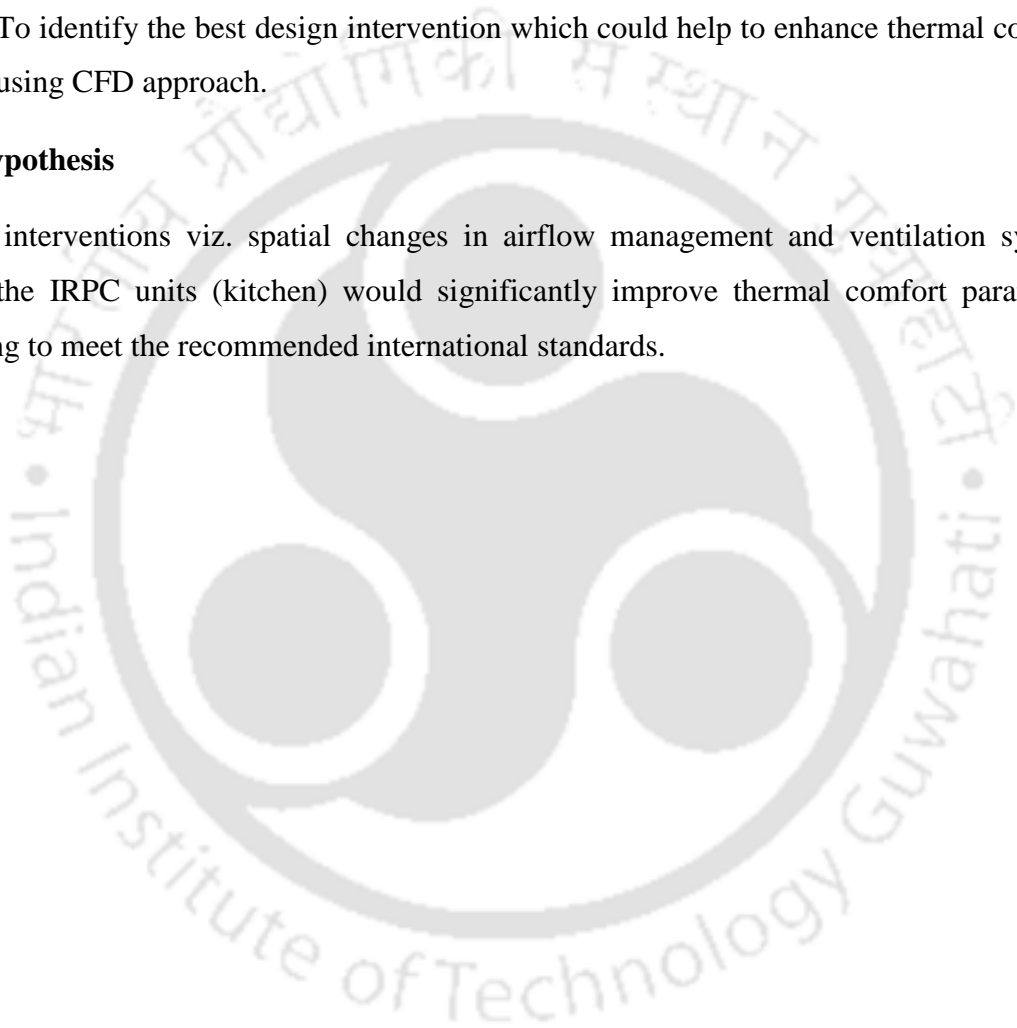
The aim of research is to evaluate the effect of thermal environment factors on the thermal comfort of chefs in Indian Railway pantry car and identify their optimal thermal comfort range for better workmanship.

Objectives of the present study are:

- To investigate thermal environmental conditions inside the Indian Railways Pantry Cars.
- To identify the nature of subjective responses related to working thermal environment.
- To determine the neutral temperature, comfort temperature range in Indian Railways Pantry Cars.
- To identify the best design intervention which could help to enhance thermal comfort, using CFD approach.

2.13 Hypothesis

Design interventions viz. spatial changes in airflow management and ventilation systems within the IRPC units (kitchen) would significantly improve thermal comfort parameters intending to meet the recommended international standards.



As addressed in the literature survey, the indoor environment becomes quite hot and humid during cooking in commercial kitchens, which causes thermal discomfort. Due to this, the work efficiency and productivity of the people living there are adversely affected (Alam et al., 2017). Therefore, a field study was carried out to investigate the pantry car kitchen's thermal comfort conditions on the Indian Railways using physical parameters measuring devices and standards checklist. The CFD model was developed to estimate thermal comfort conditions in pantry car kitchens, followed by parametric analysis, and the outcomes from field measurements were used to validate the simulation outcomes (Chapter 4).

This chapter describes the field survey evaluation and discussions; the results and discussion is divided into three sections. The first section covered the pantry car kitchens environment's objective measurement evaluation, which was done using the statistical estimation and PMV/PPD index. The second part deals with subjective assessment, where the occupant's thermal perceptions votes are presented along with demographic and job descriptions by descriptive analysis. The third section describes the pantry car's optimal temperature, which is accomplished by incorporating regression analysis. Simultaneously the obtained neutral temperature values have been compared with the other studies.

3.1 Details of the location, duration, physical structure of pantry car kitchen and subject description

3.1.1 Location

This research was carried out in two different types of climatic zones in India under the climatic classification of the Koppen system shown in Figure 3.1. The indoor and outdoor thermal environment factors of the Indian Railway Pantry Car (IRPC), was measured in humid and sub-tropical, tropical wet and dry climatic zone at different railway stations. In a humid and subtropical climate zone, the data has been taken from both up and down trains between Guwahati and Delhi railway station. While trains between Kolkata and Hyderabad has been considered for tropical wet and dry climate zone. Most of the medium and long distance trains with the pantry cars travel through these two major climatic zones. In this study, other climate zones such as; tropical wet and arid have not been monitored because, in this climate area, only a few trains run with a pantry car, and most of the trains run in the

night. However, some trains run during the day time but they do not travel throughout this climate zone for the entire day.

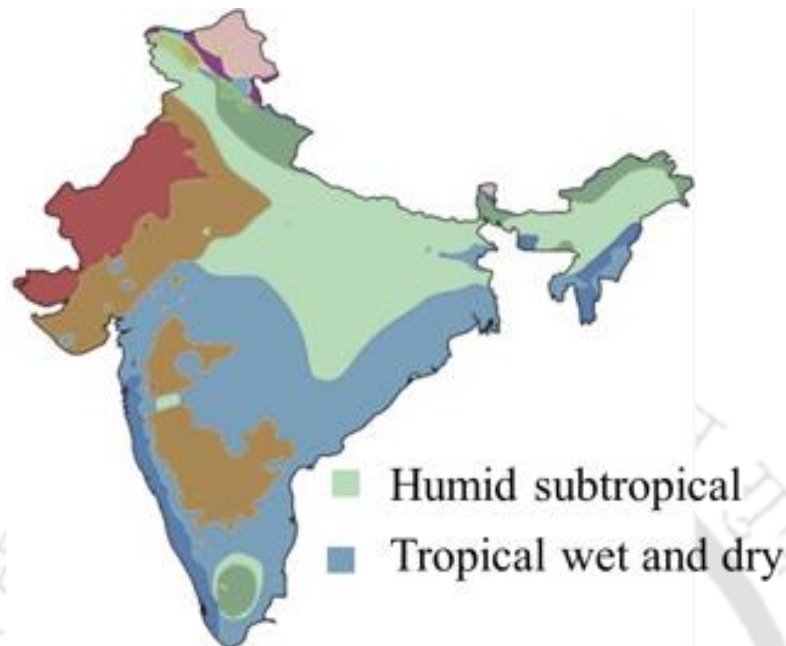


Figure 3.1. Climatic zones in India, based on the Koppen classification system (https://commons.wikimedia.org/wiki/File:India_map_of_K%C3%B6ppen_climate_classification.svg)

3.1.2 Duration

In the current study, two seasons have been selected like winter and summer. Therefore, the study was conducted in August for the summer season and similarly, it in December for the winter season. The present study majorly focused on the North-East region of India, where August is also considered the summer season. Some Indian researchers have also indicated the month of August as the summer season in their study (Dikshit & Dikshit, 2014; Singh et al., 2010; Dhaka et al., 2013; Dash & Kjellstrom, 2011). Both seasons data was taken in 2018 only. Because of safety and security intentions, the duration of this study was fixed for only sixteen days for each season. In both climate zones and seasons, during the preparation of the meal inside the pantry car, all indoor and outdoor physical measurement data were recorded at different intervals: breakfast "7:00 am", lunch "11:30 am", snack "4:00 pm" and dinner "6:30 pm". During night time, chefs do not cook food inside the pantry car. Usually, the chefs close the cooking process from 8:00 pm to 9:30 pm. Therefore, this study has been done only during the whole cooking period of the entire day. Subjective responses for each chef took 10–15 minutes across all cooking periods. These measurements were observed as much as possible without troubling the respondent's activities.

3.1.3 Physical structure of pantry car kitchen

Pantry cars play a vital role in catering systems in the Indian railway. There are currently two types of pantry car models available: non-air-conditioned and air-conditioned (Alam et al., 2017). The cooking process in both types of railway pantry car kitchens is almost the same, but the height of the cooking installation is different (Alam et al., 2017). The pilot study showed no significant difference during the cooking in terms of thermal environment between these two pantry car kitchen models (Alam et al., 2017; 2019a; 2020). In this chapter, the data was measured and analyzed for both pantry car kitchen models in general forms.

The dimensions of non-air-conditioned types of pantry car models are; length over buffer-22.29 (m), length over head stock (body)-21.33 (m), width-3.24 (m), and height of the coach body-3.11 (m) (Alam et al., 2020a). The dimensions of air-conditioned types of pantry car models are; length over buffer-24.0 (m), length over head-stock (body)-23.54 (m), width-3.24 (m), and height of the coach body-2.94 (m) (Alam et al., 2020a). The detailed physical structure of a non-air conditioned pantry car has been described in (section 4.1.1). Accordingly, section 4.2.1 describes the detailed physical structure of an air-conditioned pantry car.

3.1.4 Subject description

A total number of 338 trains in India run with a pantry car which has been reported in the railway board report (Alam et al., 2017). In which, there are 3 to 5 cooking workers (chefs) in a train (Alam et al., 2017). The determine(d) sample size was 64 on the total chef's population (1352) and confidence interval of 12. In this study, the survey was conducted on a total number of 14 IRPCs. In which 69 chefs participated. During summer season, 6 IRPCs were considered, in which total 29 chefs were included. There were 19 chefs from 4 IRPCs in humid and subtropical climate zone, and 10 chefs from 2 IRPCs in a tropical wet and dry climate zone. Similarly, in the winter season, a total number of 8 IRPCs were surveyed between 40 chefs. There were 30 chefs from 6 IRPCs in humid and subtropical climate zone, and rest of the 10 chefs from 2 IRPCs in a tropical wet and dry climate zone. All of these chefs were from different states. Most of the chefs were found to be less educated; very few among them were even matriculate. Due to security and permission issues, the authority granted only a few trains for field investigation. Therefore the number of trains (N) for both seasons was different.

3.2 Data collection

3.2.1 Objective measurement data: indoor and outdoor thermal parameters

The thermal comfort physical parameters recorded were "air temperature", "mean radiant temperature", "relative-humidity", and "air-velocity". The study comprises indoor and outdoor environmental parameters that were measured with the support of (a) Kestrel weather meter 4500 and Thermal anemometer testo-405i, (b) 6-inch black-globe thermometer. The accuracy and range of the instrument have been depicted in Table 3.1. Data of environmental parameters were measured according to ASHRAE (2013) and Simone & Olson (2013a) standards, in which, "air temperature- t_a ", "globe temperature- t_g ", "relative humidity-RH" and "air velocity- v_a " measured at 1 ft (0.3 m) near the workstation and 43 in. (1.1 m) above the workstation floor in the IRPCs kitchen. The outdoor measurements were recorded near the kitchen window of the pantry car when trains stopped short period at the platform.

All these physical measurements were observed during the meal preparation time (cooking breakfast, lunch, snacks, and dinner). All physical parameters were recorded indoor environment of the pantry car for 10-15 minutes and the outdoor environment of the pantry car for 5-10 minutes with the 5s to 10s interval. Due to the short stoppage time of the train on the platform, we have considered the monitoring timing less in outdoor conditions.

The globe temperature was measured with the help of a "(6 in.)-black globe thermometer" in the centre position of the meal preparing zone as discussed above, which estimates the "mean radiant temperature". As per the Mishra & Ramgopal (2014), mean radiant temperature " t_{mrt} " was calculated by applying equation (3.1).

$$t_{mrt} = \left[(t_g + 273)^4 + \frac{1.1 \times 10^8 v_a^{0.6}}{\varepsilon D^{0.4}} \times (t_g - t_a) \right]^{1/4} - 273 \quad (3.1)$$

Where emissivity ' ε ' of the globe surface is assumed as 0.95 and globe diameter is 'D'.

Table 3.1. Details of instruments used during the field study

| Instrument | Parameter measured | Range | Accuracy |
|--------------------------------|--------------------------|--------------------|----------|
| Kestrel weather meter 4500 | Air temperature, T_a | -29.0°C to +70.0°C | ±1°C |
| | Relative humidity, RH | 5% to 95% | ±3% |
| Thermal anemometer testo-405i | Air velocity, v_a | 0m/s to 30m/s | ±0.1m/s |
| 6-inch black-globe thermometer | Globe temperature, T_g | -5° to +95°C | - |

3.2.2 Assessing clothing insulations and metabolic activity level

ASHRAE 2010 and ISO 2005 provides standard checklist for estimation of the "clothing insulation" and "metabolic activity level". Only male chefs work inside the IRPC. Pantry car chefs are commonly attired Indian style outfit: which is a combination of "short-sleeved shirts or long-sleeved shirts", "short-sleeved dress shirts or long-sleeved dress shirts", "t-shirts", "men's briefs", "trousers/straight trousers (thin)/straight trousers (thick)" and shoes/slipper etc. We have taken 'Clo' value of all these items under ASHRAE (2010) and ISO (2005) standard as shown in Table 3.2. The average metabolic activity level of the pantry car chefs was examined during the cooking time to be nearly 2.0 met (116 W/m²) (Ainsworth et al., 2000). And it shows that the chefs were mostly "standing" and "medium" activity, according to ASHRAE 2010 and ISO 2005 standards.

Table 3.2. Insulating value of clothing elements

| Man | | Clo |
|------------|----------------------------|------|
| Under wear | singlets | 0.06 |
| | T-shirt | 0.09 |
| | briefs | 0.05 |
| | long, upper | 0.35 |
| | long, lower | 0.35 |
| Shirt | light, short sleeve | 0.14 |
| | light, long sleeve | 0.22 |
| | heavy, short sleeve | 0.25 |
| | heavy, long sleeve | 0.29 |
| | +5% for tie or turtle-neck | |
| Vest | light | 0.15 |
| | heavy | 0.29 |
| Trousers | light | 0.26 |
| | heavy | 0.32 |
| Pullover | light | 0.20 |
| | heavy | 0.37 |
| Jacket | light | 0.22 |
| | heavy | 0.49 |
| Socks | ankle length | 0.04 |
| | knee length | 0.10 |
| Footwear | sandals | 0.02 |
| | shoes | 0.04 |
| | boots | 0.08 |

3.2.3 PMV-PPD index calculation

The PMV "Predicted mean vote" and PPD "Predicted percentage dissatisfied" index method was established by Fanger's (1970) applying "heat-balance equations" and empirical research about "skin temperature" to determine comfort level. The measured environmental variables includes "air temperature", "mean radiant temperature", "relative humidity" and "air velocity" along with the predicted "metabolic rate" and "clothing insulation". These were used to compute the PMV-PDD index using CBE "Center for the Built Environment" thermal comfort software and determine thermal comfort according to ASHRAE 2017 as shown in Figure 3.2.

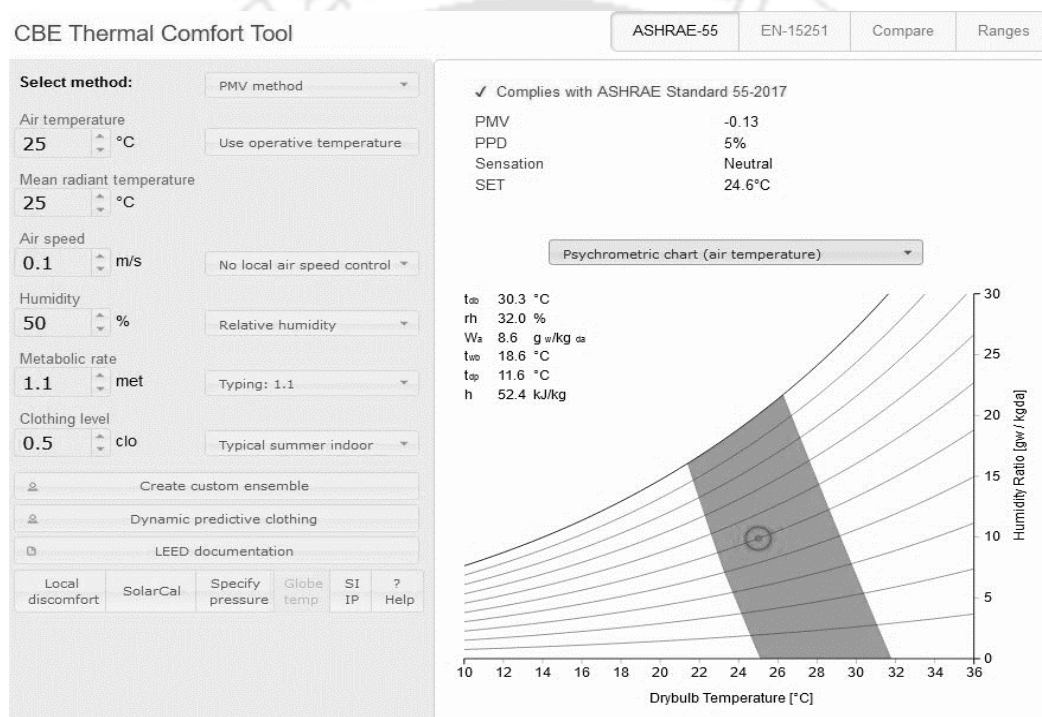


Figure 3.2. CBE thermal comfort tool

3.2.4 Subjective assessments

In the arrangement to appraise the thermal comfort of the indoor environment condition in IRPCs kitchen chefs activities, "subjective assessment" plays a vital role. A demographic data of the subject includes the parameters like age, weight, height, job experience; these were noted first in the checklist. After that, to identify the nature of subjective responses of the pantry car chefs, standard checklist was used based on the ASHRAE 2004, ISO 2006, and ISO 1995 as shown in Table 3.3. ASHRAE seven-point rating scale: -3 "cold" to +3 "hot" was applied to estimate the "thermal sensation vote - TSV". Similarly, same rating Bedford

scale from -3 "much too cool" to +3 "much too warm" was used to get the thermal comfort votes (TCV) of the IRPCs kitchen chefs. The occupant's thermal preference response was observed with the help of McIntyre index "3-point sensation scale" in which the response from -1 "cooler", 0 "no change" and +1 "warmer" as depicted in Table 3.3. Responses from acceptable (0) and not acceptable (1) has been taken for a rate of the overall thermal acceptability of the respondents inside the pantry car. Accordingly, responses have been observed from the rating scale still (-1), just right (0) and breezy (+1) for identifying feel about the airflow. For humidity, a five-point rating scale was used in which responses were 'too dry', 'slightly dry', just right, slightly humid, and too humid. About the temperature conditions at the workplace to get the responses of the pantry car chefs, 5-point scale: 'very good', 'good', 'acceptable', 'bad', or 'very bad' has been used as depicted in Table 3.4. Similarly, same 5-point rating scale was also used to assess about the indoor air quality (IAQ).

Table 3.3. Thermal comfort survey checklist of sensation and preferences for indoor parameters

| Description of scale | | | | | | |
|----------------------|---------------|-----------------|--------------------|-----------------------|------------|----------------|
| Scale | TSV | TCV | Thermal preference | Thermal acceptability | airflow | Humidity |
| +3 | Hot | Much too warm | | | | |
| +2 | Warm | Too warm | | | | Too humid |
| +1 | Slightly warm | Ok (Warm) | Warmer | Not acceptable | Breezy | Slightly humid |
| 0 | Neutral | Ok (just right) | No change | Acceptable | Just right | Just right |
| -1 | Slightly cool | Ok (cool) | Cooler | | Still | Slightly dry |
| -2 | Cool | Too Cool | | | | Too dry |
| -3 | Cold | Much too cool | | | | |

Table 3.4. Thermal comfort survey checklist of sensation and preferences for indoor parameters

| Description of scale | | |
|----------------------|------------------|------------------|
| Scale value | Feel temperature | Feel air quality |
| 1 | Very good | Very good |
| 2 | Good | Good |
| 3 | Acceptable | Acceptable |
| 4 | Bad | Bad |
| 5 | Very bad | Very bad |

3.3 Data analysis

Present research compares indoor and outdoor parameters of thermal comfort. We used descriptive analysis in which the data was presented as a maximum, minimum, and mean

(SD). This comparative analysis had been investigated using a scatter plot between climate zones and season changes during food preparation inside the pantry car. Mann Whitney test was used to check the significant difference between indoor and outdoor thermal parameters. While the Kruskal-Wallis test was used to investigate the significant difference between all cooking periods. For this MS Excel 2016 and SPSS version-16 software has been incorporated. CBE thermal comfort software was used for the estimation of the PMV and PDD index model for each cooking period (breakfast, lunch, snacks, and dinner) inside the pantry car and it has also been tried to know whether this tool can be applicable for pantry car kitchen or not.

For assessment of subjective responses, "TCV", "TSV", 'thermal acceptability" and "thermal preference" votes have been used to determine the chef's perception in the present thermal environment. And the distribution of chef votes about thermal responses for each climate zone and season was analysed with the help of a histogram of percentage data. While demographic detail like; age, height, weight and job experience data of pantry car chefs being reported as a range, percentage, mean (SD). To determine the "neutral temperature and comfort temperature range" of chefs inside the pantry car during the "summer and winter" season, linear regression analyses were carried out using "Microsoft Office Excel 2016".

3.4 Results and discussion

3.4.1 Objective measurement evaluation of indoor and outdoor environments during cooking periods

Thermal comfort study basically consists of four important environmental factors such as; "air temperature", "mean radiant temperature (assessing through globe temperature)", "relative humidity" and "air velocity" (Fang et al., 2018; Fanger, 1970; Frontczak & Wargocki, 2011; Halawa & Van Hoof, 2012; Havenith et al., 2002; Hollies & Goldman, 1977; Simion et al., 2016; Yamtraipat et al., 2005; Yao et al., 2009; Yin et al., 2012), which was measured in this investigation. The details of measured "indoor and outdoor" environmental variables observed during the seasonal and climatic variation is depicted in Table 3.5, where data of indoor and outdoor environmental factors of the thermal comfort parameters has been presented as mean (SD), maximum, and minimum. Simultaneously, all thermal parameters' while cooking breakfast, lunch, snacks, and dinner is described individually.

Table 3.5. Indoor and outdoor environmental factors based on the seasonal variation and climate zone

| | | Indoor environment factors | | | | Outdoor environment factors | | | |
|-----------------------|------|----------------------------|-------|------|-------|-----------------------------|-------|------|-------|
| Season variation | | t_a | t_g | RH | v_a | t_a | t_g | RH | v_a |
| | | <i>N=6</i> | | | | | | | |
| Summer | Min | 26 | 28 | 69 | 0.00 | 27 | 24 | 66 | 0.00 |
| | Mean | 32 | 32 | 76 | 0.03 | 30 | 28 | 84 | 1.43 |
| | Max | 37 | 37 | 87 | 0.20 | 36 | 32 | 96 | 3.61 |
| | SD | 3 | 3 | 4 | 0.05 | 2 | 2 | 9 | 1.12 |
| | | <i>N=8</i> | | | | | | | |
| Winter | Min | 25 | 20 | 43 | 0.00 | 17 | 19 | 33 | 0.00 |
| | Mean | 29 | 26 | 64 | 0.03 | 23 | 24 | 54 | 1.54 |
| | Max | 34 | 30 | 79 | 0.30 | 31 | 31 | 83 | 4.16 |
| | SD | 3 | 2 | 7 | 0.08 | 4 | 3 | 13 | 1.12 |
| | | Indoor environment factors | | | | Outdoor environment factors | | | |
| Climate zone | | t_a | t_g | RH | v_a | t_a | t_g | RH | v_a |
| | | <i>N=10</i> | | | | | | | |
| Humid and Subtropical | Min | 25 | 22 | 55 | 0.00 | 17 | 19 | 33 | 0.00 |
| | Mean | 31 | 29 | 70 | 0.04 | 25 | 26 | 67 | 1.33 |
| | Max | 37 | 37 | 87 | 0.30 | 36 | 32 | 96 | 3.61 |
| | SD | 3 | 4 | 7 | 0.08 | 5 | 4 | 18 | 1.10 |
| | | <i>N=4</i> | | | | | | | |
| Tropical wet and dry | Min | 25 | 20 | 43 | 0.00 | 19 | 20 | 36 | 0.00 |
| | Mean | 30 | 29 | 68 | 0.02 | 27 | 26 | 66 | 1.91 |
| | Max | 36 | 36 | 80 | 0.10 | 32 | 30 | 95 | 4.16 |
| | SD | 4 | 4 | 11 | 0.04 | 4 | 3 | 21 | 1.05 |

[Note: t_a & t_g (in °C), v_a (in m/s), RH (in %)]

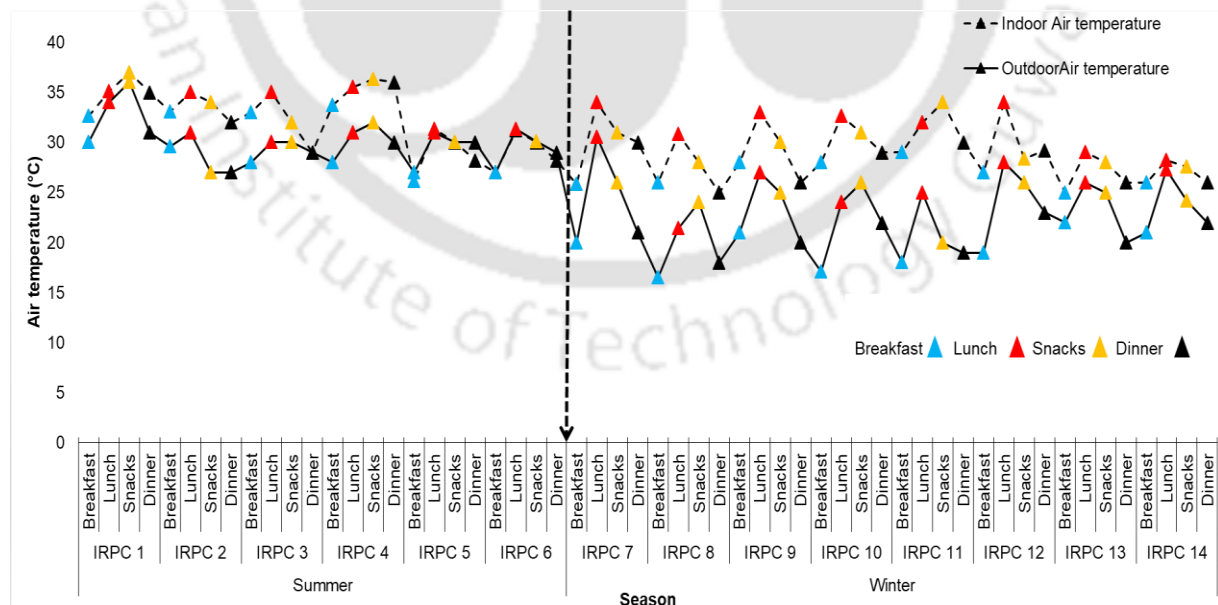
a). Air temperature

Air temperature is the most influential environmental factor for "thermal comfort", as presented in earlier studies. Figure 3.3 (a) shows air temperature variation in the summer and winter season, taken in the pantry car kitchen's indoor and outdoor sides. The indoor and outdoor temperatures have been measured four times a day during cooking (breakfast, lunch, snacks, and dinner), as described above. According to the graphical representation, the indoor air temperature was higher in both seasons than the outdoor air temperature. During the summer season, the maximum indoor air temperature was 37°C snacks and 36°C lunch cooking time. In contrast, the minimum indoor temperature was at 26°C at breakfast time. However, the average value of indoor air temperature in the entire summer season was 32°C during the all cooking period. At the same period, maximum and minimum outdoor air temperature values were 36°C and 27°C, respectively. In the winter season, the maximum value of indoor air temperature (34°C) was found at lunch and snacks, as shown in Figure 3.3

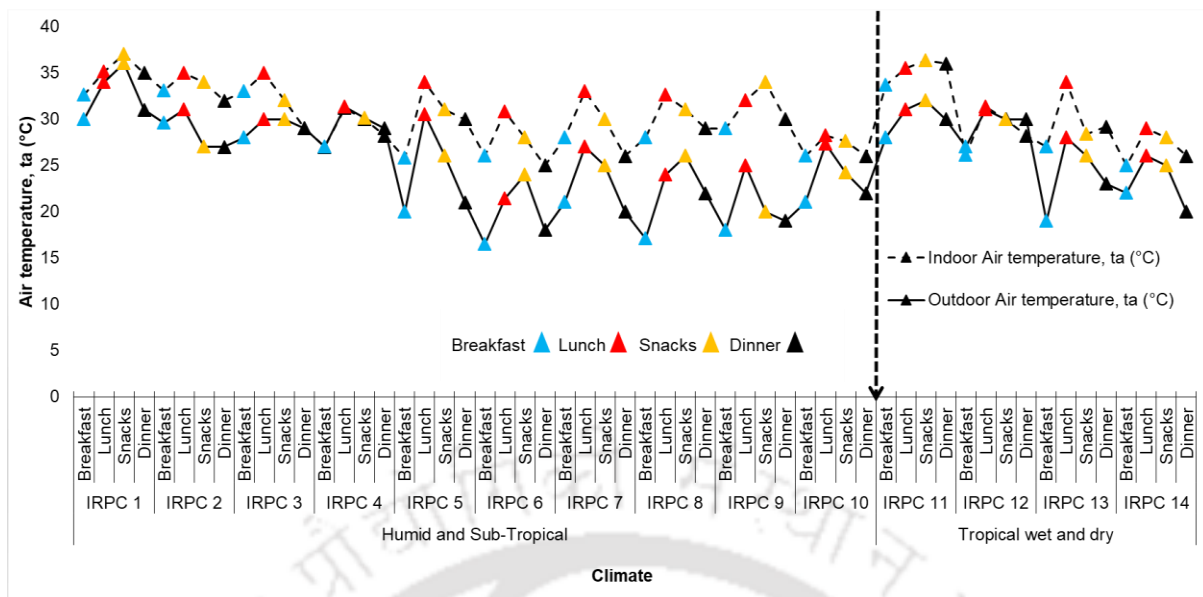
(a). Whereas, the minimum indoor air temperature was 25°C breakfast and dinner time. However, during the cooking period of all time, the average value of the indoor air temperature was 29°C during the entire winter season. While throughout the winter season, the average value of outdoor air temperature was 23°C.

Figure 3.3 (b) indicates indoor and outdoor air temperature variation in humid and sub-tropical and tropical wet and dry regions. It can be seen here also in the graph, the indoor air temperature was higher than the outdoor air temperature in both climatic zones. In a humid and sub-tropical region, maximum indoor air temperature of 37°C was found at the time of snack preparation in the pantry car. However, the average value of indoor and outdoor air temperatures was 31°C and 25°C, respectively throughout the entire cooking period. Similarly, in a tropical wet and dry region, the maximum indoor air temperature of 36°C was found at the time of lunch and snack preparation. Meanwhile, the average value of indoor and outdoor air temperatures was 30°C and 27°C throughout the cooking period.

The above results indicate that there is a significant effect of outdoor air temperature inside the pantry car kitchen because indoor air temperature has always been high throughout the whole study period. However, indoor air temperature value does not comply with the ASHRAE 2017 standard in seasonal variation and climatic zones (ASHRAE, 2017). It was found higher in both seasonal variations and climatic zones while cooking lunch and snacks period.



(a)



(b)

Figure 3.3. Indoor and outdoor air temperature variation graph based on (a) season, and (b) climatic zone

b). Globe temperature

Figure 3.4 (a) shows the full measurements of globe temperature variation in indoor and outdoor environmental conditions during summer and winter. As illustrated in graphs, the maximum and minimum indoor globe temperatures were recorded during the summer season while cooking snacks (37°C) and breakfast (28°C). Together, the average value of indoor globe temperature of the entire summer season was 32°C. However, the average value of the outdoor globe temperature was only 28°C. In the whole summer season, the indoor globe temperature value was higher than the outdoor globe temperature. Whereas during the winter season, maximum and minimum indoor globe temperatures were at lunch (30°C) and breakfast (20°C), respectively. Simultaneously, the average indoor and outdoor globe temperature values were 26°C and 24°C respectively, throughout the winter season. While, in both indoor and outdoor conditions, the globe temperature variance was fluctuating. During the winter season, the indoor globe temperature also did not obey the ASHRAE standards at some cooking time (Alam et al., 2019a).

Figure 3.4 (b) demonstrate the climate variation of globe temperature both indoor and outdoor environment. In a humid and subtropical climate zone, the indoor globe temperature was maximum (37°C) at snack time, and its average value was around 29°C. Whereas, the average value of the outdoor globe temperature was 26°C. Similarly, in a tropical wet and dry region, it was seen that maximum indoor globe temperature on the same day was 36°C and

35°C at the time of snacks and dinner respectively, and the average value of this climate zone was 29°C. However, the average value of the outdoor globe temperature was 26°C throughout the tropical wet and dry region. The graphical result shows that the value of indoor globe temperature is almost the same during cooking in both climatic zones, while the outdoor globe temperature also did not get many variations. Even in this climate zone, the indoor globe temperature value does not follow the ASHRAE standard (Alam et al., 2019a).

