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Thermal Comfort of the Kitchen in Pantry Cars on Indian Railways

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ABSTRACT

This paper mainly investigates the thermal comfort of the kitchen in pantry cars on Indian railways in two seasons (summer and winter) and two climatic zones (humid and subtropical climate zone and tropical wet and dry climate zone). A questionnaire survey on subjective feelings of thermal comfort was conducted among 69 chefs working in 14 kitchens of pantry cars on Indian railways. Their physical parameters of thermal comfort were also measured. Based on the survey results and measured data, the authors analyzed the comfort perception and thermal responses of the chefs in the kitchens, with the aid of indices like predicted mean vote (PMV) and predicted percentage dissatisfied (PPD). The results show that outdoor environmental parameters have an effect on indoor environmental parameters during the cooking; the maximum range of thermal comfort parameters was found at lunch and snack preparations, while the minimum was observed at breakfast; the PMV/PPD index method does not apply directly to the evaluation of thermal comfort in the kitchen in pantry cars on railways; the neutral temperature of chefs in summer and winter was 23°C and 21.62°C, respectively. These findings help to improve the indoor working environment of chefs on Indian railways.

1. INTRODUCTION

Indian Railways is one of the second biggest rail networks in the world in the 21st century. It plays a vital role in transportation facilities, which carries more than twenty million passengers and more than two million tons of freight regularly [1]. Moreover, 12,000 passenger trains like; mail, express, and superfast-express trains run throughout the country [2]. Catering system is one of the main characteristics of Indian railways, which provides food to railway passengers through its present approximately 338 pairs of railway pantry car coaches and 11,237 catering-stalls [3]. Pantry car, play a significant role in the catering system, it serves the food, onboard passengers, which is an integral part of every medium and long route train [3, 4]. In a pantry car coach, there are 3-5 chefs, while 40-50 meal servers, and 2 railway pantry car employees [5, 6]. There are two types of pantry car coaches' model running at present, such as; air-conditioned and non-air-conditioned. Air-conditioned pantry car coaches have a better aesthetic design and equipped with better passenger comfort but as per the previous research indicated that at the cooking time there is no significant difference in thermal environment between both these two types of pantry car coaches [6]. Both these pantry cars use common equipment for cooking such as; ovens, heater, kettle, soup warmer, deep fryers, etc. While preparation of the meal these types of instrument leads to humidity, fumes and heat generation. Because of this, the indoor environment of a pantry car kitchen becomes severely hot and humid [7]. The existing hot and humid conditions cause excessive sweating and make chefs work difficult in a pantry car, which is not conducive to human work. This uncomfortable situation of work adversely affects the physical and mental health of the chefs. No researcher has concentrated on an appraisal of the situation of chef's thermal comfort in pantry car kitchen. While few researchers have studied the thermal environment in commercial kitchens.

Ravindra et al. [8] organized the thermal comfort research in a household kitchen in Punjab, in this paper identify the thermal sensation range during winter season slightly cool to neutral and neutral to slightly warm during the summer season. Similarly, research of Rahmillah et at. [9] indicated the PMV and PDD index results found the 'hot' thermal sensation value and most of the subjective responses voted to preferred morning cooking time in the kitchen. Kajtar et al. [10] observed the environmental parameters demonstrated a higher percentage of dissatisfaction than a complaint of occupancy in the kitchen environment. Whereas, the "non-uniform" thermal environmental situation in a home kitchen, when the outer air temperature is low the temperature inside the kitchen changes drastically, especially in the outer window region [11]. Similarly, the result of Livchak et al. [12] shows that when the temperature inside the kitchen becomes 5.5°C more than comfort temperature, the productivity would have reduced by 30%. The research of Simone et al. [13] determined that PMV-PPD method is not directly applicable for commercial kitchen environment due to high globe temperature, air temperature, and high level of activity.

Above mentioned research shows that different studies concerned to thermal comfort are available for commercial kitchen workers, and factors affecting the human thermal comfort has considered. While literature related to these issues has not been found on the Indian railway's pantry car kitchen. However, railway pantry cars are similar to commercial kitchens, but there is some difference in this such as; work-flow, job demand, indoor architecture, and moving nature of the railway pantry car. Therefore, this research article efforts to appraisal the thermal comfort in a railway pantry car kitchen in Indian by utilizing objective measurement and subjective

assessment.

It has the following objectives:

1. Compare indoor and outdoor environmental factors based on seasonal and climatic zone variations during the different cooking times (breakfast, lunch, snack, and dinner);

2. To evaluate whether the PMV model is applicable or not for predicting the thermal comfort of chefs in Indian railway pantry car kitchens, and identify the neutral (comfort) temperature for them.

2. METHOD

2.1 Location, duration and subject description

2.1.1 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 1. The indoor and outdoor thermal environment factors of the Indian Railway Pantry Car (IRPC), was measured in humid and sub-tropical, and 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 from Guwahati to Delhi railway station. While trains between Kolkata to 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.

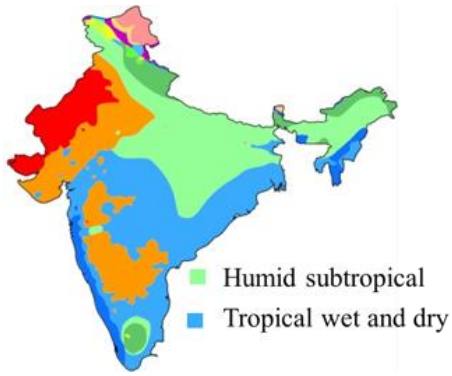


Figure 1. Climatic zones in India, based on the Koppen classification system

2.1.2 Duration

In the current study, two seasons have been selected like winter and summer. Therefore, the period of study was for the summer season in August and similarly, it was in December for the winter season. 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: 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. These measurements were observed as much as possible without troubling the respondent's activities.

2.1.3 Subject description

A total number of 338 trains in India run with a pantry car which has been reported in the railway board report. In which, there are 3 to 5 cooking workers (chefs) in a train. The determine 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 were taken. 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. The general education level of chefs was found to be very low, very few among them were even matriculate.

2.2 Data collection

2.2.1 Physical measurement data: Indoor and outdoor environmental 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) handheld anemometer: Kestrel weather meter 4500, (b) 6-inch black-globe thermometer. The accuracy and range of the instrument have been depicted in Table 1. Data of environmental parameters were measured according to ASHRAE 55 Standard [14] and Simone and Olson [15], 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 (where the time of cooking [breakfast, lunch, snacks, and dinner] chef's operating hours were at peak throughout the day). All these physical measurements were observed during the meal preparation time as discussed above. 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. The train generally stops at the designated railway station for a very short time, due to this the timing of outdoor parameters measurement has been considered less.

