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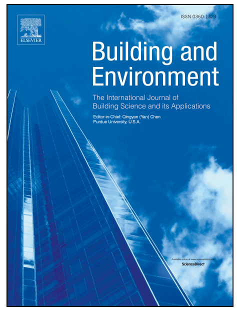

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Thermal comfort guidelines for production spaces within multi-storey garment factories located in Bangladesh

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Abstract

This research presents extensive field data on indoor thermal conditions along with workers' comfort votes taken at their workstations within three existing multi-storied garment factories during the three seasons (cool-dry, hot-dry and warm-humid) of Bangladesh. The main objective of the study was to observe the impact of thermal conditions on workers' indoor thermal perception during each season of a year and from this identify thermal comfort guidelines (e.g. neutral temperatures, comfort ranges, preferred airspeeds and directions) to execute their production work comfortably. Subjective votes were collected from a total of 908 workers with the thermal data, physiological data and adaptive measures recorded simultaneously. Statistical analyses revealed that workers can accept a wider and relatively higher comfort range than the predicted band during cool-dry and hot-dry seasons, for instance, 22.7-29.1°C and 22.3-30.4°C respectively. A narrower comfort band (e.g. 28.7-30.9°C), close to the predicted range, was found during the warm-humid season, which can be maintained by reducing radiant temperature and elevating airspeed. Further analyses indicated that workers prefer a mean airspeed of 0.3m/s and comfort range of 0-3.0m/s specific to their activities preferably from inlets located on south,

north and east facades while upward and downward air movement, from for example ceiling fans, causes a rise of air temperature in the occupational zone and thermal discomfort. This research also suggested that the maximum distances of workstations from the ventilation inlets (windows) should be maintained at 12-18 meters for sufficient cross ventilation, personal controls and adaptive opportunities to help maintain preferred thermal condition.

Highlights

- Workers adapt with wider comfort range during the cool-dry and hot-dry seasons.
- Favoured air temperature and speed ranges for production activities were determined.
- Upward and downward airflow increase air temperature and thermal discomfort.
- Workers prefer airflow from the inlets located in north and south facades.
- The width of workspaces should be between 12-18m to enhance thermal comfort.

Keywords

Thermal comfort; comfort range; Preferred airflow; Production spaces; Tropical climate

Nomenclature:

AT: Air Temperature (^{o}C)

$AT_{\_out}$: Outdoor Air Temperature (^{o}C)

AV: Air Velocity (m/s)

AVFR: Air Volume Flow Rate (m^3/s)

BGMEA: Bangladesh Garment Manufacturers and Exporters Association

Clo: Clothing Insulation

CS: Cutting Section

FS: Finishing Section

GT: Globe Temperature (^{o}C)

Max: Maximum

Min: Minimum

MRT: Mean Radiant Temperature (^oC)

Met: Metabolic Rate

NT: Neutral Temperature (^oC)

OAV: Overall Acceptability Vote

OT: Operative Temperature (^oC)

PPD: Predicted Percentage of Dissatisfied (%)

PMV: Predicted Mean Vote

RH: Relative Humidity (%)

$RH_{\_out}$: Outdoor Relative Humidity (%)

RMG: Ready-made Garment

SD: Standard Deviation

SS: Sewing Section

TCV: Thermal Comfort Vote

TPV: Thermal Preference Vote

TSV: Thermal Sensation Vote

T_a: Air Temperature (^oC)

T_g: Globe Temperature (^oC)

T_{mrt}: Mean Radiant Temperature (^oC)

T_{op}: Operative Temperature (^oC)

T_{wb}: Wet Bulb Temperature (^oC)

T_{wbn}: Wet Bulb Temperature - Naturally Aspirated (^oC)

T_{wbgt}: Wet Bulb Globe Temperature (^oC)

v: Airspeed (m/s)

WBGT: Wet Bulb Globe Temperature (^oC)

1. Introduction

The ready-made garment (RMG) products from international clothing brands are produced in garment factories where the workers suffer from thermal discomfort to complete 10-12-hour shifts remaining at their production workspaces inside the factory buildings (Mirdha, 2016, Hossain and Ahmed 2012, Hossain et al., 2014). The main production spaces common to most factories include cutting sections (CS), sewing sections (SS) and finishing sections (FS). In the tropical climatic context of Bangladesh (Peel et al., 2007: 468), multi-storied garment factories are ventilated during all seasons using auxiliary fans placed on an external wall to extract the indoor hot air and replace it with fresh outdoor air entering through inlet windows typically located in an opposite wall (Hossain et al., 2015; Hossain et al., 2016). Ceiling fans and occasionally pedestal fans are additionally provided and induce local air movement over the workspaces intending to reduce workers' thermal discomfort.

For buildings of this type in Bangladesh, Fatemi (2014) proposed a thermal comfort range with air temperature (AT) of 28.5-33° and relative humidity (RH) of 56-72% for airspeed in the range of 0.8-1.5m/s. The study was based on a limited data set and sample size and was undertaken during the warm-humid season. Since the ventilation strategy employed in RMG factories cannot ensure uniform airflow within the workspaces (Hossain et al., 2014, Hossain et al., 2015), this comfort range may not be applicable in all production spaces (i.e. CS, SS and FS) nor to all positions within all climatic seasons. Other relevant studies used computer simulations of thermal performance to explore the fluctuation of indoor air temperature in different production zones (Fatemi 2014, Chowdhury et al., 2015) and the resulting heat stress likely to be experienced by RMG workers during the course of a full year (Chowdhury et al., 2017a). However, these studies lack empirical field evidence including workers' feedback on their levels of thermal comfort and how this varies during the course of a year and across the different production zones. Local codes and regulations, which are focused on air-conditioned buildings, were used to contextualise comfort (Ahmed, 2011) rather than surveying workers and the ventilation strategies used as the primary strategy to limit overheating of indoor workspaces were not fully considered (Hossain et al., 2014).

As human thermal comfort varies with the ventilation profile, climatic adaptation (Toe and Kubota, 2013), contextual factors (O'Brien and Gunay, 2014) and the construction of a building (Berthold et al., 2007: 22), this study explores the thermal comfort perception of the RMG workers based in three different types of production space during the three seasons that characterise the climate of Bangladesh. The primary objective of the study is to establish the indoor neutral temperature (NT) that represent RMG workers' thermal comfort and the adaptive thermal comfort ranges for workers with a focus on how these vary in the different production spaces and with seasons. The study also focuses on the effect of airspeed and airflow direction on workers' thermal comfort suggesting changes to current practice intended to improve the effectiveness of this strategy.

2. Research method

Figure 1 provided an overview of the major steps and methods used in the research.