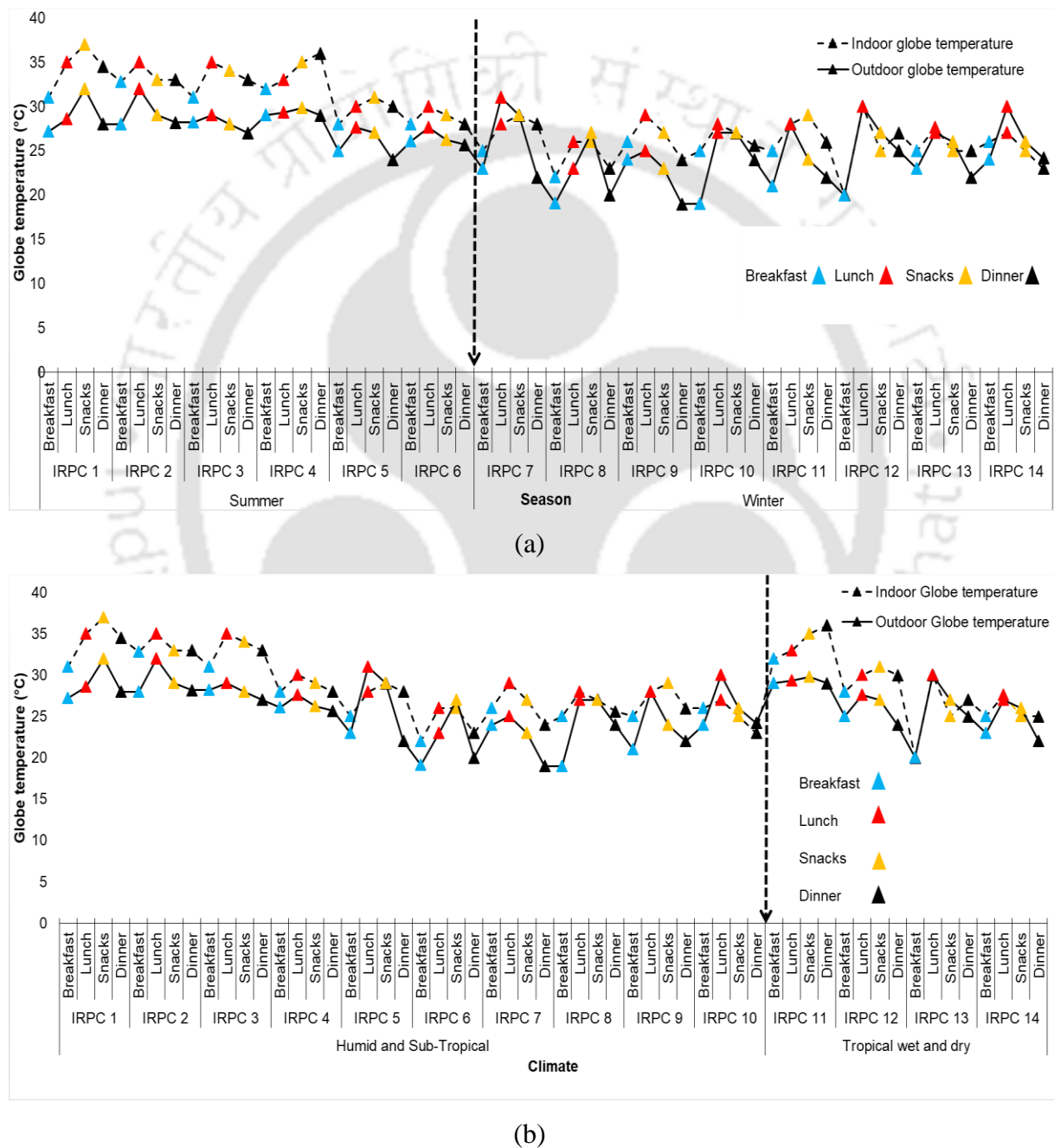


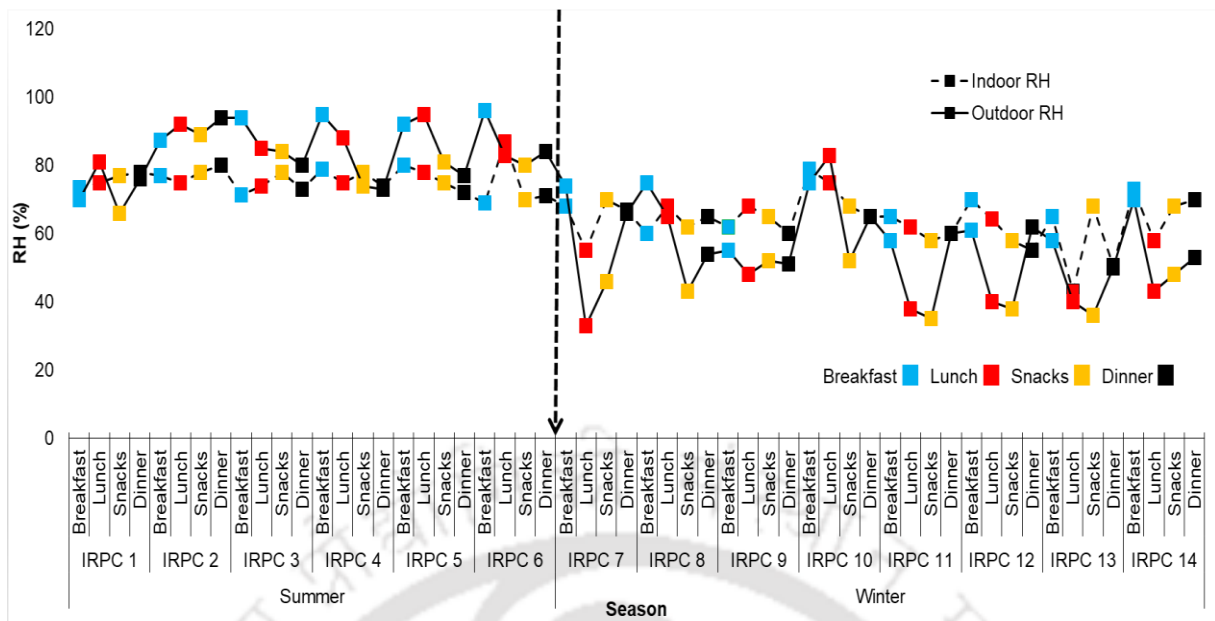
Figure 3.4. Indoor and outdoor globe temperature variation graph based on (a) season, and (b) climatic zone

c). Relative humidity

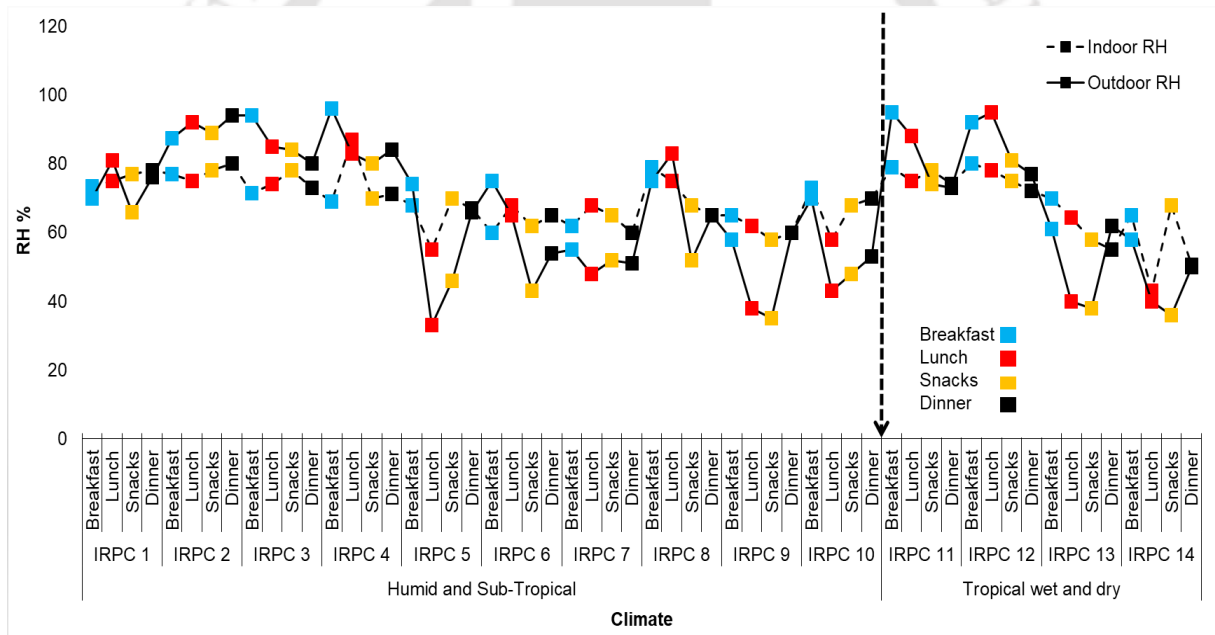
Relative humidity (RH) is the essential factor representing the comfort level in the hot and humid environment, and its high percentage may slow down the work process and cause discomfort. Figure 3.5 (a) shows the variation of relative humidity percentage RH (%) in indoor and outdoor environments during the summer and winter season. In the summer season, 87% and 69% of indoor RH were found the maximum and minimum respectively at lunch and breakfast on a similar day. While 76% mean value of indoor RH at all cooking times was measured in the summer season. In contrast, the average value of outdoor RH was 84%. Approximately during the entire summer season outdoor RH (%) amounts were more than indoor conditions. Similarly, in the winter season, the indoor and outdoor RH was recorded between 43% to 79% and 33% to 83%, respectively. Simultaneously, the average rate of RH% of both indoor and outdoor was 64% and 54%. The RH percentages were highest inside the pantry car during the winter season at breakfast and lunch. Throughout the measurement, indoor and outdoor RH percentage was low in the winter season than the summer season.

Figure 3.5 (b) also shows RH (%) climatic variation on the basis of indoor and outdoor environment conditions. In the humid and sub-tropical climatic zone, the maximum indoor RH was 87% at lunch preparation time. While on different day, minimum indoor RH (55%) was recorded at lunch preparation time. However, the rest of the other cooking time, the indoor RH value was outside the recommended range. In this climate zone, the average rate of indoor and outdoor RH% was 70% and 67% throughout the entire measurement, respectively. Similarly, in a tropical wet and dry region, indoor RH value was maximum and minimum at breakfast 80% and lunch 43% respectively, with a 68% average value. Simultaneously, average outdoor RH in this climatic zone recorded during cooking periods was 66%.

As mentioned in previous studies, for the outdoor environment condition, when the air temperature increases, the relative humidity decreases (Valsson & Bharat, 2011). However, ASHRAE 2016 recommended a standard range of RH values; 30% to 60% (comfortable), 40% to 60% (optimum), 50% (ideal) (ASHRAE, 2016; Alam et al., 2019a). In both the climate zone, indoor RH % was higher than the recommended range while cooking. At the same time, the rate of outdoor RH fluctuated during this period.



(a)



(b)

Figure 3.5. Indoor and outdoor relative humidity variation graph based on (a) season, and (b) climatic zone

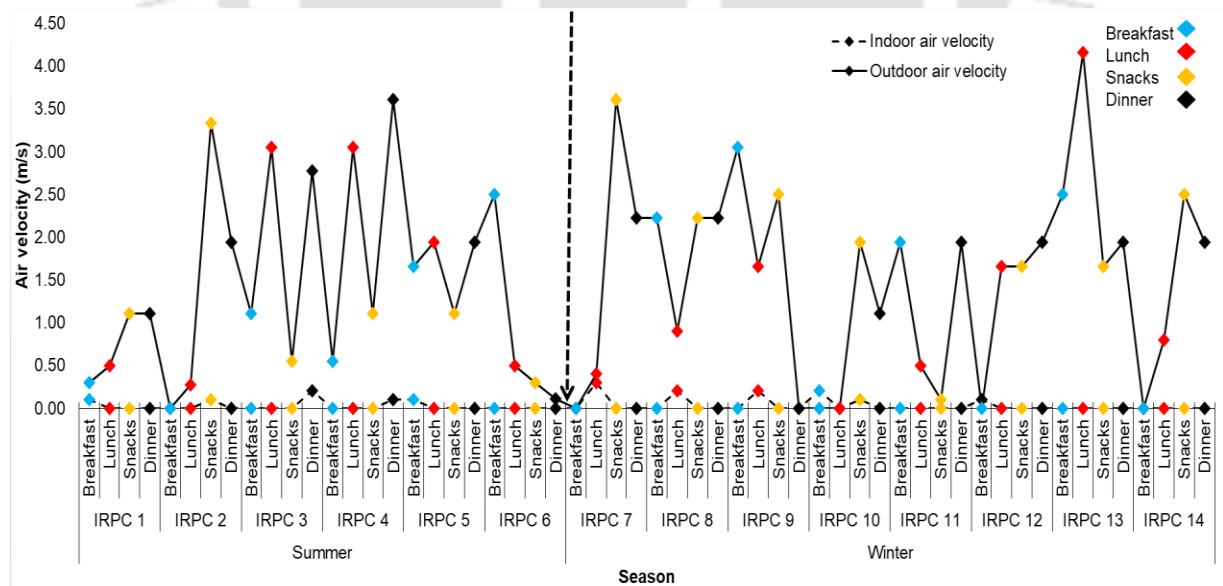
d). Air velocity

Figure 3.6 (a) demonstrates that air velocity values at indoor and outdoor environmental conditions during the summer and winter seasons. In the summer season, the minimum and maximum value of indoor and outdoor air velocity were recorded between 0.00m/s and 0.20m/s and 0.00m/s to 3.61m/s respectively. The average air velocity was 0.03m/s and 1.43m/s observed for indoor and outdoor conditions respectively during the entire summer

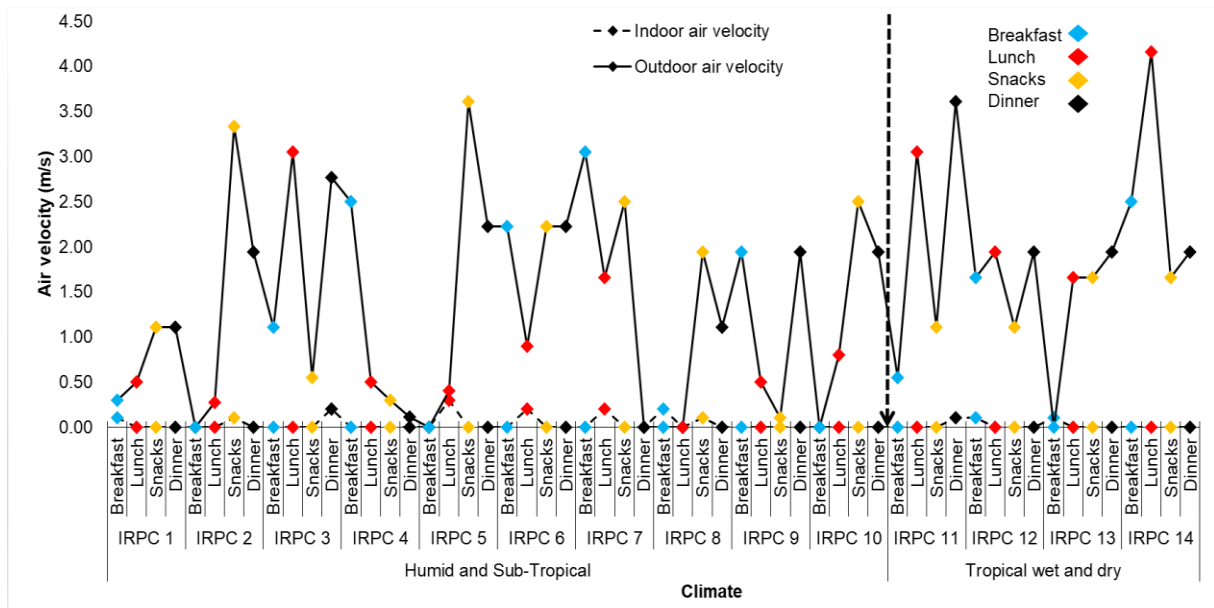
season. In the winter season, the indoor air velocity was minimum (0.00m/s) and maximum (0.30m/s) with an average (0.03m/s), which was almost the same as the summer season. Whereas, the outdoor air velocity was observed in the range 0.00m/s to 4.16m/s with an average of 1.54m/s.

Figure 3.6 (b) shows the estimated effect of indoor and outdoor air movement in two different climate zones. In humid and sub-tropical climate zone, the minimum and maximum indoor air velocity were found 0.00m/s and 0.30m/s, respectively, with mean value 0.04m/s. Simultaneously, the outdoor air velocity was measured minimum and maximum of 0.0m/s and 3.61m/s, respectively, with an average value of 1.33m/s. Entirely in this climate zone, the recorded indoor air velocities were found significantly less. Similarly, in tropical wet and dry climate zone, the indoor and outdoor air velocity was observed during the cooking time, 0.00m/s to 0.10m/s and 0.00m/s to 4.16m/s. The average value of both was 0.02m/s and 1.91m/s.

There is no much difference in the movement of indoor air velocity in both seasons and climates while cooking period. However, the estimated outdoor air velocity was very high during the same cooking period. According to the recommended value of "ASHRAE Standard 55-2004", the air velocity of (<0.25m/s) should be for summer and (<0.15m/s) for winter (ASHRAE, 2004).



(a)



(b)

Figure 3.6. Indoor and outdoor air velocity graph based on (a) season, and (b) climatic zone

3.4.1.1 Significant difference testing between indoor and outdoor thermal parameters

Significant differences between indoor and outdoor thermal parameters have been investigated in this study using the Mann Whitney test. The result of the Mann Whitney test are depicted in Table 3.6 and Table 3.7.

For air temperature (T_a) case, test indicates that, on average the “ T_a ” values of the indoor conditions (*Mean Rank* = 71.63, $n = 56$) significantly exceed the outdoor conditions (*Mean Rank* = 41.37, $n = 56$), $U = 720.500$, $z = -4.938$, $p = 0.000$, two tailed. Similarly, for globe temperature (T_g) case, test indicated that, on average, the “ T_g ” values of the indoor conditions (*Mean Rank* = 66.42, $n = 56$) significantly exceed of the outdoor conditions (*Mean Rank* = 46.58, $n = 56$), $U = 1012.500$, $z = -3.239$, $p = 0.001$, two tailed. While for relative humidity (RH) case, test indicated that, there no difference between indoor condition (*Mean Rank* = 57.31, $n = 56$) and outdoor condition (*Mean Rank* = 55.69, $n = 56$) significantly, $U = 1522.500$, $z = -0.265$, $p = 0.791$, two tailed. However, for air velocity (v_a) case, test indicated, on average, that the “ v_a ” values of the outdoor conditions (*Mean Rank* = 80.04, $n = 56$) significantly exceed of the indoor conditions (*Mean Rank* = 32.96, $n = 56$), $U = 249.500$, $z = -8.093$, $p = 0.001$, two tailed.

Table 3.6. Mann Whitney test ranks for both indoor and outdoor thermal parameters

| Thermal comfort variables | Condition | n | Mean Rank | Sum of Ranks |
|---------------------------|-----------|----|-----------|--------------|
| Ta(°C) | Indoor | 56 | 71.63 | 4011.50 |
| | Outdoor | 56 | 41.37 | 2316.50 |
| Tg(°C) | Indoor | 56 | 66.42 | 3719.50 |
| | Outdoor | 56 | 46.58 | 2608.50 |
| RH% | Indoor | 56 | 57.31 | 3209.50 |
| | Outdoor | 56 | 55.69 | 3118.50 |
| va (m/s) | Indoor | 56 | 32.96 | 1845.50 |
| | Outdoor | 56 | 80.04 | 4482.50 |

Table 3.7. Mann Whitney test statistics for thermal parameters

| | Ta(°C) | Tg(°C) | RH% | va (m/s) |
|------------------------|----------|----------|----------|----------|
| Mann-Whitney U | 720.500 | 1012.500 | 1522.500 | 249.500 |
| Wilcoxon W | 2316.500 | 2608.500 | 3118.500 | 1845.500 |
| Z | -4.938 | -3.239 | -0.265 | -8.093 |
| Asymp. Sig. (2-tailed) | 0.000 | 0.001 | 0.791 | 0.000 |

The statistical test result revealed a significant difference in air temperature and globe temperature between the pantry cars' "indoor and outdoor environmental conditions". Whereas, there was no considerable difference in "relative humidity in both" conditions. However, the outside air velocity was much higher than the pantry car's indoor air velocity. As distinguished in the previous study, most of the cooks closed the party car window and door during the cooking period. Therefore, minimal air movement is found inside the pantry as it creates a problem for food preparation. Due to this, the "indoor environment becomes hot and humid" of the pantry cars.

3.4.1.2 Significant difference testing between cooking periods

This study checked the significant difference between all different cooking periods during winter and summer seasons using the Kruskal-Wallis test.

Table 3.8 shows the "Kruskal-Wallis test significant difference" between different cooking periods during the summer season. During summer season p-value of the "Ta (°C), Tg(°C), RH%, va (m/s)" was found more than significance level of 0.05. Hence, there is "no statistically significant difference" found between all cooking time during the summer season.

Similarly, during the winter season (see Table 3.8) p-value of the “Ta (°C), Tg(°C)” was found less than the significance level of 0.05. It means that there is a statistically significant difference found of “Ta (°C), Tg(°C)” between all cooking period. However, the p-value of the “RH%, v_a (m/s)” was found more than the significance level of 0.05. It implies that there is no statistically significant difference found of “RH%, v_a (m/s)” between all cooking periods. Statistical results indicate no significant difference in thermal parameters between all cooking periods throughout the summer season. Simultaneously, there were significant differences between thermal parameters during the cooking period throughout the winter season except for relative humidity and air velocity.

Table 3.8. Kruskal-Wallis test - summer and winter season

| Seasons | Parameters | Mean Rank | | | | χ^2 | Sig. |
|---------|-------------|-----------|-------|--------|--------|----------|---------|
| | | Breakfast | lunch | Snacks | Dinner | | |
| Summer | Ta(°C) | 9.5 | 15.67 | 14.42 | 10.42 | 3.255 | 0.354 |
| | Tg(°C) | 7.5 | 14.67 | 14.83 | 13 | 4.307 | 0.23 |
| | RH% | 11.67 | 14.17 | 13.67 | 10.5 | 1.075 | 0.783 |
| | v_a (m/s) | 13.83 | 10 | 11.92 | 14.25 | 2.743 | 0.433 |
| Winter | Ta(°C) | 8.56 | 25.38 | 19.38 | 12.69 | 15.083 | 0.002** |
| | Tg(°C) | 9.38 | 25.5 | 18.56 | 12.56 | 14.108 | 0.003** |
| | RH% | 21.06 | 14.31 | 17.44 | 13.19 | 3.45 | 0.327 |
| | v_a (m/s) | 17.31 | 19.94 | 15.25 | 13.5 | 4.524 | 0.21 |

** There is a statistically significant difference

3.4.1.3 Evaluation of PMV-PPD index

In this study, chefs' thermal comfort condition during the meal preparation period inside the pantry cars was estimated based on a PMV-PPD index method. The PMV model predicted that the mean impedance of many individuals exposed to a determinate environment following the "7-point thermal sensation scale" concurring to the ASHRAE Standard. And PPD is the "predicted percentage of dissatisfied" people at each level of PMV (Hussin et al., 2014). A thermal comfort criterion necessitates the PPD value to be lower than "10% correspond to a PMV" value of range -0.5 "slightly cool sensation" and +0.5 "slightly warm sensation" (Alam et al., 2020; Hussin et al., 2014). Thermal comfort result of pantry car kitchens during the cooking period/time (breakfast, lunch, snacks, and dinner) based on the seasons and climatic zones as depicted in Table 3.9.

During the summer season, the maximum PMV value of 2.97 was estimated with 97.33% PPD during lunch preparation, while minimum PMV value 2.43 was found at the time of breakfast preparation with PPD 87.83%. Similarly, in the winter season, the maximum value

of PMV 1.91 was calculated with 70.25% of PPD at lunch cooking period, while the minimum value of PMV 1.28 was found with 40.75% PPD at breakfast time. However, the PMV-PPD index's value was also found to be higher at other cooking times in both seasons. In a humid and subtropical climate zone, maximum PMV value 2.33 and 2.32 was found at snacks and lunch with PPD 81.20% and 79.30%, respectively. Similarly, in a tropical wet and dry climate zone, at lunch cooking period the maximum value of PMV and PPD index was found as 2.48% and 88.25% respectively.

Entirely in both seasons and climate zones, the calculated mean value of PMV and PPD indexes does not comply with the ASHRAE 55 standard. Even if the mean PMV index values are within the PMV standard range -3 to +3, (view Table 3.9), many individual values are outside this standard range (view Figure 3.7). This demonstrates that the PMV method is not practically applicable in every context; "ISO Standard-2005 (EN 7730)" recommends the PMV value only in the interval - 2 to +2 (Simone et al., 2013; Simone & Olesen, 2012), means that most of the measured conditions are outside the range, which indicate a high percentage of dissatisfaction. PMV and PPD index method is not directly suitable for the pantry car kitchen's thermal comfort application because of high temperature, high activity, and less air movement. Few studies have also shown the same outcomes, that PMV-PPD index is not suitable for evaluating thermal comfort in the kitchen environment, due to high temperature and high metabolic rate (Alam et al., 2019; Rahmillah et al., 2017; Simone & Olesen, 2012).

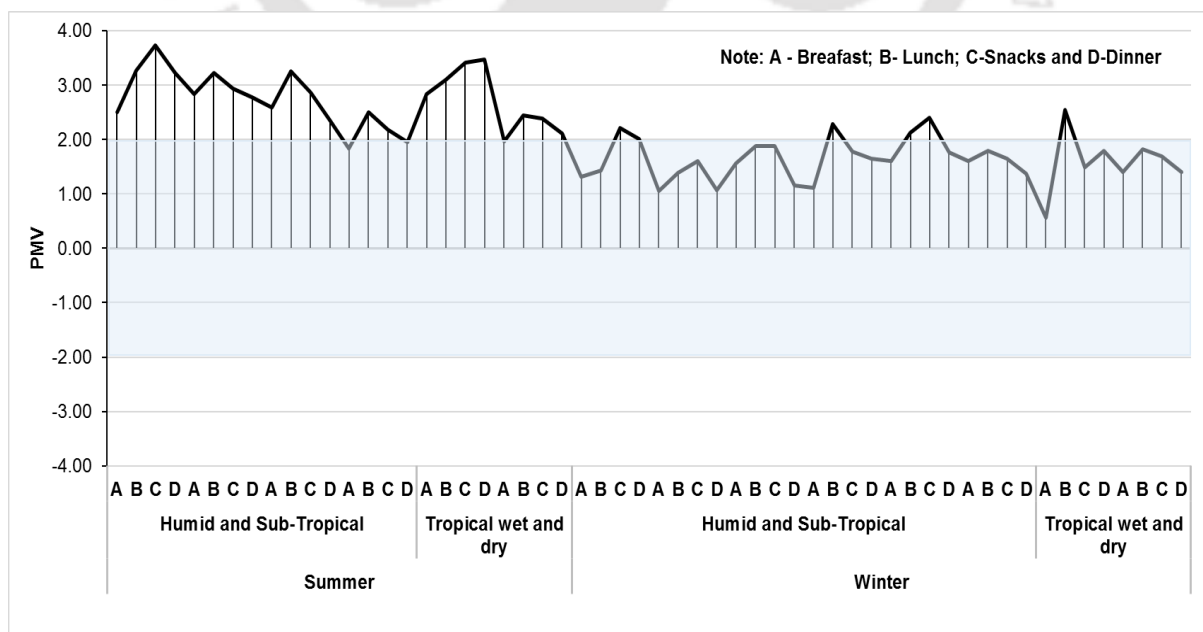


Figure 3.7. Distribution of PMV value at the cooking time

Table 3.9. Average data of field measurements and thermal comfort indices during cooking period based on season and climatic zone

| | | Input parameters | | | | | Output | | | |
|-----------------------|----------------|------------------|----------------|-------|-------------|------|--------|------|-------|--|
| Season | Cooking period | t_a (°C) | t_{mrt} (°C) | RH % | v_a , m/s | Clo | met | PMV | PPD | |
| Summer | Breakfast | 30.92 | 30.75 | 74.97 | 0.03 | 0.58 | 2.0 | 2.43 | 87.83 | |
| | Lunch | 33.85 | 33.00 | 77.33 | 0.00 | 0.58 | 2.0 | 2.97 | 97.33 | |
| | Snacks | 33.22 | 33.08 | 76.00 | 0.02 | 0.58 | 2.0 | 2.92 | 95.50 | |
| | Dinner | 31.40 | 32.95 | 74.70 | 0.05 | 0.58 | 2.0 | 2.65 | 90.83 | |
| Winter | Breakfast | 26.85 | 23.35 | 67.75 | 0.04 | 0.58 | 2.0 | 1.28 | 40.75 | |
| | Lunch | 31.70 | 26.10 | 61.68 | 0.09 | 0.58 | 2.0 | 1.91 | 70.25 | |
| | Snacks | 29.75 | 26.33 | 64.63 | 0.01 | 0.58 | 2.0 | 1.84 | 67.75 | |
| | Dinner | 27.65 | 25.20 | 61.59 | 0.00 | 0.58 | 2.0 | 1.53 | 52.13 | |
| Climate | Cooking time | t_a (°C) | t_{mrt} (°C) | RH % | v_a , m/s | Clo | met | PMV | PPD | |
| Humid and Subtropical | Breakfast | 28.85 | 26.82 | 69.78 | 0.03 | 0.55 | 2.0 | 1.80 | 62.30 | |
| | Lunch | 32.69 | 28.62 | 69.70 | 0.07 | 0.55 | 2.0 | 2.32 | 79.30 | |
| | Snacks | 31.46 | 29.31 | 69.40 | 0.02 | 0.55 | 2.0 | 2.33 | 81.20 | |
| | Dinner | 29.02 | 28.13 | 68.92 | 0.02 | 0.55 | 2.0 | 1.93 | 67.00 | |
| Tropical wet and dry | Breakfast | 27.95 | 25.78 | 73.50 | 0.05 | 0.64 | 2.0 | 1.69 | 57.50 | |
| | Lunch | 32.45 | 30.15 | 65.10 | 0.00 | 0.64 | 2.0 | 2.48 | 88.25 | |
| | Snacks | 30.68 | 29.00 | 69.75 | 0.00 | 0.64 | 2.0 | 2.25 | 75.75 | |
| | Dinner | 29.85 | 29.50 | 62.93 | 0.03 | 0.64 | 2.0 | 2.20 | 73.00 | |

Note: Metabolic rate (met) for standing, medium activity-cooking according to ANSI/ASHRAE.

3.4.2 Subjective measurement evaluation

The railway pantry car chefs' demographic and job characteristics are presented in Tables 3.10 and 3.11, respectively, with data being presented as mean (SD), range and percentages. The chef's age ranges from 24 to 51 years (mean = 36.87 years; SD = 6.36 years), and the mean daily working time was 12.07 (SD = 1.95) hours. Inside the pantry car, 36.23% of chefs were having work experience between 3-5 years. The mean daily resting time was 7.71 (SD = 0.57) hours. The rest time frequency ranged from 10 – 30 minutes (mean = 15.14 minutes; SD = 4.85 minutes). In the railway pantry car, 49.27% of chefs indicated that they consume alcohol, although 50.73% of chefs indicated they do not drink alcohol. The majority of chefs (69.56%) indicated that they do not have a smoking habit.

Table 3.10. Demographic details of railway pantry car chefs (n = 69)

| Study variables | |
|--------------------------------|-----------------|
| Age (years) | |
| Mean (SD) | 36.87 (6.36) |
| Range | 24 – 51 |
| Weight (kg) | |
| Mean (SD) | 68.18 (6.28) |
| Range | 55 – 84 |
| Height (cm) | |
| Mean (SD) | 171.03 (5.17) |
| Range | 160.02 – 182.88 |
| BMI (kg/m ²) | |
| Mean (SD) | 23.32 (2.03) |
| Range | 18.3 – 29 |
| Smoking (% sample) | |
| Yes | 30.43 |
| No | 69.56 |
| Alcohol consumption (% sample) | |
| Yes | 49.27 |
| No | 50.73 |
| Resting heart rate (beats/min) | |
| Mean (SD) | 69.67 (1.98) |
| Range | 65 - 74 |
| Working heart rate (beats/min) | |
| Mean (SD) | 82.78 (4.92) |
| Range | 71 - 93 |

Table 3.11. Job characteristics of railway pantry car chefs (n = 69)

| Study variables | |
|-------------------------------------|--------------|
| Daily working time (h) | |
| Mean (SD) | 12.07 (1.95) |
| Range | 7 – 14 |
| Daily resting time (h) | |
| Mean (SD) | 7.71 (0.57) |
| Range | 6 – 9 |
| Frequency of rest time (min.) | |
| Mean (SD) | 15.14 (4.85) |
| Range | 10 – 30 |
| Job experience (% sample) | |
| < 1 year | 10.14 |
| 1-2 years | 21.76 |
| 3-5 years | 36.23 |
| > 5 years | 31.87 |
| Clothing insulation/ensembles (Clo) | |
| Mean (SD) | 0.58 (0.18) |
| Range | 0.20 – 1.01 |

Figure 3.8 demonstrates the subjective responses of thermal comfort votes (TCV) on the rating scale, -3 "much too cool", -2 "too cool", -1 "ok cool", 0 "ok just right", +1 "ok warm", +2 "too warm", +3 "much too warm". During the summer season, the result shows that the 19 respondents (65.5%) from the humid and sub-tropical climate zone voted sensation value (+1, +2 and +3). Simultaneously, the values of votes were (+1, +2, +3), which consists of 10 respondents (34.5%) for the tropical wet and dry climate region. All the thermal comfort votes in both climate zones were found on the "hot" side only during the summer season and its vote range was +1 to +3.

Similarly, in the winter season, 30 respondents (75%) from the humid and sub-tropical climate zone voted sensation value (+1, +2, +3). Similarly, in the tropical wet and dry climatic zones, 10 respondents (25%) voted for sensational value +1 to +3. None of the respondents has voted for cool sensation inside the pantry car even during the winter season in both climate zones. Most of the respondents have voted on the hot range side, which is out of the acceptable range. As ASHRAE Standard 55, 80% of people living in acceptable thermal environments should vote for the central three categories "-1, 0, +1" (ASHRAE, 2004; Hussin et al., 2014). In this study, no respondents' votes were found with central three categories.

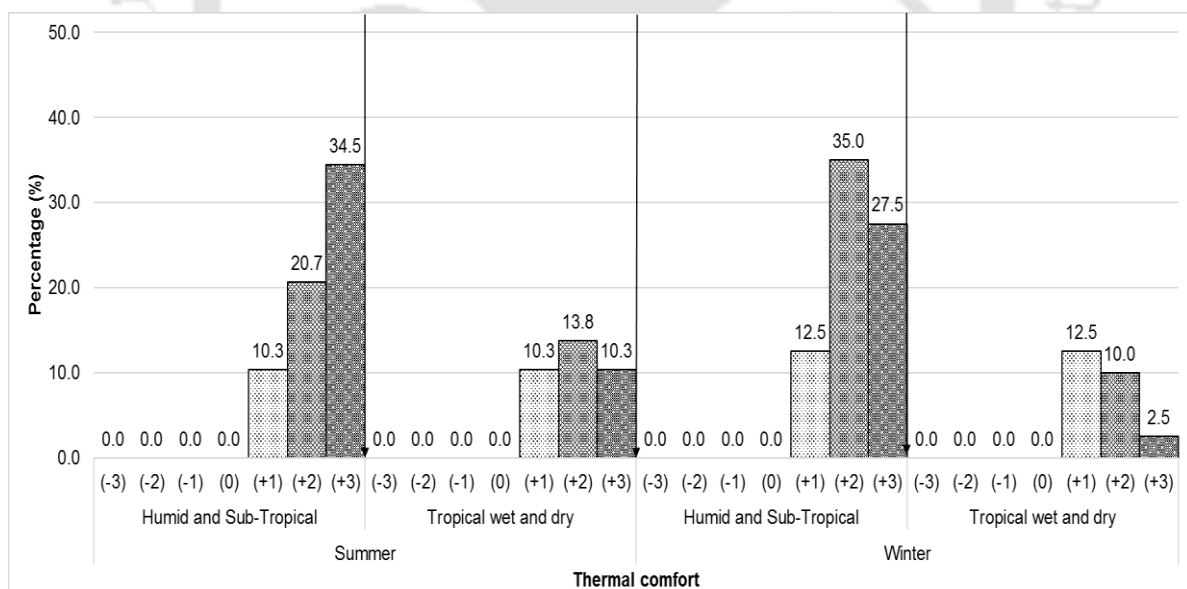


Figure 3.8. Dispensation percentage of subjective response to thermal comfort

Figure 3.9 demonstrate the subjective responses to thermal sensation votes (TSV) from -3 "cold", -2 "cool", -1 "slightly cool", 0 "neutral", +1 "slightly warm", +2 "warm", +3 "hot". At the summer season in a humid and subtropical climate zone, 65.5% voted from the range +1 to +3. Even in the tropical wet and dry climate areas, 34.5% of the respondents' votes

ranged from +1 to +3. There is no vote in the entire summer season in both climatic zones according to the central three categories. During the winter season in the humid and subtropical climate zone, votes ranged +1 to +3, consisting of 30 respondents (75%). While for tropical wet and dry climate region, the votes were from 0 to +3, in which there were 10 respondents (25%). This climatic zone also does not follow the central three categories mentioned above (-1, 0, +1). Respondents have not given TSV in the negative (cool) side in this study. While only one respondent did vote in 0 (neutral), but the votes of all the other respondents do not follow the standards.

