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Appraisal of Thermal Comfort in Non-Air-conditioned and Air-conditioned Railway Pantry Car Kitchens

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Abstract: This study details the consequences of a thermal comfort survey conducted in N-AC "Non-Airconditioned" and AC "Airconditioned" pantry car kitchens in Indian Railways. The research was carried out on 6 railway pantry car kitchens in which 29 chefs participated. Field measurement and subjective evaluation techniques performed in this study during the working period of chefs. The aim of the present research to compare N-AC and AC railway pantry car kitchen. While the objective of the study was to determine the thermal comfort parameters "air temperature, mean radiant temperature, relative humidity and air velocity" of both pantry car kitchens and examine the subjective responses; and to evaluate the thermal comfort of both pantry car kitchens using the PMV "Predicted Mean Vote" and PPD "Predicted Percent Dissatisfied" indices and compare them with actual sensation votes. A result of this study revealed that all thermal comfort parameters do not comply with the recommended ASHRAE 55 Standard in both pantry car kitchens. There is no considerable difference between both pantry car kitchen based on the subjective assessment during the working period and all the chefs' votes were found to be outside the range of the ASHRAE 55 central three categories (-1, 0, +1) votes. Which indicates that the chefs are not satisfied with the current environment. While for N-AC pantry car, PMV and PPD value estimated were 3.10 and 99% respectively, with "hot" thermal sensation. Similarly, for AC pantry car, PMV and PPD value estimated were 2.21 and 85% respectively, with "warm" thermal sensation. The estimated values of PMV and PPD do not follow the ASHRAE-55 2017 and ISO 7730 standard. Therefore, PMV indices are not directly applicable for thermal comfort application in a pantry car kitchen environment due to high temperature. In both the pantry car kitchen, there is no difference between predicted and actual sensation votes. In further establish the other method and technique to identify the comfort temperature for better workmanship of chefs in a pantry car kitchen.

Keywords: Thermal comfort, pantry car, kitchen, PMV/PPD index, railway

1. Introduction

Numerous thermal comfort studies have been established in a developed and developing country in the various sector based on the field survey and laboratory experiment. It established in both indoor and outdoor environments for occupants' comfort. Whereas most of the research has concentrated on building environment, hospital, school, vehicle, etc., [1]-[4]. In which, the measured thermal comfort parameters such as; "air temperature," "radiant temperature," "relative humidity," and "air velocity" were compared to the comfort range of the ASHRAE standard and also, evaluated the perception rate of workers regarding the thermal environment. However, few kinds of thermal comfort research also have been done in the environment of commercial kitchens, restaurant kitchens, household kitchens, and domestic kitchens that detailed the data collection procedure and identified the comfort temperature [5], [6]. Ravindra et al. [5]

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conducted the thermal comfort research on the rural household kitchen in India during the summer, pre-summer, and winter season and estimated the indoor "air temperature" and "relative humidity" at working time. Also, predicted the PMV index vote range between -0.32 to 1.25 based on the ASHRAE 55-2017 standards. Similarly, PMV and PPD votes range found 1.73 to 2.36 and 63% to 90%, respectively, during the working hours inside the home kitchens in Indonesia [7]. While in Finland, Pekkinen [8] established thermal comfort research in the commercial kitchen based on the laboratory test using a variety of cooling methods with incorporate of PMV and PPD methods. Simone and Olesen [9] conducted thermal comfort research on commercial kitchens that introduced the data collection techniques based on the physical and subjective parameters and identified the most effective cooking zones. Similarly, the same types of research conducted by Simone and Olesen [10] 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. [6] in commercial kitchens based on the physical measurements and examine the applicability of thermal comfort standards in the commercial kitchen. A result of this research also indicated PMV is not directly suitable for the commercial kitchen environment.

But no research has been focused on the pantry car kitchen environment in Indian Railway till now. However, Alam et al. [11] conducted a small study on this with a few sample sizes and identified the comfortable cooking time. Pantry car is an essential part of every short and long route trains which play a significant role in Indian railway catering systems. It serves the meal every onboard passenger between traveling on trains. According to the report of the railway board, there are 338 pairs of pantry car coaches running with the trains in the current scenario [11], [12]. Approximately 3-5 chefs, 40-50 caterers, and 2-3 railway employees are living in a pantry car coach. However, there are two types of pantry car coaches available such as; non-air conditioned (N-AC) and air-conditioned (AC) [13]. In which only few AC pantry car coaches running with trains at present time. Both pantry car coach has significant differences such as; better aesthetic design, indoor space, cooking installation height, etc., but as per the Alam et al. [11] indicated there is no difference of thermal environment between both these pantry car coaches at the time of cooking based on the physical measurement. While during the meal preparation time in both pantry car kitchen, chefs are using common cooking equipment like; heater or gas, oven, kettle, and soup warmer, etc. These devices produce heat and humidity during food preparation, due to which the indoor environment of the pantry car becomes hot and humid [14]. Which, creates a harmful work environment for chefs and directly impacts work efficiency and performance.