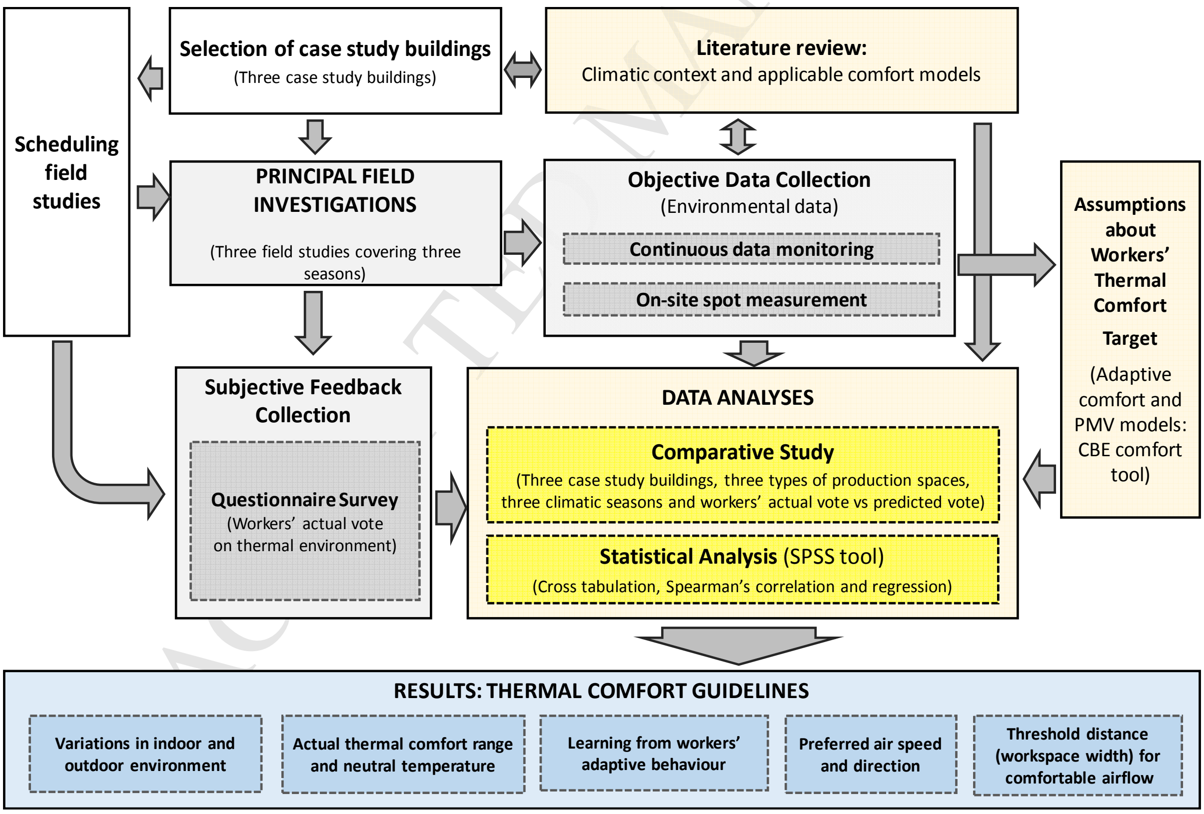
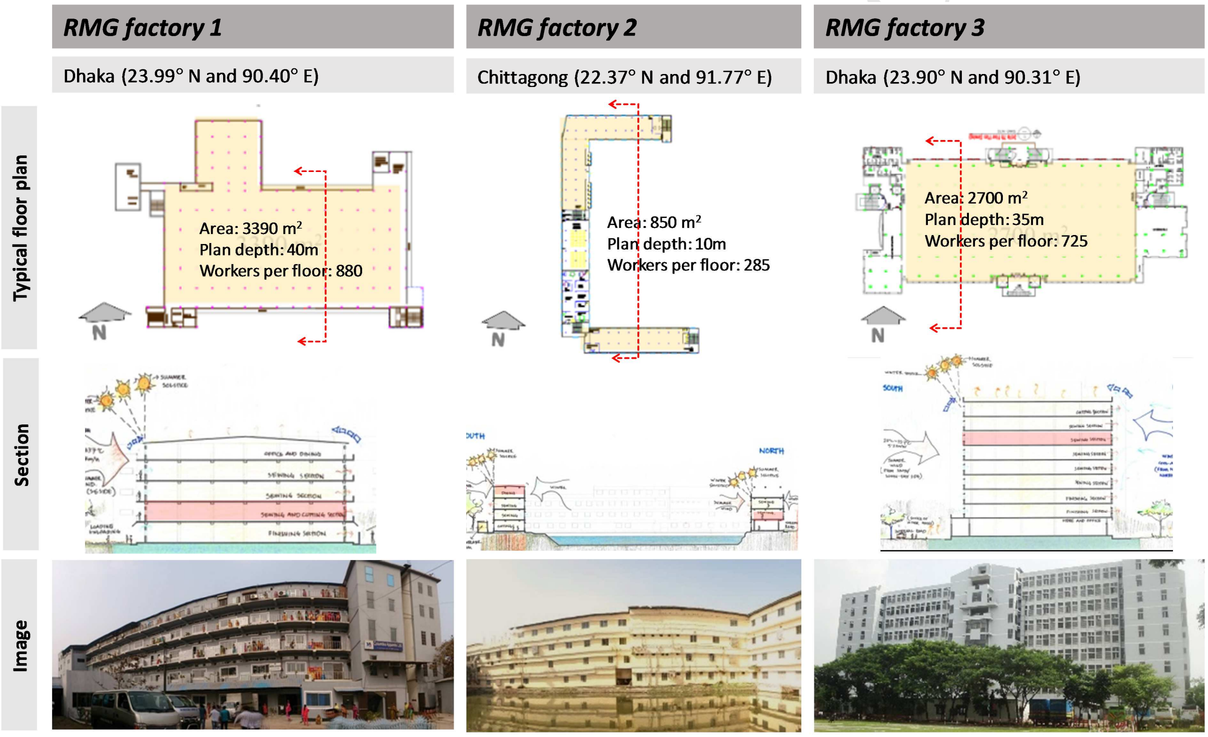


Figure 1: Summary of the major steps and methods

2.1. Selection of case study buildings

The database of over 6000 enlisted members of Bangladesh Garment Manufacturers and Exporters Association (BGMEA), in October 2014, was used as the primary source of information for selecting case study factories. Seven multi-storied buildings were initially shortlisted based on the selection criteria considered by Hossain (2011). Based on the discussions with the owners, three multi-storey case study buildings (as shown in Figure 2, i.e. *RMG factory 1*, *RMG factory 2* and *RMG factory 3*) were selected for the principal investigations. These differ in terms of site size and surrounding context, building orientation, number of stories, planning etc. While they do not represent the entire building stock, they are indicative of some of the variations that exist within it.



**For protecting the privacy of the factory companies, the factories were kept anonymous*

Figure 2: Selected case study buildings – RMG factory 1, RMG factory 2 and RMG factory 3*

All the selected case study buildings are mechanically ventilated using extract fans on the external walls. *RMG factory 1* and *RMG factory 2* have ceiling fans, while *RMG factory 3* does not have any ceiling fan.

2.2. Review of Climate and Comfort Model

2.2.1. Climatic Context Study

According to the updated 'Koppen-Geiger climate classification map' (Peel et al., 2007: 468), Bangladesh is within the tropical region (i.e. Tropical monsoon: A_m and tropical savannah: A_w) with a daily mean average global outside air temperature 10-20°C in January and 20-30°C in July (Berthold et al., 2007: 49). The main climatic seasons were classified into three major categories: cool-dry with mean AT of 20.6°C (December to February), hot-dry with mean AT of 28.3°C (March-May), and warm-humid with mean AT of 27.9°C (June-November) (Meteorological Department of Dhaka 2016, Hossain et al., 2014). The warm-humid season has a high mean RH of 82% and a low of 70%. The meteorological data for the Chittagong region (years: 2008-2015) also exhibit the same climatic seasons with a higher mean RH (96.6%) during the warm-humid season (Meteorological department of Chittagong, 2016). The AT for this region also varies between 24.2°C and 35.0°C across all seasons. The variations observed in the climatic data for Dhaka and the Chittagong region are representative of the climate of Bangladesh as a whole and basing the case studies across these two regions provides a picture of how this variation might affect the conditions within RMG factories.

2.2.2. Applicable Comfort Model

A Previous study shows that comfort studies in the field provide variations in temperature preferences, whereas the studies based on 'comfort chambers' provide a similar range of preference (Humphreys et al., 2007). This study suggests that comfort is context dependent. For instance, it was also found that occupants from warm-humid regions have higher thermal tolerance due to acclimatisation to a high level of humidity and AT (Mallick, 1996). Therefore, PMV method, based on which several international standards, such as ASHRAE design standard, established, did not represent the comfort conditions of occupants in the tropical climates with various seasonal changes (Brager and de Dear, 1998).

On the other hand, the adaptive approach provides a more precise estimation of thermal comfort range for the occupants of passive buildings (Orosa and Oliveira, 2011). It supports the concept of NT which is directly related to mean outdoor AT (Szokolay, 2008, Nicol and Humphreys, 2002, de Dear et al., 1997). There are a number of equations provided by the pervious researchers where comfort temperature is as a function of outdoor air temperature. However, the shortcoming of these equations is the too much dependence on outdoor AT ignoring some of the important variables, such as radiant temperature, of PMV model (Halawa et al., 2014). A number of comfort studies in context of South Asia and Bangladesh established the usefulness of utilising Operative Temperature (OT) as a criterion, which combines the effect of AT and MRT and expresses into a single value (in °C) to estimate NT and preferred comfort range of occupants (CIBSE, 2015, Indraganti et al., 2014, Shajahan and Ahmed 2016). Mallick (1996) showed that increasing fan-speed setting and thus increasing airspeed from 0 to 0.45 m/s could extend the mean comfort AT from 28.9°C to 31.6°C in Bangladesh. Hence, AV is also required to be evaluated for any space as a part of comfort study. Further elaborations with relevant equations can be found in Section 2.6.

To sum up, where the PMV method tends to provide narrow comfort ranges, the adaptive method actually considers occupants' adaptive capacities to cope with a wider range of thermal comfort respecting the seasonal changes. Adaptive thermal comfort model is certainly a better approach; however, it recommends field studies based on person-environment system approach (de Dear, 2004, Humphreys et al., 2007, Nicol, 2004, Ferrari and Zanotto, 2012, Chang, 2016). A previous study suggests that the PMV model is useful for preliminary prediction of thermal comfort of occupants. However, field studies are more reliable within the diversity of environments to determine the NT and comfort range corresponding to the adaptive model before inclusion in relevant standards (Nicol and Humphreys, 2002). Since the indoor thermal environment of RMG factories is not steady state and not fully naturally ventilated, both PMV and Adaptive models will be used for preliminary predictions of thermal comfort of RMG factory workers and will be compared with the field studies (Sections 2.6 and 3.2.1).