The globe temperature was measured with the help of a "(6 in.)-black globe thermometer" in the center position of the meal preparing zone as discussed above, which estimates the "mean radiant temperature". As per the Mishra and Ramgopal [16], mean radiant temperature "t_{mrt}" was approximated with the combination of "air temperature-t_a", "globe temperature-t_g", and "air velocity-v_a" applying Eq. (1).

$$t_{mrt} = \left[\left(t_g + 273\right)^4 + \frac{1.1\times10^8 {v_a}^{0.6}}{\varepsilon D^{0.4}} \times \left(t_g - t_a\right)\right]^{1/4} - 273 \quad (1)$$

where, emissivity of the globe surface (has assumed as 0.95) is 'ε' and globe diameter is 'D'.

Table 1. Details of instruments used during the field study

Instrument and type	Parameter measured	Range	Accuracy
Kestrel weather meter 4500	(i) Indoor and outdoor air temperature, T_a	-29.0°C to +70.0°C	-5° to +95°C
	(ii) Indoor and outdoor relative humidity, RH	5% to 95%	±3%
	(iii) Indoor and outdoor air velocity, V_a	0.4 m/s to 60 m/s	± 0.1 m/s
6-inch black-globe thermometer	(i) Indoor and outdoor globe temperature, T_g	-5° to +95°C	

2.2.2 Assessing clothing insulations and metabolic activity level

In this research for estimation of the "clothing insulation" and "metabolic activity level" using the standard checklist which is provided by ASHRAE 55 Standard [14] and ISO 7730 Standard [17]. Only male chefs work inside the IRPC. A pantry car chef commonly attired of 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 standard as exhibited in Table 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/m^2) [18]. And it shows that the chefs were mostly "standing" and "medium" activity, according to ASHRAE 55 Standard [14] and ISO 7730 Standard [17].

Table 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	0.04a
	boots	0.08

2.2.3 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 including "air temperature", "mean radiant temperature", "relative humidity" and "air velocity" along with the predicted "metabolic rate" and "clothing insulation" was used to compute the PMV-PPD index using a CBE "Center for the Built Environment" thermal comfort software to determine thermal comfort according to ASHRAE 55 Standard [19].

2.2.4 Subjective assessments

In the arrangement to appraise the thermal comfort of the indoor environment condition in IRPCs kitchen chef's 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 chef's standard checklist was used based on the ASHRAE 55 Standard [20], ISO 14505-3 Standard [21], and ISO 10551 Standard [22] as shown in Table 3. In which 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" were used to getting the thermal comfort votes (TCV) of the IRPCs kitchen chefs. The occupant's thermal preference response 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. 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.

Table 3. Thermal comfort survey checklist of preferences and sensation for indoor parameters

	Description of scale			
Scale	TSV	TCV	Thermal preference	Thermal acceptability
+3	Hot	Much too warm		
+2	Warm	Too warm		
+1	Slightly warm	Ok (Warm)	Warme	Not acceptable
0	Neutral	Ok (just right)	No change	Acceptable
−1	Slightly cool	Ok (cool)	Cooler	
-2	Cool	Too Cool		
-3	Cold	Much too cool		

2.3 Data analysis

Present research comparison between the indoor and outdoor parameters of thermal comfort we used descriptive analysis in which the data 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. The data was not normally distributed; therefore, graphical techniques were used to compare rather than statistical methods. Also, the difference between indoor and outdoor environmental parameters was high in the descriptive analysis itself. Therefore, performing statistical analysis (like T-test) was found to be unnecessary. For this MS Excel 2016 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 is reported 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". After that, neutral (comfort) temperatures have been compared with ASHRAE standard and some other thermal comfort research conducted in hot and humid regions for validation of this study.

3. RESULTS AND DISCUSSION

3.1 Indoor and outdoor environments

Thermal comfort study basically consists of four important environmental factors such as; "air temperature", "radiant temperature (assessing through globe temperature)", "humidity" and "air velocity", which was measured in this research. The details of measured "indoor and outdoor" environmental variables observed during the seasonal and climatic variation are depicted in Table 4.

Table 4. 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
	N=6								
	Min	26	28	69	0.00	27	24	66	0.00
Summer	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
	N=8								
	Min	25	20	43	0.00	17	19	33	0.00
Winter	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
	N=10								
	Min	25	22	55	0.00	17	19	33	0.00
Humid and	Mean	31	29	70	0.04	25	26	67	1.33
Subtropical	Max	37	37	87	0.30	36	32	96	3.61
	SD	3	4	7	0.08	5	4	18	1.10
	N=4								
	Min	25	20	43	0.00	19	20	36	0.00
Tropical wet and dry	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

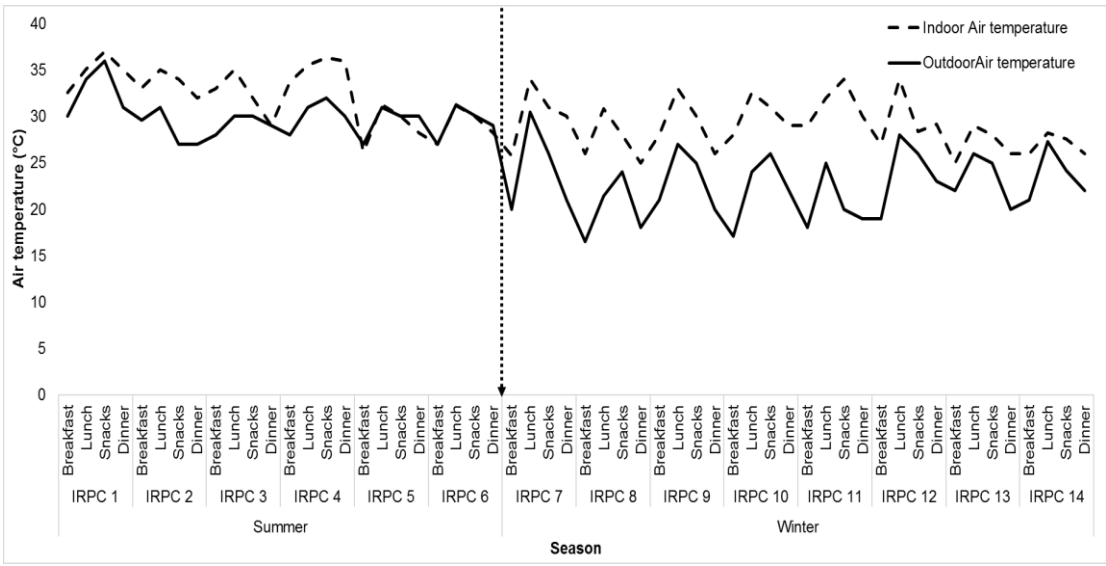
3.1.1 Air temperature

Air temperature is the most influential environmental factor for "thermal comfort", as shown in earlier studies. Which we have also taken in this study. Figure 2 (a) shows air temperature variation in the summer and winter season, which was taken in the indoor and outdoor sides of the pantry car kitchen. Generally, indoor and outdoor temperatures were measured four times a day during the cooking (breakfast, lunch, snacks, and dinner). According to a graphical representation, averages of indoor air temperature was found more in both seasons than the outdoor air temperature. During the summer season, maximum indoor air temperature was found to be 37°C snacks and 36°C lunch time. While the minimum indoor temperature was found at 26°C breakfast time. However, the average value of indoor air temperature in the entire summer season was 32°C during the all cooking period. And we can see that maximum and minimum values of outdoor air temperature are 36°C and 27°C respectively. In the winter season, it can be seen in the graph that the maximum value of indoor air temperature is up to 34°C lunch and snack time respectively. 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.