The above literature indicates that thermal comfort assessment is essential for Indian railway pantry car kitchens for better workmanship. Hence, the present thermal comfort study has been conducted on both (N-AC and AC) types of railway pantry car coaches during the working hours. The purpose of this study to compare N-AC and AC pantry car kitchens based on objective and subjective evaluation. Therefore, the objective of present research was to (i) determine the thermal comfort parameters (air temperature, mean radiant temperature, humidity, and air velocity) of both pantry cars kitchen, and examine the subjective responses; and (ii) evaluate the thermal comfort of both pantry car kitchen using the PMV and PPD index method and compare it with actual sensation votes.

2. Methods

2.1. Sample and Period

As per the railway-board repot 2015, a total number of 338 trains are running with pantry car coaches in which 3-5 cooking workers (chefs) are working in one pantry coaches. The determined sample size was 24 on the total chef's population (1352) with a confidence level of 95% and a confidence interval of 20. Hence, in this study, a total number of six railway pantry car coaches have considered in which 29 chefs participated. Therefore, data taken were among 19 chefs from four non-air conditioned (N-AC) pantry cars and 10 chefs from two air-conditioned (AC) pantry cars during the summer season. Railway pantry car kitchen workers have to face various activities as mentioned above, and they are very busy during working hours. So, due to safety and security reasons, this research was scheduled only fifteen days for field study in August 2018 without disturbing the worker's activity during working hours.

2.2. Field Measurement

Thermal comfort mainly consists of the four environmental factors described above, such as; "air temperature," "mean radiant temperature," "relative humidity," and "air velocity," which measured in this study. In this research, air temperature, relative humidity, and air velocity measured with the help of handheld anemometer: Kestrel weather meter 4500. In which, air temperature (t_a) measured with the range -29.0°C to +70.0°C, and accuracy ±1°C, and relative humidity (RH) measured with the range 5% to 95% and accuracy ±3%, and accordingly, air velocity (v_a) measured with the range 0.4m/s to 60m/s, and accuracy ± 0.1m/s at 1ft (0.3m) near the workstation, and 43in. (1.1m), above the workstation floor inside the pantry car based on the ASHRAE 55 Standard [15]. Whereas globe temperature (t_g) measured with the help of "6-inch black-globe thermometer" with accuracy -5° to +95°C at the center of the cooking zone, which estimates the "mean radiant temperature". A mean radiant temperature (t_{mrt}) approximated with the combination of "air temperature-t_a", "globe temperature-t_g", and "air velocity- v_a", applying equation (1) as per the Alam et al. [11]. While all thermal comfort parameters measured were during food preparation time [breakfast, lunch, snacks, and dinner] inside the pantry car with 10-15 minutes of interval throughout the day, according to ASHRAE 55 Standard [15].

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

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

2.3. Approximation of Clothing Insulation Leval and Metabolic Rate (Activity)

Chefs in the railway pantry car kitchen live in a combination of Indian style outfit as; "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. Therefore, for both types of railway pantry car kitchens (N-AC and AC), the chef's clothing insulation level was estimated based on ASHRAE 55 Standard [15] and ISO 7730 Standard [16]. While cooking period inside the pantry car kitchens, the chef's activities mostly remain at a standing and medium level. So, in this study, the chef's metabolic rate has been considered during the cooking period based on Ainsworth et al. [17]. The estimated mean value of "clothing insulation" and chef's "metabolic rate" is derived in this study, shown in Table 1.

Table 1 - Estimated value of clothing insulation level and metabolic rate

Pantry Types	Clothing insulation value (*Clo*)	Metabolic rate (*met*)
N-AC	0.50	2.0
AC	0.77	2.0

2.4. Questionnaire Survey

In this study, research was carried out based on the questionnaire survey to assess the impact of the thermal environment during working hours, and it's developed according to the ISO 10551 Standard [18]. The questionnaire survey had two parts. The first part asked for chefs regarding demographic information such as; "age", "height", "weight", "metabolic activity", and "clothing". The second part recorded the chef's thermal votes like; sensation, comfort, and acceptability. Chef's thermal sensation votes (TSV) were recorded using the conventional ASHRAE 7-point scale; -3 "very cold", -2 "cold", -1 "cool", 0 "neutral", +1 "warm", +2 "hot", and +3 "very hot". Similarly, the same rating Bedford scale was used to assess the chef's thermal comfort vote (TCV) in which the chef responded to the votes; -3 "much too cool", -2 "too cool", -1 "ok (cool)", 0 "ok (just right)", +1 "ok (warm)", + 2 "too warm", and "+3 much too warm". Whereas the chef's thermal acceptability votes recorded with (acceptable, and not accepted). Table 2 demonstrates the questionnaire.