2.3. Scheduling field studies for principal investigations

Three main field studies were conducted, one during each of the seasons during 2015 and each gathering data from the three case study buildings. The data collected are therefore assumed to provide a representative picture of a full year. The detailed schedule of the field studies was shown in Appendix A.

2.4. Objective data collection

Outdoor AT and RH were measured in the ground floor and roof level locations using Tinytag data logging sensors (Appendix B). To collect continuous indoor AT and RH data, data loggers were placed approximately 1.6m and 3.2m above floor level (Figure 3) in all production floors. Since the building archetype for *RMG factory 2* is C-shaped, the building was divided into a south-wing, north-wing and west-wing and data were collected separately for each. Data were collected every 30 minutes for a minimum of 7 days, covering at least a weekend or an official closure day to pursuit thermal performance with and without internal heat gains to be compared.

The spot measurements included AT, RH, surface temperature (ST), air volume flow rate (AVFR), globe temperature (GT), air velocity (AV) and thermal images. These were made using hand-held instruments shown in Appendix B. To ensure the accuracy of the spot measurements at workstations during worker comfort surveys, both 'CLASS I' and 'CLASS II' protocols were maintained (Brager and de Dear, 1998, Gossauer and Wagner, 2007). The hand-held instruments were placed close to the workers' personal work areas at heights of 0.1m, 0.6m and 1.1m above floor level, similar to the standard 'Cart Mk II' practice used for indoor environment data acquisition (de Dear and Fountain, 1994, Brager and de Dear, 1998). The airspeed was also measured at the three vertical levels as well as in different directions (North-south, East-west and Up-down).

Figure 3: Data collection process during field studies

2.5. Subjective feedback collection

A 'Transverse survey' (i.e. snapshot survey) method was applied and the questionnaire provided in Appendix C was designed accordingly (Humphreys et al., 2007). A pilot study was completed to refine the 'structured questionnaire' and the way in which it was determined (Yin, 2018). Since the workers were not allowed to leave their workstations while answering the questions and since the majority were unlike to read the questionnaire; each individual's questionnaire form was completed by the researcher while interviewing the workers at their workstations with help from assistance provided by the factory authority (Figure 3). Responses relating to three environmental variables and indoor ventilation were collected with a minor repetition of similar questions to cross-check answers. The questions relating directly to comfort (i.e. sensation, comfort-perception and preference) and adaptive behaviour were asked of the subjects during the spot measurements.

The 'Personal comfort' part of the questionnaire was developed following the established comfort models and was based on the literature review of methods for developing thermal comfort standards by Peretti and Schiavon (2011). The 'ASHRAE 55' comfort model was chosen to collect the 'Thermal Sensation Vote' (TSV) through a 7-scale questionnaire study (Wilson and Corlett, 2005, p.556) and also for measuring votes of humidity and airflow. Four additional customised questions exploring general comfort using scales of 'comfortable' or 'uncomfortable' were also added by the researcher to generate data for comparison with the TSV. The 'McIntyre' preference scale (Fountain et al., 1996) was also adopted in three questions for this research. For the convenience of the workers, an additional 'not sure' option was also included.

Due to the frequent turnover of staff in the factory, it was not feasible to choose the same group of subjects for the comfort study in each field study. However, the locations of the workstations were kept similar in all three field study visits to maintain some consistency of the data set. In each field study, the subjects were selected to ensure an equal percentage of subjects in each zone shown in Figure 4.

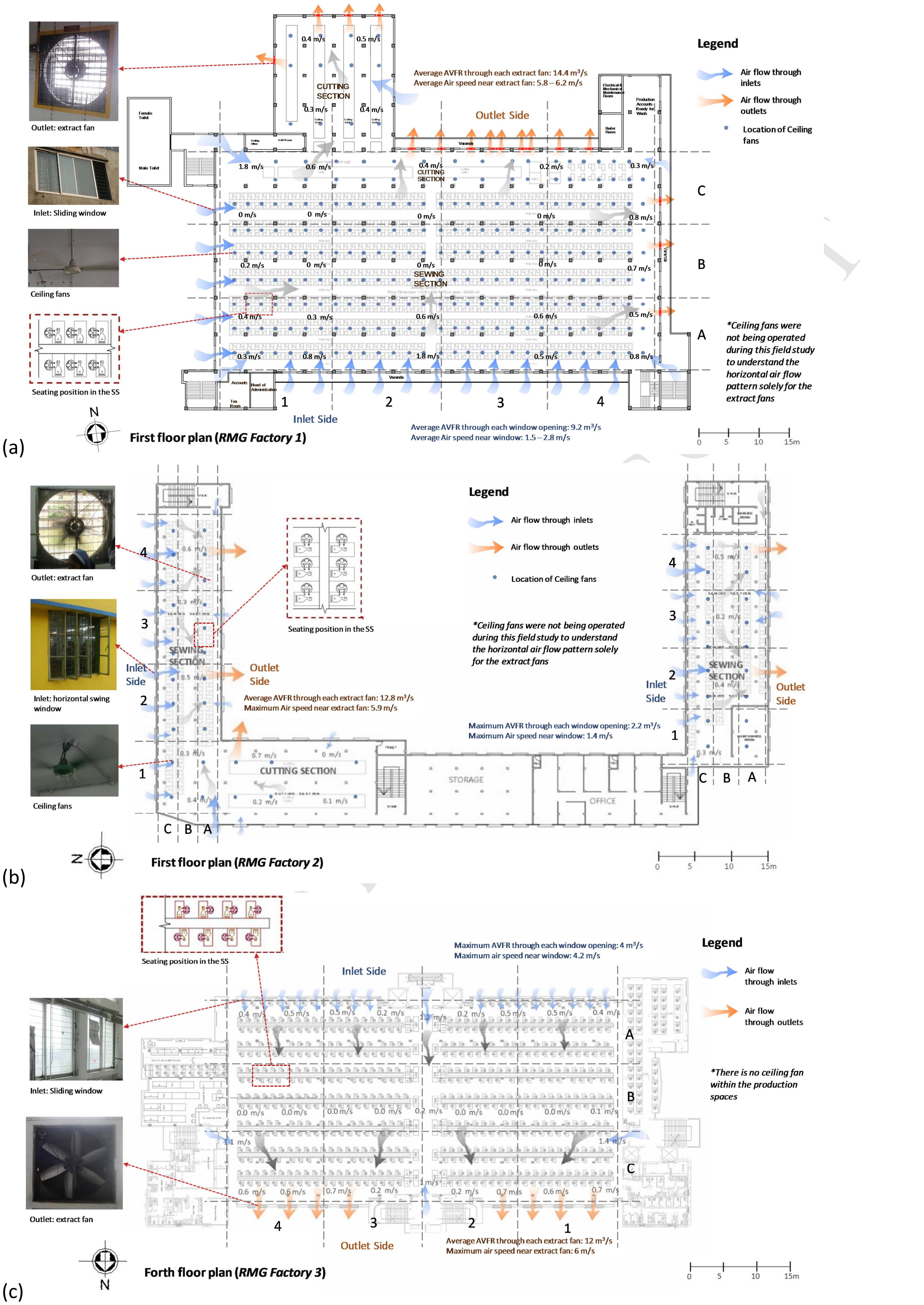


Figure 4: Defined zones within the typical building floor indicating the distribution of subjects surveyed in each field study

The comfort survey was conducted with a response rate of 98%. Appendix D provides the profile of the participants who participated in the comfort study. The sample size was determined according to the published guide provided by the University of Westminster, UK; and BRE Building Performance Guide for Post-Occupancy Evaluations (Mishra and Ramgopal, 2015, Field and Hole, 2006, HEFCE, 2006, Jaunzens et al., 2003). The mean work experiences of the male and female subjects were 23.3 months and 17.8 months respectively, which ensures that as a population they had sufficient time to become acclimatised to the local climate and the indoor environment. The personal factors, such as Clothing insulation (Clo) and met (metabolic rate) values of all subjects, were estimated using the standard lists and summation formula (ASHRAE, 2017, ASHRAE, 2013, Berthold et al., 2007, Indraganti, 2010, CIBSE, 2013). In particular, 1.4, 1.8 and 1.7 were estimated as met values for bias cutting, fabric cutting and stamping respectively in the CS, while 1.4 was estimated for sewing in the SS, button sewing and packing activities in the FS (Gouvêa et al., 2006, p.5). 1.0 and 1.2 are likely met values for seated and standing workers respectively (Butera, 1998, p.41). Previous studies suggested that these variations of met values which may change over time as well, even without noteworthy physical actions, have a direct impact on users' perception on thermal comfort (Hasan et al., 2016, De Dear & Brager, 2002, Fountain et al., 1999). In particular, workers may have no practical limit on humidity to reduce their thermal discomfort up to 25% while the metabolic rate is 1.6 or above (Fountain et al., 1999). Hence, it is very important to categorise the comfort ranges for CS, SS and FS relying more on field data and workers activities rather than assuming through comfort models only (Hasan et al., 2016).