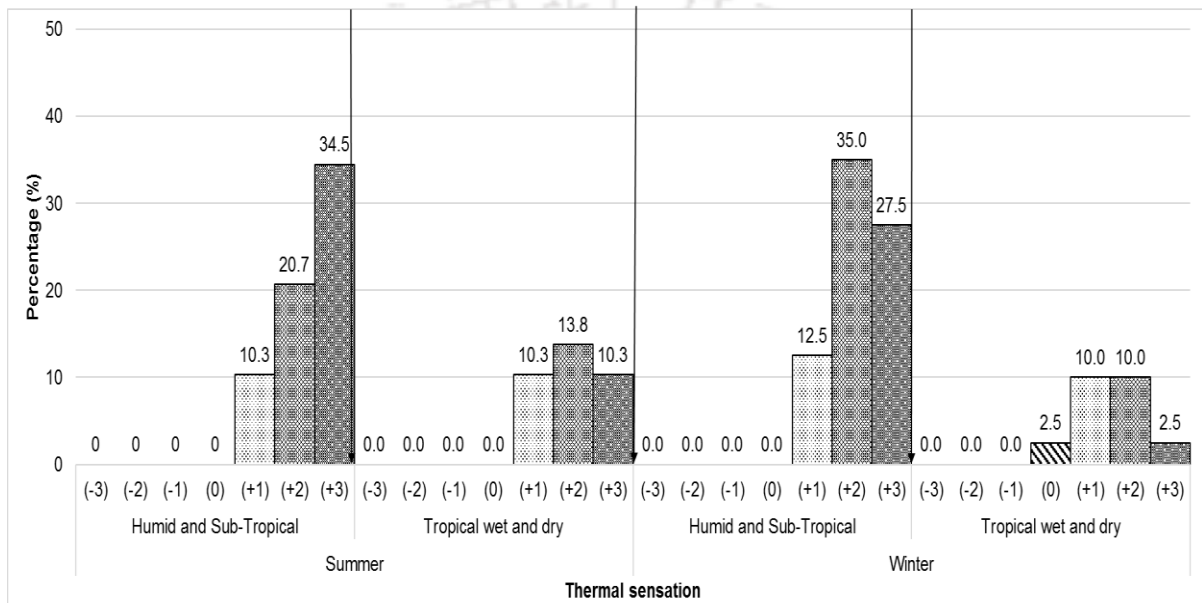


Figure 3.9 Dispensation percentage of subjective response to thermal sensation

Occupants' (chefs) perception of thermal acceptability based on the season and climate variation is shown in Figure 3.10. The rating scale: acceptable (0) and not acceptable (1) was used to obtain the occupants' thermal acceptability response. It was observed that during the summer season in both climate zones, almost 24% of respondents accepted the thermal environment and the other nearly 76% did not accepted it. Similarly, during the winter season in both climatic zones, only 5% of chefs accepted the thermal environment while 95% did not accepted. As many studies have suggested, the percentage of respondent satisfaction in any thermal environment should be above 80% (Adrian et al., 2008; Nasrollahi et al., 2008).

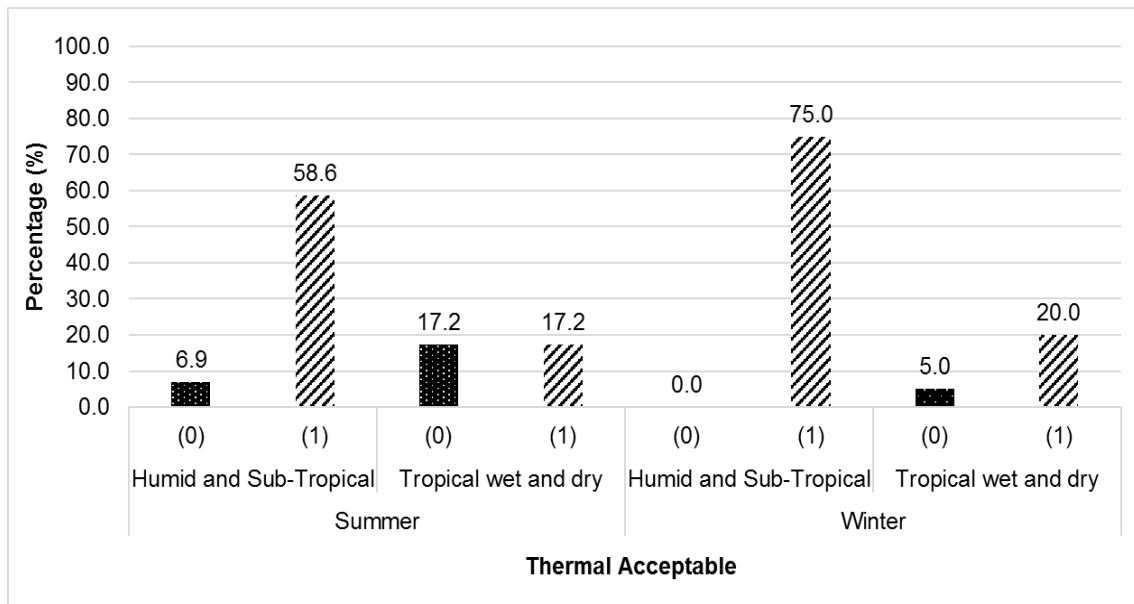


Figure 3.10. Dispensation percentage of subjective response to thermal acceptability

Figure 3.11 demonstrates the dispensation percentage of subjective response to thermal preference based on the seasonal variation and climate zone. Thermal preference votes were estimated directly according to the answer to the question in the pantry car kitchen environment, -1 "cooler", 0 "no change", +1 "warmer". It can be seen in (Figure 3.11) that throughout the summer season in both climate zones, 79.3% of the chefs want to prefer "cooler" side while 20.7% of the chefs preferred with the existing environment inside the pantry car. None of the chefs liked the "warmer" side. Similarly, during the winter season in both climatic zones, 77.5% of the chefs want to prefer the "cooler" side, and 22.5% of the chefs prefer the existing environment. Throughout the winter season in both climate zones, not anyone picked to "warmer" side. However, some respondents preferred staying with the pantry car's environment in both season and climatic zones due to cooking habits. Many thermal comfort studies have reported that the most of the subjects does not want any change at workplace (Hussin et al., 2014; Hwang et al., 2009). But in this result, most of the respondents prefer to stay on the cool side.

Figure 3.12 depicts the distribution percentage of subjective response to feel airflow movement based on the climate zones and seasonal changes inside the pantry car. Scale rating; still (-1), just right (0) and breezy (+1) were used to understand the movement of the airflow of the respondent. Throughout the summer season in humid and subtropical and tropical wet and dry climate zones, 62% of respondents felt lower wind speed. In comparison,

31% of respondents agreed with the movement of airflow inside the pantry car. However, nearly 6.9 (7%) respondents voted for more airflow movement.

Similarly, during the winter season in both climate zones, 62.5% of respondents felt lower air velocity while 37.5% agreed with airflow movement inside the pantry car. But no respondent here voted for feeling more airflow movement. It occurs because food is prepared by closing all windows and doors in the pantry car during the winter season, as reported in the pilot study (Alam et al., 2019a).

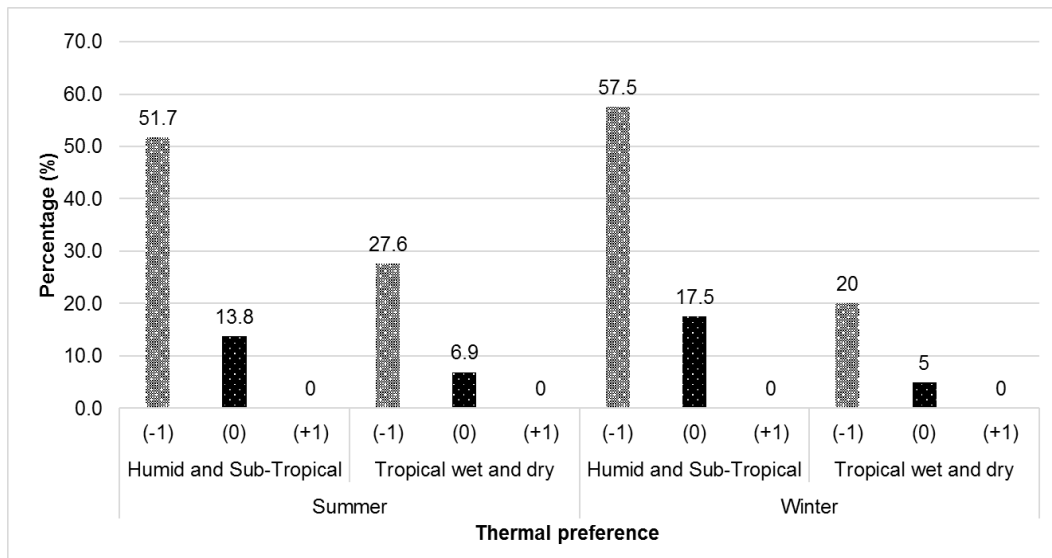


Figure 3.11. Dispensation percentage of subjective response to thermal preference

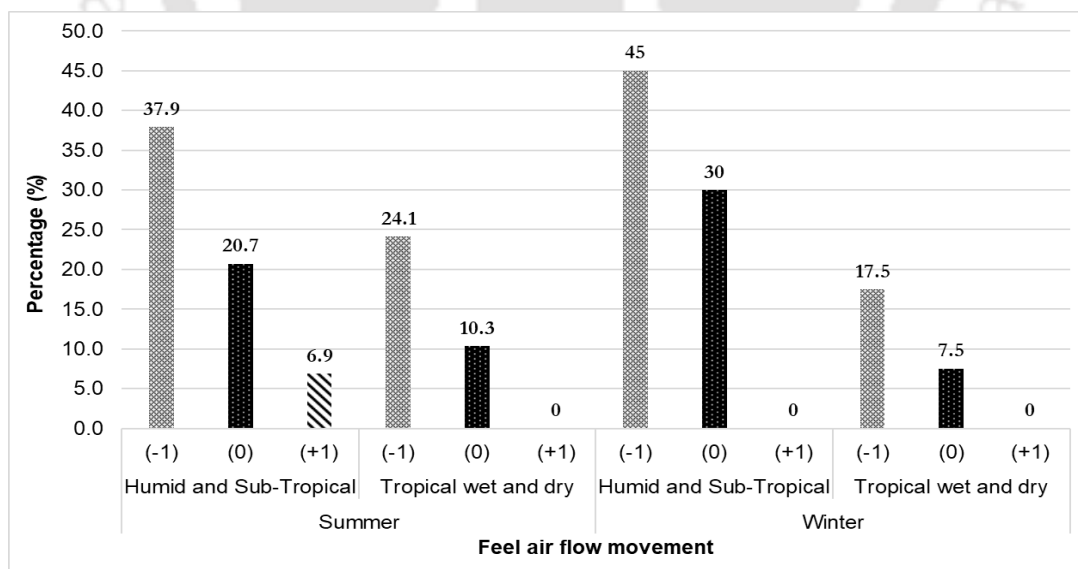


Figure 3.12. Dispensation percentage of subjective response to feel air-flow movement

Distribution percentage of personal discrimination on perceived humidity is depicted in Figure 3.13 during the seasonal and climate change variation. In order to feel the humidity,

the responses of the subjects were from too dry (-2), slightly dry (-1), just right (0), slightly humid (+1), too humid (+2). It was observed that almost 55% of the respondents felt very high humidity, while approximately 45% of the respondents felt slightly humid throughout the summer season in both climatic zones. During the winter season in both climatic zones, 45% of the respondents voted to feel very high humidity and 47.5% of the respondents felt slightly humid. Whereas only 5% of respondents had agreed with the existing environment and the remaining 2.5% of respondents felt slightly dry inside of the pantry car. The present result reveals that most of the workers have experienced humidity inside the pantry car which will affect working efficiency and productivity (Vellei et al., 2017).

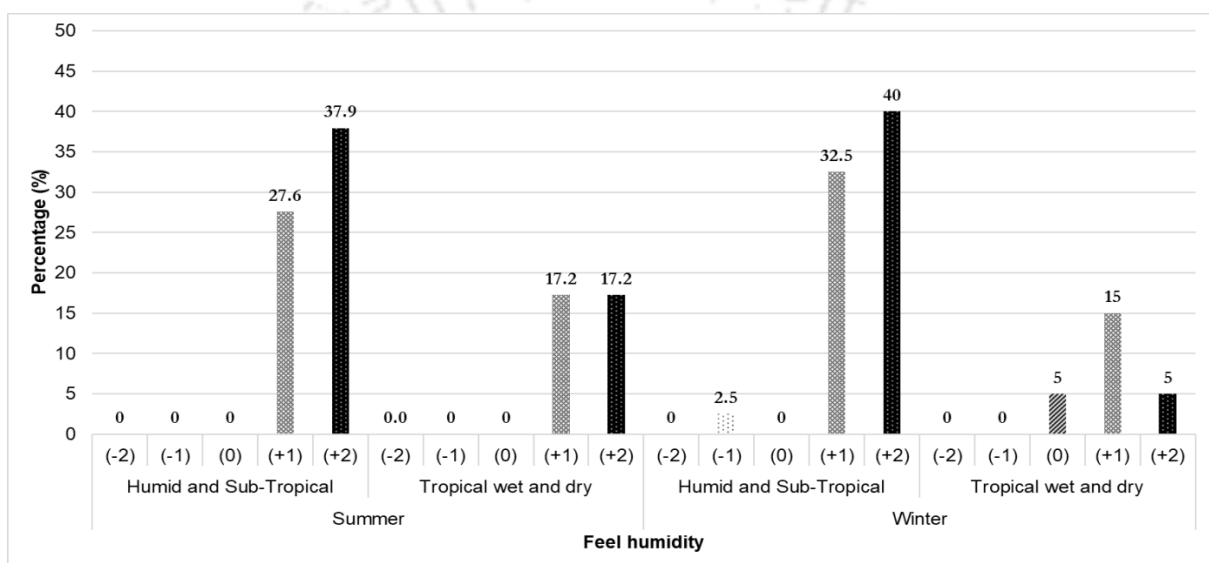


Figure 3.13. Dispensation percentage of subjective response to feel humidity

The air temperature is a crucial parameter for thermal comfort research, which every subject feel differently in any thermal environment. Figure 3.14 shows the distribution percentage of the subjective response to feel the temperature based on the season and climatic zones. The subjective responses were taken to feel the temperature from very good (1), good (2), acceptable (3), bad (4), very bad (5). In both climate zones during the summer season, it was observed that 44.8% of occupants voted to feel very bad temperature. Similarly, 48.3% respondents voted to feel bad temperature inside the pantry car during cooking. However, approximately 7% of the respondents accepted the current environmental temperature.

Similarly, during the winter season in both climate zones, it was perceived that 37.5% of respondents felt the temperature to be very bad. Also, 57.5% of the respondents' voted to feel the bad temperature. Only 5% of the respondents accepted current atmosphere inside the

pantry car. At the same time, no occupants voted to feel good temperature during the entire period.

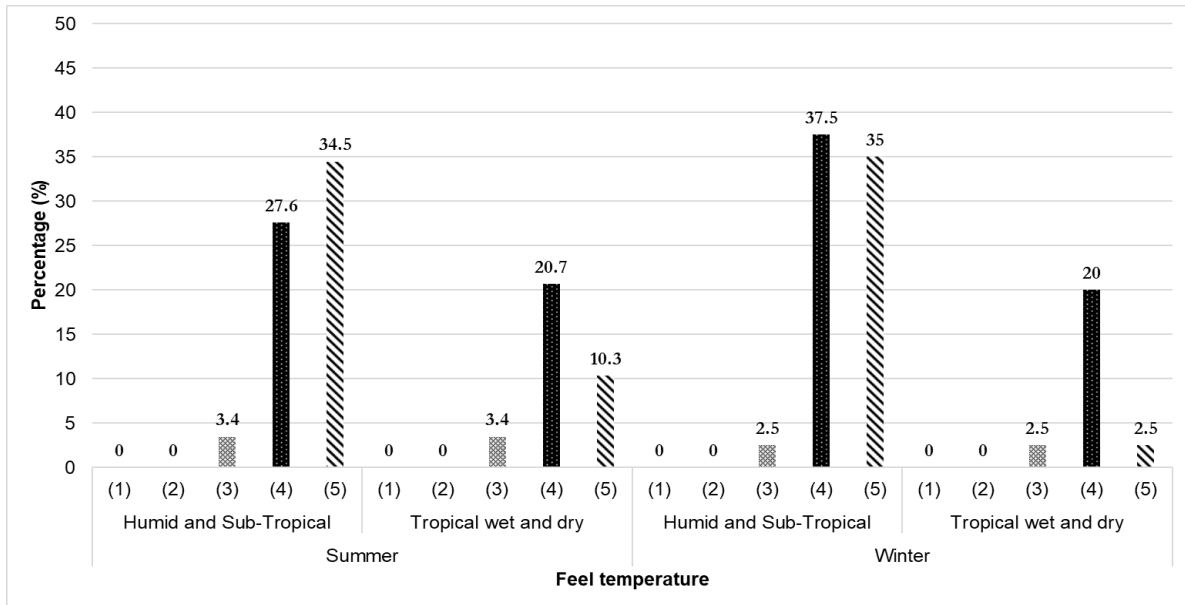


Figure 3.14. Dispensation percentage of subjective response to feel temperature

Indoor air quality (IAQ) is a function which depends on several factors including interior space design, outdoor air quality and the ventilation design systems. Figure 3.15 demonstrates that the subjective responses of air quality votes were taken during the seasonal and climatic variation on the rating scale: very good (1), good (2), acceptable (3), bad (4), very bad (5). During the summer season in a humid and subtropical climate zone, most of the respondents felt IAQ level bad while 20.7% respondents reported IAQ level very bad and only 3.4% of respondents accepted the present IAQ level in a pantry car. Similarly, during the summer season in a tropical wet and dry climate zone, the maximum percentage of responded voted to feel bad. Only 13.8% of the respondent accepted the existing situation of IAQ level. In the survey, almost in both climate zones in the summer season, most of the workers have felt IAQ level worse inside the pantry car kitchen during the cooking period.

Accordingly, at the time of winter season in a humid and subtropical climate zone, 50% and 12.5% responded that the IAQ level as bad and very-bad respectively. However, 12.5% of respondents have accepted the IAQ level in the existing situation. Similarly, in a tropical wet and dry climate zone, the maximum percentage of the responded voted to feel bad IAQ level during entire winter season while, 2.5% of respondents felt the very bad IAQ level in the current environment. Only 5% of the respondent does not want to change with the current working environment. They have accepted the indoor condition for cooking purpose.

Throughout the winter season in both climate zones, the maximum percentage of respondents felt the bad and very bad IAQ level.

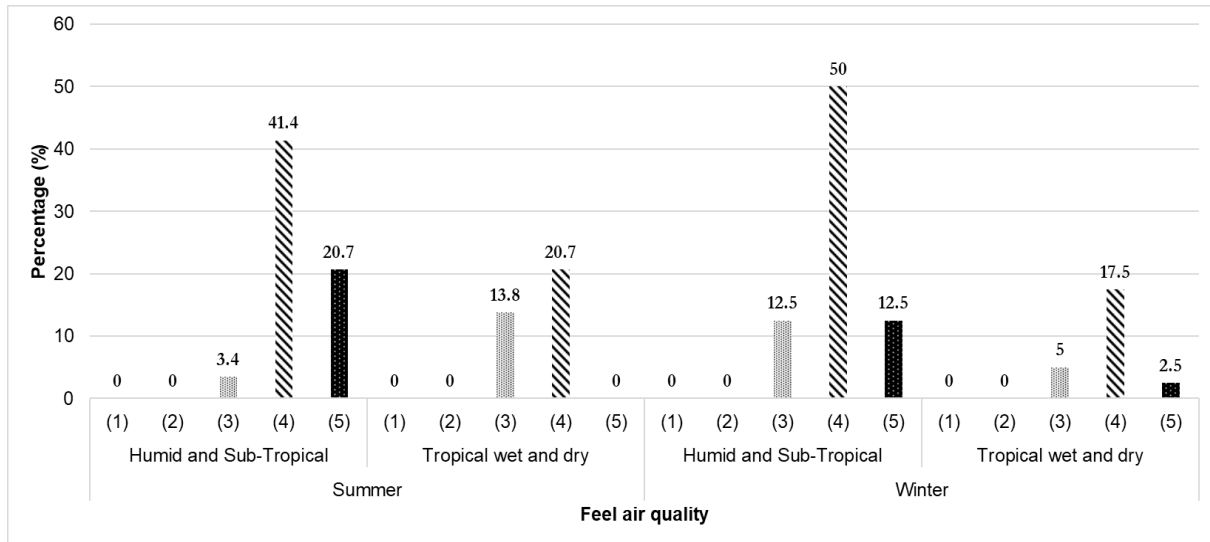


Figure 3.15. Dispensation percentage of subjective votes about the air quality

3.4.3 Optimum temperature

3.4.3.1 Neutral (comfort) temperature

To predict the T_n "neutral temperature" and T_{cr} "comfort temperature range", regression analyses were carried out using "MS Excel 2016". Figure 3.16 (a) and (b), demonstrate the regression of "thermal sensation votes-TSV" on "air temperature-Ta" in summer and winter are:

Summer:

$$TSV = 0.2193Ta - 4.8324 \quad r^2 = 0.5315 \quad (3.2)$$

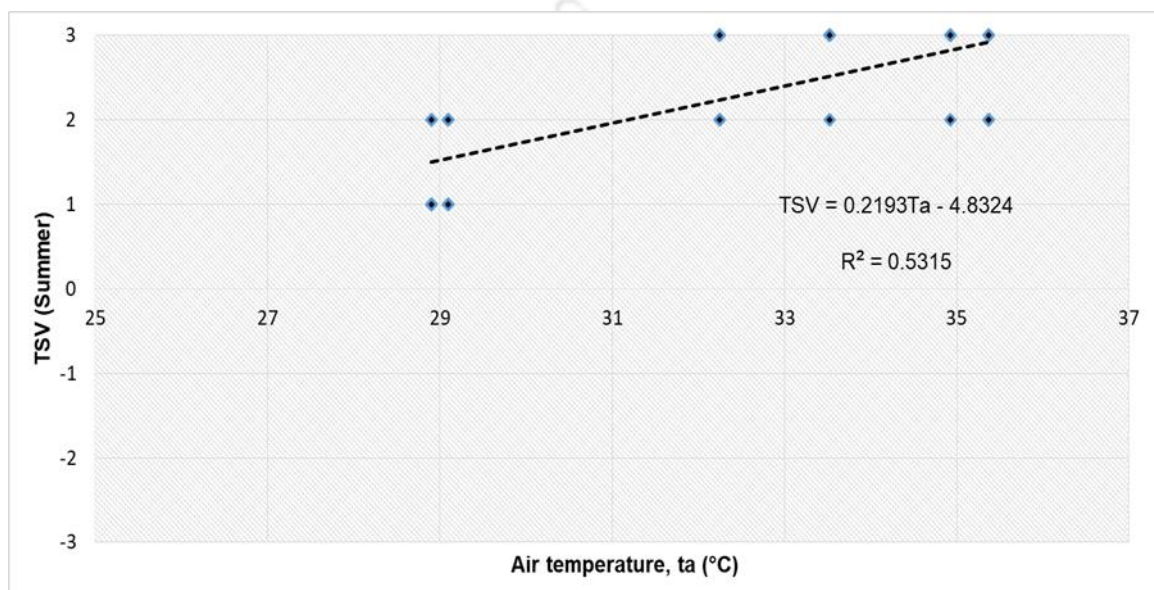
Winter:

$$TSV = 0.2646Ta - 5.6207 \quad r^2 = 0.3024 \quad (3.3)$$

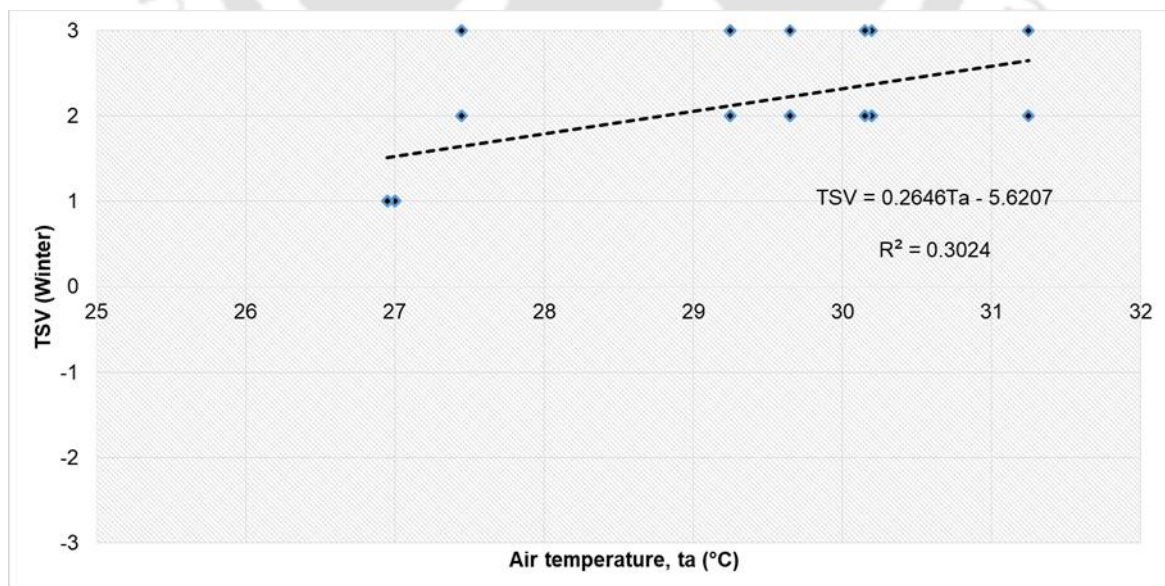
The coefficient of the determinant (r^2) between TSV and the Ta in summer is 0.5315 by equation (3.2) and in winter is 0.3024 by equation (3.3). This study found moderate r-values in the regression analysis (TSV Equations). Some authors also determined and indicated the neutral temperature (TSV Equations) with the r-value low and medium in the thermal comfort study (Karyono et al., 2015; Zhang et al., 2007; Gong et al., 2021; Samsuddin et al.,

2016; Kaja & Srikonda, 2019). Table 2.6 also shows the various researchers who obtained the comfort temperature using the TSV equation.

Table 3.12 demonstrates the neutral "comfort" temperature and comfort range of chefs in the railway pantry car. During the summer and winter season, the neutrality condition was derived by solving equation (3.2-3.3) for a zero thermal sensation vote. In the summer season in the pantry car, chef's neutral temperature was 23°C Ta. Similarly, in the pantry car in the winter season, the chef's neutral temperature was 21.62°C Ta.



(a)



(b)

Figure 3.16. The regression analyses between the TSV and Ta during (a) summer and (b) winter, season inside the pantry car

Table 3.12. Summer and winter season T_n and T_{cr} for chefs inside the pantry car

| Season | T_n (°C) | T_{cr} (°C) | Regression Equation | r^2 | Significance |
|--------|------------|---------------|----------------------------|--------|--------------|
| Summer | 23 | 18.50-27.80 | $TSV = 0.2193T_a - 4.8324$ | 0.5315 | $p < 0.01$ |
| Winter | 21.62 | 17.80-25.50 | $TSV = 0.2646T_a - 5.6207$ | 0.3024 | $p < 0.01$ |

3.4.3.2 Comfort temperature range

The comfort temperature range was determined based on the ASHRAE 55 standard, in which "comfort zone" is defined as thermal environmental conditions in which more than 80% of living people express satisfaction (Karmann et al., 2018). So, the percentages of dissatisfaction resulting from the above votes "central three categories (-1, 0, +1)" of ASHRAE scales in each temperature bin were plotted (Figures 3.17 and 3.18) as a function of air temperature.

Figures 3.17 and 3.18 shows the thermal sensation votes plotted against air temperature within each half-degree bin in summer and winter in the pantry car. The summer regression model ($r^2 = 0.5315$ $p < 0.01$ for regression coefficient and constant) fitted to bin vote is calculated by equation (3.2) and the winter regression model ($r^2 = 0.3024$ $p < 0.01$ for regression coefficient and constant) fitted to bin vote is by equation (3.3). Regression equations describing the dependence of sample thermal sensation on indoor air temperature are often used to define acceptable temperature limits for a particular sample. The indoor air temperatures corresponding to thermal sensations of +1 and -1 is stretch from 18.50 to 27.80°C in summer and from 17.80 to 25.50°C in winter. Compared to ASHRAE's comfort range 24.5–27.0°C during the summer season, pantry car chefs' comfortable range shifts to "slightly warm temperatures" by about 0.80°C. Similarly, compared to ASHRAE's comfort range 19.5–22.5°C during the winter season, pantry car chefs' comfortable range shifts to warm temperatures by about 3°C. This finding indicates a completely different phenomenon because pantry car chefs have different thermal adaptation to their climate.

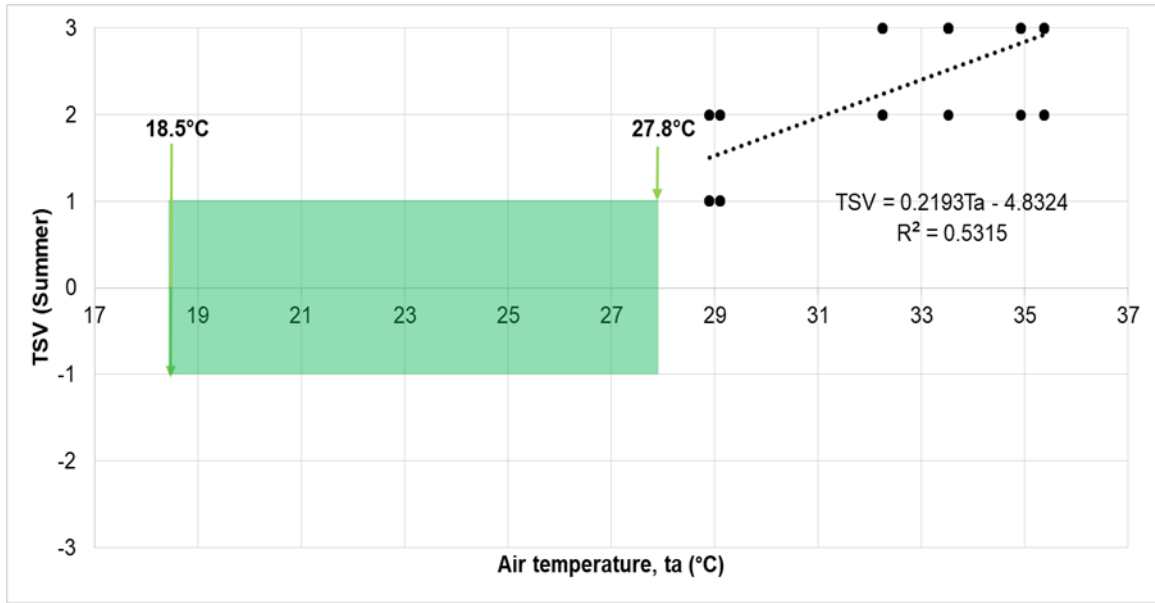


Figure 3.17. Comfort temperature range during summer

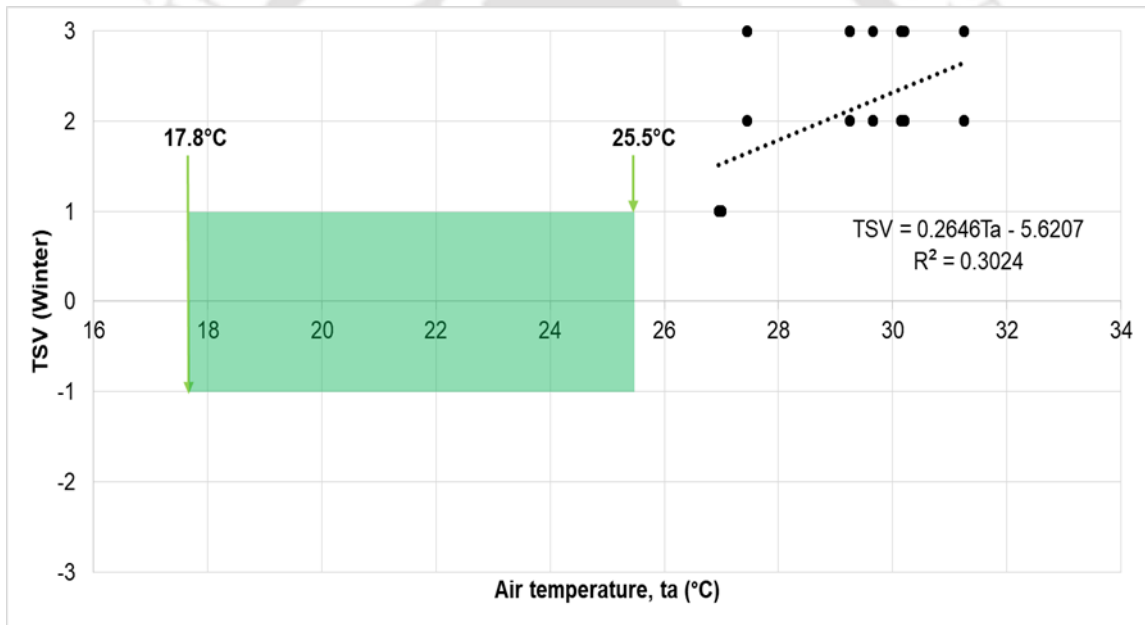


Figure 3.18. Comfort temperature range during winter

3.4.3.3 Subjects neutral temperature compared with other studies

Various researchers have studied to identify neutral temperatures in their thermal environment, as shown in Table 3.13. Chan et al. (1998) organized thermal comfort research on office premises in Hong Kong to improve the work environment.

Table 3.13. A summary of subjects neutral temperature some previous thermal comfort studies

| Researcher | Country/Location | Neutral temperature |
|-----------------------|---------------------|---------------------|
| Chan <i>et al.</i> | Hong Kong | 23.5°C |
| Ye <i>et al.</i> | China | 23.3°C |
| Lin <i>et al.</i> | Taiwan | 26.2°C and 27.4°C |
| Hwan & Cheng | Taichung, Taiwan | 25.6°C |
| Hamzah <i>et al.</i> | Makassar, Indonesia | 24.1°C |
| Karyono | Jakarta, Indonesia | 24.1°C |
| Hussein <i>et al.</i> | Malaysia | 24.4°C and 28.4°C |
| Deb & Ramachandraiah | Chennai, India | 31.93°C |

Similarly, in China, Ye et al. (2005) carried out the research on passenger train's coaches to determine the thermal environment and thermal comfort. Also, Lin et al. (2010) examined the thermal comfort study in "short-and long-haul" bus(s) and train(s) among the passengers in Taiwan. Furthermore, Hwang & Cheng (2007) reported on "human thermal comfort in air-conditioned offices workers in Taiwan", in which the authors computed and compared the comfort temperature with ASHRAE standard 55. Similar research was conducted by Hamzah et al. (2016) in "Indonesia" on naturally ventilated university classrooms to understand the "thermal environment condition and subjects responses", in which the authors estimated the comfort temperature and compared it with ASHRAE standard 55 and Indonesian National Standard. Karyono (2000) also finished a similar kind of research in Indonesia on university students to identify the comfort temperature. Hussein et al. (2009) conducted the study in Malaysia on "air-conditioned and non-air-conditioned in two schools buildings". Deb & Ramachandraiah (2010) researched on passenger thermal comfort in south railway stations in India to investigate the neutral temperature.

3.5 Summary

Objective assessment: the objective assessment indicates that the outdoor thermal parameters have an effect on the indoor thermal parameters during the seasonal and climatic variation at the time of cooking inside the pantry car. The maximum range of thermal parameters was found at lunch and snack preparation time and minimum range at the time of breakfast. The indoor physical conditions, "air temperature, globe temperature, relative humidity, and air velocity" were found to exceed limits of thermal comfort standards. During each cooking

period (breakfast, lunch, snacks, and dinner) inside the pantry car, the calculated value of the PMV-PPD index method does not comply with the ASHRAE 55 and ISO 7730 standard. A PMV-PPD index is not suitable for the thermal comfort application of pantry car kitchen due to high temperature.