Table 2 - Thermal comfort questionnaires used in this research

Demographic detail:	Age (year):	Height (cm):		Height (kg):		Clothing (Clo):	
Present activity state:	Sitting	Standing	Walking				
	Medium	Moderate	Heavy Movement	Other			
Thermal sensation vote (TSV):	Very cold (-3)	Cold (-2)	Cool (-1)	Neutral (0)	Warm (+1)	Hot (+2)	Very hot (+3)
Thermal comfort vote (TCV):	Much too cool (-3)	Too cool (-2)	Ok (cool) (-1)	Ok (just right) (0)	Ok (warm) (+1)	Too warm (+2)	Much too warm (+3)
Thermal acceptability vote:	Acceptable	Not acceptable					

2.5. Thermal Comfort Estimation

In this study, PMV and PPD indices were used to predict the thermal environmental condition of pantry cars using the CBE (Center for Built Environment) thermal comfort tool based on the ASHRAE 55 Standard [19]. PMV and PPD index consists of six input parameters, as depicted in Fig. 1 such as; "air temperature", "mean radiant temperature," "relative humidity," and "air velocity" along with "metabolic rate" and "clothing insulation". All parameters have been incorporated in this study. According to the International Organization for Standardization, ISO EN-7730 Standard [20] and ASHRAE 55 standard [19], usually for thermal comfort required the range of PPD value should be less than 10% as well as the PMV value range between "−0.5 (slightly cool sensation) and +0.5 (slightly warm sensation)". As per the standards mentioned earlier, both limits are validated and applicable for occupants because of the physiological transformation of people.

Fig. 1 - CBE thermal comfort tool

2.6. Data Analysis

Descriptive analysis has been performed to appraisal the measured value of "air-temperature," "mean radiant temperature," "relative humidity," and "air velocity" variation inside the N-AC and AC pantry car kitchen during the working hours. While demographic information of pantry car chefs such as; "age, height, weight and clothing levels", data reported as range (minimum to maximum), and average (SD), and the recommended "ASHRAE and Bedford" 7-point rating scale was used to appraise chef's thermal responses regarding the thermal environment of the pantry car kitchen in which the percentage of data reported in a histogram. MS Excel 2016 software included for all calculations in this study. Although, for estimation of PMV and PPD indices "CBE thermal comfort tool" has been incorporated based on ASHRAE 55 2017, which discussed earlier.

3. Results and Discussion

3.1 Indoor Environmental Condition

A thermal comfort study is required four physical parameters like; "air temperature," "mean radiant temperature," "relative humidity," and "air velocity" [21], which measured in this study. Fig. 2 shows the distributed value of "air temperature" and "mean radiant temperature" inside the N-AC and AC pantry car's kitchen. The maximum measured value of indoor "air temperature" was recorded at 35.40°C in the N-AC pantry car, while the minimum air temperature in the AC pantry car recorded at 28.90°C. The average values of air temperature for N-AC and AC pantry car kitchens were found to be 34.58°C and 29.30°C, respectively. Both pantry car kitchens, air temperature values were outside the thermal comfort zone according to the ASHRAE 55 Standard [22]. The measured value also does not comply with the NBC "National Building Code" of India in that the recommended range of temperature was for "summer (23-26°C) and winter (21-23°C)" [23]. Similarly, the maximum and minimum ranges of mean radiant temperatures were recorded at 33.35°C to 34.20°C and 28.75°C to 30.40°C for the N-AC and AC pantry car kitchen respectively. While the average value of "mean radiant temperature" recorded for the N-AC pantry car 34.05°C and 29.57°C for the AC pantry car. It does not follow the recommended limit range of the above-mentioned specific standards.

Fig. 3 shows the distributed measured value of relative humidity percentage (RH %) inside the N-AC and AC pantry car's kitchen. Throughout the measurements, a minimum and maximum values of RH% were recorded 74.10% and 76.50%, respectively, only in the N-AC pantry car kitchen. The average RH% of both railway pantry car kitchens measured during the entire summer season correspondingly, 76% for N-AC, and 75% for AC. As per Tarim et al. [21] indicates the percentage of indoor relative humidity for the thermal comfort condition should be range from 55% to 70%.