2.6. Assumptions about workers' thermal comfort target

The 'CBE Thermal Comfort Tool' was used to visualise spot measured data on a psychrometric and Adaptive Charts and obtain a preliminary prediction of the thermal comfort vote (Tyler et al., 2013, Schiavon et al., 2014). By utilising an additional feature of this tool, all the onsite spot measurements and respondent's physiological data (i.e. AT, MRT, AV, RH, Met and Clo) were uploaded and plotted on the ASHRAE psychrometric chart to visualise the predicted thermal comfort scenarios for the different climatic seasons in respect to ASHRAE-55 standard (Section 3.2.1). The results obtained using the PMV model from this tool were only used for comparing with and validating the actual comfort votes during field studies. Moreover, 'Adaptive Chart' of the CBE thermal comfort and SPSS tools were utilised to visualise the predicted adaptive comfort from the field data and compare them among different factories and seasons (Section 3.2.1). Here, OT, prevailing mean outdoor AT and airspeed (0.3-0.6 m/s) were used as input parameters collected directly from the field surveys.

The calculation methods of a summary database for spot measurements are explained below. OT (or T_{op}) combines the mean radiant temperature (MRT or T_{mrt}) and AT (T_a) and has been widely used in previous research studies combining the factors of behavioural and physiological adaptations (Schweiker and Wagner, 2015). To predict the comfortable OT range, the adaptive method was applied, and the prevailing mean outdoor AT data was used. The results were compared with those obtained from the PMV method (Luo et al., 2015, Yau and Chew, 2012). Data were used for those workers whose Met values close to 1.0-1.3, (from seated, i.e. 1.0, to sewing, button sewing and packing activities, i.e. 1.4, as referred in Section 2.5), who have full provision to operate the nearby windows or fans as well as the freedom to change their clothing within the Clo values 0.5-1.0 (Schiavon et al., 2014). To assess the heat stress of the workers, wet bulb globe temperature (WBGT or T_{wbgt}) was used, which combines the effects of AT, RH, MRT and airspeed in a single value (Bernard and Hanna, 1998, Parsons, 2006, Chowdhury et al., 2017a). For indoor workspaces exposed to negligible levels of solar radiation, WBGT was calculated using the following formula (Moran et al., 2001):

$$T_{wbgt} = 0.7T_{wb} + 0.3T_g$$

Equation 1

This is valid for observations made when AV lies between 0.25 and 3.00m/s and wet-bulb temperature, $T_{wb} = T_{wbn}$ and Globe temperature, T_g=T_a

The MRT (T_{mrt}) at workstations was derived from the measured 'globe temperature' based on the following formula and utilising the 'CBE Thermal Comfort Tool' (ASHRAE 2017, 37.32, ISO, 1998, Schiavon et al., 2014, p.333):

$$T_{mrt} = \left[(T_g + 273)^4 + \frac{1.10 \times 10^8 . v^{0.6}}{\varepsilon . D^{0.4}}(T_g - T_a)\right]^{1/4} - 273$$

Equation 2

Where all temperatures are in °C, T_g is globe temperature, D and ε are the diameter and emissivity of the globe respectively and airspeed (v) is in m/s. The globe thermometer used in this study (diameter: 0.025m), was manufactured and calibrated to provide the same result as that obtained from a standard globe (diameter: 0.15 m). As a part of quantifying the combined effect of T_{mrt} and T_a, T_{op} was calculated based on the Equation 3 (Tymkow et al., 2013), where T_{mrt}, T_a and v are the same as Equation 2:

$$T_{op} = \{T_{mrt} + (T_a \times \sqrt{10v})\}/(1 + \sqrt{10v})$$

Equation 3

When v tends to be below 0.2m/s, $T_{mrt} = T_g$. Hence, it is usually assumed,

$$T_{op} = (T_{mrt} + T_a)/2 \text{ and/or } T_{op} = (T_g + T_a)/2$$

Equation 4

2.7. Comparative study and statistical analysis

For comparative study, descriptive statistics of the field measured data were used to identify the notable similarities and difference among the indoor thermal condition of the workspaces (i.e. CS, SS and FS) in three case study buildings and climatic seasons. 'IBM SPSS Statistics' (version 24) tool was used for the data management and analysis. The data of each building was treated separately categorising each into three different seasons or field studies. However, to determine the comfort ranges, data from all case study buildings were analysed together. The different occupants, i.e. workers, of the same building was categorised according to their workspaces, i.e. CS, SS and FS reflecting the met values (Section 2.5) and treated as survey average for each season despite having variations in subjects' personal provide, such as, mean ages of 24-25 years (Appendix D). To determine the expected airspeed ranges for the workers to work comfortably their specific production floors, the analysis was bounded to each building separately as well as together in the warm humid season only. For analysing the threshold distance, only the sewing sections of *RMG factory 1* and *RMG factory 3* were considered.

Spearman's rank-order correlation and regression models among workers' various comfort votes (i.e. votes in ASHRAE, McIntyre scale) and onsite spot measured data were executed to reveal the Neutral temperatures (AT and OT), comfort ranges, preferred airspeed ranges and threshold distance for the workers (Field, 2013).

3. Results and discussion

3.1. Variations in indoor and outdoor environment

3.1.1. Comparative study of continuous AT and RH

A comprehensive summary of continuously recorded AT and RH of three RMG buildings are presented in Appendix E with respect to the immediate outdoor thermal environment. SD during both cool-dry and hot-dry seasons showed the higher diurnal ranges of AT (SD: 3.4°C - 5.2°C) and RH (SD: 13.4% – 19.6%) compared to that of the warm-humid season (SD of AT: 1.8°C -2.6°C, SD of RH: 7.8%-12.8%). These higher SDs are the result of the diurnal range AT within a day in cool-dry and hot-dry seasons which can be also observed from Figure 5(a). These scenarios represent the meteorological data as described in Section 2.2. Indoor and outdoor ATs for the SS of the three case study buildings are compared in Figure 5(b). The indoor of the SS in RMG factory 2 appeared to be more sensitive than the other two factories. The main reasons behind of this character are to narrow width of the building allowing more natural ventilation, higher effective area of swing windows (Figure 4) and the high value of the 'window: floor area ration' (Hossain et al., 2017, Hossain et al. 2015). It also shows that the SS remained hot reaching ATs of up to 32°C during the hot-dry seasons. However, RH is relatively higher in the warm-humid season (highest 36.9°C AT and 100% RH). Hence, the warm-humid season was considered the 'worst-case' condition in terms of bringing fresh air from outdoor micro-climate.

Appendix E comprehends that the outdoor micro-climate conditions of all three RMG buildings represented the environmental characteristics of the three seasons of Bangladesh regardless of the sites were in different locations (Figure 2). However, these data did not reveal the indoor thermal conditions that the workers actually experience during the working hours at their workstations.