Subjective assessment: the subjective assessment towards "thermal sensation, thermal comfort, thermal acceptability, and thermal preference votes" generally indicates that the chefs were dissatisfied with the existing condition in the pantry car kitchens.

The thermal neutrality of chefs occurred at 23°C and 21.62°C during the summer and winter season respectively. Similarly, responses from those chefs suggest a comfort temperature range of 18.50-27.80 °C and 17.80-25.50 °C during summer and winter season was found respectively. This indicates shifts to slightly warm temperature for summer and warmer temperature for winter by about 0.80 °C and 3 °C respectively as recommended by ASHRAE 55 standards.

The consequences of this chapter revealed that the indoor environment inside the railway pantry car is inconvenient during the cooking work period. As per the literature, proper airflow supply management could help to maintain/improve thermal comfort. For this purpose, a modeling and simulations approach could be performed in further investigation.

This chapter demonstrates the enhancement of thermal comfort inside the kitchen of non-air-conditioned and air-conditioned railway pantry cars using the computational fluid dynamics (CFD) approach and SET indices during different cooking periods. Figure 4.1 illustrates the study design of the CFD simulation, modelling and analysis. Simulation analysis was performed separately for both types of pantry cars due to the different physical structures.

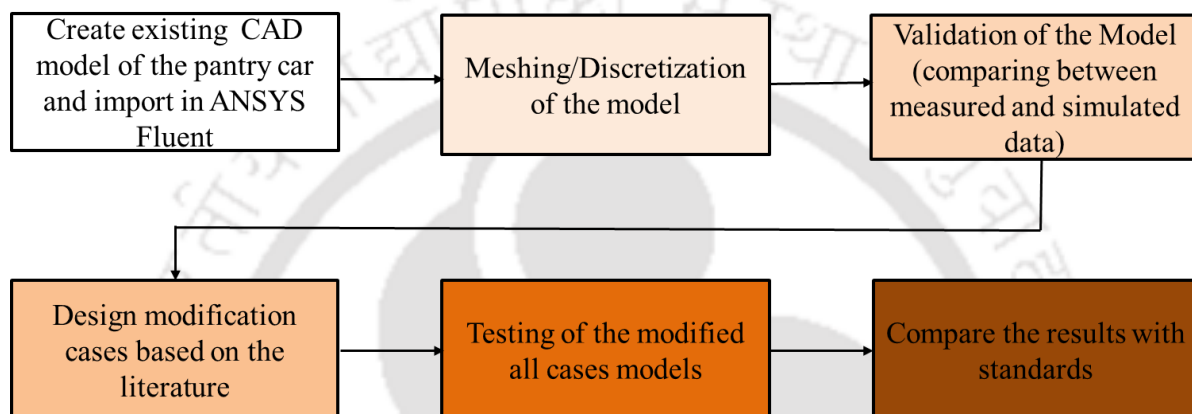


Figure 4.1. Study design of CFD simulation analysis

4.1 Improving thermal comfort inside the kitchen of non-air-conditioned pantry car

4.1.1 Details of the non-air-conditioned pantry car kitchen

The existing situation of the non-air-conditioned kitchen of the Indian railway pantry car is depicted in Figure 4.2.



Figure 4.2. Existing model of non-air-conditioned pantry car kitchen

As shown in Figure 4.3, non-air-conditioned pantry cars are usually rectangular shaped with the length (L), width (W), and height (H) as 22.29m, 3.24m, and 3.11m respectively. There are four doors on both sides and seventeen windows on the opposite side of the kitchen area, however, around eleven windows on the kitchen side-wall. The dimensions of the kitchen area are, L=8.10m, W=2.20m, and H=3.11m approx. As discussed in previous studies, four or five chefs work in kitchen area (Alam et al., 2019a). This type of pantry car model is usually manufactured from corten steel and mild steel. No ventilation system is included in this pantry car to reduce indoor hot air, and the air velocity also found to be very low, according to previous studies (Alam et al., 2019b).

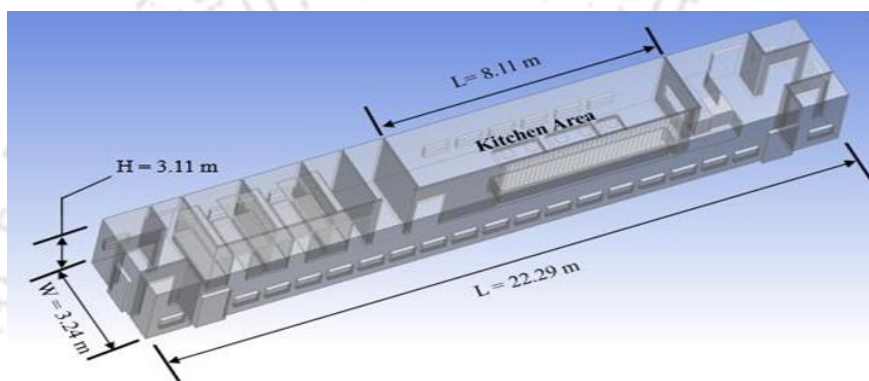


Figure 4.3. Description of the non-air-conditioned pantry car

4.1.2 Measurement

Figure 4.4 shows the measuring point inside the kitchen area of the pantry car, where the following parameters were measured, such as; "air temperature, globe temperature, relative humidity, and air velocity". During the field study, the data was taken with the help of instrument at 1.1m above the floor height and 0.3m near to the cooking area during summer and winter seasons. All data were taken in a pantry car during the cooking period of "breakfast (7:00 am), lunch (11:30 am), snack (4:00 pm), and dinner (6:30 pm)". In the previous chapter, a description of the instrument's accuracy and range was shown in Table 3.1.

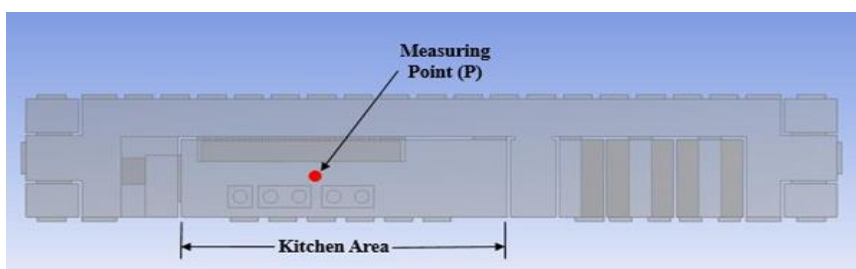


Figure 4.4. Location of field measurement data collection point

4.1.3 Standard effective temperature (SET) index estimation

In the current investigation, the “standard effective temperature-SET” index was used in the pantry car kitchens for predicting thermal comfort. Six key input parameters are necessary for estimating the SET index, where four are environmental factors such as; air temperature, mean radiant temperature (based on the globe temperature), relative humidity, air velocity; and two personal factors are metabolic rate and clothing level. In this index, the thermal sensation range based on SET is “Cool $<17^{\circ}\text{C}$ ”, “Comfortable $17\text{-}30^{\circ}\text{C}$ ”, “Warm $30\text{-}34^{\circ}\text{C}$ ”, “Hot $34\text{-}37^{\circ}\text{C}$ ”, “Very Hot $>37^{\circ}\text{C}$ ” (Zare et al., 2018). The CBE thermal comfort software was mainly included in this study to estimate the SET index according to the ASHRAE-55 2017 standard. In this experiment, metabolic rate and clothing insulation values were assumed 1.5 to 2.0 (met) and 0.5 to 0.58 (clo), respectively, as per the earlier thermal comfort study of the pantry car (Alam et al., 2019a; Alam et al., 2019b). The “mean radiant temperature” was assumed to be equal to the air temperature while performing the simulation, and the percentage of relative humidity was taken as “50-60%” (Alam et al., 2019b; Hussin et al., 2014; Lebon et al., 2017; Chena et al., 2019).

4.1.4 CFD modelling and simulation

"Computational Fluid Dynamics-CFD" technique was incorporated to demonstrate the flow simulation to estimate the air temperature and airflow velocity dispensation inside the railway pantry car's kitchen. This technique was also applied to predict pantry cars' thermal comfort estimation based on the parametric study to recognize the appropriate strategy and enhance thermal comfort. Solidworks 2015 was used to construct the 3D-model of the existing railway pantry car kitchen as depicted in Figure 4.5, and then the created 3D-model (in “.igs” file format) was imported in the ANSYS fluent R14.5 version software.

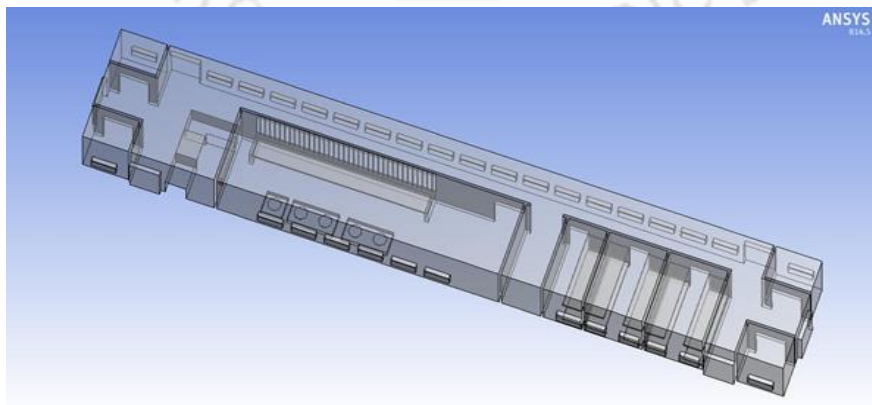


Figure 4.5. 3D-model of the railway pantry car kitchen

Governing equations viz., mass, momentum, and energy were used for CFD analysis of the model (see Appendix-II).

According to the literature the "k-epsilon RNG" turbulence flow model is included for simulation analysis that is more suitable for kitchen environments (Abanto & Reggio, 2006; Fujimura et al., 2017; Mak & Yik, 2002; Ren et al., 2012; Saha et al., 2012). In particular tetrahedral volume elements were used for the lattice of the CFD model. However, the patch conforming technique was included to develop the mesh with a "fine relevance centre" (Yahya et al., 2019). Finer meshing was performed at particular specific importance regions like doors, air vents, exhaust, burner, and fan using edge-sizing and face-sizing meshing. The total number of nodes and elements of the mesh model were 99786 and 523873 respectively. The ultimate mesh model of the railway pantry car kitchen is demonstrated in Figure 4.6. Table 4.1 shows the pantry car's entire cooking period's boundary conditions during the winter and summer seasons. The inward air velocity was considered in boundary conditions as air comes from the left and right door's sides. However, both the front and opposite side of the kitchen window was considered closed, as chefs tend to close the windows on each side of the kitchen while cooking, as reported by Alam et al. (2019a). Therefore, "air temperature and air velocity" were recorded near the same specified doors. The heat source was taken as the burner temperature according to the workload of different cooking times, which was assumed based on the standard gas burner temperature limit (Brannigan et al., 1980). As earlier study indicated that the busiest and hottest cooking period inside the kitchen of pantry car was during lunch and snacks, while breakfast and dinner cooking had lower temperatures (Alam et al., 2019b). In this analysis, the fan speed with speed 1200-1500 rpm was selected based on the literature (Mathan Kumar et al., 2020; Abanto & Reggio, 2006). In this study, the convergence criteria of the energy equation were taken 10^{-6} , while for all others equations the convergence criteria were considered 10^{-4} according to literature (Hussin et al., 2014b; Noman et al., 2016; Saha et al., 2012).

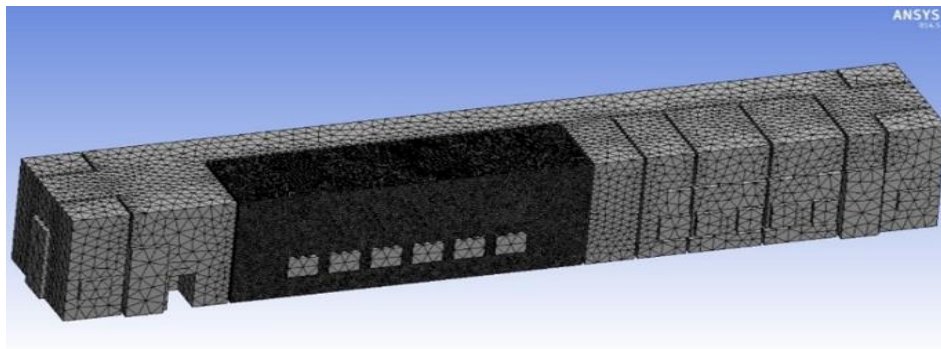


Figure 4.6. Mesh model of the railway pantry car kitchen

Table 4.1. Boundary conditions of the entire cooking period in the pantry car

| Boundary Conditions | | | |
|---|-----------------|--------------|--------------------|
| <i>Summer Season</i> | | | |
| Cooking period | Air temperature | Air velocity | Burner temperature |
| Breakfast | 301K (27.85°C) | 0.2m/s | 755K (481.85°C) |
| Lunch | 304K (30.85°C) | 0.1m/s | 905K (631.85°C) |
| Snacks | 303K (29.85°C) | 0.15m/s | 823K (549.85°C) |
| Dinner | 302K (28.85°C) | 0.30 m/s | 905K (631.85°C) |
| <i>Winter Season</i> | | | |
| Breakfast | 296K (22.85°C) | 0.25m/s | 755K (481.85°C) |
| Lunch | 300K (26.85°C) | 0.3m/s | 905K (631.85°C) |
| Snacks | 298K (24.85°C) | 0.2m/s | 823K (549.85°C) |
| Dinner | 297K (23.85°C) | 0.1m/s | 905K (631.85°C) |
| Exhaust mass flow rate: 1.2 to 1.5 kg/s | | | |
| Fan speed: 1200 rpm to 1500 rpm | | | |
| Solver model: k-epsilon RNG model | | | |
| Number of elements: 523873 | | | |
| Number of nodes: 99786 | | | |

The pantry car's CFD model was validated by comparing the measured value of air temperature and air velocity at the centre of the cooking zone with the corresponding values acquired from the simulation analysis. Table 4.2 and Table 4.3 correspondingly demonstrate the comparison between measured and simulated data of "air temperature and air velocity" based on the percentage difference during summer and winter seasons. The percentage differences in "air temperature and air velocity" in both seasons were found to be less than 5% and 20%, respectively, which is found to be satisfactory according to the ASHRAE-55 standard (Malek et al., 2015; Noman et al., 2016). As reported by Noman et al. (2016) for complex geometry, 20% error between measured and simulated data is agreeable for flow simulation analysis.

Table 4.2. Comparison of measured and simulated air temperature (in °C)

| Seasons | Cooking | Measured | Simulated | % Difference |
|---------|-----------|----------|-----------|--------------|
| Summer | Breakfast | 30.92 | 30.20 | 2.35 |
| | Lunch | 33.85 | 32.66 | 3.57 |
| | Snacks | 33.22 | 32.80 | 1.27 |
| | Dinner | 31.40 | 30.86 | 1.73 |
| Winter | Breakfast | 26.85 | 26.20 | 2.45 |
| | Lunch | 31.70 | 31.22 | 1.52 |
| | Snacks | 29.75 | 29.50 | 0.84 |
| | Dinner | 27.65 | 27.15 | 1.82 |

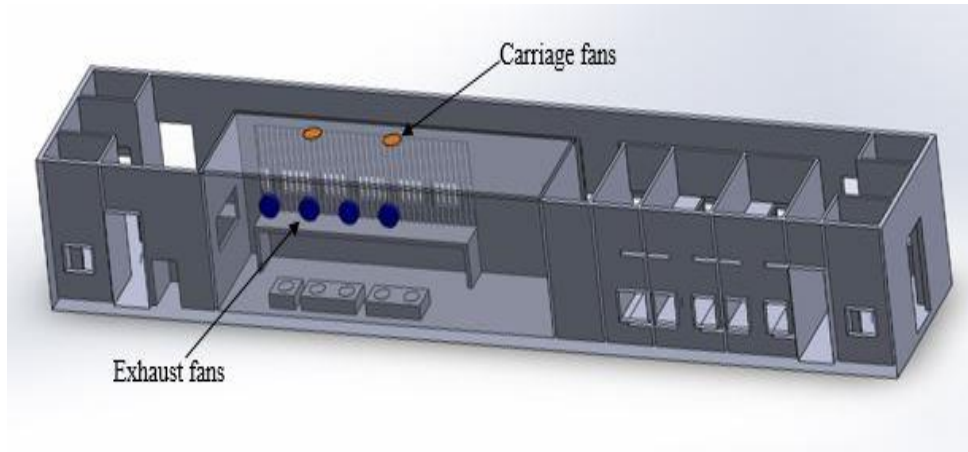
Table 4.3. Comparison of measured and simulated air velocity (in m/s)

| Seasons | Cooking | Measured | Simulated | % Difference |
|---------|-----------|----------|-----------|--------------|
| Summer | Breakfast | 0.033 | 0.038 | 14.08 |
| | Lunch | 0.00 | 0.00 | 0.00 |
| | Snacks | 0.017 | 0.015 | 12.50 |
| | Dinner | 0.050 | 0.046 | 8.33 |
| Winter | Breakfast | 0.040 | 0.046 | 13.95 |
| | Lunch | 0.088 | 0.080 | 9.50 |
| | Snacks | 0.013 | 0.011 | 16.60 |
| | Dinner | 0.00 | 0.00 | 0.00 |

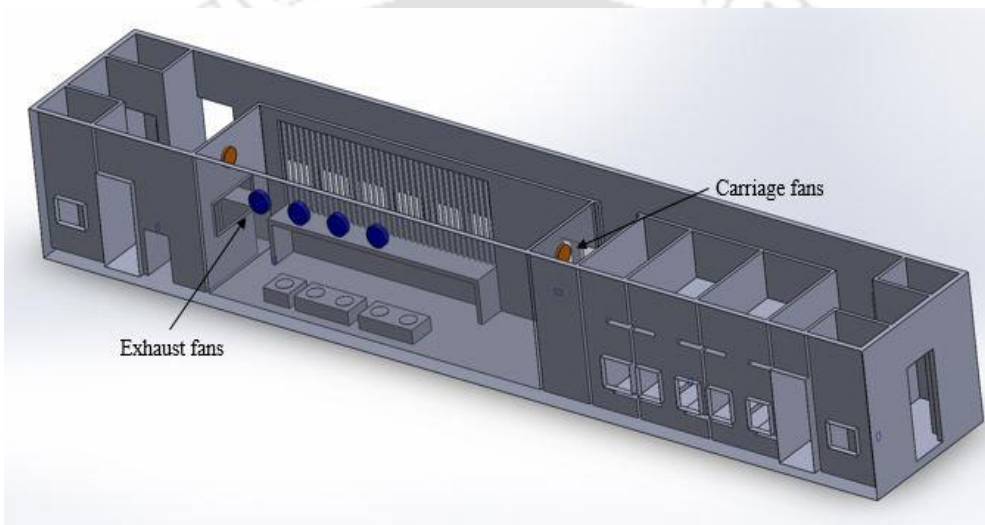
Previous thermal comfort studies suggested that indoor thermal comfort can be effectively increased by improving the ventilation system (Zomorodian et al., 2016). A proper ventilation system helps to maintain the distribution of air temperature and airflow velocity inside the workplace. The study of Noman et al. (2016) directed the installation of the four exhaust fan on the workplace wall to enhance thermal comfort. Another researcher Kamar et al. (2019) informed that thermal comfort could increase by installing ten standard/typical wall exhaust fans on the wall with different air supplies. It also has advantage of consumption of less power (Kamar et al., 2019). According to the literature in this study, four exhaust fans have been considered with different air supply positions of carriage fans and air-vents as shown in Table 4.4. Four different cases of pantry car kitchens were considered which are shown in Figure 4.7 and Table 4.4. Proposed design models were created in Solidworks 2015 and thereafter imported (“.igs” format) in ANSYS 14.5 workbench for CFD analysis using ANSYS fluent.

Table 4.4. Modification of the cases of pantry car kitchen

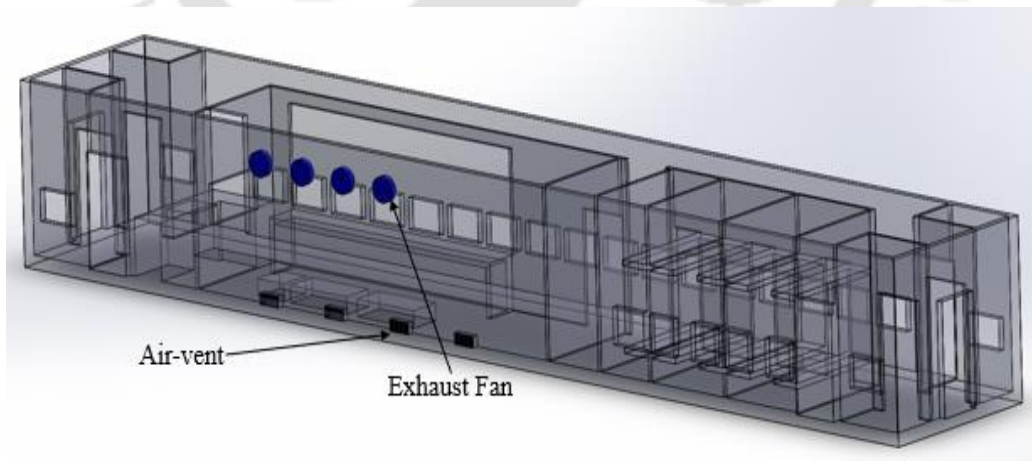
| Cases | Number | | Location | |
|----------|--------------|----------------------------|--------------|----------------------------|
| | Exhaust fans | Carriage fans and Air-vent | Exhaust fans | Carriage fans and Air-vent |
| Case I | 4 | 2 | Front wall | Roof |
| Case II | 4 | 2 | Front wall | Right & left side wall |
| Case III | 4 | 4 (air vents) | Front wall | Lower side front wall |
| Case IV | 4 | 3 | Front wall | Bottom surface |



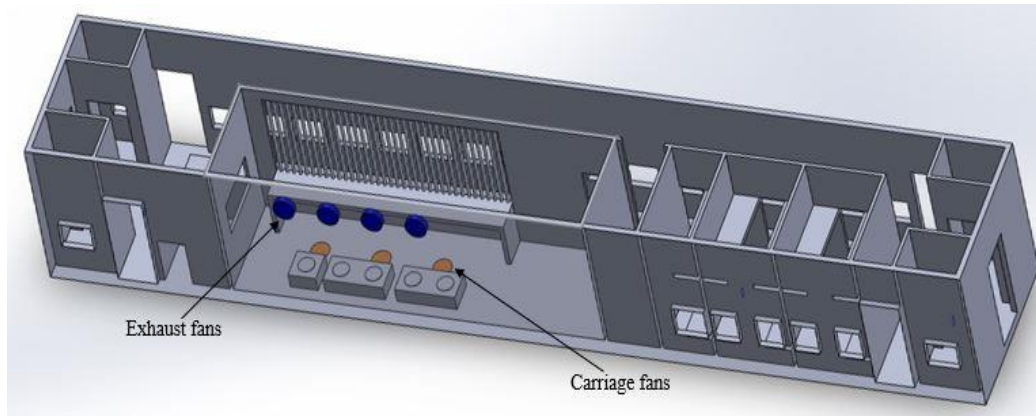
(a) Case I



(b) Case II



(c) Case III



(d) Case IV

Figure 4.7. Various modification cases – (a) Case I, (b) Case II, (c) Case III, and (d) Case IV

For all cases, the exhaust fan's airflow velocity was considered according to the ASHARE 55 standard (ASHRAE, 2013; 1992). In this study, 450 mm diameter of exhaust fan was taken, which is readily available in the market. Based on the fan speed (1200-1500 rpm), we have taken fan diameter 450 mm in this study to perform simulation analysis. This equipped exhaust fan dia was suitable as the fan manufacturer specified their product specifications. Also, a previous study suggested that increasing exhaust fan volume will reduce the dissatisfaction of human thermal sensation inside the kitchen environment (Chen et al., 2020). The simulation was performed by placing it 2 ft. (609.6 mm) below the roof on the kitchen's front wall, and the distance between the two exhaust fans was taken up to 950 mm. In this study, the distance between two exhaust fans has been taken as the window distance of the railway coach. Also, we placed it below the roof while doing the simulation based on the guidelines of the previous literature (Noman et al., 2016). And the fan distance we took was based on the indoor architecture of the railway pantry car. Various researchers performed similar concepts while performing CFD simulations in non-airconditioned environments (Noman et al., 2016; Kamar et al., 2019; Sugiono et al., 2019).

Case I includes two carriage fans were installed on the roof with a diameter of 400 mm at a distance of 670 mm from the kitchen side wall, while the distance between the two carriage fans was 1900 mm. Similarly at a distance of 609.60 mm from the roof, the same size of the carriage fan was fitted in *Case II* on the kitchen's left and right side. Whereas in *Case III*, 97.49 × 209.32 mm size of air-vent used at the lower side of the front wall, and the distance between two vents was 1500 mm. In *Case IV* also, the same size of carriage fans was installed on the bottom surface, while here, the distance between the two fans was 1900 mm.

The values of air temperature and air velocity acquired from the CFD analysis were used to calculate the new values of 'SET'. After that, the values of 'SET' were compared with the existing case values and to assess the appropriate design modifications for improving thermal comfort.

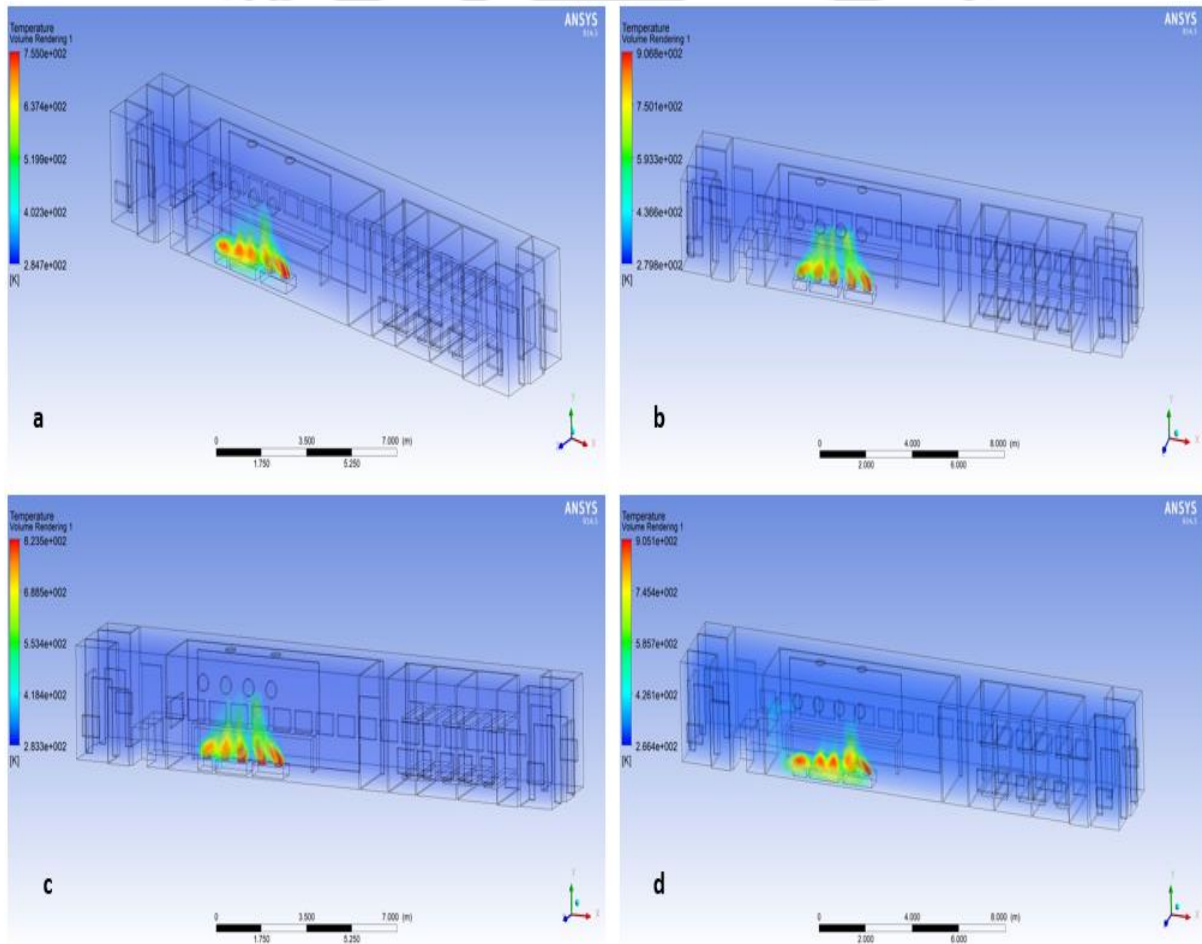
4.1.5 Results and discussion

In this study, all four modified cases have been numerically simulated by the ANSYS Fluent R14.5 software for redistribution of air supply and exhaust systems inside the kitchen of the pantry car. The consequences of the air temperature and air velocity within the pantry car kitchen has been taken 1.1m above the bottom surface and 0.3m distance from the working space. Figure 4.8 and Figure 4.9 shows the *Case I*, summer and winter seasons (i) air temperature and (ii) air velocity distribution profile of CFD at various cooking periods; (a) breakfast, (b) lunch, (c) snacks, and (d) dinner. In this case, during the summer season, the maximum distribution value of air temperature (27.8°C) was predicted at lunch-time. While minimum temperature (27.13°C) was observed at breakfast time. However, maximum (0.19m/s) and minimum (0.13m/s) air velocity distribution values were simulated at dinner and lunch, time respectively. Similarly, in the winter season, the maximum value of air temperature (25.7°C) was simulated at lunch-time, and the minimum temperature (22.8°C) was found at dinner time. However, the maximum (0.15m/s) and minimum (0.11m/s) air velocity values were rooted at lunch and snack time respectively. Furthermore, Figure 4.10 and Figure 4.11 demonstrates the *Case II*, summer and winter seasons air temperature and air velocity distribution profile at different cooking periods. In the summer season, at snacks and breakfast, air temperature value was maximum (30.89°C) and minimum (28.16°C). Simultaneously, air velocity value was calculated as maximum (0.15m/s) at dinner and minimum (0.06m/s) at lunch. In the winter season, the maximum (29.8°C) air temperature was found at dinner time and minimum (22°C) at breakfast. The value of air velocity was found highest at 0.12m/s at breakfast and lunch, while the minimum value was 0.08m/s at dinner.

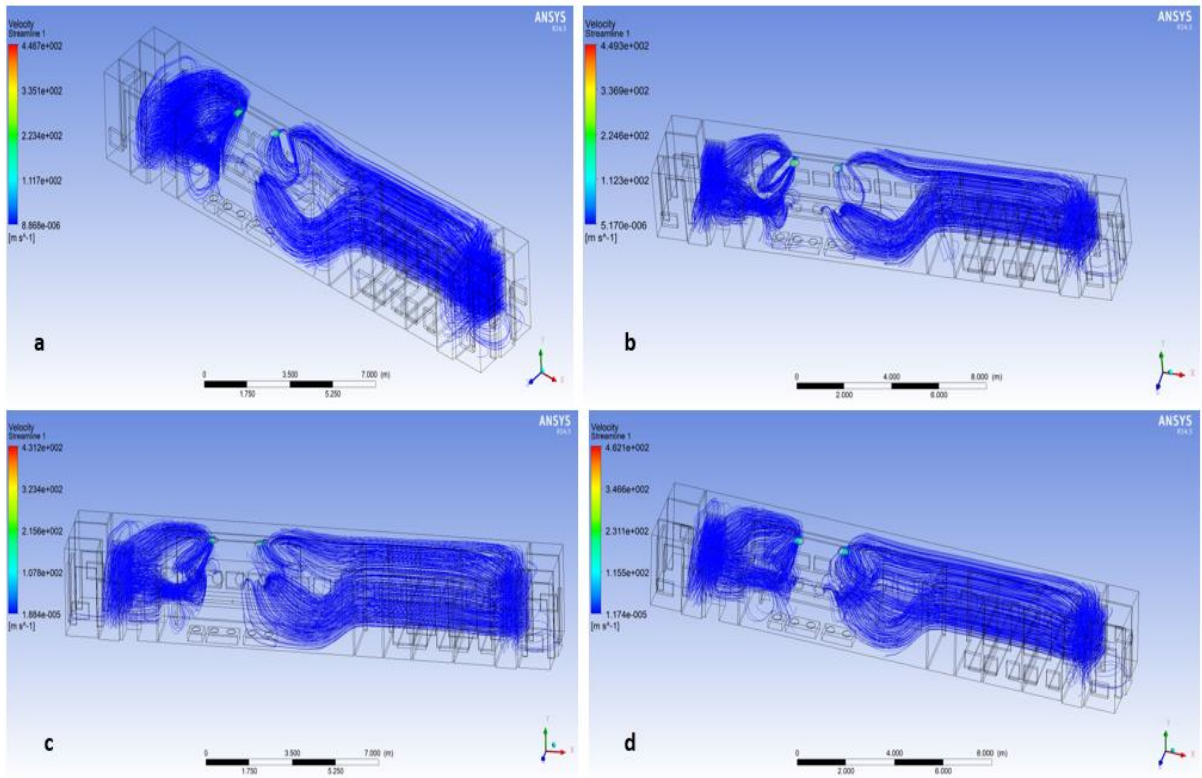
Similarly, for *Case III*, Figure 4.12 and Figure 4.13 shows the summer and winter seasons, air temperature and air velocity distribution profile at different cooking periods. In this case, during the summer season, the value of air temperature was found highest (30.83°C) and lowest (27.59°C) at lunch and breakfast periods respectively. Meanwhile, the air velocity speed was found to be highest at dinner (0.06m/s) and lowest (0.01m/s) at the lunch periods. However, in the winter season, the value of air temperature was found maximum (26.61°C)

and minimum (22.63°C) at lunch and breakfast periods. The air velocity movement was rooted highest (0.06m/s) at lunch and lowest (0.01m/s) at dinner.

Figure 4.14 and Figure 4.15 shows the *Case IV*, summer and winter seasons air temperature, and air velocity distribution profile at various cooking periods inside the railway pantry car's kitchen. During the summer season, maximum (31.07°C) and minimum (27.8°C) air temperatures was calculated over the lunch and breakfast periods respectively. Likewise, the air velocity movement was found highest (0.05m/s) at dinner and lowest (0.01m/s) at lunch preparation time. Similarly, during the winter season, the air temperature was found maximum (26.77°C) at lunch and minimum (22.64°C) at breakfast. The air velocity movement was noted highest (0.05m/s) and lowest (0.01m/s) at lunch and dinner respectively.