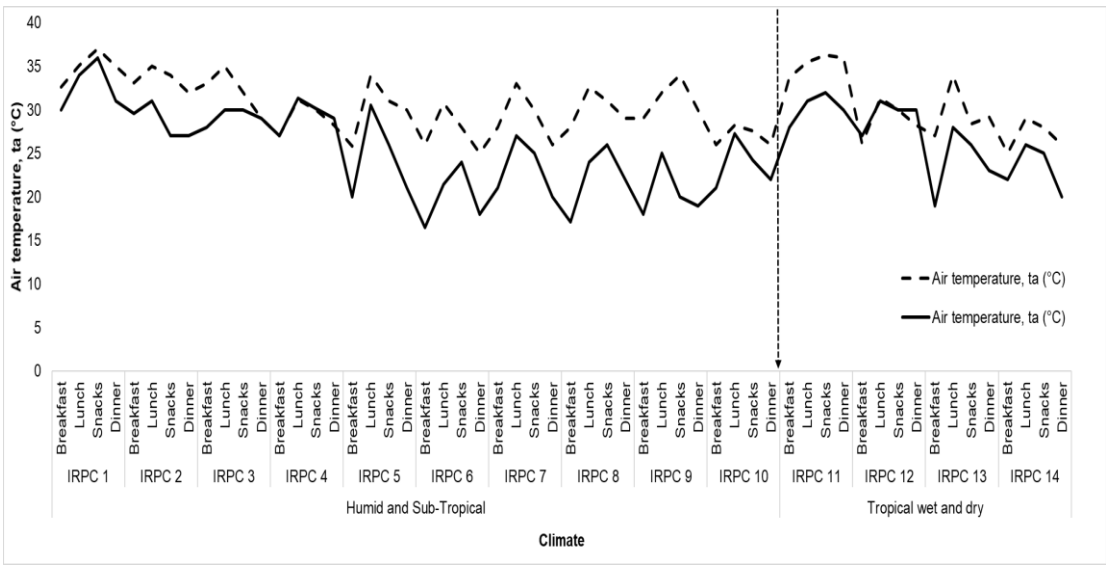
Figure 2 (b) indicates indoor and outdoor air temperature variation in humid and sub-tropical and tropical wet and dry regions. It can be seen here also in the graph the indoor air temperature was higher than the outdoor air temperature in both climatic zones. In a humid and sub-tropical region, maximum indoor air temperature 37°C was found at the time of snack preparation in pantry car. However, the average value of indoor and outdoor air temperatures was 32°C and 25°C respectively throughout the entire period. Similarly, in a tropical wet and dry region maximum indoor air temperature 36°C was found at the time of lunch and snack preparation. While the entire cooking period, indoor and outdoor air temperature was found at 30°C and 27°C, respectively.

As the above results indicate, there is a significant effect of outdoor air temperature inside the pantry car kitchen. Because indoor air temperature has always been found high throughout the whole study period. However, the value of indoor air temperature also does not comply with ASHRAE 55 Standard

[19] both in the seasonal variation and climatic zones. Indoor air temperature has been found to be more at lunch and snack time in both summer and winter season and climatic zone (humid and sub-tropical and tropical wet and dry).



(a) Season



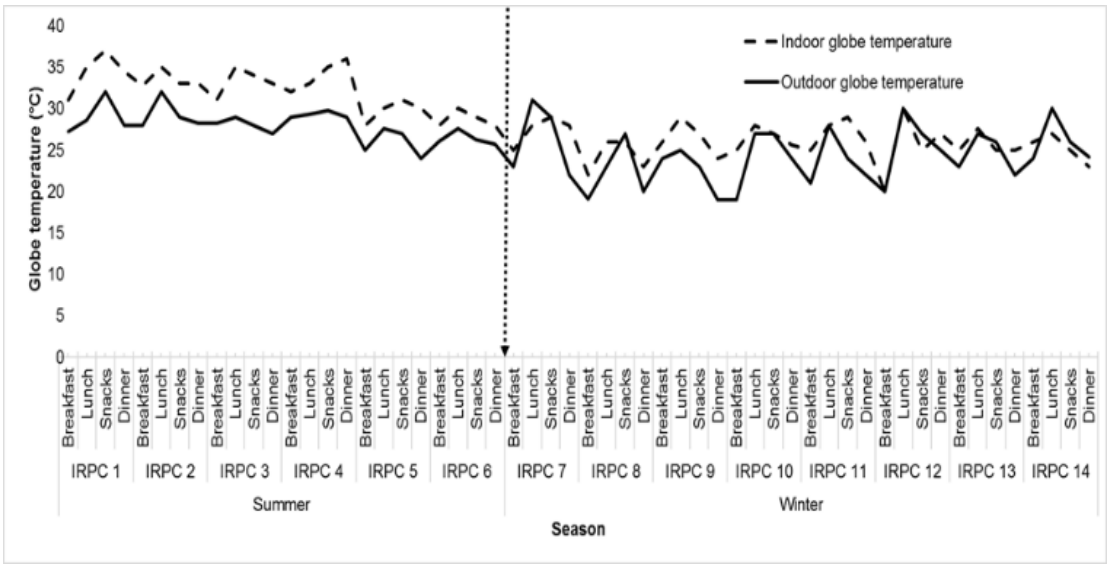
(b) Climate

Figure 2. Indoor and outdoor air temperature variation graph based on (a) season, and (b) climatic zone