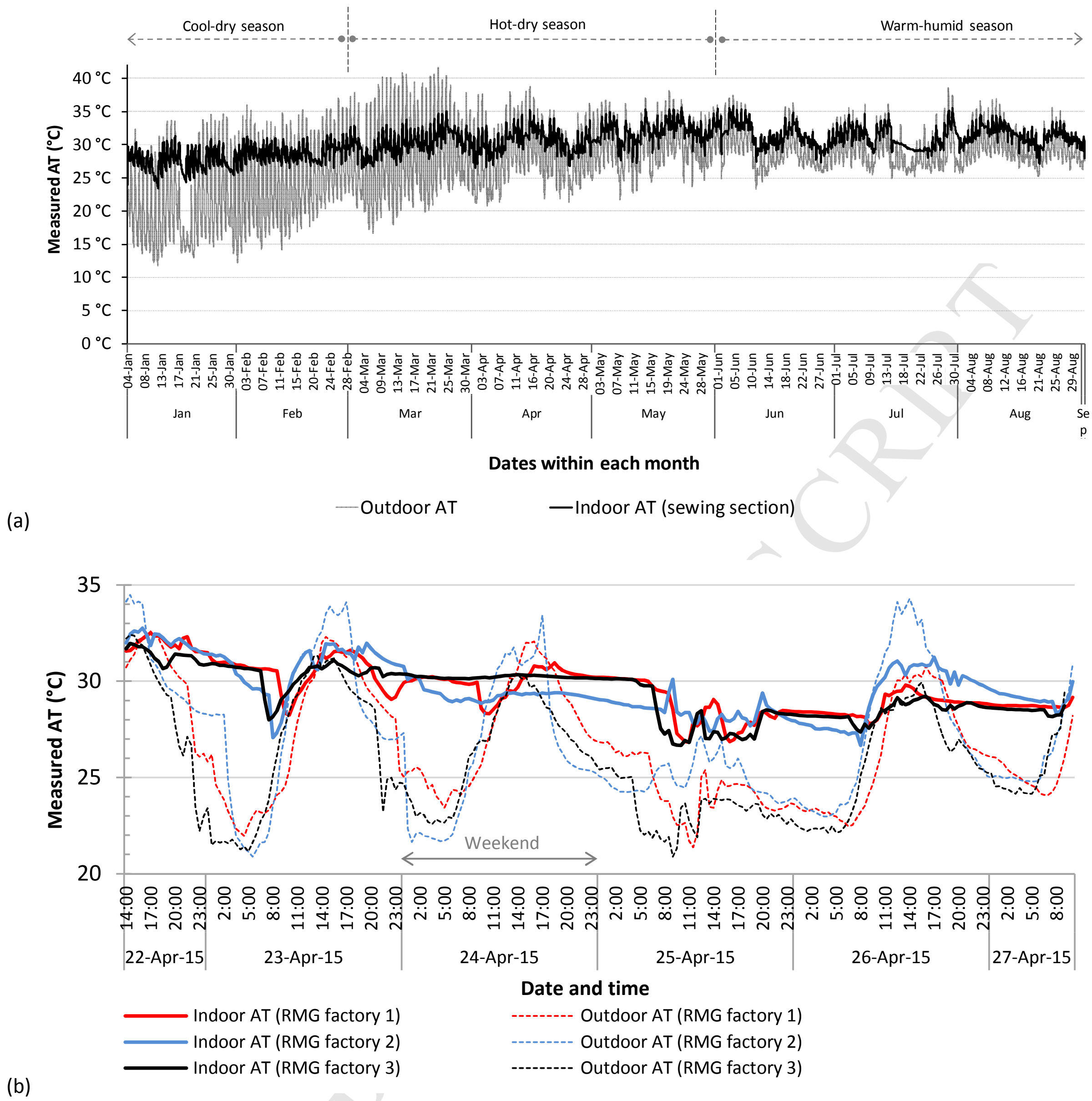


Figure 5: (a) Continuously measured AT from the SS and outdoor in the RMG factory-1 and (b) Measured AT from the SS in three case study buildings during the hot-dry season (Source: Hossain et al., 2017)

3.1.2. Comparative study of spot measurements

A comparative summary of the actual thermal conditions (i.e. average spot measurements of all workspaces) of all case studies is illustrated in Appendix F. The impact of seasonal variations can be observed in AT and RH in case studies (e.g. mean values of indoor AT are 27.1°C, 31.1°C and 31.2°C while the mean values of outdoor AT are 23.1°C, 30.9°C and 30.8°C in three seasons respectively), same as the Appendix E. Similar situations can be observed for the values of RH. However, the small SD values (e.g. 0.9°C to 1.4°C for WBGT) among the all three case studies in the Appendix F justified that the selected cases can be analysed together assuming the climatic season as the first key variable for adaptive comfort (Lin et al., 2011), though outdoor microclimate diversity and urban geometry have significant impact on outdoor thermal perception (Sharmin et al., 2015).

Appendix G provides an insight into the thermal conditions of three type of production spaces. Despite the impact of the key variable (i.e. outdoor thermal environment and solar radiation pattern in three seasons), the variations in workspaces' indoor thermal condition were also statistically significant. For instance, the AT, GT, WBGT, MRT and OT of the CS are relatively lower than sewing and ironing sections in all climatic seasons. The values of GT and MRT also reflected the internal heat gain profiles (e.g. internal heat gain at the CS varies from 45- 110W/m^2 while 180-225W/m^2 at the SS and 150-220W/m^2 at the FS) and thermal images (Appendix H). Analysing the mean WBGT revealed that the workstations had 15.4%-22.2% lower WBGT in term of risk factor criteria (i.e. lower risk factor: ≤26.5°C) of heat stress on workers' body (Parsons, 2006, Chowdhury et al., 2017a). However, the SS and FS during the hot-dry season and all workspaces during the warm-humid season were within the 'moderate' (26.7°C -29.3°C) and 'moderate to risk' (29.4°C -31.0°C) factor (Chowdhury et al., 2017a, Parsons, 2006). This also implied that the indoor conditions during these two seasons were uncomfortable for the workers. Retaining the existing RH range, the only ways to elevate comfort level were reducing the AT (Equation 1) and increase airspeed by fans (Nicol and Roaf, 2005).

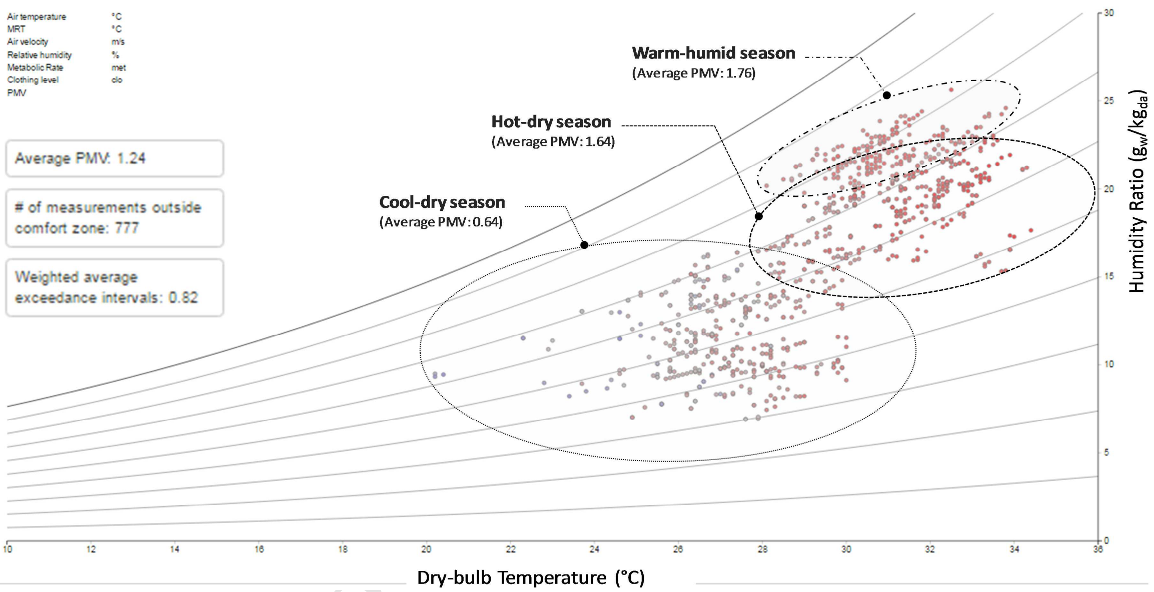
The observed variations of indoor and outdoor thermal condition fostered evaluating the actual comfort condition and NT of the RMG factory workers according to the two variable cases which are the climatic seasons and workspace types (Chowdhury et al., 2017a, Chowdhury et al., 2017b, de Dear et al., 2015, Brager et al., 2004, de Dear and Brager, 2001).