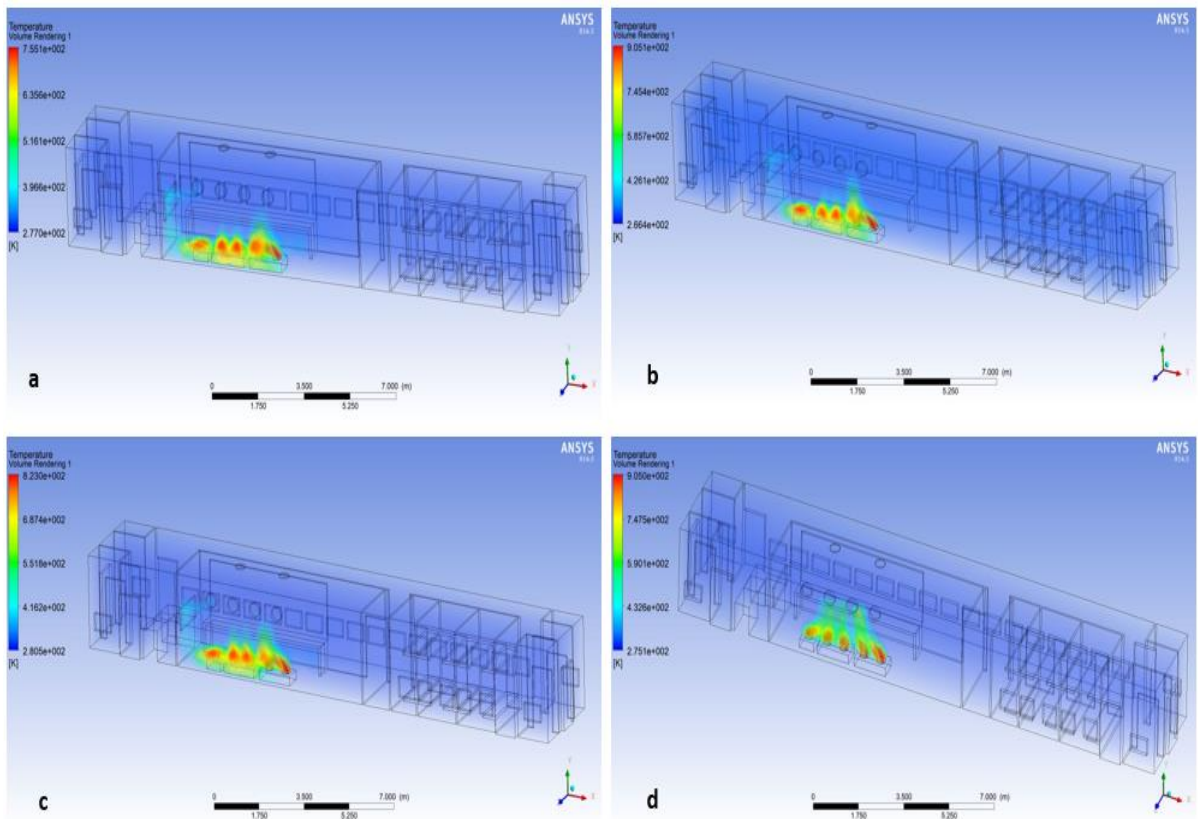


(i) Air temperature

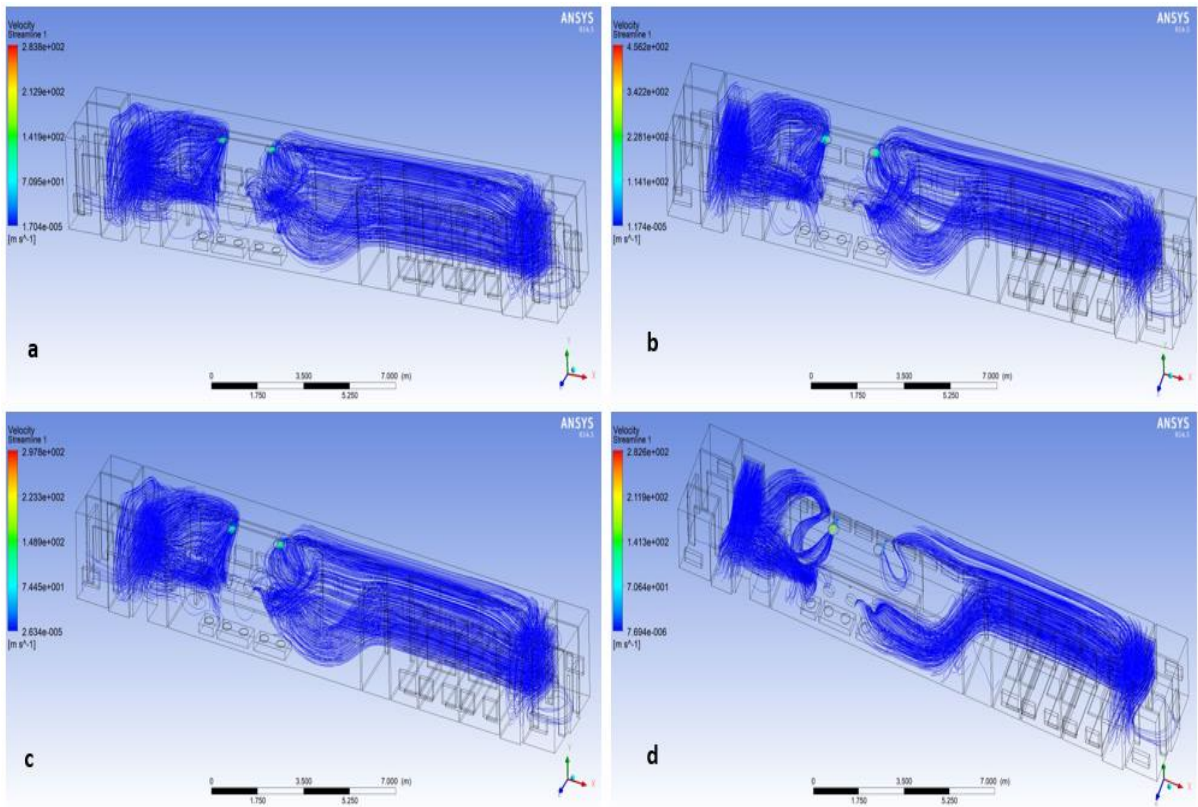


(ii) Velocity

Figure 4.8. Case I, summer season (i) air temperature and (ii) velocity, distribution profile of CFD at various cooking period; (a) breakfast, (b) lunch, (c) snacks, and (d) dinner

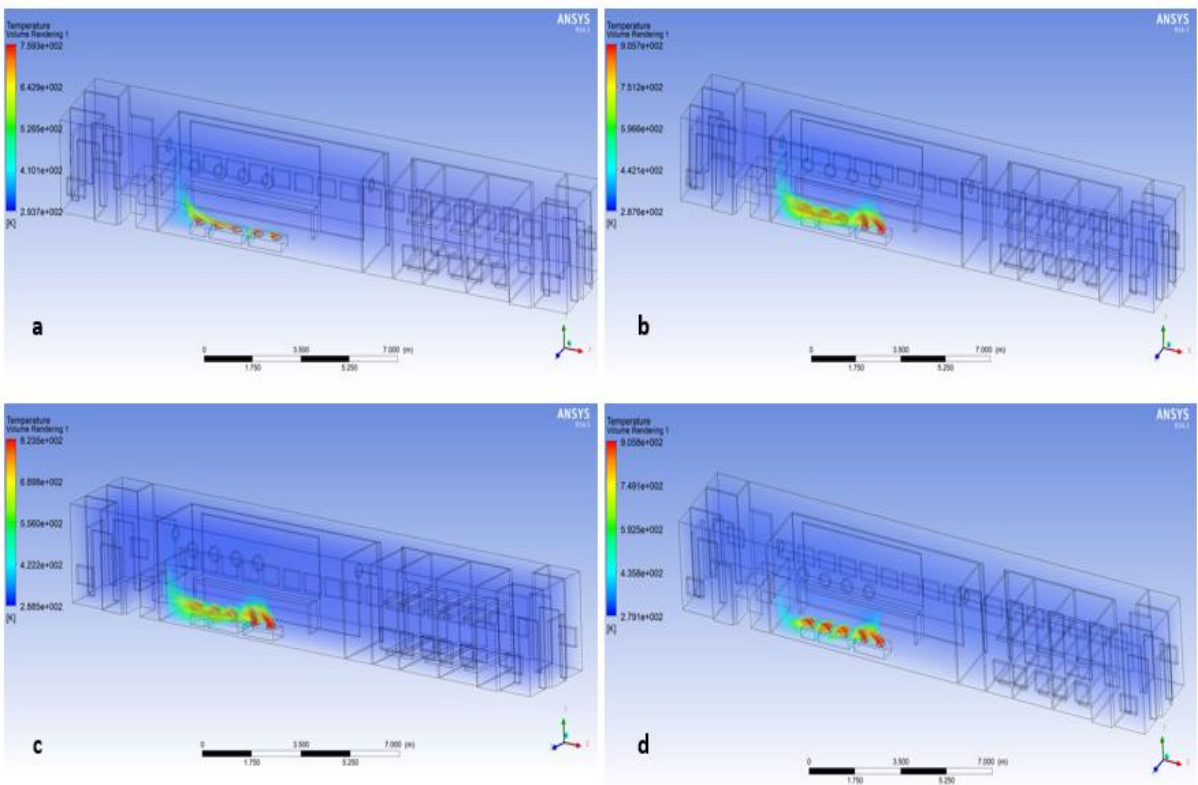


(i) Air temperature

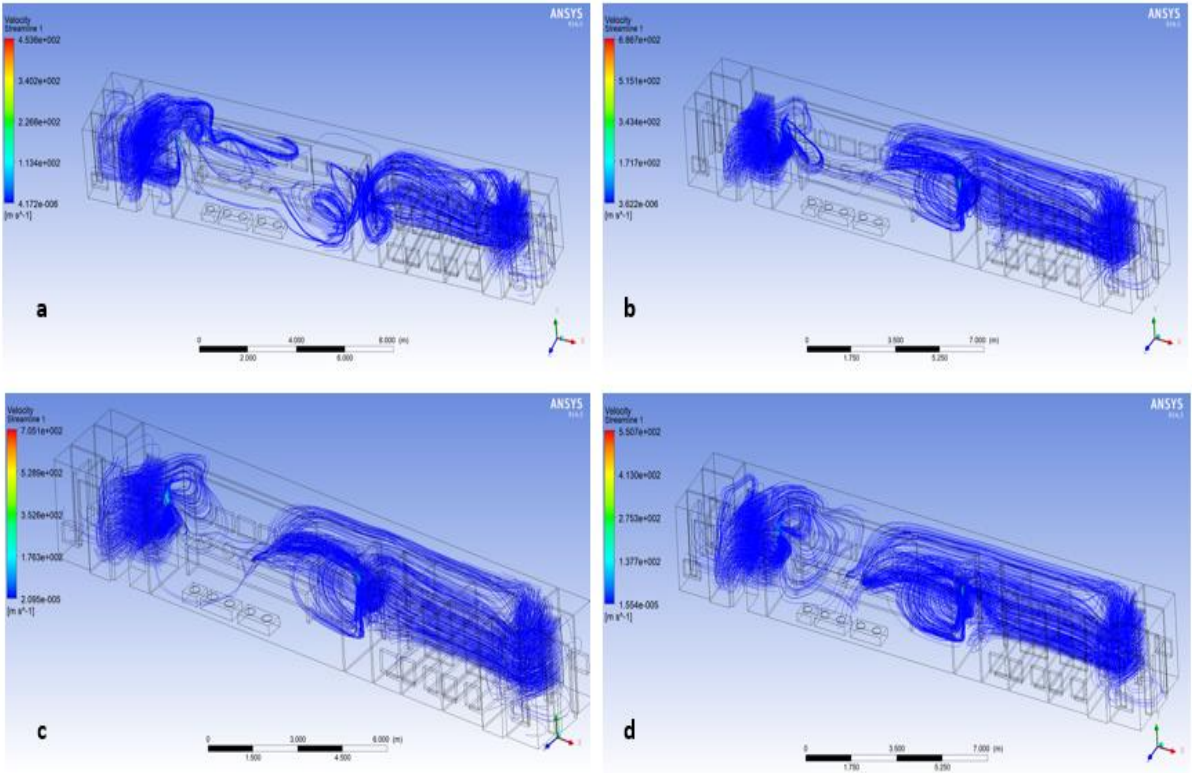


(ii) Velocity

Figure 4.9. Case I, winter season (i) air temperature and (ii) velocity, distribution profile of CFD at various cooking period; (a) breakfast, (b) lunch, (c) snacks, and (d) dinner

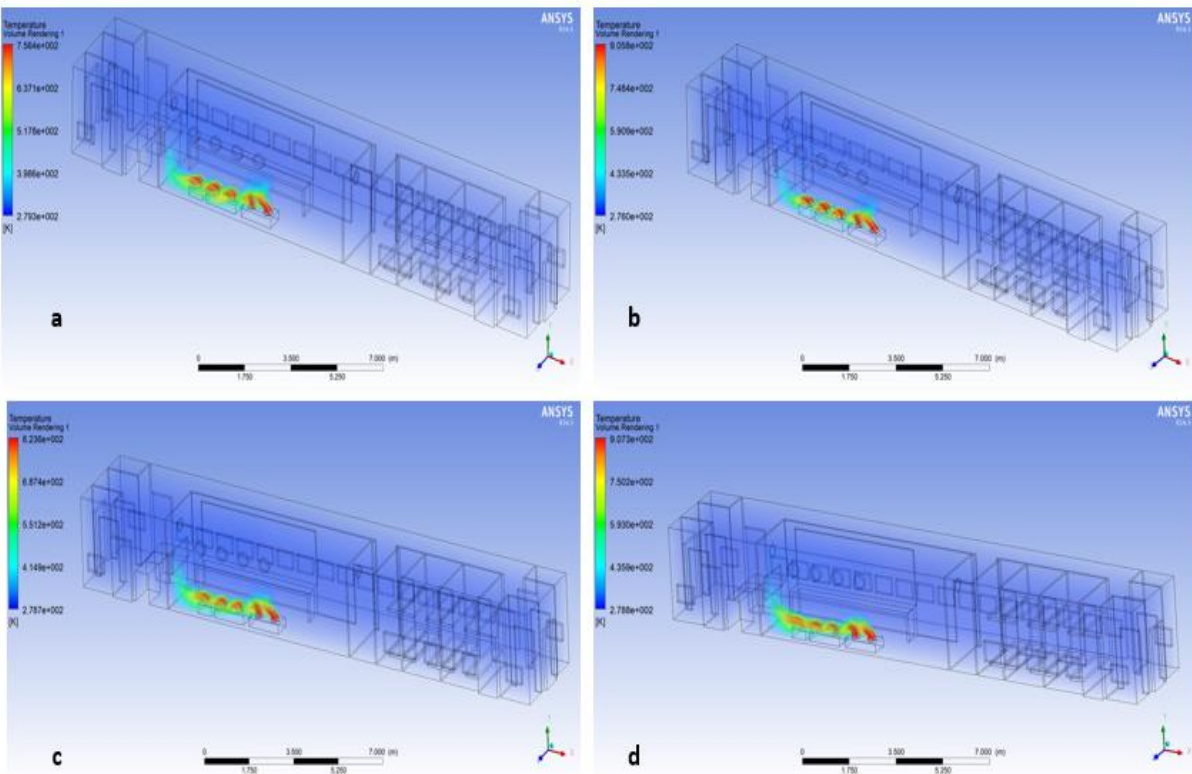


(i) Air temperature

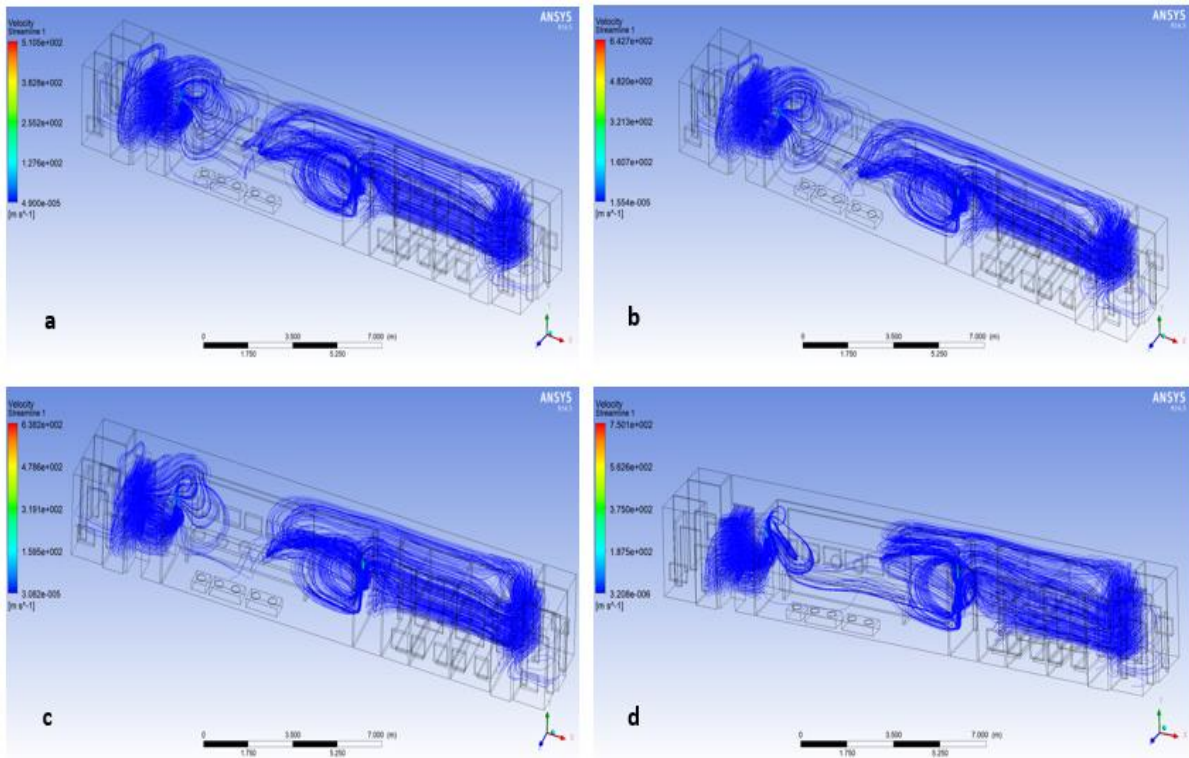


(ii) Velocity

Figure 4.10. Case II, summer season (i) air temperature and (ii) velocity, distribution profile of CFD at various cooking period; (a) breakfast, (b) lunch, (c) snacks, and (d) dinner

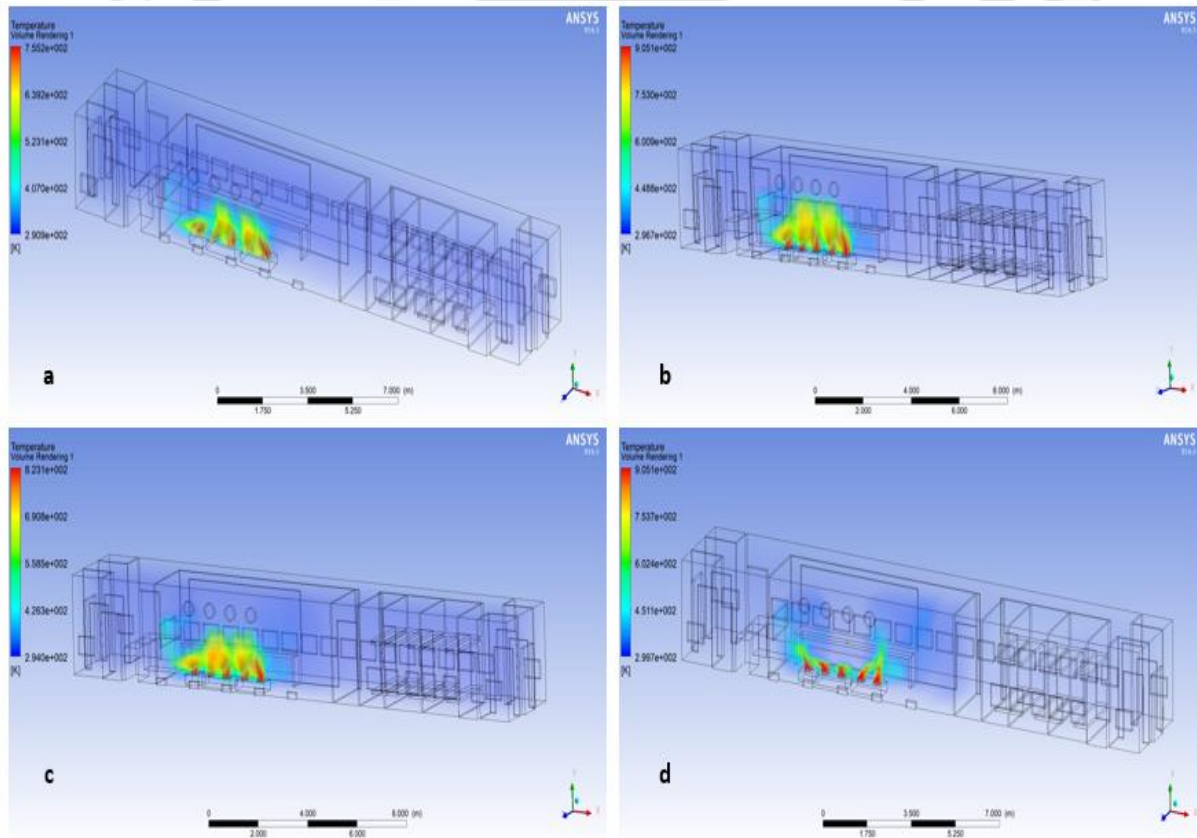


(i) Air temperature

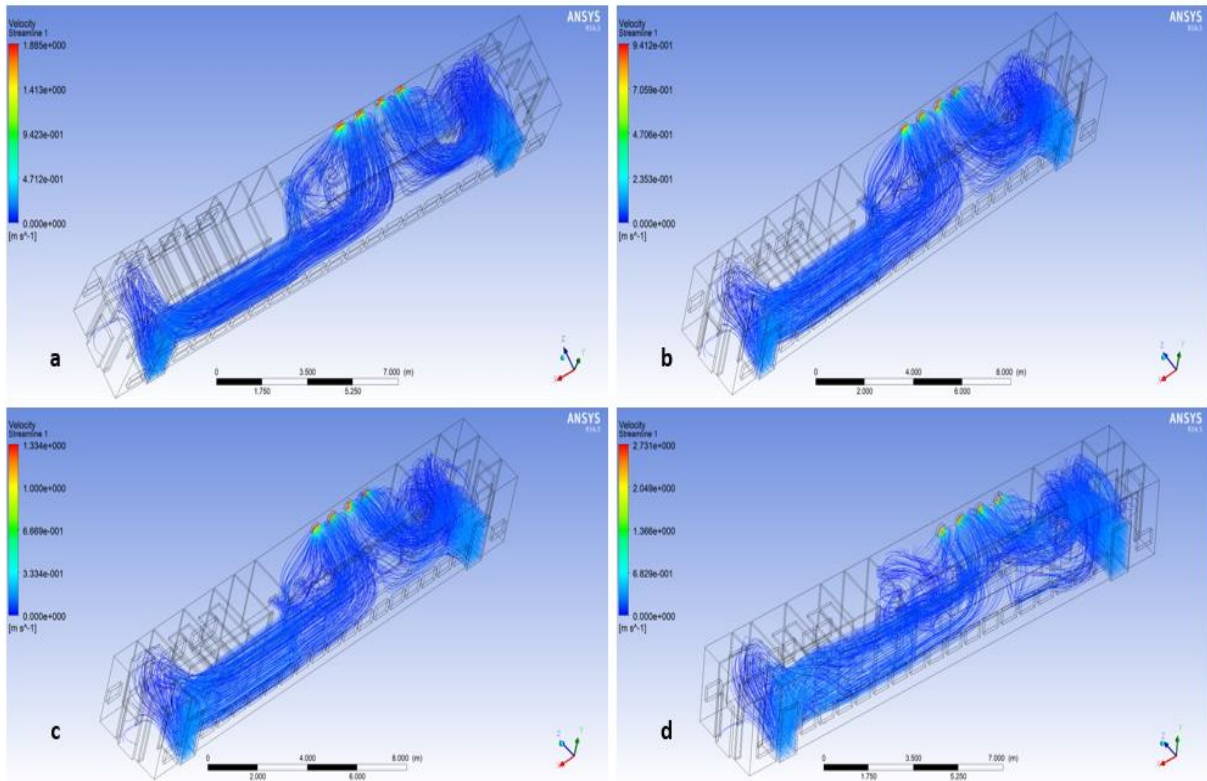


(ii) Velocity

Figure 4.11. Case II, winter season (i) air temperature and (ii) velocity, distribution profile of CFD at various cooking period; (a) breakfast, (b) lunch, (c) snacks, and (d) dinner

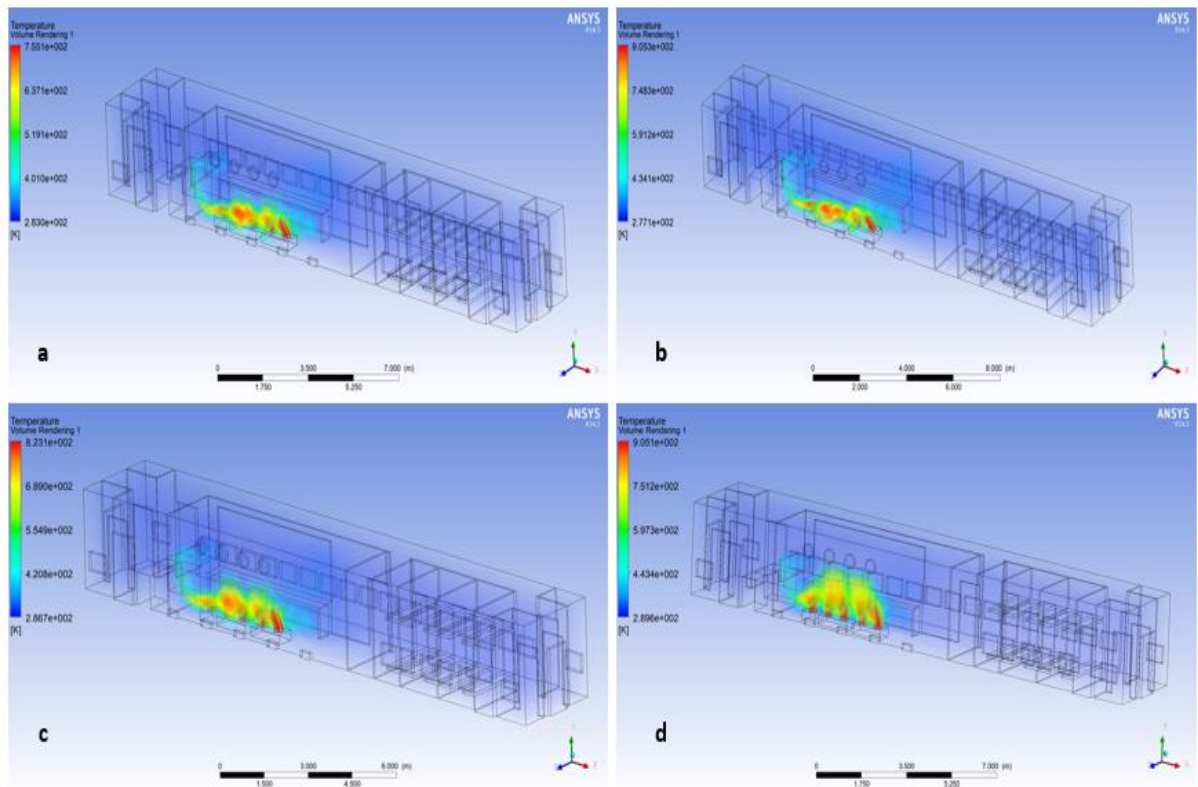


(i) Air temperature

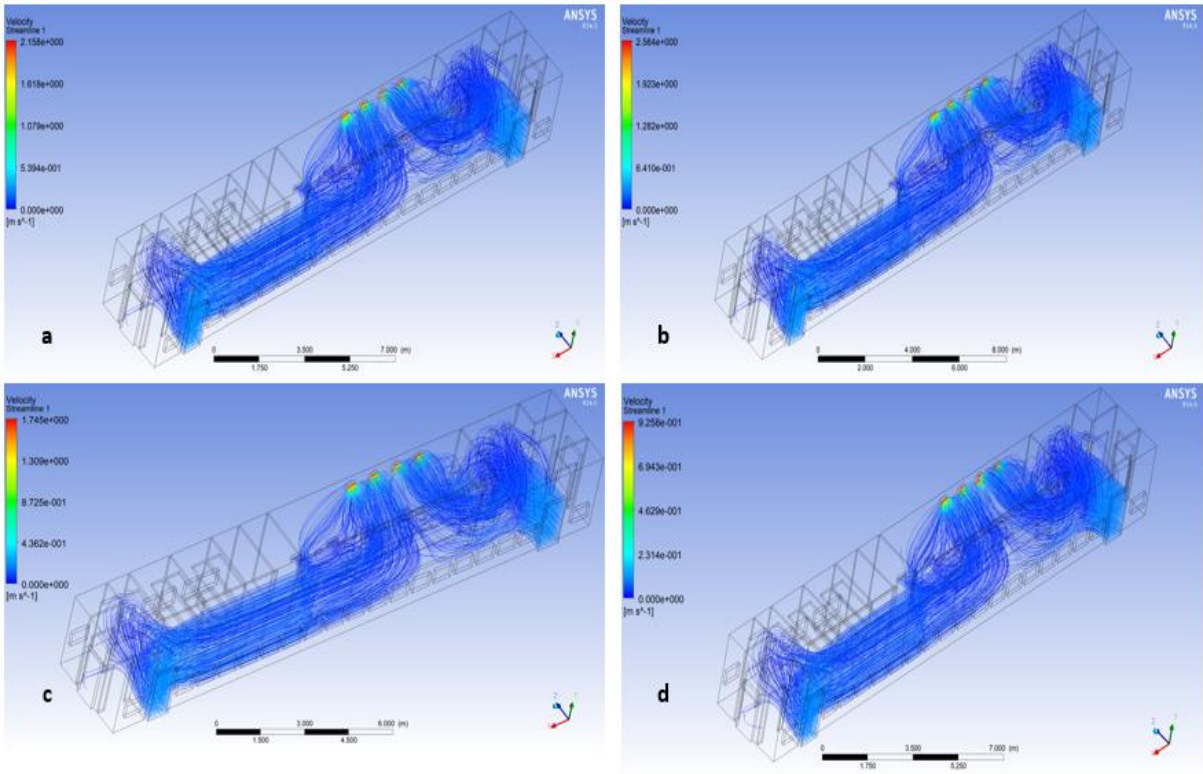


(ii) Velocity

Figure 4.12. Case III, summer season (i) air temperature and (ii) velocity, distribution profile of CFD at various cooking period; (a) breakfast, (b) lunch, (c) snacks, and (d) dinner

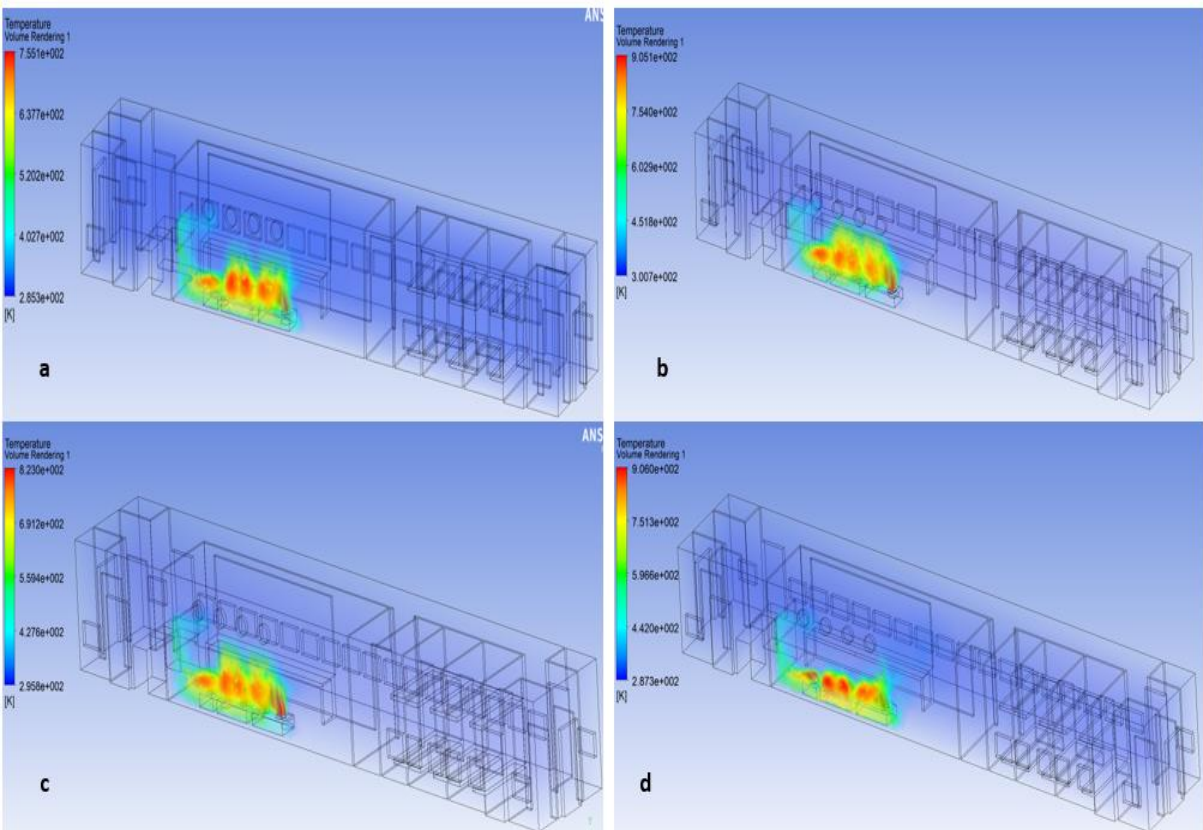


(i) Air temperature

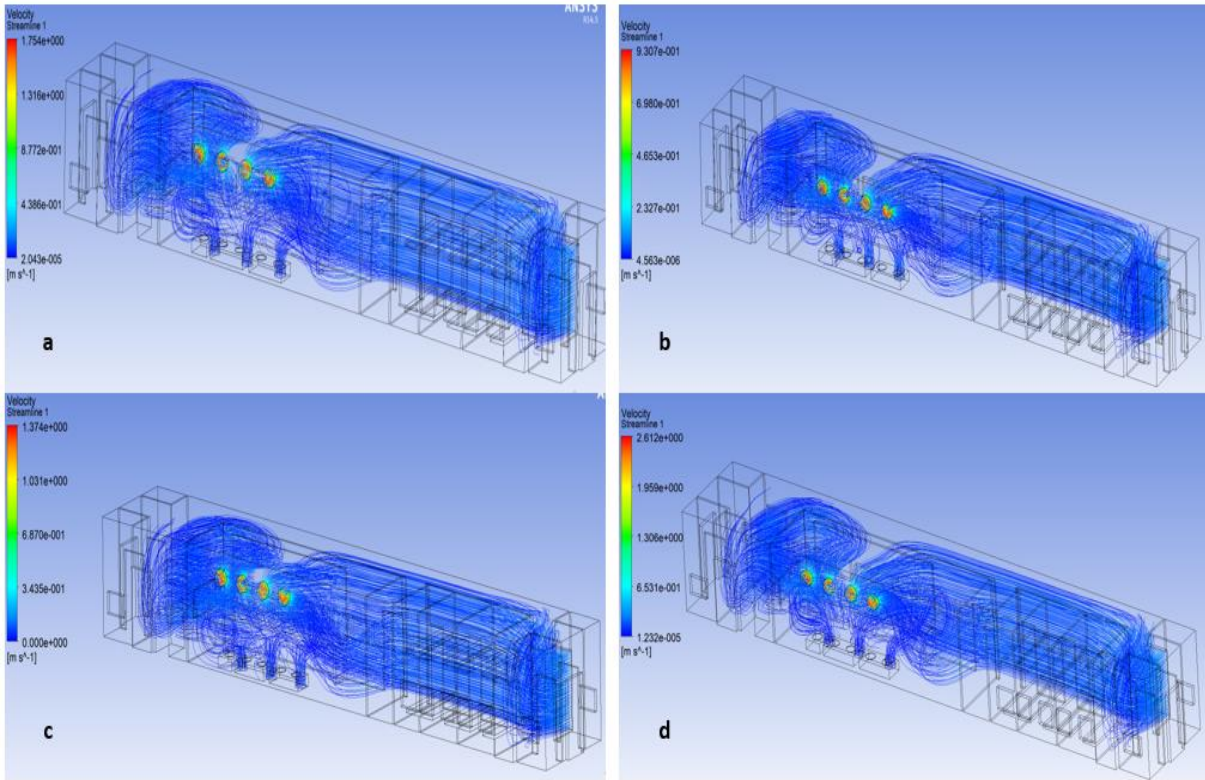


(ii) Velocity

Figure 4.13. Case III, winter season (i) air temperature and (ii) velocity, distribution profile of CFD at various cooking period; (a) breakfast, (b) lunch, (c) snacks, and (d) dinner