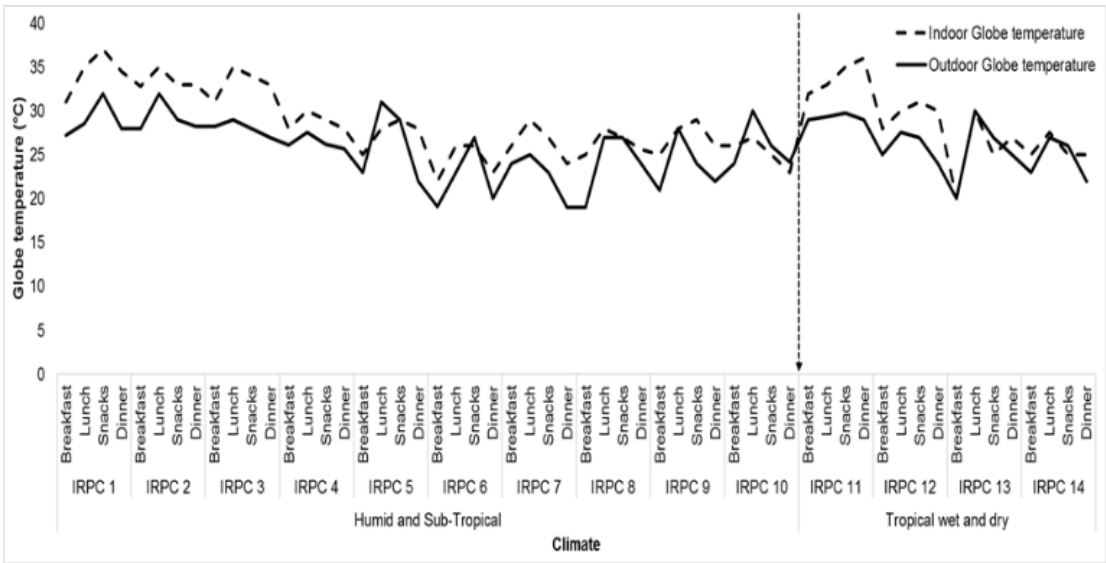
3.1.2 Globe temperature

Figure 3 (a) shows the full measurements of globe temperature variation in both indoor and outdoor environmental conditions during summer and winter season. In the summer season, it can be seen that the maximum and minimum indoor global temperatures are 37°C snacks and 28°C breakfast at the time of cooking. Together, the average value of indoor globe temperature of the entire summer season was 32°C. However, the average value of outdoor globe temperature was only 28°C. In the entire summer season, the value of the indoor globe temperature was higher than the outdoor globe temperature. While during the winter season, the maximum and minimum indoor globe temperatures were found at 30°C lunch and 20°C breakfast time respectively. And in the entire winter season, the average indoor and outdoor global temperature was found at 26°C and 24°C respectively. In the winter season, the variation of the globe temperature varies less and more in both indoor and outdoor conditions. However, during the winter season also the indoor globe temperature did not obey the ASHRAE standards at some time of cooking.

Figure 3 (b) demonstrate the climate variation of globe temperature both indoor and outdoor environment. In a humid and subtropical climate region also the indoor globe temperature was maximum 37°C at snack time and its average value was found to be around 29°C. Whereas, the average value of the outdoor globe temperature was 26°C. Similarly, in a tropical wet and dry region, it can see that maximum indoor globe temperature was found on the same day 36°C and 35°C at the time of snacks and dinner respectively and the average value of this climate zone was 29°C. Although, 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 value of the indoor globe temperature does not follow the ASHRAE standard.



(a) Season



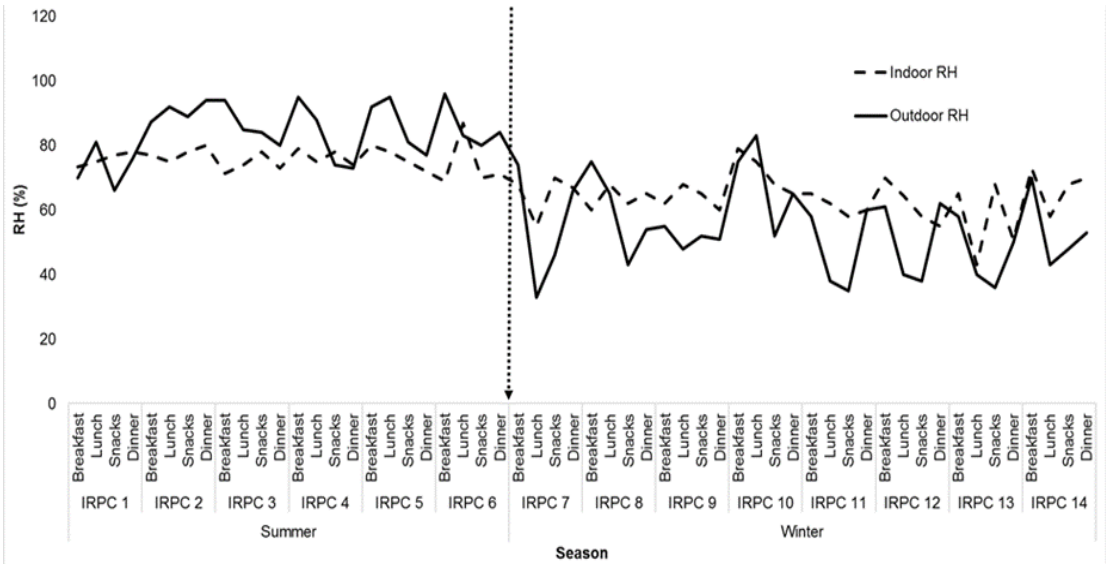
(b) Climate

Figure 3. Indoor and outdoor globe temperature variation graph based on (a) season, and (b) climatic zone