3.2. Neutral Temperatures and Comfort Benchmarks for Workers

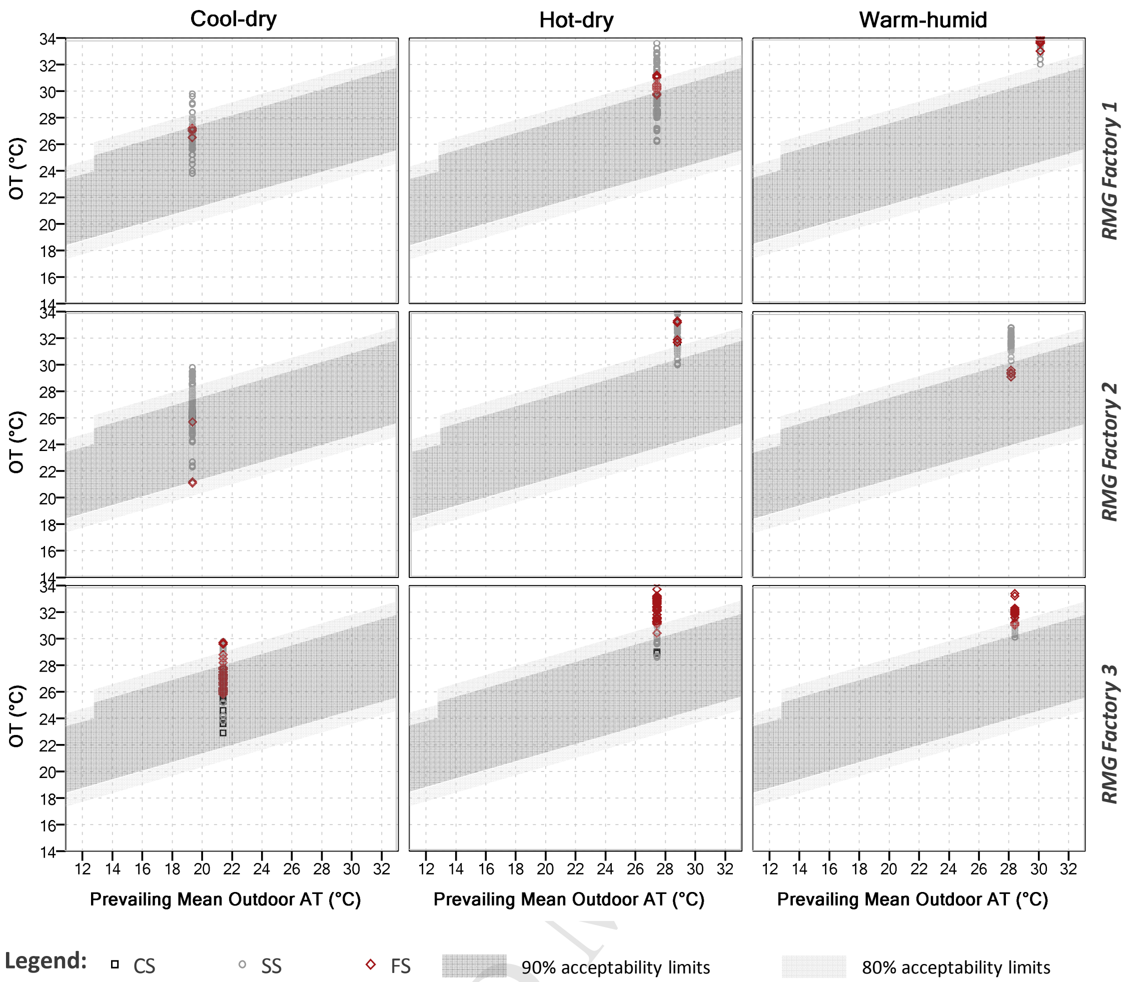
3.2.1. Predicted vote vs actual comfort vote

Based on the results gained from the CBE comfort tool in the year 2017, Figure 6(a) indicated that 777 of studied workstations (i.e. 85.6% of the total 908 working locations) were outside of ASHRAE comfort zone with an average PMV of 1.24 during three climatic seasons. In particular, 68.2% of 384 measurements during the cool-dry season (PMV: 0.64), 97.2% of 327 measurements during hot-dry (PMV: 1.64) and 100% of 197 during the warm-humid season (PMV: 1.76) were found out of ASHRAE comfort zone. It also gave an insight into the wider range of thermal condition during the cool-dry and hot-dry season rather than that during the warm-humid season.

Total 754 subjects' location where subjects' met values were within 1.0-1.4 was considered for applying adaptive comfort model (the chart was adopted from CBE tool assuming the airspeed up to 0.6m/s). According to the adaptive model, 373 (49%) of the above subjects' working environment should comply with adaptive comfort (Figure 7).



(a)



(b)

Figure 6: Visualisation of measured data using (a) Psychrometric chart - ASHRAE comfort model and (b) Adaptive chart - Adaptive comfort model

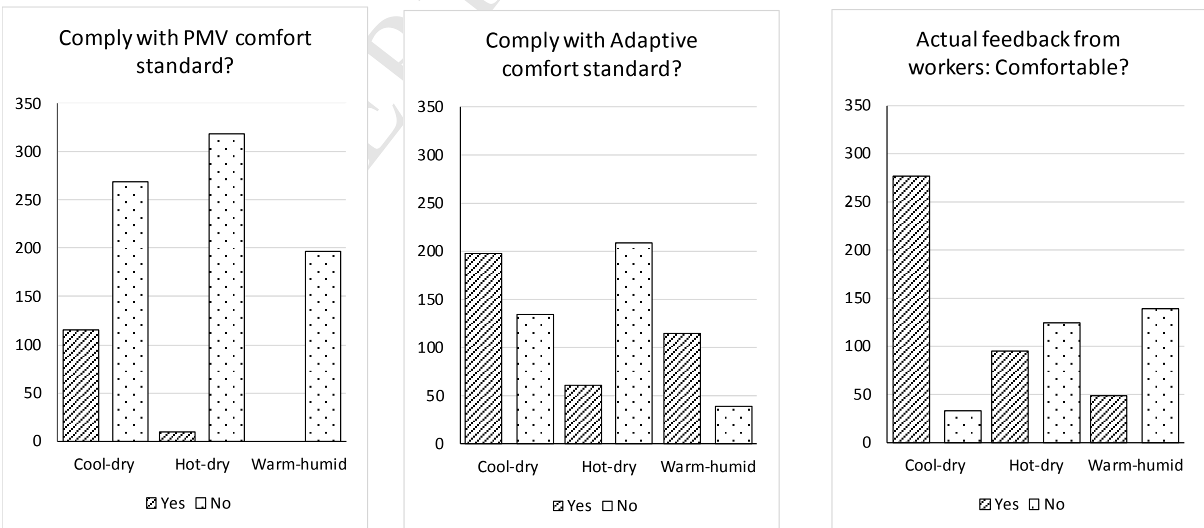


Figure 7: Histogram showing predicted and actual comfort votes from all three case study buildings

However, the actual feedback of the workers revealed that 314 (42%) out of 747 workers (excluding the total of 161 subjects were not sure about their comfort level) were uncomfortable at their workstations. This is still lower than the 85.6% found by the CBE tool. In particular, only 10.7% out of 309 (excluded 77 'not sure' vote), 56.8% out of 219 (excluded 75 'not sure' vote) and 73.9% out of 188 subjects (excluded 9 'not sure vote') were uncomfortable with the thermal environment during season 1, 2 and 3 respectively. It implied that the rest of the workers, i.e. 43.6% of the 747 respondents, were either acclimatised or adapted with their indoor environment to be comfortable (Brager et al., 2004). Previous research showed that physiologically acclimatised users' usually experience their thermal comfort within the close range of the NT (Indraganti, 2010, Shajahan and Ahmed, 2016, de Dear and Brager, 2001). It fostered to investigate further on workers' actual NT and adaptive comfort zone.

The total 72.1% participants among which 96.1%, 59.1% and 30.8%, during the cool-dry, hot-dry and warm-humid seasons respectively, were voted as 'overall acceptable' about their workstations. After analysing the data, 53.13%, 83.9% and 66.4% of acceptability rates were found within *RMG Factory 1*, *RMG Factory 2* and *RMG Factory 3* case studies. However, Rijal et al. (2002) suggested that 80% -90% of the occupants should accept the environment as comfortable. It should be around the central three scales (vote -1, 0 and +1) of ASHRAE seven-point TSV scales (-3 to +3). This section also reveals that the predicted comfort votes from the adaptive comfort model are more relevant to actual votes than that gained from PMV

3.2.2. Cross-tabulations between various scales and thermal data

To examine the actual thermal comfort vote, TSV scale was cross-tabulated against the TPV scale (McIntyre scale) (Appendix C). Total 56.7% of the participants voted within (+1, 0, -1) scale and the 45.8% of the measured environment revealed as the neural TSV also voted as 'no change' in preference scale. However, 28.5% of the workers, who voted as slightly warm (ASHRAE +1 vote) also suggested preferring a cooler environment. 3.7% of workers who voted slightly cool (-1), had also voted for 'no change' while the 7.2% of participants who felt slightly warm (+1) voted 'no change' as their preference. This cross-tabulation validated the previous findings suggesting the occupants with 'no change' vote do not fully have 'neutral' thermal sensation (Shajahan and Ahmed, 2016, Feriadi and Wong, 2004, Peeters et al., 2009). A summary of this statistical database was presented in Table 1.

Table 1: Statistical summary of subjective votes in four different scales

Seasons	All votes	Thermal sensation vote (TSV)		Thermal preference vote (TPV)		Thermal Comfort vote (TCV)*		Overall acceptability vote (OAV)	
		All votes	'Neutral' votes	All votes	'No change' votes	Votes, excluding 'not sure' votes	'Comfortable' votes	Votes excluding 'not sure'	'Acceptable' votes
	Nos.	Mean (SD)	Nos. (%)	Mean (SD)	Nos. (%)	Nos.	Nos. (%)	Nos.	Nos. (%)
Cool-dry	384	+0.21 (0.66)	216 (56.3)	+0.17 (0.49)	285 (74.2)	309	276 (89.3)	363	349 (96.1)
Hot-dry	327	+0.63 (0.75)	157 (48.0)	+0.50 (0.68)	174 (53.2)	250	108 (43.2)	311	216 (59.5)
Warm-humid	197	+1.16 (0.87)	47 (23.9)	+0.86 (0.68)	61 (31.0)	188	49 (26.1)	191	59 (30.8)

**Author generated customise scale for crosschecking purpose only*

To observe the relation among AT, MRT and OT, these temperatures were plotted against each other, AT vs. OT, AT vs. MRT and MRT vs. OT (Figure 8). The figure reveals that MRT is high in the SS and FS due to high internal heat gains and it has an impact on the indoor OT and AT. High MRT values were also observed in SS of the *RMG factory 2.*

Figure 9 gave an insight into the workers' neutral AT ranges from 23.7°C-29.5°C during the cool-dry season, 26.3°C -33.9°C during the hot-dry season and 28.3°C -31.7°C during the warm-humid season. However, it was not confirmed whether these ranges were also accepted and preferred by the workers.