Whereas, based on the ASHRAE 62 standard [24], recommended the comfortable percentage range of relative humidity should be 30% to 60%, and for the optimum range, it should between 40% to 60%.

Fig. 4 shows the distributed measured value of air velocity inside the N-AC and AC pantry car's kitchen. The average air velocity measured during field measurement of both railway pantry car kitchens was 0.03m/s and 0.01m/s for "N-AC" and "AC," respectively. However, as per the ASHRAE 55 standard [22], the comfortable air velocity limit should be for “summer (<0.25 m/s) and winter (<0.15 m/s)”. Entire measurement in both types of pantry car kitchens, the ranges of air velocity has been measured to be very low, as seen in the graph. Because when the train runs, due to which there is very strong air enter inside the pantry car, hence the chefs mostly keep the door or window closed while cooking in the kitchen of the N-AC pantry car. Whereas in an AC pantry car, the supply of air-conditioning load during food preparation is slowed down because chefs cannot cook a large quantity of food with more air conditioning facilities. Due to more air-conditioning, it takes too much time for boiling or heating; water, or food items [11]. All physical parameters such as “air temperature, mean radiant temperature, relative humidity, and air velocity”, do not comply with the recommended limits during cooking inside both pantry cars, as discussed above, the specified standard. So, there is no significant difference in these two types of pantry car kitchens based on physical measurements as all variables were found to be outside the comfort zone.