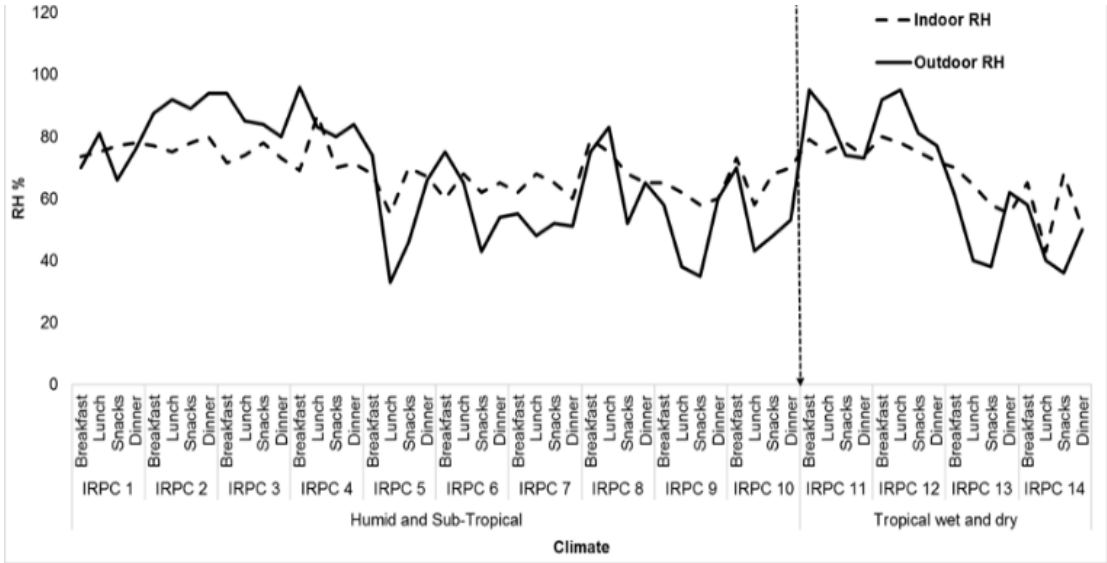
3.1.3 Relative humidity

Relative humidity (RH) is the vital 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 4 (a) shows the variation of relative humidity percentage RH (%) in both 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 the time of lunch and breakfast on a similar day. While the 76% average value of indoor RH measured throughout the summer season during the all cooking time. And the average value of the outdoor RH was 84%. Approximately, the outdoor RH (%) was estimated higher according to indoor in the entire summer season. Similarly in the winter season, the indoor and outdoor RH was recorded between 43% to 79% and 33% to 83%, respectively. While the average rate of RH% of both indoor and outdoor was 64% and 54%. In the winter season, while preparing breakfast and lunch, humidity was found more inside the pantry car. Indoor and outdoor RH was found to be low in winter season as compared to the summer season. As per the ASHRAE 55 Standard [23], comfortable range of RH between 30% to 60%, optimum range of RH between 40% to 60% and considered ideal RH for 50%.

Figure 4 (b) also shows the variation of RH (%) on the based climatic zone both indoor and outdoor conditions. In the humid and sub-tropical climatic zone, the maximum indoor RH was at 87% lunch preparation time, while the different day minimum indoor RH was also found 55% at the lunch preparation time. However, rest of the other cooking time, the value of indoor RH value was found out of the recommended range. In this climate zone, the average rate of indoor and outdoor RH% was 70% and 67% throughout the entire measurement respectively. Correspondingly in a tropical wet and dry region, the value of Indoor RH value was maximum and minimum at the time of breakfast 80% and lunch 43% respectively with 68% average value. Whereas outdoor RH in this climate zone was observed during all periods with an average rate of 66%. As mentioned in previous studies, for the outdoor environment condition, when the temperature of the air increases, the relative humidity decreases [24]. In both the climate zone, indoor RH% was found to be higher than the recommended range mostly while cooking. While the rate of outdoor RH fluctuated during this period.

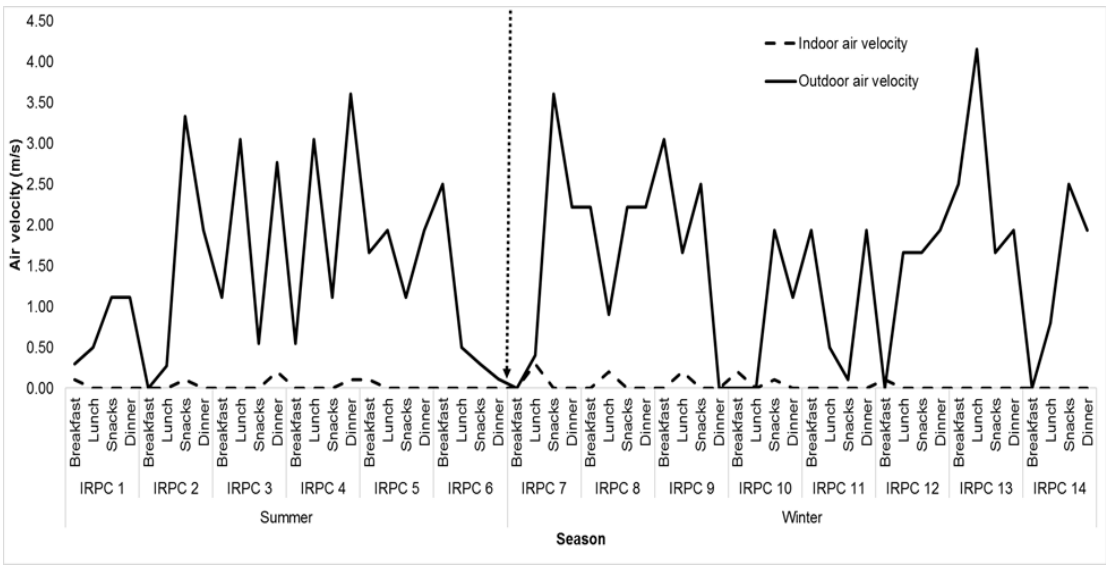


(a) Season

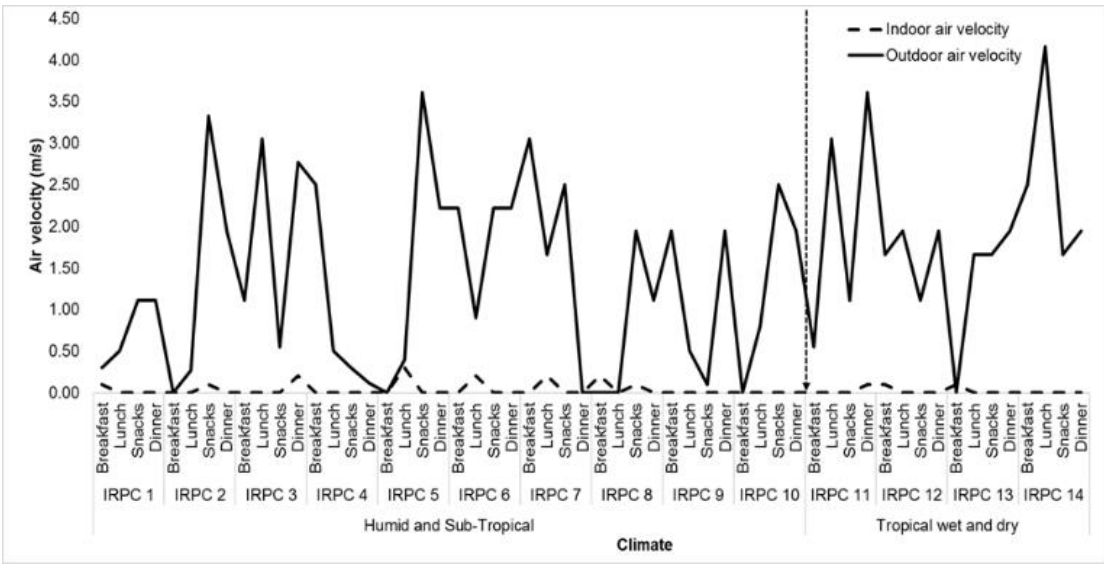


(b) Climate

Figure 4. Indoor and outdoor relative humidity variation graph based on (a) season, and (b) climatic zone



(a) Season



(b) Climate

Figure 5. Indoor and outdoor air velocity graph based on (a) season, and (b) climatic zone

3.1.4 Air velocity

Figure 5 (a) demonstrates that air velocity values both indoor and outdoor environmental conditions during the summer and winter season. In a summer season, indoor and outdoor air velocity was within 0.00 m/s to 0.20 m/s and 0.00 m/s to 3.61 m/s respectively. The average air velocity was 0.03 m/s and 1.43 m/s observed for indoor and outdoor conditions during the whole summer season. During the winter season, the air velocity in the indoor environment was found from 0.00 m/s to 0.30 m/s with an average 0.03 m/s, which was almost the same as the summer season. Whereas the outdoor air velocity was observed range 0.00 m/s to 4.16 m/s with an average 1.54 m/s. There is no difference in movement of indoor air velocity in both seasons. Inside the pantry car, no significant movement of air velocity was found at the time of cooking. However, during this time the outdoor wind speed measured was very high. According to the recommended value of "ASHRAE 55 Standard [20]", the air velocity should be for summer (<0.25 m/s) and winter (<0.15 m/s).