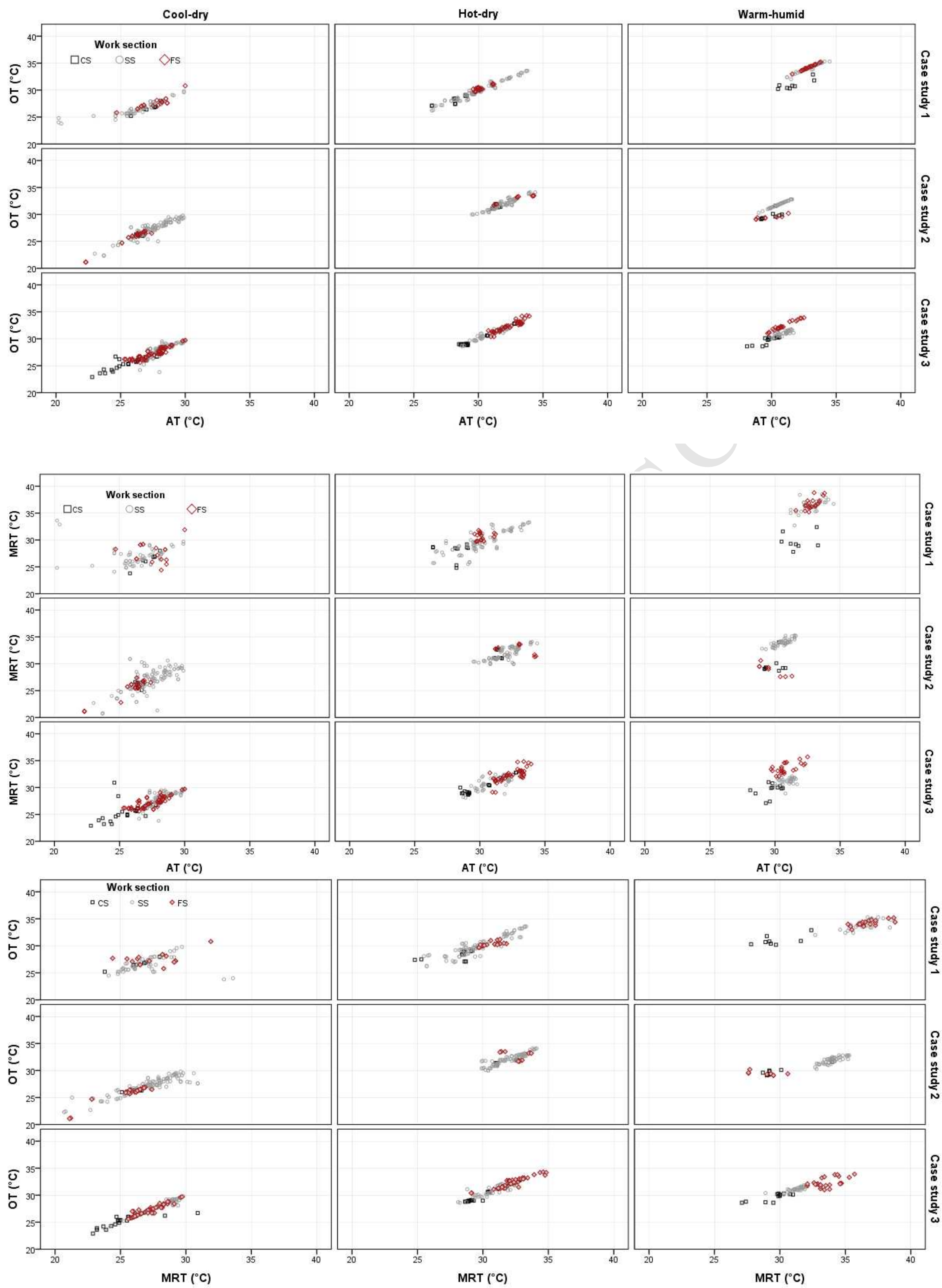


Figure 8: Relation between indoor AT, MART and OT during different climatic seasons

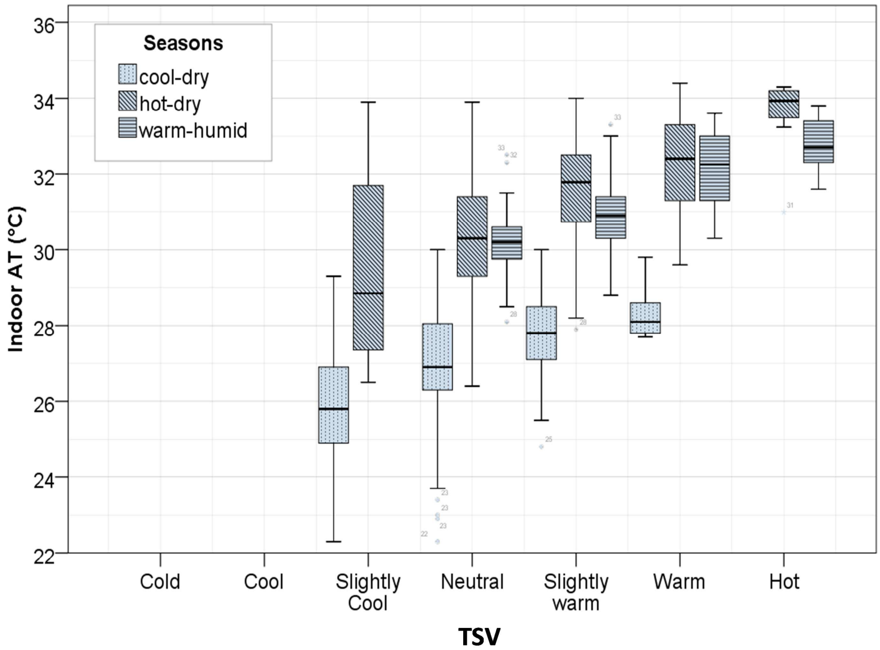


Figure 9: Indoor AT ranges measured against TSV during different climatic seasons

While these AT ranges (voted as 'neutral'), in Figure 9, reflected mainly the impact of climatic seasons, the MRT ranges (voted as 'neutral') of Figure 10 represented the variations of thermal environment workers actually experienced (Halawa et al., 2014) in different production spaces of three factory buildings as a combined effect of AT, GT and AV (Equation 2). It reveals that workers in SS and FS who were exposed to high MRT were also reported high TSV so as their 'neutral' votes.