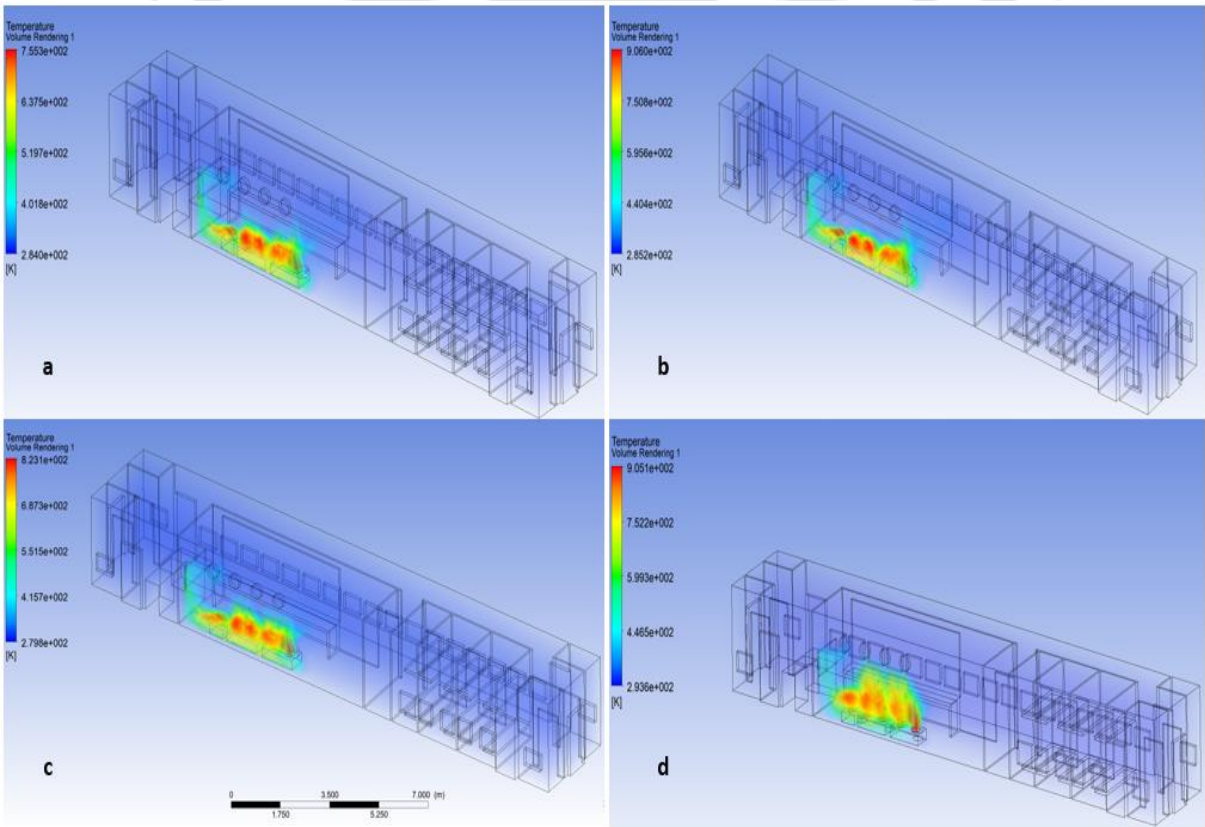


(i) Air temperature

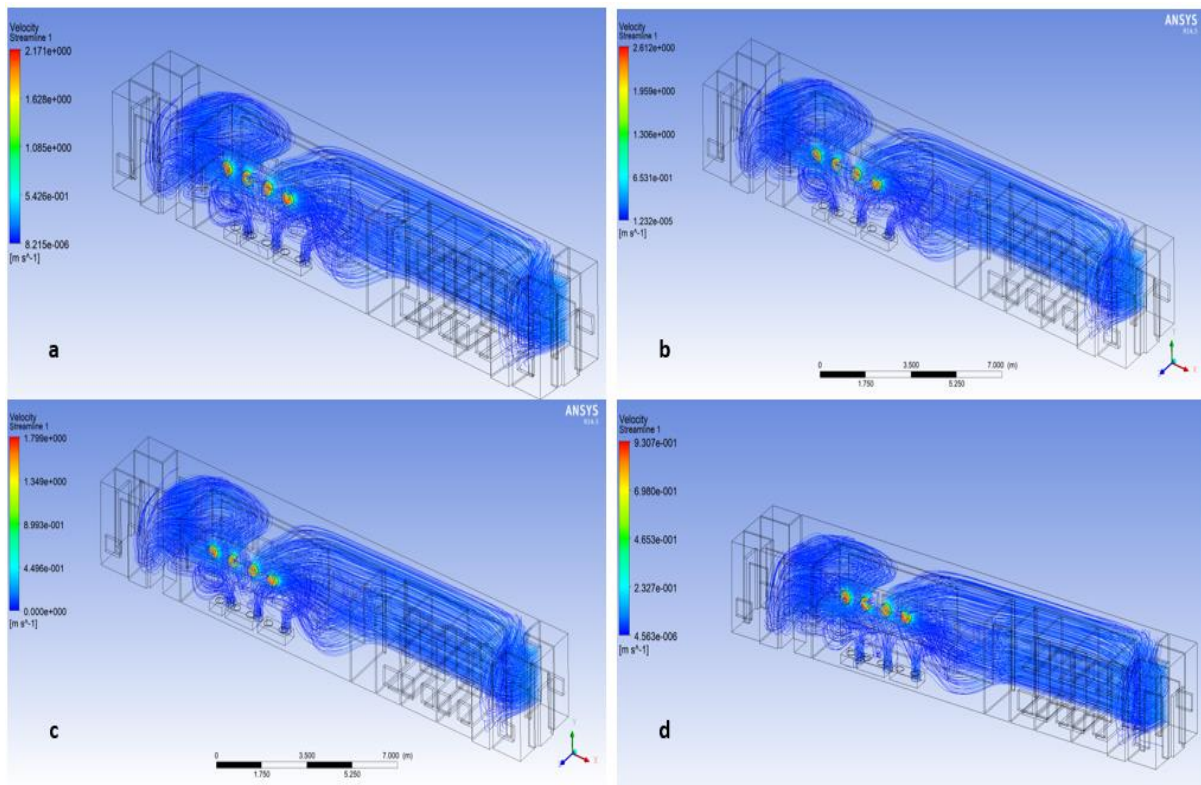


(ii) Velocity

Figure 4.14. Case IV, summer season (i) air temperature and (ii) velocity, distribution profile of CFD at various cooking period; (a) breakfast, (b) lunch, (c) snacks, and (d) dinner



(i) Air temperature



(ii) Velocity

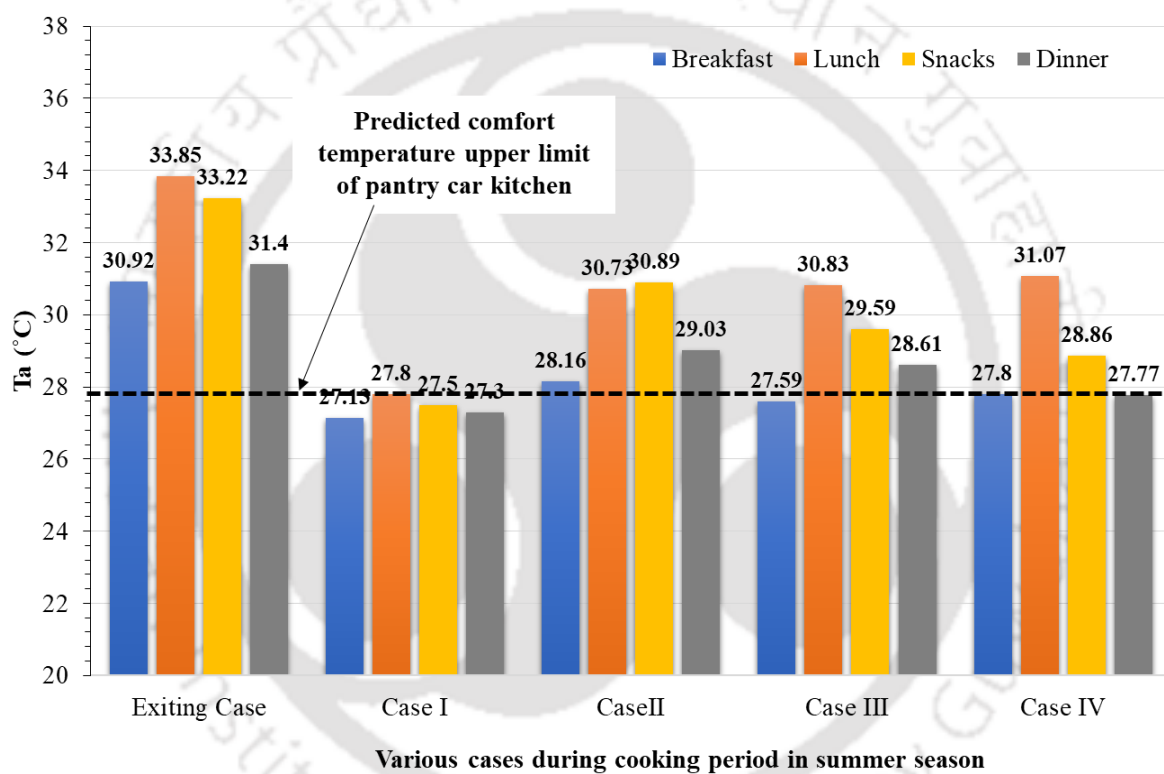
Figure 4.15. Case IV, winter season (i) air temperature and (ii) velocity, distribution profile of CFD at various cooking period; (a) breakfast, (b) lunch, (c) snacks, and (d) dinner

4.1.5.1 Temperature field analysis between all cases

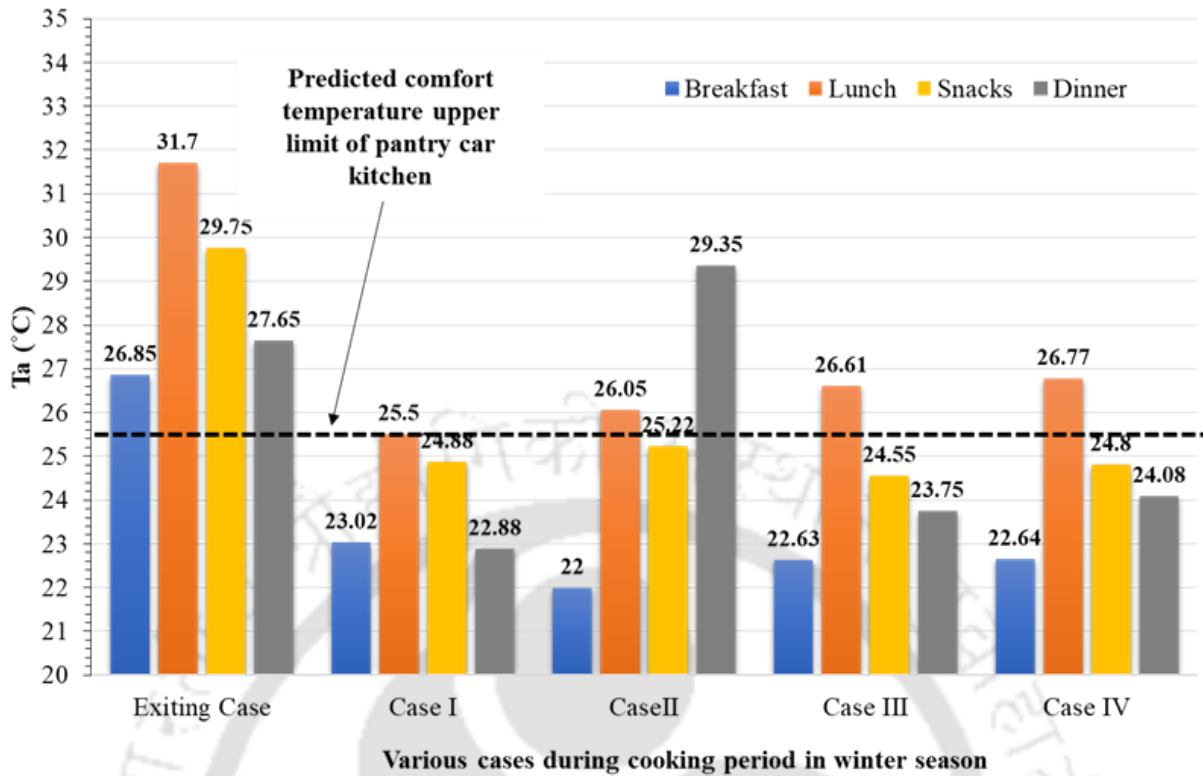
The earlier thermal comfort studies predicted comfort air temperature limits of railway pantry car kitchen workers for both the seasons, summer (18.50–27.80°C) and winter (17.80–25.50°C) (Alam et al., 2019b). This study compared all modified pantry car models with existing cases based on the air supply system and air temperature upper limit.

Figure 4.16 (a) shows the comparison between modified and existing cases of pantry car kitchens based on the air temperature during the summer season. The graphical result indicates the value of air temperature in *Case I* is coming within the recommended comfort temperature range as compared to the other modified cases because it keeps all cooking periods under the comfort temperature zone. It can be observed that in *Case I*, entire cooking periods like breakfast, lunch, snacks, dinner the temperature has dropped 3.79°C, 6.05°C, 5.72°C, 4.1°C respectively as compare to the existing case. However, in other modified cases also, the temperature has dropped as corresponding to the existing model but during most of the cooking periods, the temperature has gone beyond the recommended comfort temperature limit.

Similarly, Figure 4.16 (b) demonstrates the comparison between modified and existing cases of pantry car kitchens based on the air temperature during the winter season. During the entire winter season, the graphical results indicate that the *Case I* is better than other modified pantry car models at the various cooking periods. It complies with the recommended limit of comfort temperature. While comparing *Case I* with the existing case model, it was found that the temperature has decreased by 3.83°C, 6.2°C, 4.87°C, and 4.77°C at breakfast, lunch, snacks, and dinner time respectively. In the winter season, all modified cases temperature was decreased while comparing to the existing model, but in a few cooking periods, the temperature has gone beyond the upper limit of the comfort temperature.



(a) Summer season



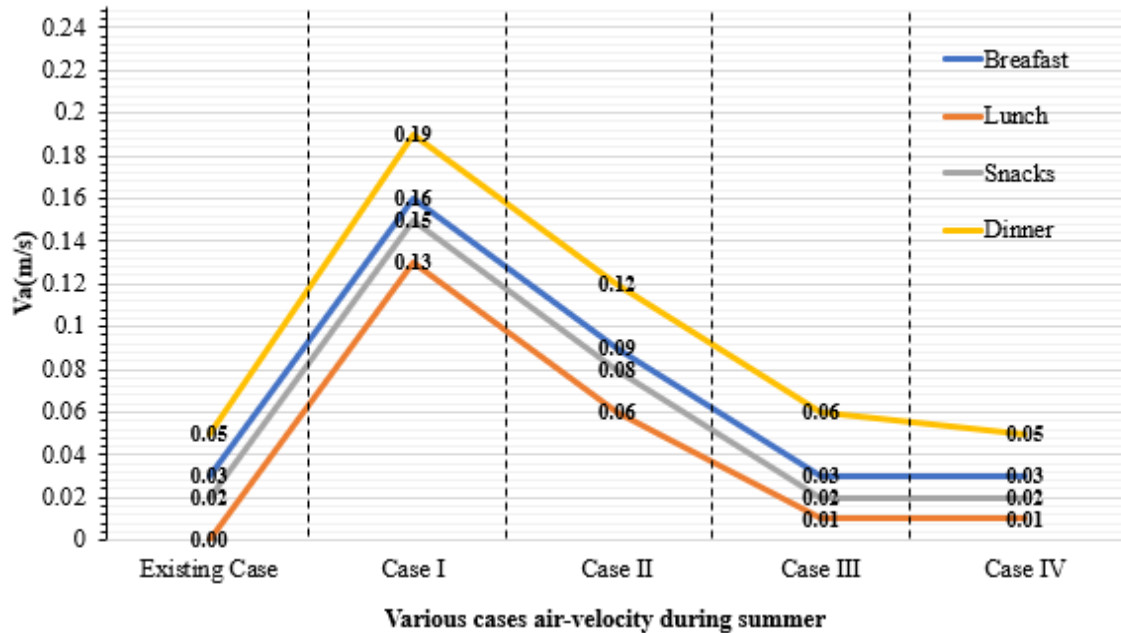
(b) Winter season

Figure 4.16. Temperature field of various cases model of pantry car kitchens during the different cooking periods a) summer, and (b) winter season

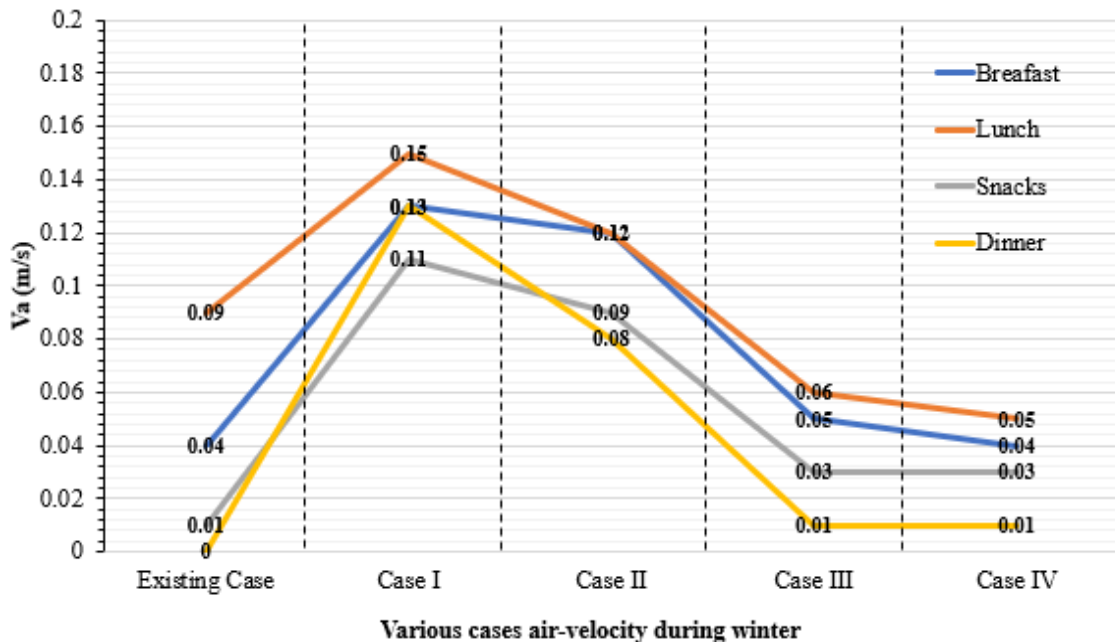
4.1.5.2 Air velocity analysis between all cases

Figure 4.17 (a) shows the comparative graph of air velocity between existing and modified cases at different cooking periods inside the pantry car's kitchen. From the graphical results, during the entire summer season, it can be observed that *Case I* have better air velocity movement than the modified cases at all cooking periods; breakfast (0.13m/s), lunch (0.13m/s), snacks (0.13m/s), and dinner (0.14m/s). However, there are no considerable air movement changes in *Case III* and *Case IV* modified model corresponding to the current model. Similarly, for the winter season, the comparative graph of air velocity between existing and modified cases at different cooking periods is illustrated in Figure 4.17 (b). During the winter season, it was observed that *Case I* has maximum air velocity. However, apart from *Case I*, the maximum air velocity was found in *Case II* at all cooking periods. In *Case III* and *Case IV*, no change was seen in the air velocity movement. The movement of air velocity was found to be increased at cooking period; breakfast (0.09m/s), lunch (0.06m/s), snacks (0.1m/s), and dinner (0.13m/s) in *Case I* as compared to the existing case. According

to the ASHRAE standard-55, the recommended values of air velocity for the summer and winter seasons should be ($<0.25\text{m/s}$) and ($<0.15\text{m/s}$) respectively (ASHRAE, 2004). These findings had considerable compatibility with both air temperature and air velocity in the present investigation, which is an essential factor for thermal comfort.



(a) Summer season



(b) Winter season

Figure 4.17. Air velocity movement of various cases model of pantry car kitchens during the different cooking periods at (a) summer, and (b) winter season

4.1.5.3 Estimation of thermal comfort between the cases of pantry car

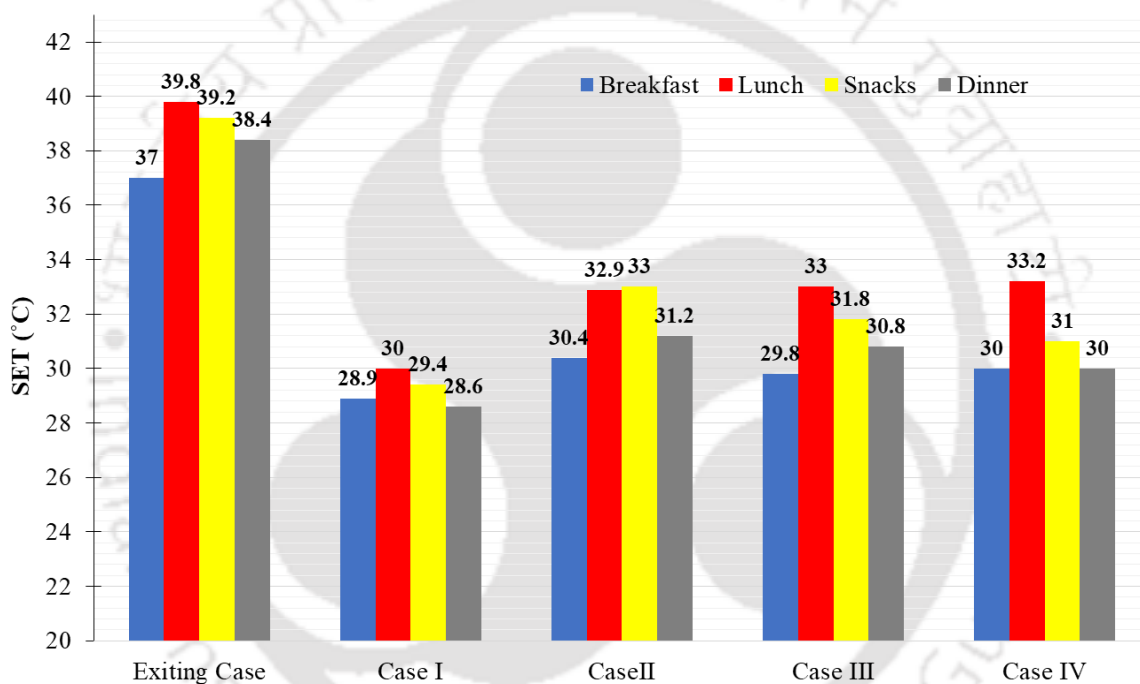
The SET index was used to predict "thermal comfort conditions" in the present study, which identifies the position of the "thermal sensation range" in applied ventilation systems. All of the modified cases models were compared to the existing case model based on the estimate of the SET index.

A comparison of the current case with all the modified cases during the summer season according to the SET variation is depicted in Figure 4.18 (a). The calculated results of SET values in entire summer season indicates that the *Case I* has a better comfort model than the other cases. In *Case I*, the SET temperature range (28.6–30°C) was found between all cooking periods which dictate a comfortable thermal sensation value. Similarly in *Case II*, the SET range (30.4–33°C) was observed between the whole cooking periods with a "warm" thermal sensation value. However, in *Case III* only breakfast timing has a comfortable thermal sensation with SET (29.8°C) and other cooking periods were warm thermal sensation. In the *Case IV*, the total duration of cooking was found within the SET range (30–33.2°C) with a warm thermal sensation. Accordingly, in the existing case model, the range of all cooking period SETs was calculated at 37–39.8°C with a "very hot" thermal sensation that does not comply with human thermal comfort. While comparing the existing case model with the *Case I* model, the SET temperature was reduced at all cooking period; breakfast (8.1°C), lunch (9.8°C), snacks (9.8°C) and dinner (9.8°C). Other modified cases also had lower SET values than the existing case model but the "warm" thermal sensation was found, which is slightly uncomfortable.

Similarly, Figure 4.18 (b) compares SET values between existing and modified case models during the winter season. In *Case I*, the SET value (27–29.3°C) was found with a "comfortable" thermal sensation throughout the cooking period. Correspondingly, in *Case II* found SET values (30.2–32.6°C) with a "warm" thermal sensation in all cooking periods except for the breakfast time only. In the *case of III*, a "comfortable" thermal sensation was observed in the breakfast and dinner preparation periods, while in other periods "warm" thermal sensation was observed. However, in *Case IV*, SET (31°C) with a "warm" thermal sensation was found during lunch preparation time, while the rest of the other cooking periods had a "comfortable" thermal sensation with the SET value range (27–29.1°C). Throughout the winter season, the temperature of SET was significantly reduced in *Case I* at each cooking period; breakfast (5.5°C), lunch (6°C), snacks (5.7°C), and dinner (6.2°C) respectively as compared to the existing case. The simulation result of the existing case has

directed the thermal sensation range "warm to hot", which indicates a discomfort thermal environment for occupants. Even the other modified case's SET values was also come down but this was inconvenient as the range of thermal sensation "warm" was found a bit uncomfortable for the workers.

The above results directed that installing four exhaust fans with a diameter of 450mm in front of the kitchen wall and two carriage fans with a diameter of 400mm on the roof would increase the thermal comfort in the kitchen environment of the Indian railway non-air-conditioned pantry car. These interventions can be applied in Indian railways pantry car kitchens because it consumes less power consumption and its maintenance cost is also low.



Various cases during cooking period in summer season

(a) Summer season

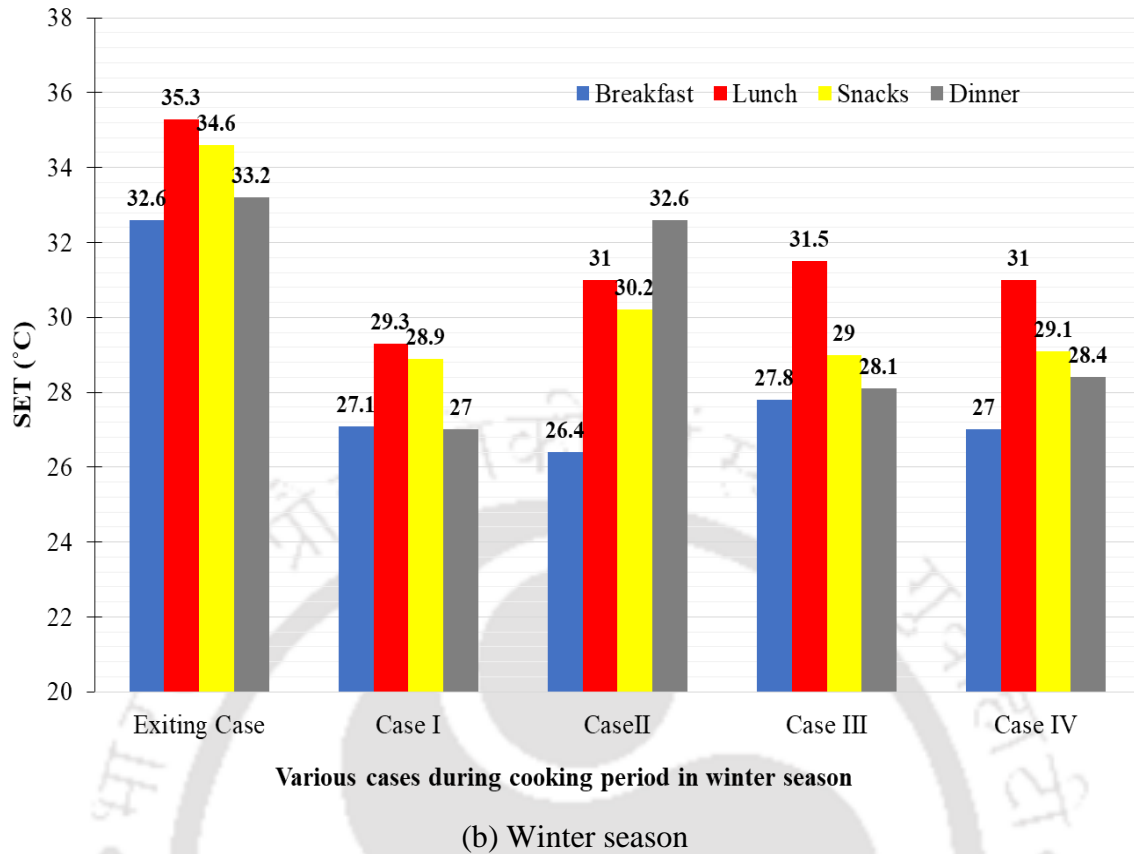


Figure 4.18. SET thermal sensation comparison of the existing case with all modified cases during (a) summer, and (b) winter season

4.1.6 Summary

In this analysis, it was found that the existing case model is outside the recommended range of the SET index which is not favourable for occupants. Four cases were taken based on the literature review (*Case I*; 4 exhaust fans on the front wall and 2 carriage fans on the roof, *Case II*; 4 exhaust fans on the front wall and 2 carriage fans on the right & left side wall, *Case III*; 4 exhaust fans on the front wall and 4 air-vent on the lower side of the front wall, *Case IV*; 4 exhaust fans on the front wall and 3 carriage fans on the bottom surface). CFD approach was used to analyse the proposed design case modifications. *Case I* was found to give best results for non-air-conditioned Indian railways pantry car occupants.

4.2 Improving thermal comfort inside the kitchen of air-conditioned pantry car

4.2.1 Details of the air-conditioned pantry car kitchen

The indoor working environmental conditions of the air-conditioned pantry car kitchen of the Indian railways are illustrated in Figure 4.19. Figure 4.20 shows the full dimensions of the pantry car, length (L) × width (W) × height (H) are 24.00m × 3.24m × 2.94m, respectively. While the dimensions of the kitchen area are; L × W × H = 10.57m × 3.24m × 2.94m approximately. This type of pantry car usually has four doors and thirteen windows on the opposite side of the kitchen area, while four to five windows on the side of the kitchen wall. Especially stainless steel materials are used to make these types of pantry car bogies (Mane, 2017). There are five cooking workers in an air-conditioned pantry car, as shown in previous studies (Alam et al., 2019a). It uses a mixing ventilation system and provides a chimney from which the gas comes out, as shown in Figure 4.19.



Figure 4.19. Existing condition of the air-conditioned pantry car kitchen

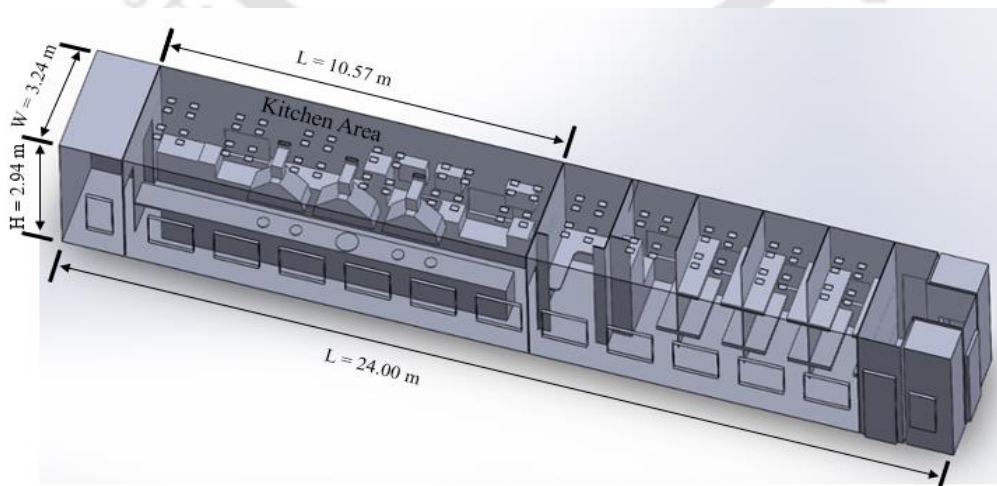


Figure 4.20. Details of the air-conditioned pantry car kitchen

4.2.2 Measurement and SET index estimations

Figure 4.21 illustrates the measuring point (P) location of the measured thermal parameters, which is 1.1m above the floor height and 0.3m near the cooking zone. This experiment was conducted during the peak cooking period [breakfast-7:00 am, lunch-11:30 am, snack-4:00 pm, dinner-6:30 pm] inside the pantry car in the summer. The details of the instrument accuracy and range have been illustrated in Table 3.1. In the air-conditioned kitchen of pantry car also, the SET index was used to estimate thermal comfort. The details of SET index estimation is shown in section (4.1.3).

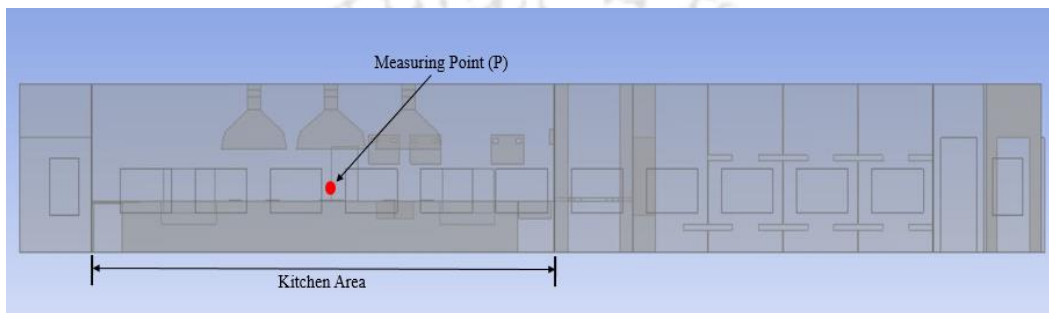


Figure 4.21. Measuring point of thermal parameters inside the pantry car

4.2.3 CFD modelling and simulation

In this study, “Computational fluid dynamics-CFD” simulations have been used to evaluate air temperature and air velocity distribution in the kitchen of an air-conditioned pantry car. Further, thermal comfort was estimated in this analysis by identifying the thermal sensation range of occupants inside pantry car kitchens based on parametric studies. To construct the 3D-models (existing and design modifications case models) of the pantry car, “Solid works 2015” was incorporated, as illustrated in Figure 4.22. After that, in ANSYS fluent R14.5 version software, the CAD model (in igs file format) of the pantry car has been imported. Simultaneously, governing equations such as mass, momentum, and energy were utilized for CFD analysis of the model (see Appendix-II).

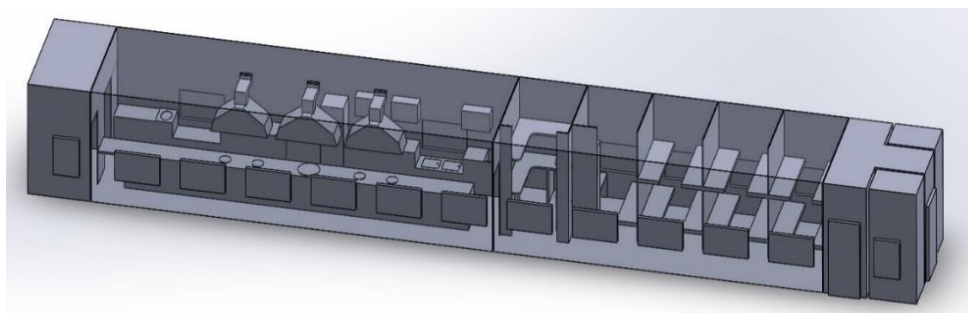


Figure 4.22. Air-conditioned railway pantry car 3D-model

In this study, to evaluate CFD simulations "k-epsilon RNG" turbulence flow model was taken, which are more applicable for kitchen environments, as reported by many researchers (Livchak et al., 2005; Abanto & Reggio, 2006; Mak et al., 2002; Fujimura et al., 2017). Whereas for the lattice of the CFD model, "tetrahedral volume elements" were employed. Correspondingly patch conforming method was adopted to stimulate the mesh with a "fine relevance center". A "finer meshing" was obtained at particular areas such as doors, air-vents, exhaust hoods, heater using the "face-sizing" and "edge-sizing" mesh. In the present simulation, the total number of recorded elements and nodes were 138920 and 756022, respectively, found in the final mesh model, which is considered appropriate for CFD estimation (Yahya et al., 2019). Figure 2.23 illustrates the mesh model of an air-conditioned railway pantry car kitchen.