Figure 5 (b) shows the estimated effect of indoor and outdoor air movement in two different climate zone. In humid and sub-tropical climate zone, the minimum and maximum indoor air velocity were found 0.00 m/s and 0.30 m/s respectively with mean value 0.04 m/s. Whereas the outdoor air velocity was measured; minimum and maximum 0.0 m/s and 361 m/s respectively with an average value of 1.33 m/s. Entirely in this climate zone the indoor air velocity was found less. While in tropical wet and dry climate zone, the indoor and outdoor air velocity was observed during the cooking time 0.00 m/s to 0.10 m/s and 0.00 m/s to 4.16 m/s respectively and the average value of both was 0.02 m/s and 1.91 m/s.

3.2 Evaluation of PMV-PPD index

In this study, a thermal comfort condition of chefs during the meal preparation period in the pantry cars were estimated based on a PMV-PPD index method. The PMV model predicted the mean impedance of a huge bunch of 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. A thermal comfort criterion necessitates the PPD value to be lower than "10% to correspond to a PMV" value of between range –0.5 "slightly cool sensation" and +0.5 "slightly warm sensation". Thermal comfort result of pantry car kitchens during the cooking period/time (breakfast, lunch, snacks, and dinner) based on the seasons and climatic zones are depicted in Table 5.

During the summer season, the maximum PMV value of 2.97 was estimated with 97.33% PPD during the preparation of lunch. While minimum PMV value 2.43 was found at the time of breakfast preparation with PPD 87.83%. Similarly, in the winter season, maximum value of PMV 1.91 was calculated with 70.25% of PPD at lunch cooking period. While minimum value of PMV 1.28 was found with 40.75% PPD at breakfast time. However, the value of PMV-PPD index was found more during other time cooking periods also in both seasons. In a humid and subtropical climate zone, maximum PMV value 2.33 and 2.32 was found at the time of snacks and lunch with PPD 81.20% and 79.30% respectively. Similarly, in a tropical wet and dry climate zone, the maximum value of PMV and PPD index was found at lunch cooking period 2.48 and 88.25% respectively. Entirely in both seasons and climate zones, the calculated mean value of PMV and PPD index 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 5). But many individual values are outside this standard range (view Figure 6), demonstrating that the PMV method is not practically applicable in every context; "ISO Standard EN 7730 [25]" recommends using the PMV value only in the interval - 2 to +2, meaning that most of the measured conditions are outside the range, indicating a high percentage of dissatisfaction. PMV and PPD index method is not directly suitable for thermal comfort application of pantry car kitchen because of high temperature, high activity, and less air movement.

Table 5. 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	95.5
	Dinner	32.39	31.88	76.15	0.02	0.58	2.0	2.70	92.58
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

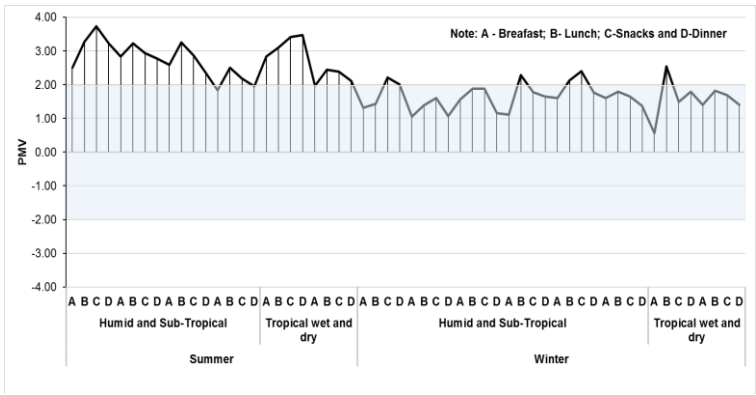


Figure 6. Distribution of PMV value at the cooking time

3.3 Subjective assessment

Demographic detail of the railway pantry car chefs is presented in Table 6 with data being presented, like mean (SD), range, and percentages. The chef's age ranges from 24 to 51 years (mean = 36.87 years; SD = 6.36 years). Maximum 36.23% of chefs were having work experience between 3-5 years, while minimum 10.14% of pantry car chefs were having work experience less than one year. Another majority of the chefs had worked in the pantry car for more than five years.

Figure 7 demonstrates the subjective responses to thermal comfort votes (TCV) from –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 results show that 65.5% of the 19 respondents from the humid and sub-tropical climate zone voted sensation value (+1, +2 and +3). While for the tropical wet and dry climate region, the alue of votes was (+1, +2, +3) which consists of 34.5% of the 10 respondents. 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, 75% of the 30 respondents from the humid and sub-tropical climate zone voted sensation value (+1, +2, +3). Although similar in the tropical wet and dry climatic zones, 25% of the 10 respondents voted for sensational range value +1 to +3. Inside the pantry car, none of the respondents have voted for cool sensation 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 55 Standard [20] specifies that 80% of people living in acceptable thermal environments should vote for the central three categories "-1, 0, +1". In this study, no respondents' votes were found especially with central three categories.