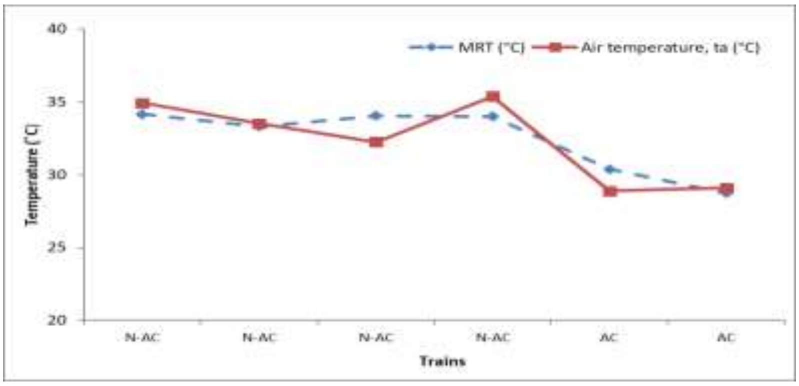

Fig. 2 - Temperature distribution in trains

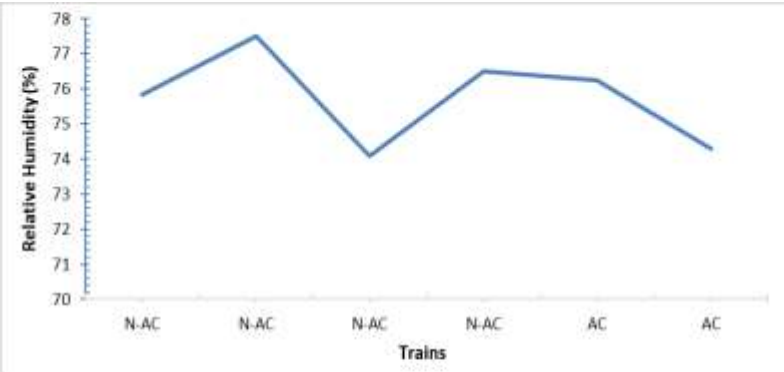

Fig. 3 - Relative humidity distribution in trains

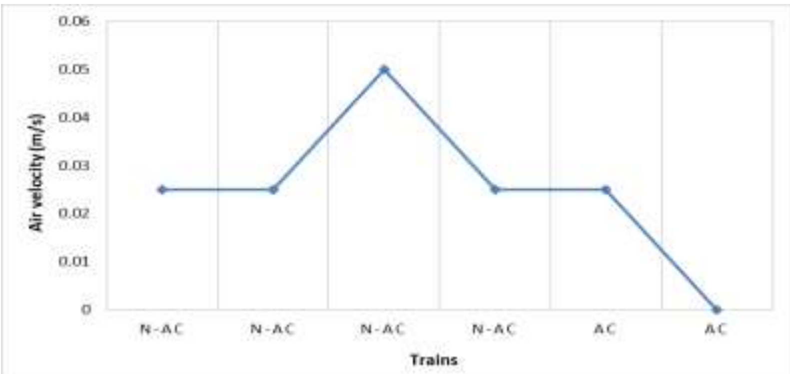

Fig. 4 - Air velocity distribution in trains

3.2 Subjective Evaluation

In the N-AC pantry car kitchen, chef's age range were from 27 to 51 years (average = 37.00 years; SD = 6.7 years) and height range from 167.64 to 182.88 cm (average = 170.68 cm; SD = 6.09 cm). Similarly, weight range were from 121.25 to 185.18 lbs. (average = 147.71 lbs.; SD = 15.43 lbs.). While the chefs clothing level range were from 0.30 to 0.61 clo (average = 0.50 clo; SD = 0.11 clo). Similarly, to the AC pantry car kitchen, chef's age range was from 28 to 43 years (average = 34.00 years; SD = 5.3 years) and height range from 176.78 to 155.75 cm (average = 167.64 cm; SD = 9.14 cm). Similarly, weight range were from 127.86 to 169.75 lbs. (average = 147.71 lbs.; SD = 13.22 lbs.). Although the chefs clothing level range were from 0.65 to 0.99 clo (average = 0.77 clo; SD = 0.11 clo).

Fig. 5 shows the distribution vote of TSV "thermal sensation votes' and TCV "thermal comfort votes" during the working hours of chefs in the N-AC pantry car kitchen. For TSV, 6 chefs voted to feel the thermal sensation "hot" while 13 chefs responded to feel "very hot" inside the pantry car. Similarly, for TCV, 10 chefs responded to feel the thermal comfort "too warm" while 9 chefs voted to feel "much too warm" in the pantry car. In the N-AC pantry car kitchen, the total votes of chefs voted to the hot and warm side. While there was no responded to feel cool inside the pantry car during the working time.

Fig. 6 shows the distribution vote of TSV and TCV during the working hours of chefs in the AC pantry car kitchen. In this also for TSV, 6 chefs voted to feel the thermal sensation "warm" while 4 chefs responded to feel "hot" inside the pantry car. Correspondingly, for TCV, 9 chefs responded to feel the thermal comfort "ok (warm)" while only 1 chef voted to feel "too warm" in the pantry car. In the AC pantry car kitchen also, the total votes of chefs voted to the hot and warm side. Although there were also no chefs, who responded to feel cool inside the pantry car kitchen, as per the ASHRAE 55 standard [22] for thermal comfort requirements, the subjective responses should follow the central three categories (-1, 0, +1) votes [25]. But in the present research, the chefs' votes do not follow the central three categories of votes during the working hours inside both pantry car kitchen, which indicates a high thermal dissatisfaction rate of the working environment condition for workers.

The distributed percentage of the thermal acceptability votes of the chef's in the N-AC and AC pantry car kitchen depicted in Fig. 7 and Fig. 8. In N-AC pantry car kitchens, 67% of chefs did not accept thermal environmental conditions to feel a "hot" thermal sensation. However, no respondent accepted the current thermal environmental conditions in the N-AC pantry car kitchen in order to feel a "very hot" thermal sensation. Similarly, in the AC pantry car kitchens, 70% of the chefs did not accept thermal environmental conditions to feel a "warm" thermal sensation. While 80% of the chefs have not accepted the present thermal environmental conditions in the AC pantry car kitchen to feel a "hot" thermal sensation. Both pantry car results indicated that chefs do not accept the existing environment scenario during the entire working time. According to ASHRAE (2004) standards, for thermal comfort, the percentage of thermal acceptability votes of occupants must exceed 80% in any hot and humid environment [25], [26], [27]. The subjective responses of chefs show that there is no difference between the two types of railway pantry car kitchen environments while preparing food. As shown earlier in some studies, during cooking in the kitchen, people disagree with the situation of the thermal environment. As research by Kim et al. [28] indicated that kitchen occupant's subjective votes go to the high percentage of dissatisfaction during the working period, and it does not follow the recommended 80% acceptability limits of the ASHRAE 55 standard [29].