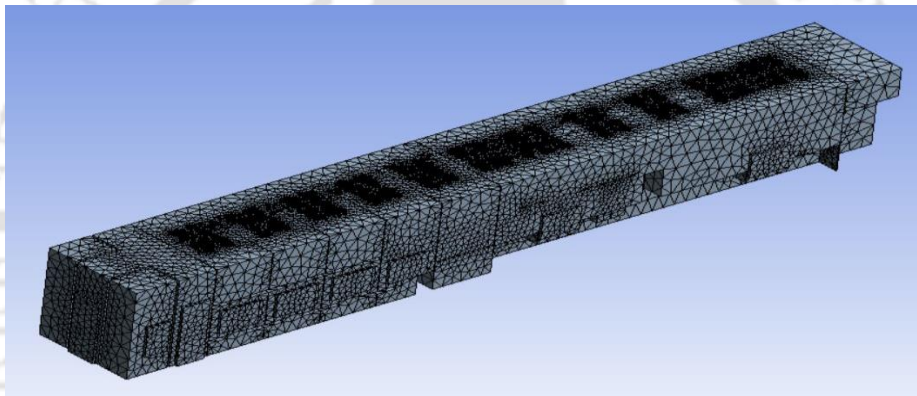


Figure 4.23. Air-conditioned pantry car mesh model

Table 4.5 shows the boundary conditions during the meal preparation period inside the air-conditioned pantry car. Due to the air conditioning facility in this pantry car, the inlet velocity has taken as the air coming from the air conditioner, with vents installed on the ceiling area. However, the heater's surface temperature during cooking is considered a heat source (Brannigan et al., 1980; Fink & Beaty, 1978; Beaty & Fink, 2013). As shown in a pilot study, temperatures during lunch and snacks were higher than breakfast and dinner in the pantry car kitchen (Alam et al., 2019a). In this study, we have simulated all the cooking periods accordingly. Both air temperature and air velocity were measured at the measuring point (P) as stated in Figure 4.21.

While the simulation is performed, the energy equation's convergence criterion has been taken as 10^{-6} , while 10^{-4} was considered for all other equations. Some researchers have used

this concept in a simulation study in air-conditioned kitchen environments (Livchak et al., 2005; Li et al., 2014; Ren et al., 2012).

Table 4.5. Boundary conditions of the entire cooking period in the pantry car

| Cooking period | Boundary Conditions | | | |
|----------------|---------------------|---------------------|------------------|-------------------------------------|
| | Wall temperature | Ac vent temperature | Ac vent velocity | Electric heater surface temperature |
| Breakfast | 301K (27.85°C) | 297K (23.85°C) | 0.28m/s | 755K (481.85°C) |
| Lunch | 304K (30.85°C) | 299K (25.85°C) | 0.14m/s | 905K (631.85°C) |
| Snacks | 303K (29.85°C) | 298K (24.85°C) | 0.22m/s | 823K (549.85°C) |
| Dinner | 302K (28.85°C) | 297K (23.85°C) | 0.42m/s | 905K (631.85°C) |

Exhaust mass flow rate: 1.585 kg/s
 Exhaust gauge pressure: 120 pa
 Solver model: k-epsilon RNG model
 Number of elements: 756022
 Number of nodes: 138920

A baseline CFD model of the pantry car kitchen was validated by comparing it with the measured value of air temperature and air velocity (at the measured point shown in Fig. 4.21 of the pantry car kitchen) with data obtained from simulation. Figure 4.24 and Figure 4.25 describe the comparison among the measured, simulated air temperature and air velocity data based on the percentage difference during the cooking period. Throughout the cooking period inside the kitchen of an air-conditioned pantry car, the percentage difference between air temperature and air velocity was less than 5% and 20%, respectively which is a good compromise for model validation according to the ASHRAE-55 standard (Malek et al., 2015; Noman et al., 2016).

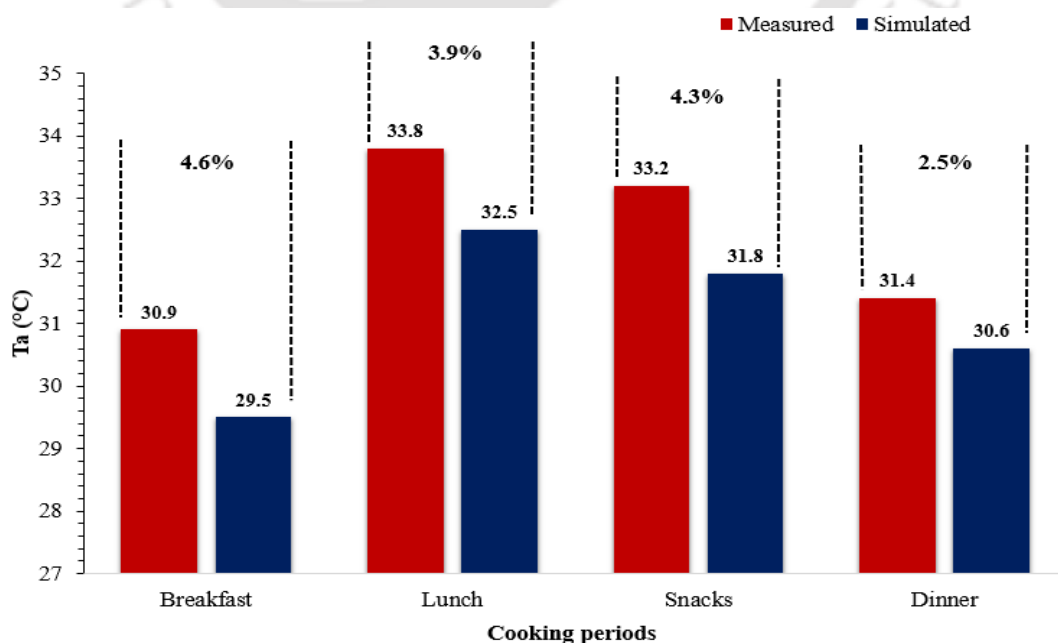


Figure 4.24. Comparison of measured and simulated air temperature data at different cooking periods inside the kitchen of pantry car

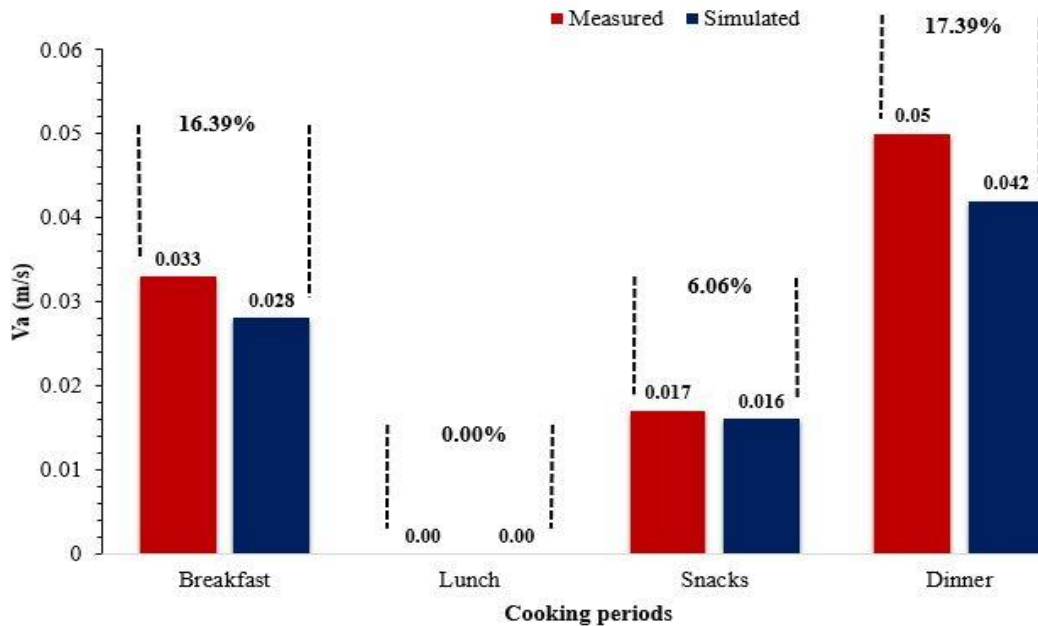


Figure 4.25. Comparison of measured and simulated air velocity data at different cooking periods inside the kitchen of pantry car

Some researchers analysed adequate thermal comfort in an air-conditioned environment by properly displacing the air supply system's state (Qiu-Wang & Zhen, 2006; Sabtalistia et al., 2014; Yahya et al., 2019). An experiment has been conducted by Livchak et al. (2005) in the United States. They tested two types of ventilation systems (mixing and displacement) and found that the kitchen's temperature is much lower in displacement-ventilation without enhancing the air-conditioning system capacity. Simultaneously, indoor temperature has reduced by 10°F (5.5°C) during the simulation operation. Similarly, Yuan et al. (2013) performed a simulation study in a catering kitchen environment in China. The authors suggested that the supply of air through diffusers installed at the walls is more applicable for kitchen as in displacement ventilation system. This led to enhanced work satisfaction. In Malaysia, Zainuddin et al. (2014) conducted a thermal comfort study in the cafeteria. In this study, they experimented design of various layout positions of different air supplies and compared the measured data with simulated data. The authors concluded that an acceptable thermal comfort level could be achieved by controlling the air temperature and air velocity at the workplace.

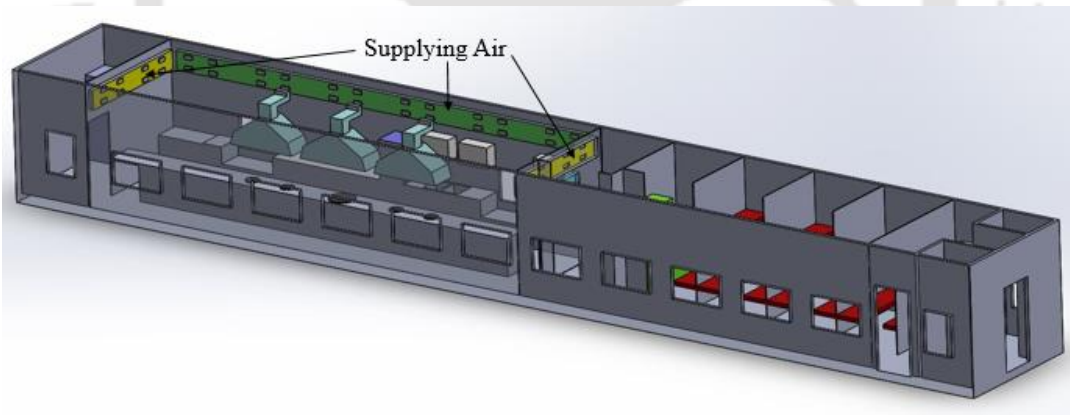
This suggestion is relatively easy, which can be implemented effectively, and maintenance cost is comparatively lower. At the same time, this will make an essential contribution to

energy savings. In this study, three air supply systems were considered, as shown in Table 4.6. Figure 4.26 depicts various CAD models of air-conditioned pantry cars.

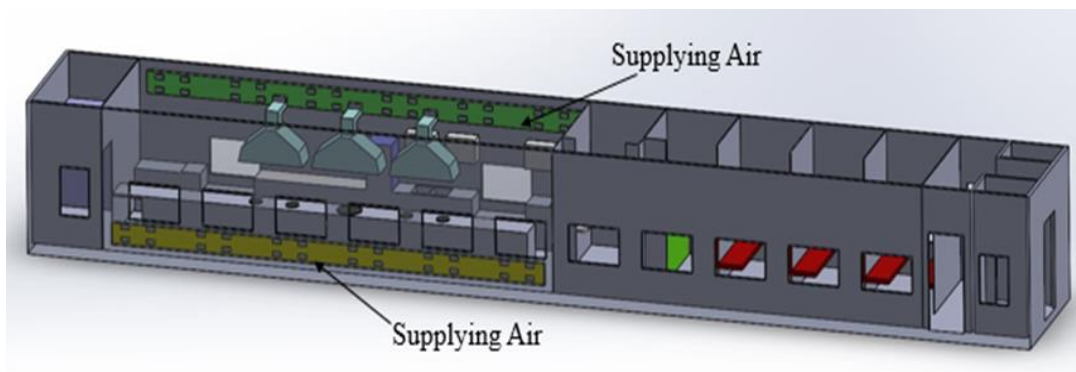
As shown in Figure 4.26, the supply air system in *Case I* was installed 304.8mm below the ceiling on the upper-side of the right and left wall and the upper side of the kitchen's back wall. In *Case II*, the supply air system has been installed below 304.8 mm from the ceiling in the kitchen's rear wall and 304.8 mm above the front wall's bottom surface. Similarly, in *Case III*, the supply air system is installed 304.8 mm below the ceiling in the kitchen's front and back walls. For all cases, the air supply through the AC vents has been taken in a constant range during the various cooking periods, as described in the boundary condition (see Table 4.5).

Table 4.6. Modified cases of pantry car kitchen

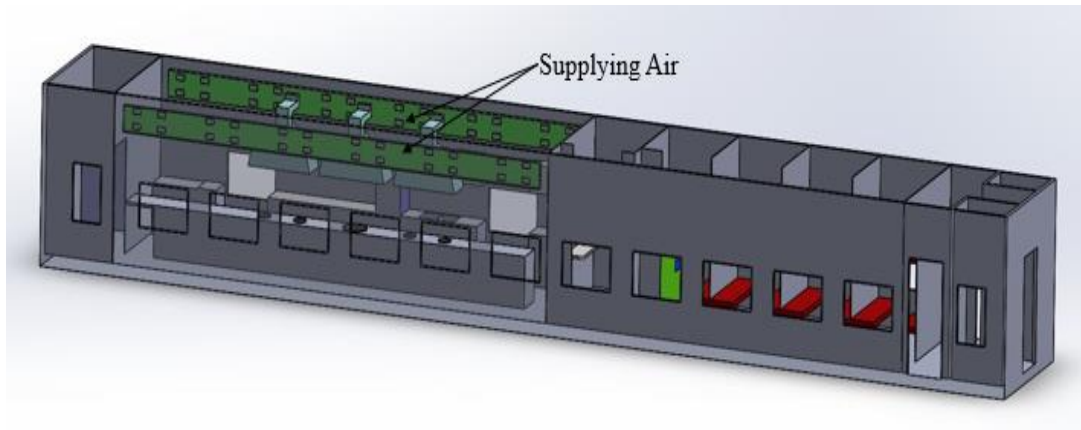
| Cases | Supplying air position |
|----------|--|
| Case I | Upper-side of the right and left wall, and upper-side of the back wall |
| Case II | Bottom-side of the front wall and upper-side of the back wall |
| Case III | Upper-side of the front and back walls of the kitchen |



(a) Case I



(b) Case II



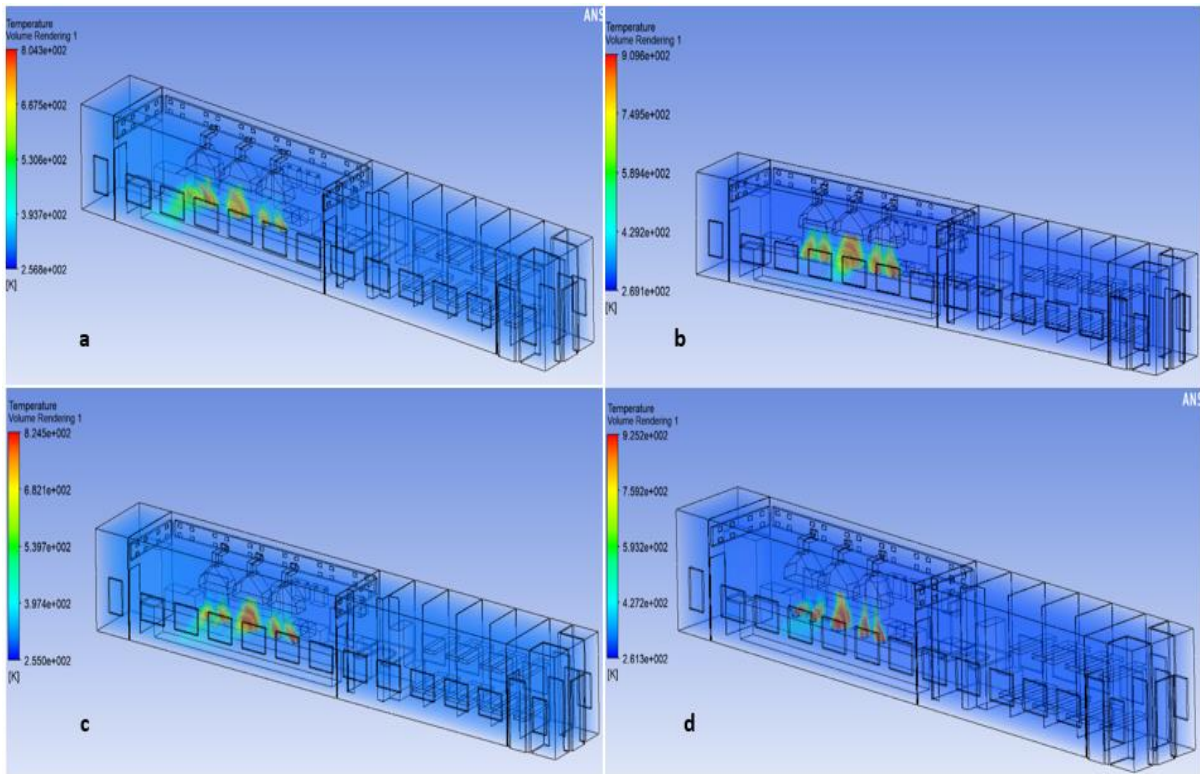
(c) Case III

Figure 4.26. Different modified cases – (a) Case I, (b) Case II, (c) Case III

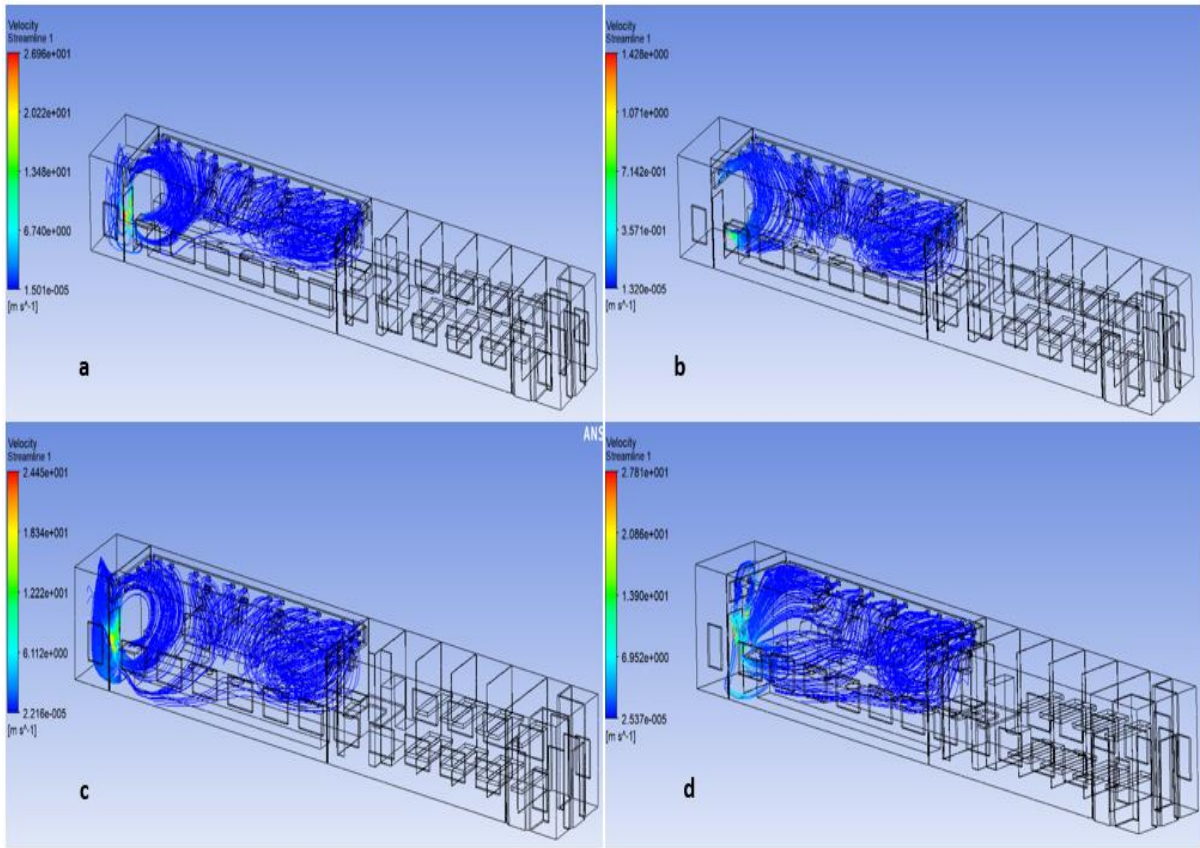
4.2.4 Results and discussion

In the present study, all three modified pantry car kitchen cases were numerically simulated with the support of ANSYS fluent R14.5. The value of the distribution of air temperature and air velocity was taken above 1.1m above the surface and at 0.3m from the work center, which is mentioned above in Figure 4.20. In this study, only the summer season was analyzed in CFD simulations. Analyzing winter season does not make any difference because we cannot assume the external parameters in the boundary condition due to the air-conditioned facility's limitation. Figure 4.27 demonstrates *Case I*, (i) air temperature and (ii) air velocity distribution profile of CFD at different cooking periods; (a) breakfast, (b) lunch, (c) snacks, and (d) dinner. In this case, air temperature values were found to be maximum at lunch (28.9°C) and minimum at dinner (25.58°C). Similarly, in this case, the air velocity value was found to be maximum at snack (0.12m/s) and minimum at lunch (0.02m/s). Figure 4.28 illustrates *Case II*, (i) air temperature and (ii) air velocity distribution profile of CFD at different cooking periods; (a) breakfast, (b) lunch, (c) snacks, and (d) dinner. In this case of pantry car, the maximum and minimum air temperature values were found to be lunch (31.55°C), and breakfast (25.08°C) respectively. Accordingly, maximum and minimum air velocity values were estimated as breakfast (0.11m/s) and dinner (0.03m/s) respectively which expresses an entirely different appearance than the *Case I*. While in the same manner, Figure 4.29 represents the “*Case III*” CFD distribution profile of (i) air temperature and (ii) air velocity at different cooking periods; (a) breakfast, (b) lunch, (c) snacks, and (d) dinner. In this case of pantry car kitchen during simulation, the maximum and minimum air temperature

values were found in lunch (27.05°C) and breakfast (25.1°C), respectively. While the maximum and minimum air velocity values were observed during analysis at snacks (0.13m/s) and lunch (0.09m/s) correspondingly. This case result is also completely different from the other two pantry car kitchen cases, in which the temperature was not increasing much during cooking, which is a good sign.

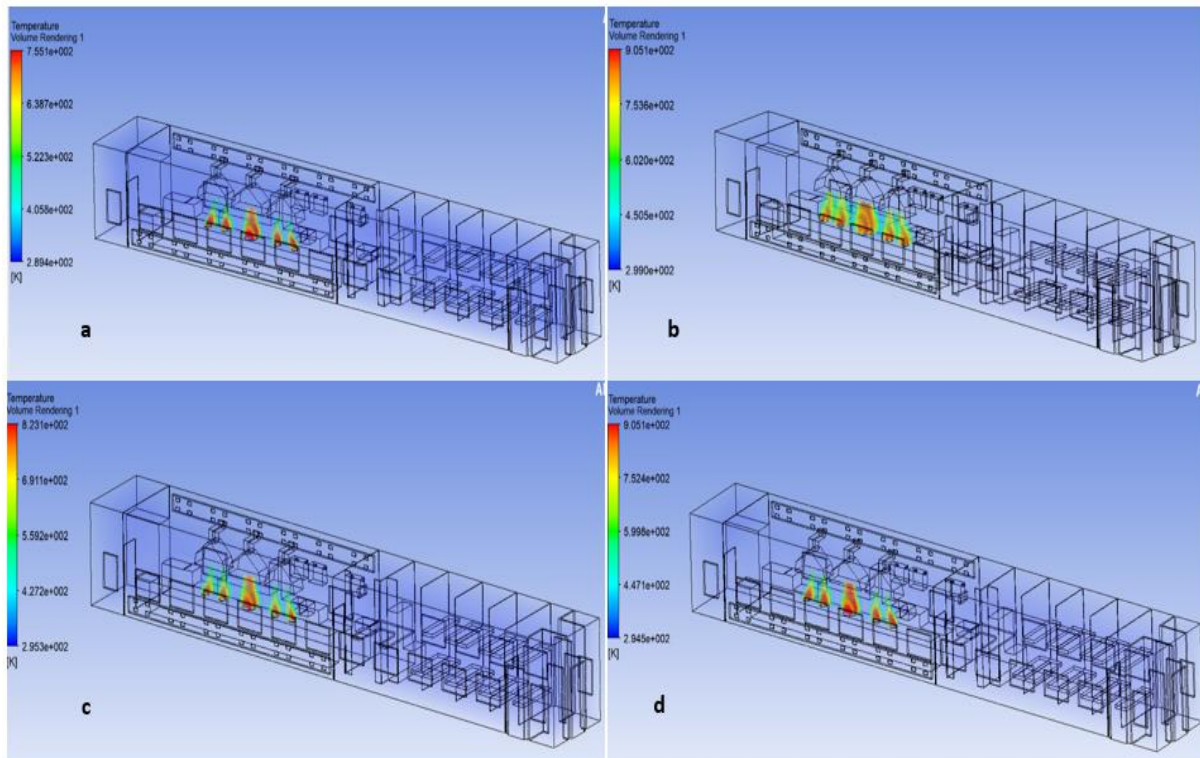


(i) Temperature

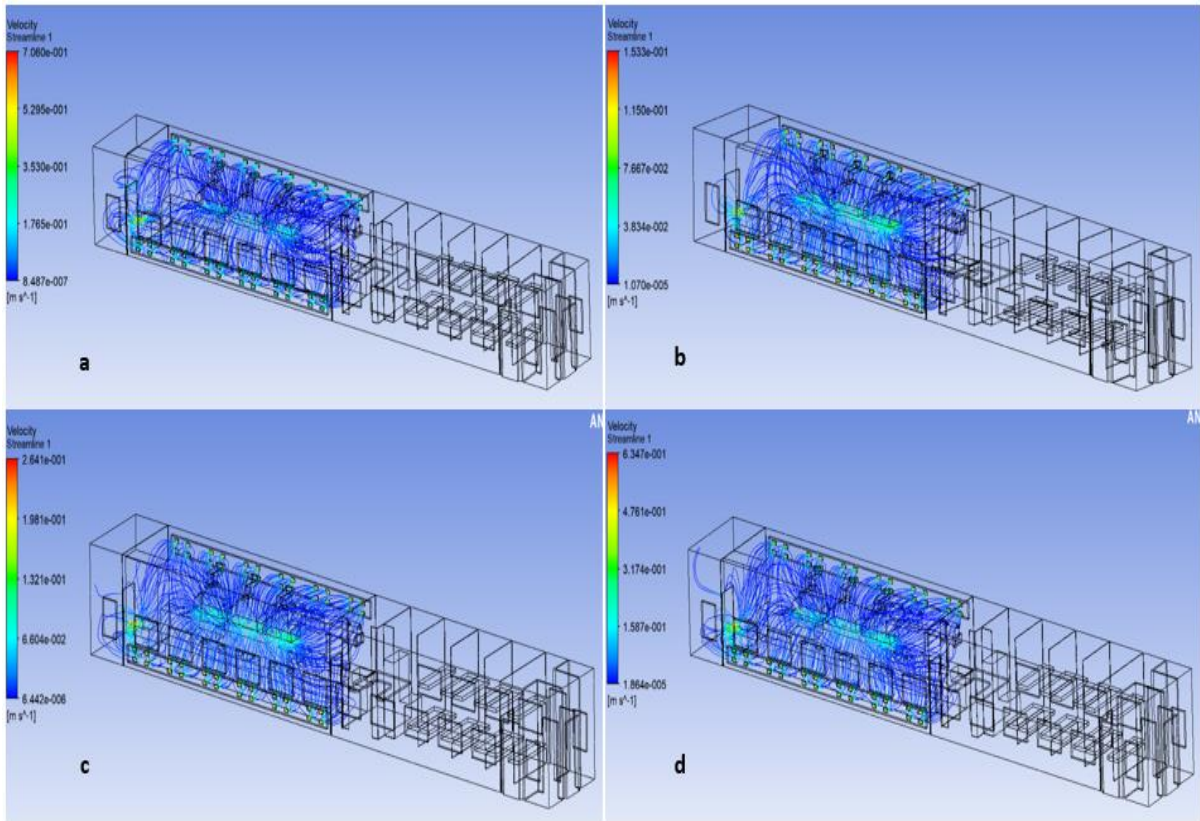


(ii) Velocity

Figure 4.27. Case I, (i) temperature and (ii) velocity, distribution profile of CFD at various cooking period; (a) breakfast, (b) lunch, (c) snacks, and (d) dinner

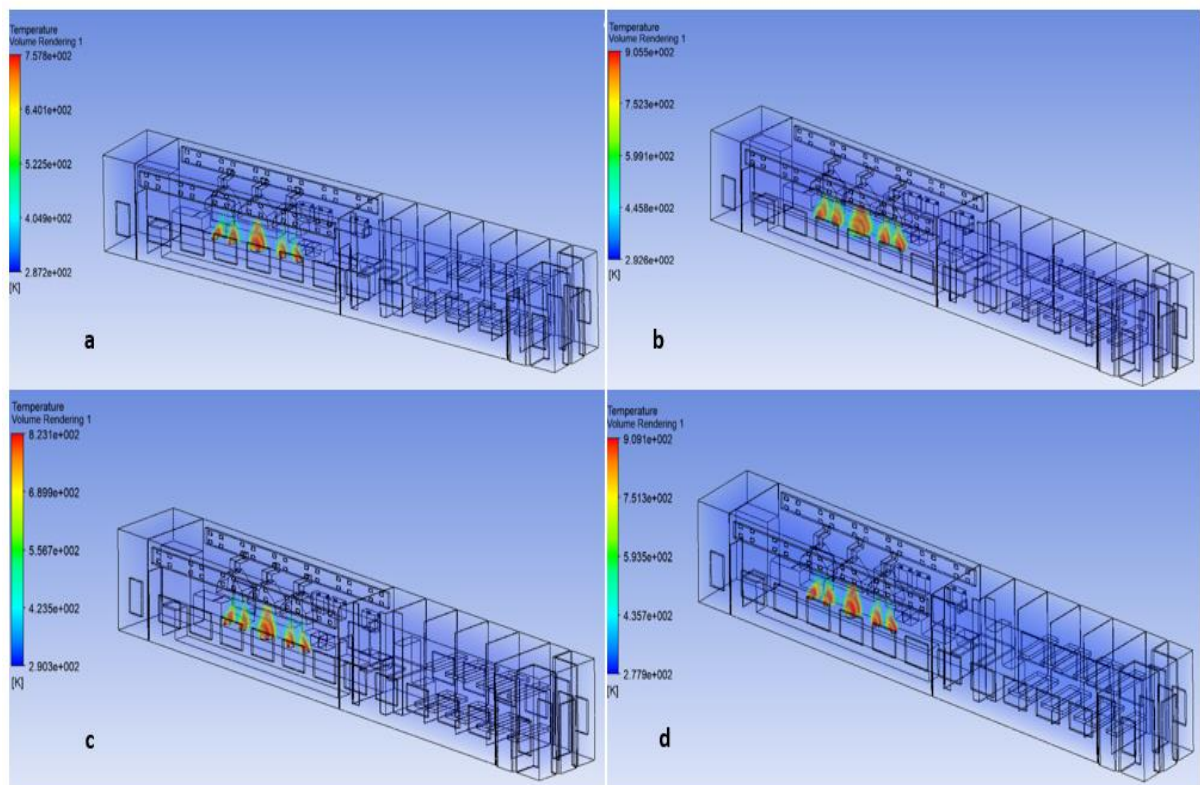


(i) Temperature

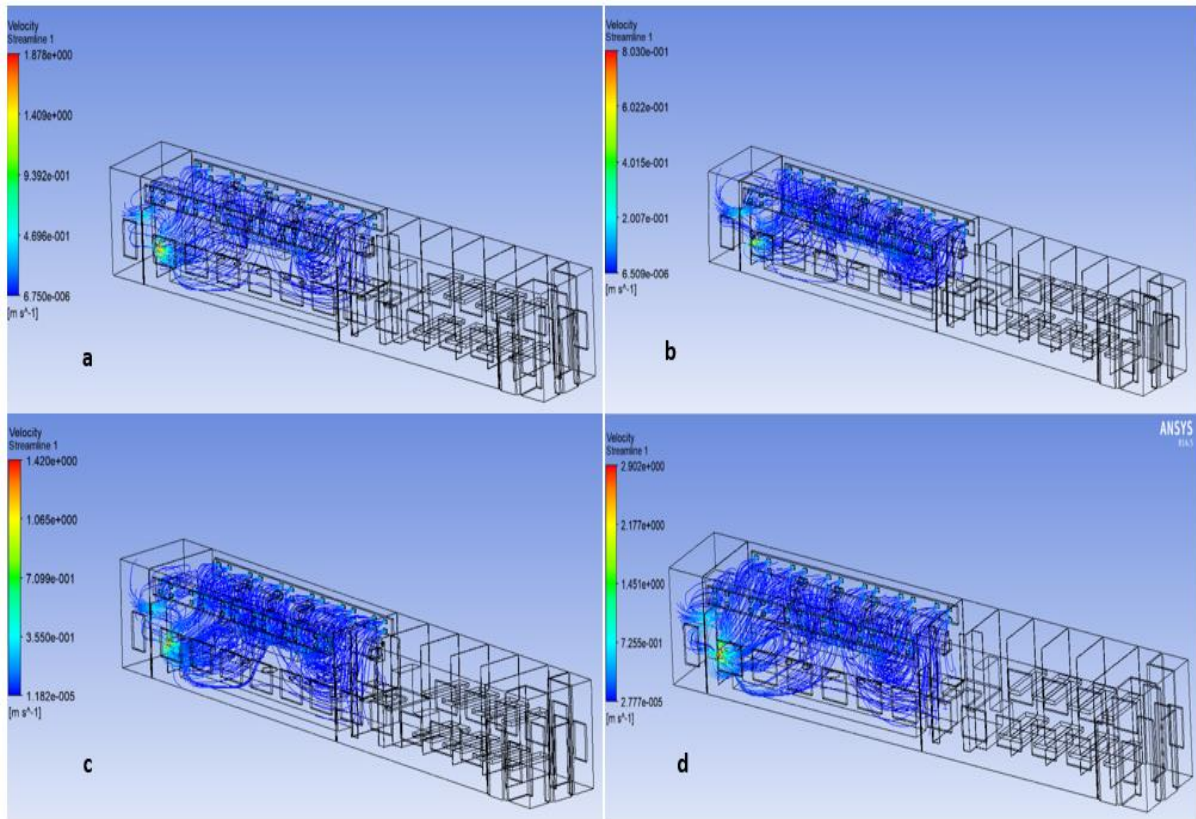


(ii) Velocity

Figure 4.28. Case II, (i) temperature and (ii) velocity, distribution profile of CFD at various cooking period; (a) breakfast, (b) lunch, (c) snacks, and (d) dinner



(i) Temperature



(ii) Velocity

Figure 4.29. Case III, (i) temperature and (ii) velocity, distribution profile of CFD at various cooking period; (a) breakfast, (b) lunch, (c) snacks, and (d) dinner

4.2.4.1 Temperature field analysis between all cases

A field study on railway pantry car kitchens was carried out by Alam et al. (2019b) to examine the occupants' thermal comfort, where they reported that the kitchen of pantry car has a predicted comfort temperature range (18.50–27.80°C) during the summer season. Therefore in this study, we analyzed all modified cases of pantry car kitchens based on the predicted comfort temperature upper limit with the existing case model.