Table 6. Demographic details of railway pantry car chefs (n = 69)

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
Job experience (% sample)	
< 1 year	10.14
1-2 years	21.76
3-5 years	36.23
> 5 years	31.87

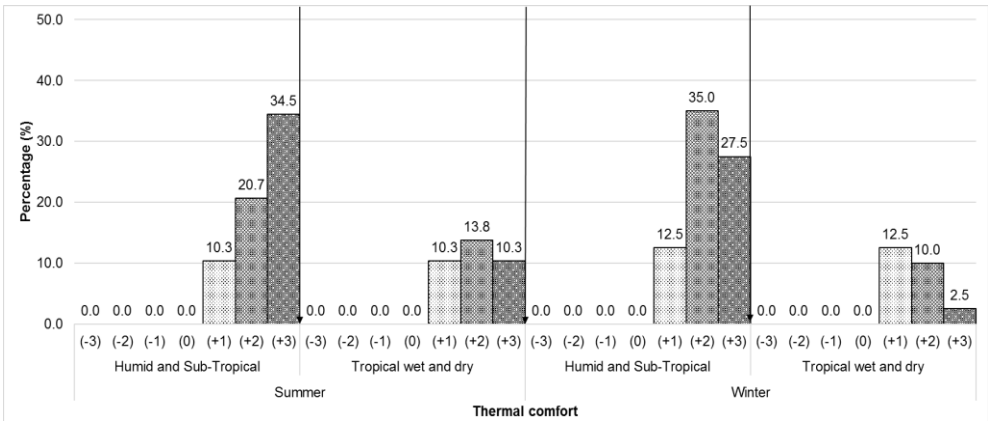


Figure 7. Dispensation percentage of subjective response to thermal comfort

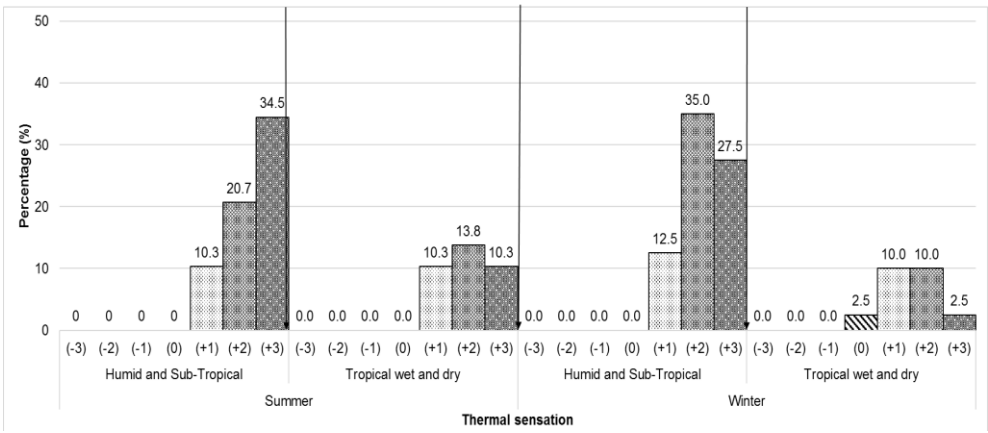


Figure 8. Dispensation percentage of subjective response to thermal sensation

Figure 8 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 time of summer season in a humid and subtropical climate zone, 66% responded voted from the range +1 to +3. Even in the tropical wet and dry climate areas, 34% of respondent's votes ranged from +1 to +3. In both climatic zones, there is no vote in the entire summer season according to the central three categories. During the winter season in the humid and subtropical climate zone, votes ranged +1 to +3 which consists of 75% of the 30 respondents. While for the tropical wet and dry climate region, the votes are from 0 to +3, in which there are 25% of 10 respondents. In 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 1 respondent did vote in 0 (neutral), but the votes of all the other respondents who do not follow the standard.

Occupants' (chefs) perception of thermal acceptability based on the season and climate is an exhibit in Figure 9. The rating scale: Acceptable (0) and Not acceptable (1) was used to obtain the occupants' thermal acceptability response. It observed that during the summer season in both climate zones, 24% of respondents accepted the thermal environment and the other 76% did not accept it. Similarly, during the winter season in both climatic zones, only 5% of chefs accepted the thermal environment while 95% did not accept it. As many studies have suggested, the percentage of respondent satisfaction in any thermal environment should be above 80% [26, 27]. Where's the percentage of the chef's satisfaction in the pantry car kitchen environment is very low.

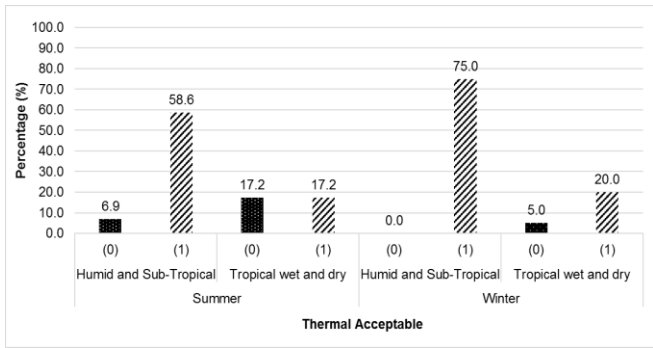


Figure 9. Dispensation percentage of subjective response to thermal acceptability

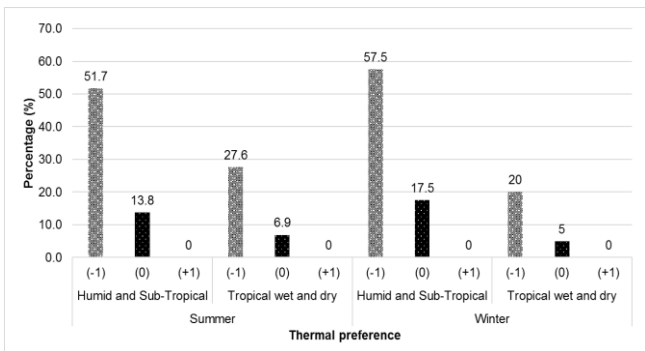


Figure 10. Dispensation percentage of subjective response to thermal preference

Figure 10 demonstrates the dispensation percentage of subjective response to thermal preference based on the seasonal variation and climate zone. Thermal preference was estimated directly according to the answer to the question: In the pantry car kitchen environment would you like to be, -1 "cooler", 0 "no change", +1 "warmer". It can be seen that throughout the summer season in both climate zones, 79.3% of the chefs want to prefer in the "cooler" side. While 20.7% of the chefs preferred with the existing environment inside the pantry car. None of the chefs preferred the "warmer" side. Similarly, at the time of winter season in both climatic zones, 77.5% of the chefs want to prefer in "cooler" side, and 22.5% of the chefs preferred with the existing environment. Throughout the winter season in both climate zones, no anyone preferred to "warmer" side. However, in both season and climatic zones, some respondents preferred staying with the environment inside the pantry car due to cooking habits. As such, some thermal comfort studies have also been reported that the largest part of the subjects does not want any change in their workplace zone [28]. But in this result, most of the respondents prefer to stay on the cool side.