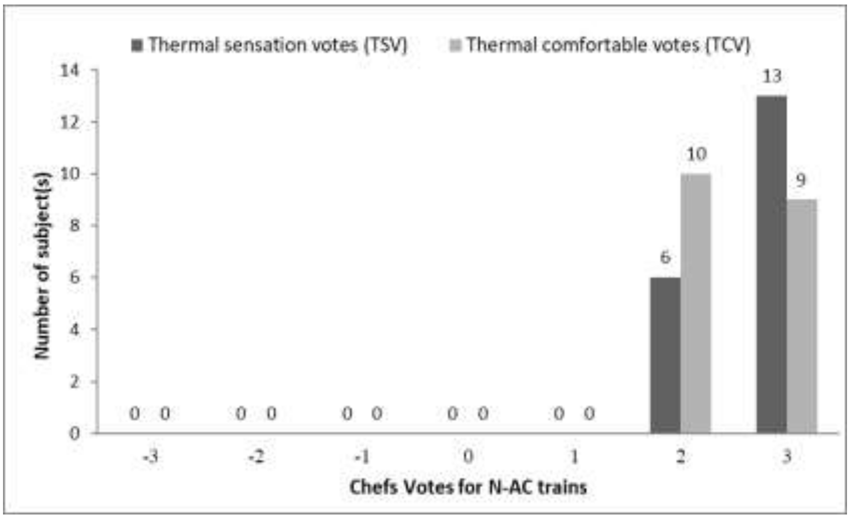

Fig. 5 - Chefs TSV and TCV responses in N-AC trains

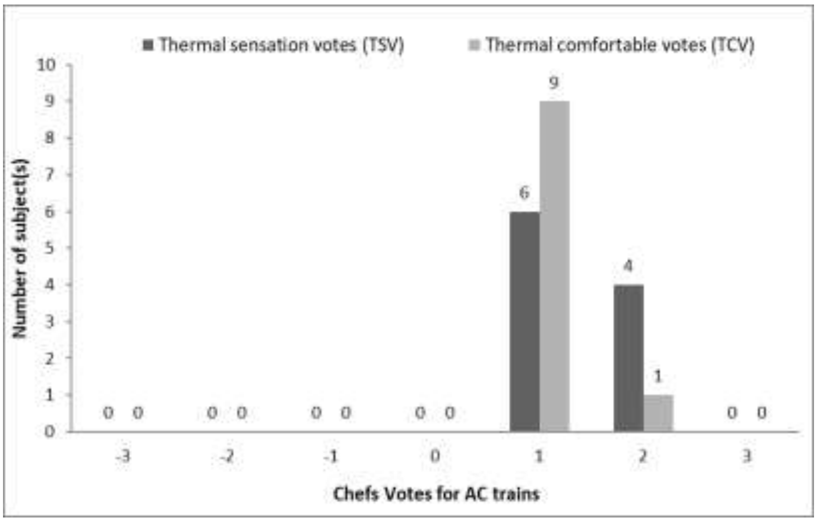

Fig. 6 - Chefs TSV and TCV responses in AC trains

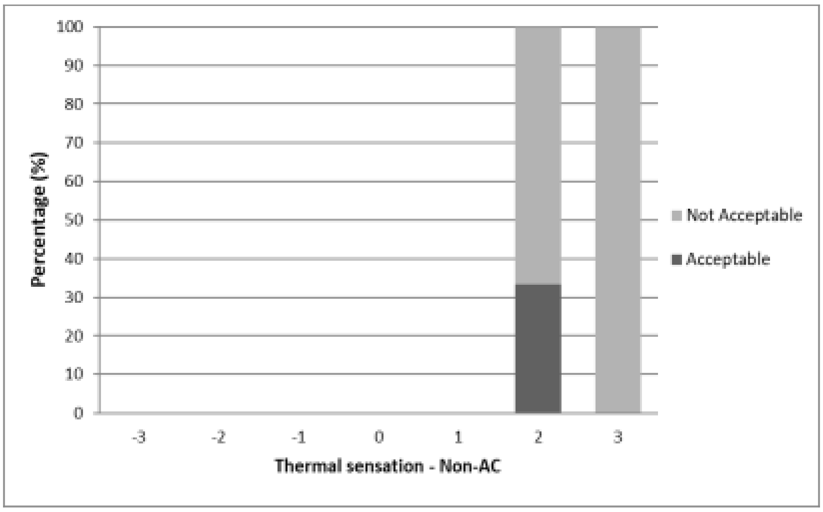

Fig. 7 - Thermal acceptability votes in N-AC train

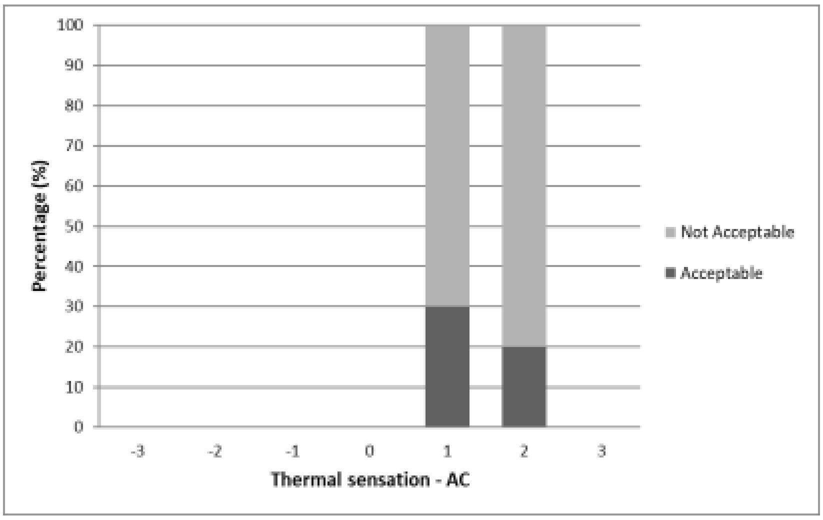

Fig. 8 - Thermal acceptability votes in AC train

3.3 PMV and PPD Estimation

The calculated average value of the PMV and PPD index results for N-AC and AC pantry car kitchen depicted in Table 3. For the N-AC pantry car kitchen, the calculated average value of PMV and PPD index was found to be 3.10 and 99%, respectively, while the thermal sensation was estimated to be "hot". Similarly, for the AC pantry car kitchen, the calculated average value of PMV and PPD index was found to be 2.21 and 85%, respectively, while the thermal sensation was estimated to be "warm". In both pantry car kitchens, the estimated values of PMV and PPD indices did not follow the recommended range of the thermal comfort standard, as discussed above. For thermal comfort application, the sensation values of PMV votes should be between -0.5 to +0.5, with the PPD percentage being less than 10% [30], [31]. This result of PMV/PPD reflects a very high dissatisfaction with the thermal environment for both pantry car kitchens. While ISO EN 7730 standard [20] recommended the limit of PMV scale from -2 to +2 with 80% of people satisfaction but the present study outcomes go beyond the standard limit due to high range of temperature [32]. Therefore, PMV indices are not directly applicable to thermal comfort applications in the railway pantry car kitchen.

Table 3 - Average appraised output values of the PMV and PPD index for N-AC and AC pantry car kitchens

	Input Parameters						Output	
Train Type	**Ta (*°C*)**	**Tmrt (*°C*)**	**RH (*%*)**	**Va (*m/s*)**	**Clo**	**Met**	**PMV**	**PPD**
N-AC	34.58	34.05	76	0.03	0.50	2.0	3.10	99