Figure 4.30 illustrates the pantry car kitchen's various model cases with varying temperature range during the different cooking periods. The graphical outcome explicates that “*Case III*” falls within the recommended comfort temperature range compared to other modified cases, as all cooking periods in this case were found to be within comfort temperature limits. However, *Case I* and *Case II* also fall within a comfortable temperature range by excluding the lunch period.

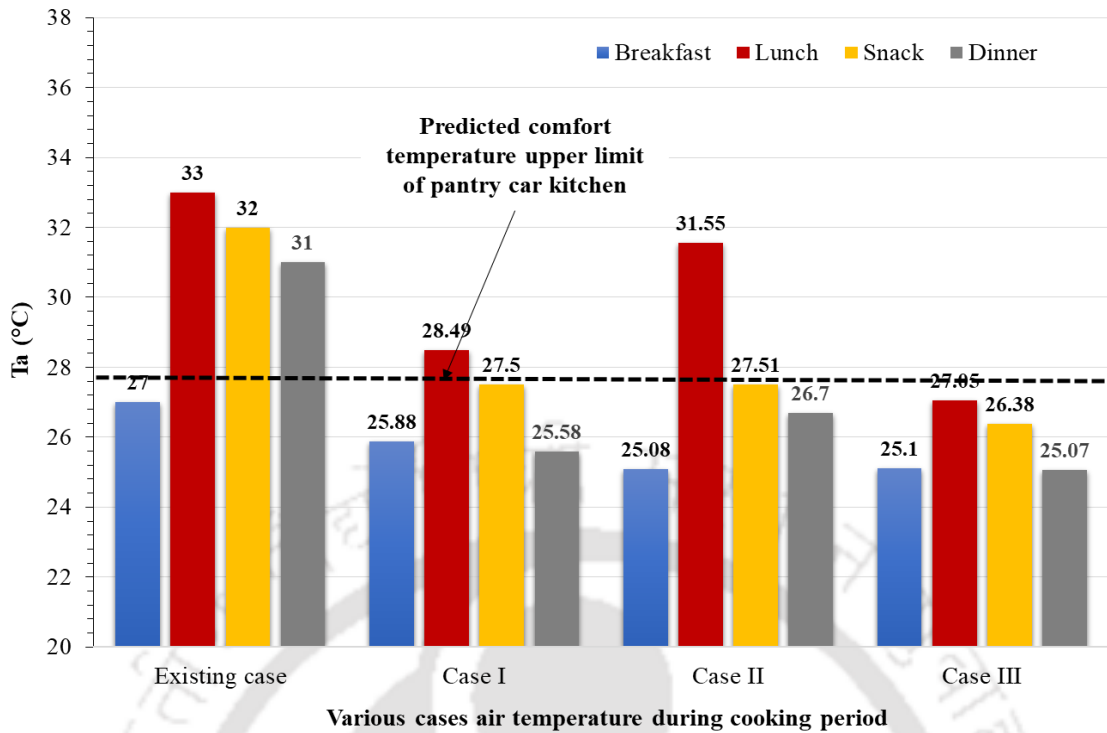


Figure 4.30. Temperature field of various cases model of pantry car kitchens during the different cooking periods

While analyzing the *Case I* model to the existing case model, it was noted that the temperature was dropped at breakfast (1.12°C), lunch (4.51°C), snack (4.5°C), dinner (5.42°C). Similarly, in *Case II*, the temperature was dropped at breakfast (1.92°C), lunch (1.45°C), snack (4.49°C), dinner (4.3°C) as compared to the existing case model. In *Case III*, the value of temperature got lowered at breakfast (1.9°C), lunch (5.95°C), snack (5.62°C), dinner (5.93°C) as compared to the existing case model. Also, high-temperature differences were found in *Case III* except for the breakfast period as compared to the existing case model. While except the *Case III*, all modified cases (*Case I* and *Case II*) did not follow the ASHRAE 55 standard at all cooking periods. As they have recommended a comfort temperature range during the summer season (24.5-27.0°C) (Alam et al., 2019b; ASHRAE, 2017).

4.2.4.2 Air velocity analysis between all cases

This study examined the air velocity movement inside the pantry car throughout the cooking periods [breakfast, lunch, snack, dinner] and compared the existing case model with all modified case models of the pantry car, illustrated in Figure 4.31.

As shown in Figure 4.31, according to the graphical interpretation, the air velocity movement is increasing in *Case III* compared to the other modified cases of the pantry car. Whereas in *Case I* and *Case II* also, the air velocity movement has increased during the cooking period, eliminating some specific cooking times.

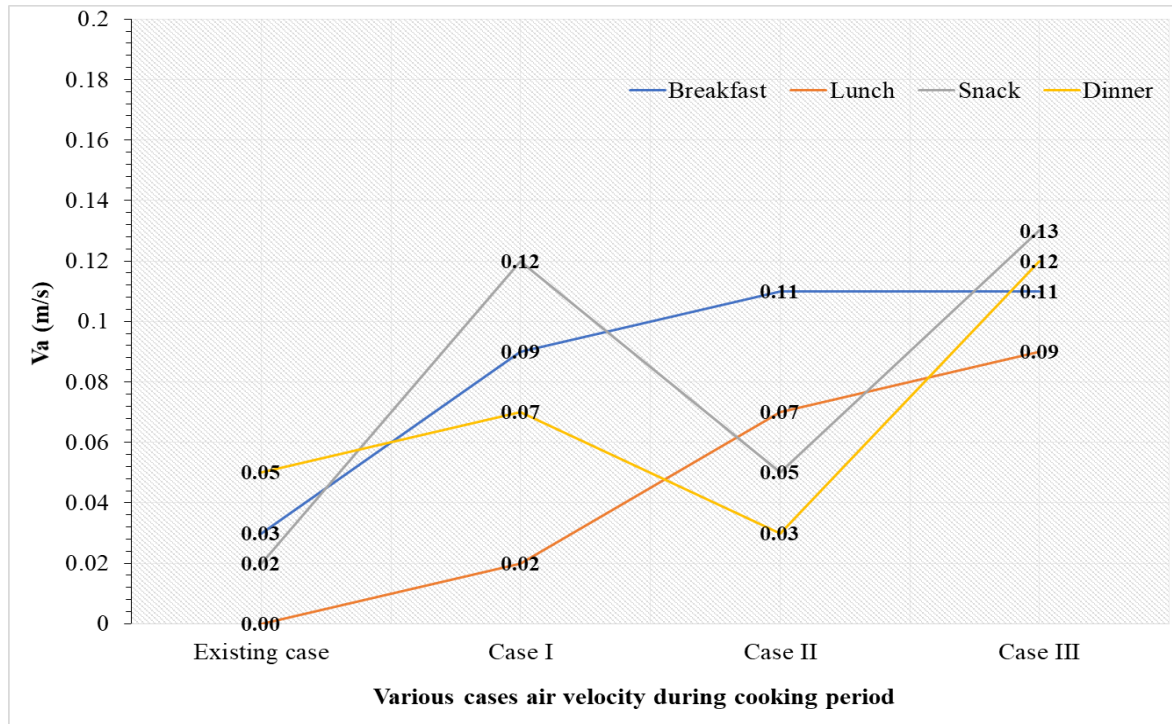


Figure 4.31. Air velocity movement of various cases model of pantry car kitchens during the different cooking periods

While comparing the “*Case I*” model with the existing case of the pantry car, it is observed that the movement of air velocity has increased during cooking at breakfast (0.06m/s), lunch (0.02m/s), snack (0.10m/s), dinner (0.02m/s). Similarly, the movement of air velocity in “*Case II*” has increased compared to the existing case model of pantry car at the time of cooking; breakfast (0.08m/s), lunch (0.07m/s), and snack (0.03m/s), while it has decreased in dinner (0.02m/s). In *Case III*, the value of air velocity at breakfast (0.08m/s), lunch (0.09m/s), snack (0.11m/s), and dinner (0.07m/s) increased as compared to the existing case model. However, according to ASHRAE Standard-55, the recommended value of air velocity for the summer season should be (<0.25m/s) in an indoor environment (Alam et al., 2020; Alam et al., 2019b; ASHRAE, 2004). The previous studies stated that more air supply could not be applied to the kitchen cooking area environment (Mansoura et al., 2014a). In this analysis, it has been observed that the “*Case III*” pantry car model may have a better concept for

improving the air velocity, as the amount of air velocities has increased expressively while cooking, during all the periods.

4.2.4.3 Estimation of thermal comfort between cases of pantry car

As discussed above, the SET index was utilized in this research to predict the thermal comfort condition inside the pantry car. The thermal sensation value was assessed at different positions of the air-supply systems. This study analyzed all the modified cases with varying cooking periods and the pantry car's existing case model.

Figure 4.32 illustrates the comparison between the existing cases with all modified cases model of pantry car based on the SET index during the various cooking period. The graphical results indicate that during the cooking periods, dinner (27.4°C), and lunch (30.4°C), the SET temperature in “*Case I*” was found to be minimum and maximum. In *Case I*, all cooking periods fall under the “comfortable” sensation range except for the lunch period, in which the sensation value was found to be “warm”. Similarly, the SET temperature in “*Case II*” was found minimum and maximum at cooking period breakfast (27.3°C) and lunch (32.8°C) respectively. In this case, the entire cooking period falls under the “comfortable” sensation range except for the lunch period, where the sensation value was “warm”. Whereas in *Case III*, maximum and minimum SET temperature values were observed with cooking period dinner (26.5°C) and lunch (28.6°C), respectively. In this particular case of the pantry car, the value of thermal sensation was found to be “comfortable” during the entire cooking period. However, in the existing case of the pantry car, the range of SET temperature was estimated maximum and minimum at snack (39.2°C) and breakfast (37°C) respectively, which indicated “hot” to “very hot” thermal sensation values.

When analyzing the *Case I* model against the existing case model during cooking periods, the temperature of SET dropped at breakfast (9.5°C), lunch (8.4°C), snack (10.4°C), dinner (11°C). Similarly, in the *Case II* model, it was determined that the SET temperature dropped at breakfast (9.7°C), lunch (6°C), snack (9.7°C), dinner (9.7°C) while comparing with the existing case model. In *Case III*, the estimated values of SET temperature decreased when comparing with the existing case model at breakfast (10.4°C), lunch (10.2°C), snack (11.5°C), dinner (11.9°C).

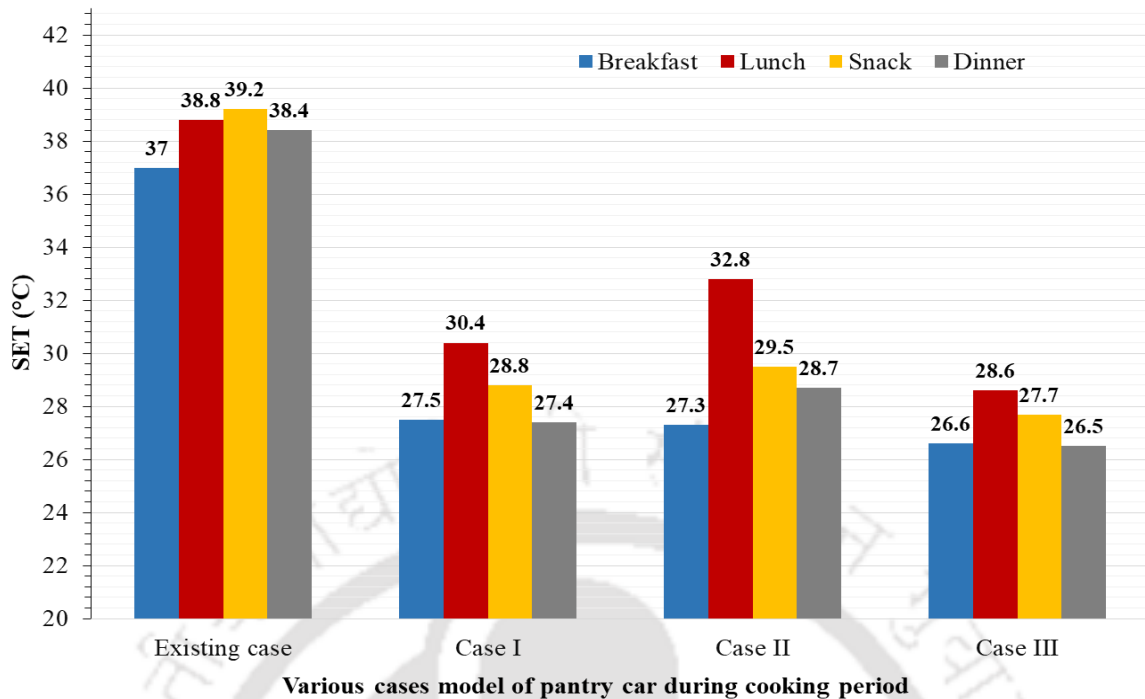


Figure 4.32. Comparison between existing case with modified cases based on the SET index during various cooking periods

This study's CFD simulation outcomes indicate that the existing case model has found thermal sensation values range from “hot to very hot” that may not be favorable for the kitchen environment. The SET index values were lower in modified cases of pantry cars such as in *Case I* and *Case II*. This was a bit inconvenient because the value of thermal sensation found to be “warm” at a few cooking periods, which was slightly uncomfortable for workers. Also in both these cases, the temperature has come down drastically compared to the existing case model.

The above interpretation shows the installation of the air supply system on the "upper side of the front and back walls of the kitchen", as shown in *Case III*, which will significantly increase thermal comfort according to the SET index estimates in pantry car kitchens. Some studies have also established such interventions in various areas and locations to improve indoor thermal comfort (see Table 4.7). Implementing these interventions will not cost much and contribute significantly to energy consumption savings in air-conditioned pantry car kitchens.

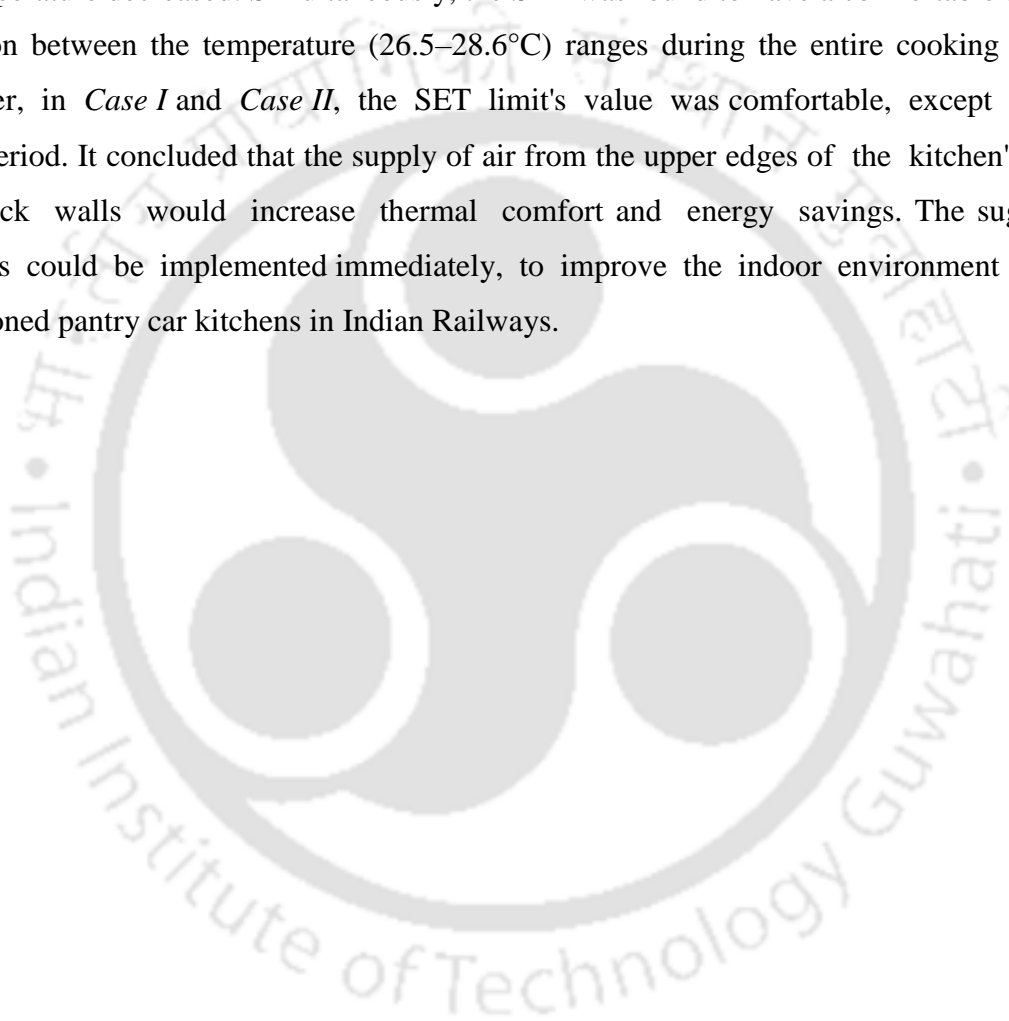
Table 4.7. Various thermal comfort studies using supply air concept in CFD analysis

| Authors | Area and location | Design approach | Finding |
|--------------------------|---------------------------------------|---|---|
| Yahya et al. (2019) | Minor Operation Theatre, Malaysia | Compared the simulation data with experimental data. | Controlled thermal parameters like; air temperature, velocity etc. |
| Zainuddin et al. (2014) | Cafeteria, Malaysia | Experimental and simulated thermal parameters viz; air temperature, air velocity were analyzed and tested for validity. Several layout positions of design modifications were verified. | Acceptable thermal comfort level was found if the air temperature and air velocity at the workplace are controlled. |
| Li et al. (2014) | Commercial kitchen, China | Three air supply temperatures cases were carried for various airflow rates and compared with field measured data. | A reasonable capture and containment efficiency was achieved using an air curtain ventilation system at an airflow rate of 12600 m ³ /h. |
| Sabtalitia et al. (2014) | Apartments (room, kitchen), Indonesia | Air conditioning (AC) supply system positions were identified. | A supply of AC on the wall near the kitchen gave better effects in thermal comfort as it is away from occupied areas as well as helps to reduce draft discomfort. |
| Yuan et al. (2013) | Catering Kitchen, China | Two typical design of ventilation systems (MV and DV) were compared using CFD simulations. | DV was found to reduce indoor temperature without increasing the cooling capacity of the AC supply system. |
| Qiu-Wang and Zhen (2006) | Buildings, China | Four cases of ventilation systems were analyzed as well as validated by comparison with simulated and experimental data | The supply of air from the walls (DV) system was a better concept for occupants' thermal comfort in the built environment. |
| Livchak et al. (2005) | Commercial kitchen (restaurant), U.S | Compared mixing ventilation (MV) and displacement ventilation (DV) based on the supply air system and tested with CFD simulation. | DV was found to reduce the temperature inside the kitchen without increasing the air conditioning system capacity. |

4.2.5 Summary

A baseline CFD model of the pantry car kitchen was validated by comparing it with the measured value of air temperature and air velocity, which was found within acceptable

limits according to the ASHRAE-55 standard. Subsequently, three modified cases of pantry cars were executed based on the supply of air system concepts and compared with the existing case model. This study's results indicate that the pantry car's existing case model did not follow the recommended range of the SET index. Comparing the existing case model with all the modified cases, it was observed that the indoor temperature was dropped in the modified cases. Among all modified pantry case models, the *Case III* model showed a better concept where the air velocity increased substantially as the temperature decreased. Simultaneously, the SET was found to have a comfortable thermal sensation between the temperature (26.5–28.6°C) ranges during the entire cooking period. However, in *Case I* and *Case II*, the SET limit's value was comfortable, except for the lunch period. It concluded that the supply of air from the upper edges of the kitchen's front and back walls would increase thermal comfort and energy savings. The suggested concepts could be implemented immediately, to improve the indoor environment of air-conditioned pantry car kitchens in Indian Railways.



The thesis attempted to evaluate and analyse the thermal environmental conditions of Indian Railway Pantry Car (IRPC) kitchens (cooking areas) during various seasons and cooking period. While looking at the thermal parameters it was obvious that subjective comfort level of IRPC chefs are in much higher position as compared to any other International Recommended Standard Values. Therefore, a necessity was identified to determine a new thermal comfort range in Indian context.

In later part of the study the above statement was verified and a new range of thermal comfort was established and validated for IRPC chefs. It was further identified that PMV-PPD index, a common thermal comfort parameter was also found not suitable for IRPC context. The subjective assessment of "thermal sensation, thermal comfort, thermal acceptability, and thermal preference votes" generally indicated that the chefs were dissatisfied with pantry car kitchens' existing conditions because most chefs voted very high dissatisfaction rate.

Finally at the end of this thesis the authors tried to identify the best design intervention which could help to enhance the thermal comfort using Computational Fluid Dynamics (CFD) approach. CFD analysis was performed for both types of pantry cars (air-conditioned and non-air-conditioned) separately to accommodate the basic design differences of indoor architecture of both the pantry cars. Four different modifications in non-air-conditioned IRPC kitchens were considered for CFD analysis. Similarly three modifications were considered for air-conditioned IRPC kitchens. Each modifications were named as (Case). All four concepts (cases) of non-air-conditioned pantry cars were developed based on changes in position of exhaust fans, carriage fans and air-vent. Among all four the very first concept (*Case I*) found to be best enhancement in air velocity and decrement in air temperature. Also *Case I* found to have better and acceptable SET index. Similar analysis was carried out for all modifications done for air-conditioned IRPC kitchens. It was observed that the *Case III* for air-conditioned IRPC turned out be best among all three specific modifications. For *Case III* it was suggested to provide air supply from upper edges of the front and back walls of the kitchen. Also SET index was found to be acceptable. These particular change enhanced thermal comfort and saved energy for IRPC kitchens. All these modifications were found to be cost effective during preliminary understanding.

5.1 Key contribution

The significant contribution of the thesis listed below:

- This thesis presents the measured parameters of thermal comfort of Indian Railway Pantry Car (IRPC) (indoor and outdoor) which found to be beyond the limits of recommended comfort level as per international standards. Also from this particular study it was realised that PMV/PPD index which normally considered as commonly used thermal comfort index, was not suitable for evaluating thermal comfort of IRPC kitchen.
- A new neutral temperature and comfort temperature range were derived for IRPC kitchens.
- This thesis further came with two specific modifications in air supply system, one for non-air-conditioned and other for air-conditioned IRPC kitchens, and found to be satisfactory while enhancing the thermal comfort conditions. Also with preliminary enquiry authors understood that these modifications are easy to install and therefore cost effective.
- The major outcomes of this thesis may be a useful takeaway for any designers and air-conditioner engineers who are involved in railway pantry car coach design.

5.2 Limitations of the present research

The limitations of the present research are illustrated below.

- The study was limited to IRPC kitchen and chefs.
- As per the ASHRAE standard, this study has measured only thermal comfort affecting factors (such as air temperature, globe temperature, relative humidity, air velocity); other issues like air quality, vibration, and jerks have not been considered.
- Thermal comfort monitoring was intermittently, only during pick cooking hours and major seasons. Continuous (full day and all seasons) thermal parameters measurements were not recorded.
- Necessary modifications to enhance thermal comfort were achieved only by changing air supply system. However, other methods were out of the scope of this study.

5.3 Scope of the future work

The scope for further work is outlined below.

- Thermal comfort study can be extended for whole pantry cars along with passenger coaches specifically in Indian context.
- The study further can be extended for other seasons as well.
- In similar way thermal stress study can also be planned for IRPC to provide an elaborate view of thermal conditions.
- Other methods apart from changes in air supply system can also be experimented to enhance the thermal comfort of IRPC.



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1. **Alam, M.S., & Salve, U.R.** (2021). Factors affecting on human thermal comfort inside the kitchen area of railway pantry car - a review, *Journal of Thermal Engineering*, 7(14), 2093–2106. **SCOPUS, Web of Science**
2. **Alam, M.S., & Salve, U.R.** (2021). Enhancement of Thermal Comfort inside the Kitchen of Non-Air-conditioned Railway Pantry Car. *International Journal of Heat and Technology*, 39(1), 275-291. **SCOPUS, Web of Science**
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International Conference Proceeding and Book Chapter

1. **Alam, M.S., Muthiah, A., & Salve, U.** (2021). A Comparative Analysis Between Indoor and Outdoor Thermal Comfort Parameters of Railway Pantry Car. In

Proceedings of International Conference on Thermofluids (pp. 411-416). Springer, Singapore. **SCOPUS, Web of Science**

2. **Alam, M. S.,** Muthiah, A., & Salve, U. (2021, January). A Field Investigation of the Average Indoor Thermal Comfort Parameters on the Railway Pantry Car Kitchen at the Different Cooking Period. In *International Conference on Research into Design* (pp. 203-212). Springer, Singapore. **SCOPUS, Web of Science**
3. **Alam, M.,** Muthiah, A., & Salve, U. (2021). A comparative study of thermal environment between two varieties of pantry car available in Indian Railway. In *Ergonomics for Improved Productivity* (pp. 425-434). **Springer, Singapore**
4. **Alam, M.S.,** Muthiah, A., & Salve, U. R. (2020, November). Thermal comfort assessment of a pantry car coaches in Indian railway. In *AIP Conference Proceedings* (Vol. 2273, No. 1, p. 060002). AIP Publishing LLC. **SCOPUS, Web of Science**
5. **Alam, M.S.,** & Salve, U.R.: Evaluating indoor and outdoor thermal comfort parameters affecting work environment of railway pantry car. *19th International Conference on Humanizing Work and Work Environment (HWWE-2021)*, 1-3 December, Dept. of Design, IIT Guwahati. **Accepted & in press [ID: 221]**.

Appendix I

Thermal Comfort Survey Inside the Kitchen of Railway Pantry Car

1. Worker's Name: _____
2. Train Types: _____
3. Train Name/No.: _____
4. Date: _____
4. Age (years): _____ Height (cm): _____ Weight (Kg): _____
5. How many years have you been working in this pantry car?
 Less than 1 year 1-2 years 3-5 years More than 5 years
6. Working hours per day:.....
7. Rest hours per day:
8. Frequency of rest:.....
9. Habit: (i) Smokers Non Smokers
 (ii) Drinkers Non Drinkers
10. Seasonal Conditions:
 Winter Spring Summer Fall
11. Approximate outside Air temperature (°F or °C):.....
12. Sky:
 Clear Mixed (Sun & Cloud) Overcast
13. Heart rate (bmp): (i) Resting heart rate.....
 (ii) Working heart rate.....
14. Worker's Clothing (Please refer to the attach Table 1) Total I_{cl} =.....clo
15. How do you feel (Thermal Sensation) at this moment?

| | | | | | | |
|------|------|---------------|---------|---------------|------|-----|
| Cold | Cool | Slightly Cool | Neutral | Slightly Warm | Warm | Hot |
| - 3 | - 2 | - 1 | 0 | + 1 | + 2 | + 3 |

16. Do you feel comfortable?

| | | | | | | |
|---------------|----------|-----------|-----------------|-----------|----------|---------------|
| Much too cool | Too Cool | Ok (cool) | Ok (just right) | Ok (Warm) | Too warm | Much too warm |
| - 3 | - 2 | - 1 | 0 | + 1 | + 2 | + 3 |

17. Would you like to be:

| | | |
|--------|-----------|--------|
| Cooler | No change | Warmer |
| - 1 | 0 | + 1 |

18. How would you rate the overall acceptability of the pantry car temperature at this moment?

| | |
|------------|----------------|
| Acceptable | Not acceptable |
| 0 | 1 |

19. How do you feel about the air flow at this moment?

| | | |
|-------|------------|--------|
| Still | Just right | Breezy |
| - 1 | 0 | + 1 |

20. How do you feel in terms of humidity?

| | | | | |
|---------|--------------|------------|----------------|-----------|
| Too dry | Slightly dry | Just right | Slightly humid | Too humid |
| - 2 | - 1 | 0 | + 1 | + 2 |

21. About Temperature conditions:

What do you think about the temperature at the work place?

- Very good Good Acceptable Bad Very bad
 (1) (2) (3) (4) (5)

Problems concerning the temperature:
(There can be more than one answer)

- far too cold during the winter
 far too cold other times
 far too warm during the summer
 far too warm other times

Are there pantry cars with temperature problems? Yes 1 No 2

If Yes, state what pantry cars:

22. About Air Quality:

What do you think about the air quality at the work place?

- Very good Good Acceptable Bad Very bad
 (1) (2) (3) (4) (5)

Problems with air quality:
(There can be more than one answer)

- worse early mornings
 worse in the afternoons
 different in different areas

 not possible to air out pantry cars/areas
 odours

If odours occur, specify what type and where from:

Are there pantry cars with bad air quality? Yes 1 No 2

If Yes, specify:

23. Seasonal Comfort, Summer

The following questions refer to your general perception of thermal comfort in your pantry car throughout the summer months.

In the summer months, how satisfied are you with the temperature in your pantry car?

Very Satisfied Very Dissatisfied

If you are dissatisfied would you describe the temperature as too hot or too cold?

- Always too hot Often too hot Occasionally too hot
 Occasionally too cold Often too cold Always too cold

If you are dissatisfied, how would you best describe the source of your discomfort?

- Too much air movement Not enough air movement
 Incoming sun Drafts from windows Drafts from vents
 Hot/cold surrounding surfaces (floor, ceiling, walls or windows)
 Heating/cooling system does not respond quickly enough to the thermostat
 Uneven temperature (some parts always hot while others always cold)
 Other Please Describe:

24. Systemic Health Problem: _____

Clothing ensembles and garments:

Table 1.

(i) - Typical Insulation for Clothing Ensembles

| Mark | S.No. | Ensemble Description | I _{cl} (clo) |
|------|-------|---|-----------------------|
| | 1 | Typical summer indoor clothing | 0.5 |
| | 2 | Typical winter indoor clothing | 1.0 |
| Mark | S.No. | Ensemble Description | I _{cl} (clo) |
| | 1 | Walking shorts, short-sleeved shirt | 0.36 |
| | 2 | Trousers, short-sleeved shirt | 0.57 |
| | 3 | Trousers, long-sleeved shirt | 0.61 |
| | 4 | Same as above, plus suit jacket | 0.96 |
| | 5 | Same as above, plus vest and T-shirt | 0.96 |
| | 6 | Trousers, long-sleeved shirt, long-sleeved sweater, T-shirt | 1.01 |
| | 7 | Same as above, plus suit jacket and long underwear bottoms | 1.30 |
| | 8 | Sweat pants, sweat shirt | 0.74 |

| | | | |
|--|----|--|------|
| | 9 | Long-sleeved pajama top, long pajama trousers, short 3/4 sleeved robe, slippers (no socks) | 0.96 |
| | 10 | Knee-length skirt, short-sleeved shirt, panty hose, sandals | 0.54 |
| | 11 | Knee-length skirt, long-sleeved shirt, full slip, panty hose | 0.67 |
| | 12 | Knee-length skirt, long-sleeved shirt, half slip, panty hose, long-sleeved sweater | 1.10 |
| | 13 | Knee-length skirt, long-sleeved shirt, half slip, panty hose, suit jacket | 1.04 |
| | 14 | Ankle-length skirt, long-sleeved shirt, suit jacket, panty hose | 1.10 |
| | 15 | Long-sleeved coveralls, T-shirt | 0.72 |
| | 16 | Overalls, long-sleeved shirt, T-shirt | 0.89 |
| | 17 | Insulated coveralls, long-sleeved thermal underwear, long underwear bottoms | 1.37 |

(ii) - Garment Insulation

| Mark | S.No. | Ensemble Description | I _{cl} (clo) |
|---------------------------------------|-------|--------------------------------|-----------------------|
| Underwear | | | |
| | 1 | Men's briefs | 0.04 |
| | 2 | T-shirt | 0.08 |
| | 3 | Half-slip | 0.14 |
| | 4 | Long underwear bottoms | 0.15 |
| | 5 | Full slip | 0.16 |
| | 6 | Long underwear top | 0.20 |
| Footwear | | | |
| | 1 | Shoes | 0.02 |
| | 2 | Slippers (quilted, pile lined) | 0.03 |
| | 3 | Boots | 0.10 |
| | 4 | Sandals/thongs | 0.02 |
| Sweaters | | | |
| | 1 | Sleeveless vest (thin) | 0.13 |
| | 2 | Sleeveless vest (thick) | 0.22 |
| | 3 | Long-sleeve (thin) | 0.25 |
| | 4 | Long-sleeve (thick) | 0.36 |
| Trousers and Coveralls | | | |
| | 1 | Short shorts | 0.06 |
| | 2 | Straight trousers (thin) | 0.15 |
| | 3 | Straight trousers (thick) | 0.24 |
| | 4 | Sweatpants | 0.28 |
| | 5 | Overalls | 0.30 |
| | 6 | Coveralls | 0.49 |
| Shirts | | | |
| | 1 | Short-sleeve dress shirt | 0.19 |
| | 2 | Long-sleeve dress shirt | 0.25 |
| | 3 | Long-sleeve sweatshirt | 0.34 |
| | 4 | Long-sleeve flannel shirt | 0.34 |
| Suit Jackets and Vests (lined) | | | |
| | 1 | Sleeveless vest (thin) | 0.10 |
| | 2 | Sleeveless vest (thick) | 0.17 |
| | 3 | Single-breasted (thin) | 0.36 |
| | 4 | Single-breasted (thick) | 0.44 |
| | 5 | Double-breasted (thin) | 0.42 |
| | 6 | Double-breasted (thick) | 0.48 |

Physical measurement:

Table 2. Environmental parameters at climatic zones and seasons during cooking

| Season | Climate Zone | Cooking periods | Time (HH:MM:SS) | t_w , (°C) | t_g , (°C) | t_a , (°C) | RH , (%) | v_a , m/s(ft/min) |
|--------|--------------|-----------------|-----------------|--------------|--------------|--------------|------------|---------------------|
| | | Breakfast | | | | | | |
| | | Lunch | | | | | | |
| | | Snacks | | | | | | |
| | | Dinner | | | | | | |



Appendix II

Governing equations:

Conservation of mass:

$$\frac{\partial \rho}{\partial t} + \frac{\partial \rho u_i}{\partial x_i} = 0 \quad (i)$$

$$\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} \right) = 0 \quad (ii)$$

$$\frac{\partial \rho}{\partial t} + \frac{\partial \rho u}{\partial x} + \frac{\partial \rho v}{\partial y} + \frac{\partial \rho w}{\partial z} = 0 \quad (iii)$$

Conservation of momentum:

For each dimension when the velocity is $V(u, v, w)$

The X-momentum equation

$$\rho \left(u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + w \frac{\partial u}{\partial z} \right) = -\frac{\partial p}{\partial x} + \mu \left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2} \right) \quad (iv)$$

The Y-momentum equation

$$\rho \left(u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} + w \frac{\partial v}{\partial z} \right) = -\frac{\partial p}{\partial y} + \mu \left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2} \right) \quad (v)$$

The Z-momentum equation

$$\rho \left(u \frac{\partial w}{\partial x} + v \frac{\partial w}{\partial y} + w \frac{\partial w}{\partial z} \right) = -\frac{\partial p}{\partial z} + \mu \left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2} \right) \quad (vi)$$

Conservation of Energy:

$$\left(\frac{\partial}{\partial t}(\rho T) + \frac{\partial}{\partial x}(\rho u T) + \frac{\partial}{\partial y}(\rho v T) + \frac{\partial}{\partial z}(\rho w T) \right) = \frac{\partial}{\partial x} \left(\Gamma \frac{\partial T}{\partial x} \right) + \frac{\partial}{\partial y} \left(\Gamma \frac{\partial T}{\partial y} \right) + \frac{\partial}{\partial z} \left(\Gamma \frac{\partial T}{\partial z} \right) \quad (vii)$$

Where u_i -velocity of fluid $x_i(i=1,2,3)$, ρ -air density, μ -dynamic viscosity, P -effective density, Γ -diffusion coefficient, and T -Coolant temperature ($^{\circ}\text{C}$).