3.4 Neutral temperature and comfort temperature range

In this research to predict the Tn "neutral temperature" and Tcr "comfort temperature range", regression analyses were carried out using "M S Excel 2016". Figure 11 (a) and (b), demonstrate the regression line of "thermal sensation votes-TSV" on "air temperature-Ta" in summer and winter are:

Summer:

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

Winter:

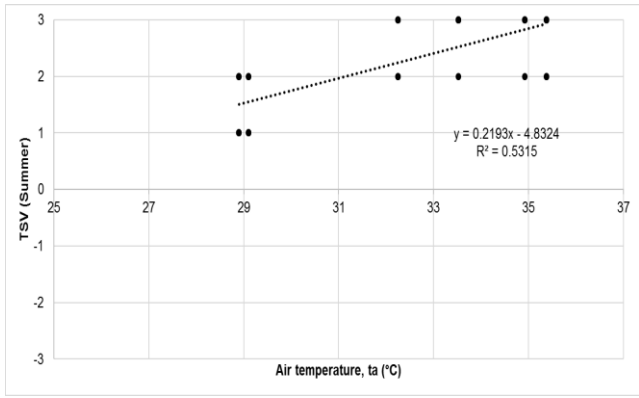
$$TSV = 0.2646Ta - 5.6207 \quad r^2 = 0.3024 \qquad (3)$$

The coefficient of the determinant (r^2) between TSV and the Ta in summer is 0.5315 for Eq. (2) and in winter is 0.3024 for Eq. (3).

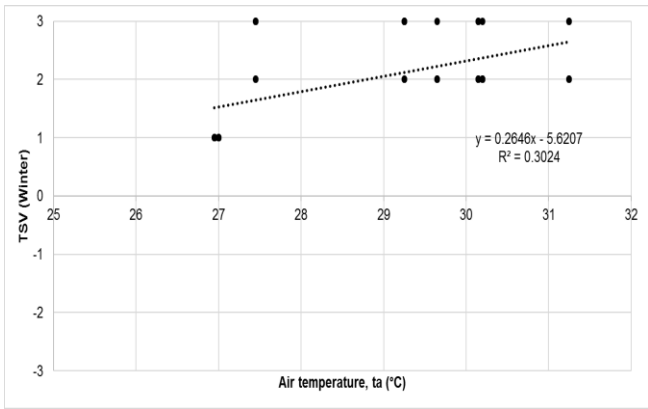
Table 7 demonstrates the neutral "comfort" temperature and comfort range of chefs in the railway pantry car. The neutrality condition during summer and winter season is derived by solving Eqns. (2-3) for a thermal sensation vote of zero. While the comfort temperature was determined on the basis of ASHRAE 55 standard, in which the "comfort zone" is defined as a limitation of thermal environmental conditions more than 80% of living people express satisfaction. So, the percentages of dissatisfaction resulting from votes above "central three categories (-1, 0, +1)" of ASHRAE scales in each temperature bin were plotted as a function of air temperature.

During the summer season in the pantry car, chef's neutral temperature was 23°C Ta, while the comfort temperature range was 18.50-27.80°C Ta. Similarly, during the winter season in the pantry car, chef's neutral temperature was 21.62°C Ta, whereas the comfort temperature range was 17.80-25.50°C Ta.

When comparing to ASHRAE's comfort range during the summer season, 24.5-27.0ºC, the comfortable range for chefs shifts to "slightly warm temperatures" by about 0.80ºC. Similarly, comparing to ASHRAE's comfort range during the winter season, 19.5-22.5ºC, the comfortable range for chefs shifts to warm temperatures by about 3ºC. This finding indicates a completely different phenomenon. Because pantry car chefs have differently acclimated to the climate. Similar types of research also have been done by the authors in other studies which indicated below.



(a) Summer



(b)Winter

Figure 11. The regression analyses between the TSV and T_a during (a) summer and (b) winter, season inside the pantry car

Table 7. Summer and winter season *Tn* and *Tcr* for chefs inside the pantry car

Season	Tn (°C)	Tcr (°C)	Regression Equation	r^2	Significance
Summer	23	18.50-27.80	TSV= 0.2193Ta – 4.8324	0.5315	$p < 0.01$
Winter	21.62	17.80-25.50	TSV = 0.2646Ta – 5.6207	0.3024	$p < 0.01$

3.4.1 Subjects neutral temperature compare with other Studies

Various researchers have studied to identify neutral temperatures in their thermal comfort work, which is shown in Table 8. Chan et al. [29] organized thermal comfort research on office premises in Hong Kong to improve the work environment.

Similarly, in China Ye et al. [30] finished the research on the passenger train's coaches to determine the thermal environment and thermal comfort. Accordingly, Lin et al. [31] directed the thermal comfort study in "short-and long-haul" buses and trains among the passengers in Taiwan. Hwang and Cheng [32] reported on "human thermal comfort in air-

conditioned offices workers in Taiwan", in which compared the computed comfort temperature to ASHRAE standard 55. Similar research conducted by Hamzah et al. [33] in "Indonesia" on naturally ventilated university classrooms to understand the "thermal environment condition and subjects responses", In which also compared the computed comfort temperature to ASHRAE standard 55 and Indonesian National Standard. Karyono [34] also finished a similar kind of research in Indonesia on university students to identify the comfort temperature among them. Hussein et al. [35] conducted the study in Malaysia on "air-conditioned and non-air-conditioned two schools buildings". In which compared the calculated neutral (comfort) temperature with the ASHRAE comfort standard. Deb and Ramachandraiah [1] conducted research on passenger thermal comfort in south railway stations in India to investigate the neutral temperature.

Table 8. A summary of subjects neutral temperature some previous thermal comfort studies

Researcher	Country/Location	Neutral temperature
Chan DW et al.	Hong Kong	23.5ºC
Ye XJ et al.	China	23.3°C
Lin TP et al.	Taiwan	26.2°C and 27.4°C
Hwang RL, Cheng MJ	Taichung, Taiwan	25.6°C
Hamzah B et al.	Makassar, Indonesia	24.1°C
Karyono TH	Jakarta, Indonesia	24.1°C
Hussein I et al.	Malaysia	24.4°C and 28.4°C
Deb C, Ramachandraiah A	Chennai, India	31.93°C

4. CONCLUSIONS

The objective assessment indicates that the outdoor thermal comfort parameters have an effect on the indoor thermal comfort parameters during the seasonal and climatic variation at the time of cooking inside the pantry car. The maximum range of thermal comfort parameters was found at the preparing of lunch and snack time and minimum range at the time of breakfast. The indoor physical condition of "air temperature, globe temperature, relative humidity, and air velocity" were out of the 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. 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 during summer and winter season was found 18.50-27.80 ºC and 17.80-25.50 ºC, respectively, that shifts to slightly warm temperature for summer and warmer temperature for winter by about 0.80 ºC and 3 ºC as comparing to comfort zone recommended in ASHRAE 55 standard. When compared to neutral temperatures found in other countries with hot-humid climate, observation shows that living in the pantry car appears less tolerant.

The workplace design of the chef (includes ventilation/windows/air-supply/layouts-design) for future development could be improved through the application of thermal comfort range and neutral temperature values. Furthermore, the proposed regression models could be used instead of the PMV/PPD index method for the thermal comfort assessment of chefs in railway pantry cars kitchens.

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