AC	29.30	29.57	75	0.01	0.77	2.0	2.21	85

Fig. 9 shows the comparing values of the actual thermal sensation votes with PMV/PPD sensation in the N-AC pantry car kitchen. Based on the questionnaire survey, the chefs responded to the actual thermal sensation votes to feel 31% "warm sensation" and 69% "hot sensation". Whereas 99% of the perceived sensation values of PMV votes were for feeling "hot sensation". It seems to be a low response rate according to the predicted rating. Because the actual responses were from warm and hot, while the predictive responses of PMV were from only hot, this is mainly due to the different acclimatization of the pantry car chefs. The determined value of both sensation scales did not follow the thermal comfort standard. According to the standard of thermal comfort for human occupancy, the sensation range should be from slightly cool to slightly warm [33], [34].

Similarly, Fig. 10 shows the comparing values of the actual thermal sensation votes with PMV/PPD sensation in the AC pantry car kitchen. For actual sensation, chefs responded to feel 60% "slightly warm sensation" and 40% "warm sensation" as depicted in the figure, while for the predicted sensation of PMV were 86% "warm sensation". In this also, both sensation votes rates do not comply with the standard as recommended. However as per predicted and actual sensation votes there is no considerable difference between N-AC and AC pantry car kitchen environment during the working period. Because in both pantry car kitchens the rate of sensation values was found to be on the warm or hot side. According to a previous study, it also indicated that there is no significant difference between “air-conditioned and non-air-conditioned” pantry car kitchens during the cooking period based on predicted thermal sensation votes. Whereas, the estimated sensations for “air-conditioned and non-air-conditioned” pantry car kitchens were warm and hot respectively [11].

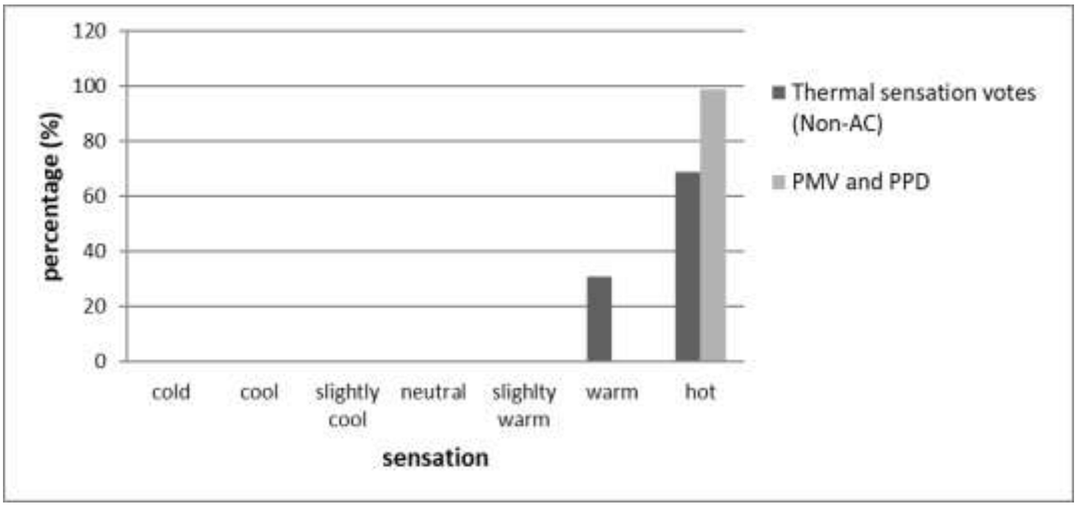

Fig. 9 - Comparing actual thermal sensation votes with PMV and PPD in N-AC train

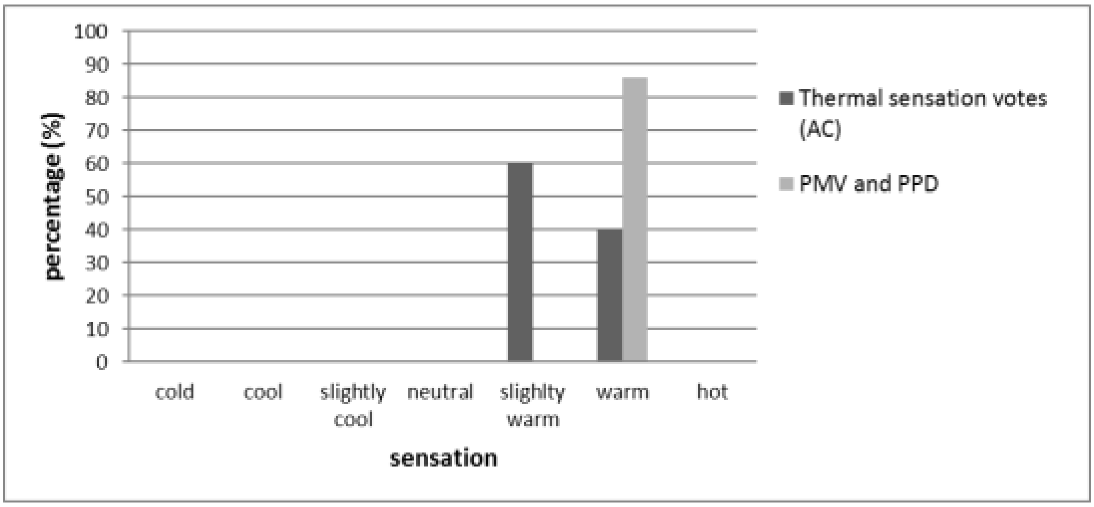

Fig. 10 - Comparing actual thermal sensation votes with PMV and PPD in AC train

4. Conclusion

The Indian railways play an essential role in the transport facility in which the railway pantry car makes a significant contribution to serving meals to the onboard passengers. The study was carried out on two different (N-AC and AC) types of railway pantry car kitchens to identify thermal comfort conditions during the working period. The outcomes of this study clearly state that the measured thermal comfort parameters "air temperature, mean radiant temperature, relative humidity, and air velocity" do not comply with ASHRAE standards during the period of work inside the pantry car kitchen. While the subjective assessment indicated that the chefs were not satisfied with the current thermal environment, and there is no significant difference in both pantry car kitchens based on thermal perception votes. The calculated value of the PMV and PPD indices also directed both pantry cars have a similar effect of the thermal sensation. Due to the high-temperature range, the PMV method not directly applicable for thermal comfort application in the pantry car environment because the measured values of PMV go beyond the recommended limit of the thermal comfort standard. Whereas, the actual and predicted thermal sensation demonstrate that all votes go to the warm and hot side. No votes found between slightly cool to slightly warm sensation range as per the ASHRAE 55 standard. This finding also indicates that in both pantry car kitchen, there is no considerable difference. These outcomes will help to understand the present situation of both railway pantry car kitchens. In a further study, establish the new approach to determine the neutral (comfort) temperature and comfort temperature range for both pantry cars.

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