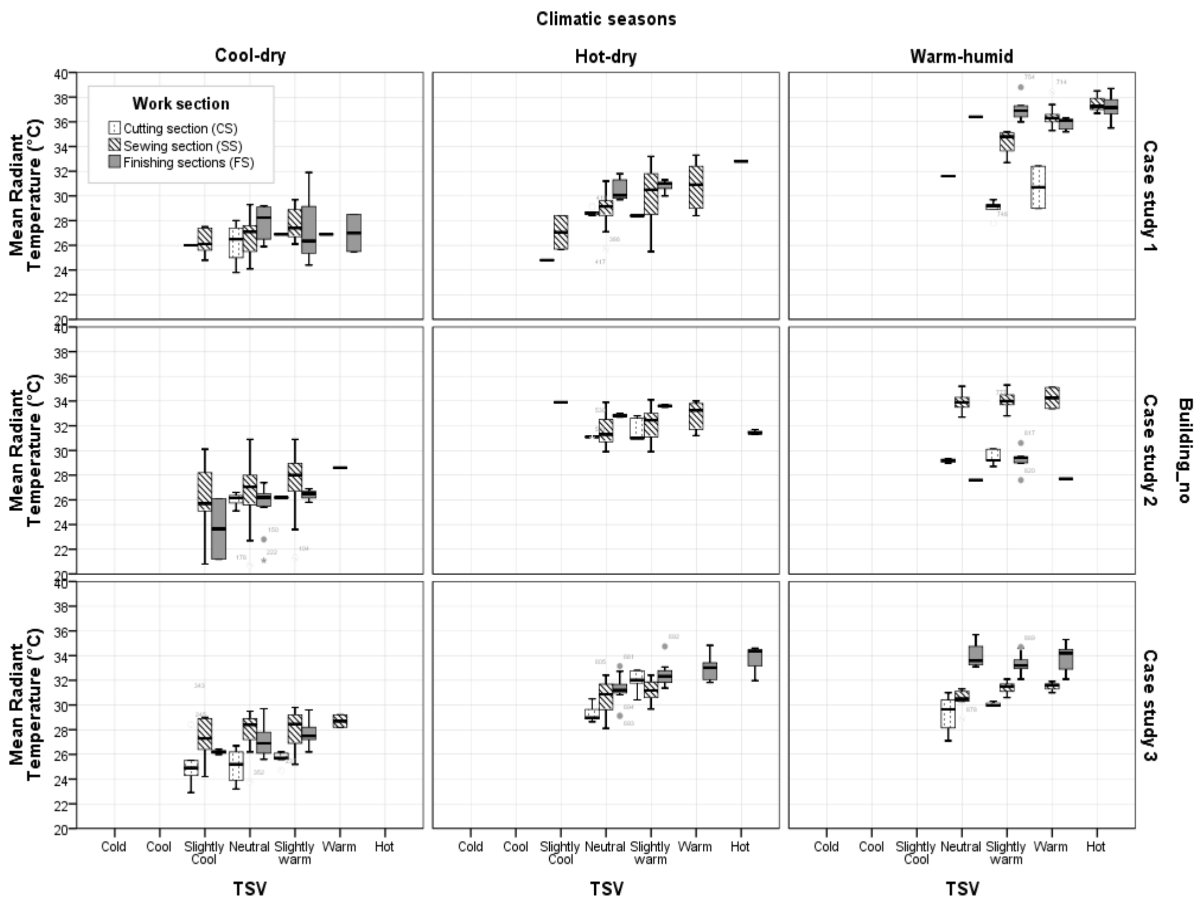


Figure 10: Indoor RMT ranges against TSV during different production sections and case study buildings

RH within the FS was high due to not only monsoon period, but also excessive steam generated through ironing activities within the FS. Local area discomfort can also be the reason of radiant temperature asymmetry up to 5°C (ASHRAE, 2013) which was prominent at the ironing workstations (Appendix H).

3.2.3. Neutral temperatures and comfort ranges

According to previous research (Indraganti, 2010, Shajahan and Ahmed, 2016), the neutral range of OT can express the actual thermal comfort range that the users desire considering their flexibility to control their environment. Neutral AT and the comfort range of AT were also calculated since ASHRAE comfort diagram considers the assumption that MRT is equal to AT (Halawa et al., 2014).

Table 2 illustrates the NT and thermal comfort ranges with 90% acceptability rate, i.e. from -0.5 to +0.5 TSV scale, for the RMG factory workers derived from the regression analyses of TSV and TPV with the AT and the OT, following the methods established by Indraganti (2010) and Shajahan and Ahmed (2016).

Table 2: Neutral temperatures and comfort ranges for RMG factory workers

Season	Work section	Neutral Temperatures – AT and OT (°C)						Comfort range (°C) (in 90% acceptability)				Details of the linear regression analysis among TSV and AT***		
		Actual*				Predicted ** (CBE tool)		Actual *		Predicted** (CBE tool)		Slope	Intercept	R^2
		ASHRAE 7-point scale		McIntyre preference scale		PMV Method	Adaptive Method	(ASHRAE scale)		PMV Method	Adaptive Method			
		TSV vs AT	TSV vs OT	TPV vs AT	TPV vs OT			TSV vs AT	TSV vs OT					
Cool-dry	CS	25.9	25.9	26.3	26.0	24.6	24.1	24.4 - 27.5	24.1-27.5	23.1 - 26.1	22.5 – 27.2	0.32	-8.2	0.29
	SS	26.1	25.9	25.8	25.6	24.5		22.8 - 29.1	**22.7-29.1**	23.1 - 26.4		0.16	-4.19	0.15
	FS	26.0	25.9	25.3	25.2	24.4		23.8 - 28.4	**23.1-28.5**	22.2 - 26.5		0.22	-5.64	0.22
Hot-dry	CS	28.5	28.6	28.9	29.0	23.8	26.7	25.5 - 31.5	25.5-31.5	21.8 - 24.5	24.9 – 30.0	0.16	-4.6	0.30
	SS	27.1	26.3	26.8	26.5	25.6		22.9 - 30.3	**22.3-30.4**	23.9 - 27.2		0.13	-3.52	0.10
	FS	29.8	**29.8**	**30.0**	30.0	26.7		28.9 - 30.9	**28.6-31.0**	28.1 - 31.5		0.46	-13.81	0.50
Warm-humid	CS	28.9	28.7	28.9	28.5	28.8	26.6	27.7 - 30.1	27.7-30.0	**27.6 - 29.9**	24.8 – 29.8	0.42	-12.18	0.65
	SS	29.4	29.8	29.0	28.9	29.3		28.6 - 30.1	**28.7-30.9**	**28.4 - 30.0**		0.57	-16.61	0.64
	FS	27.8	27.5	27.6	26.9	27.5		26.1 - 28.9	**25.4-29.1**	**26.0 - 28.7**		0.38	-10.32	0.33

**Based on the regression analysis with the actual responses from the workers during the field studies.*
*** Based on the regression analysis with the ASHRAE 55 2013 PMV index by using spot-measurement as input data in the CBE comfort tool.*
**** Regression analyses between the 'ASHRAE-55 7-point TSV and the AT collected during the field studies.*

During the cool-dry season, the workers' neutral AT occurred within 25.9°C-26.1°C while 26.3°C, 25.8°C and 25.3°C were their preferred AT. Regression analyses with OT also provide similar neutral OT with 0.4-0.8% low deviations from the same analyses with AT. However, predicted neutral temperatures by PMV and adaptive methods provides 0.4-1.2°C low NT (3.2% -5.4% deviations).

Similarly, during the hot-dry season, the preferred neutral AT were 28.9°C, 26.8°C and 30°C (with up to 1.4% deviations from TSV regression cases). However, predicted NT were 23.8°C, 25.6°C and 26.7°C in the CS, SS and FS (i.e. 3.3°C, 1.2°C and 3.3°C lower respectively). In these both seasons, the thermal comfort ranges were also higher than the predicted range. Comparing the mean AT and MRT (Appendices F and G) it reveals that the workers have adapted higher AT due to their exposure to a wider range of AT variations within a day during these two seasons. These findings are also consistent with the previous findings regarding thermal adaptation with the wider indoor and outdoor AT (Chowdhury et al., 2017b, de Dear et al., 2015, Luo et al., 2015, Schweiker and Wagner, 2015, Zhao et al., 2014, Toe and Kubota, 2013, Schweiker et al., 2013, Mishra and Ramgopal, 2013, Brager et al., 2004, de Dear and Brager, 2001).

Crosstabulation of the SPSS dataset showed that both actual NT and comfort ranges during the warm-humid seasons were very similar to predicted ones with a minor deviation up to 2.2% (0.6°C). It is also noticeable that, even workers had higher airspeed and lower MRT in the FS (Figure 10), they still preferred certain AT range (26.1°C - 28.9°C) avoiding local discomfort (ASHRAE, 2013). It also implied that the workers have less adaptive capacity during humid environment (Toe and Kubota, 2013) unless they were exposed to preferred air flow to their body skins by fans (Indraganti et al., 2014) and have enough adaptive measures to elevate their comfort (Schweiker and Wagner, 2015, Schweiker et al., 2013). On the other hand, for dry seasons the NT and comfort ranges (Table 2) can be followed maintaining the airspeed range synchronised with the AT which varies with contextual factors and the time of the day (Chowdhury et al., 2017a, O'Brien and Gunay, 2014, Toe and Kubota, 2013, Humphreys et al., 2013).

3.2.4. Acceptability of the measured comfort ranges

Form field survey, a total of 624 workers (68.7%) accepted the overall thermal environment. It has been found from the data that only 452 numbers (49.9%) of the working environment met the compliance with the ASHRAE Adaptive comfort standard (by using the CBE comfort tool) among which 242 workers (53%) has personal ability to control the nearby fans and operate the nearby windows to control the air velocity. CBE comfort tool predicted only 122 no. (50.4%) among the spots would be within the comfortable range (90% acceptability rate) and all of them (242 spots) would be within the adaptive comfort zone. It indicates that providing sufficient adaptive opportunities in their work environment may also increase the acceptability rate (Mishra and Ramgopal, 2013). The regression analyses with OT also gave comfort ranges with up to 0.7°C higher adaptation capacity. Due to various GT and AT, MRT also varied according to the type of the workspaces. For the value of airspeed less than 0.2m/s, OT=MRT=GT (Equations 3 and 4), this finding also validated previous research where RH influenced adaptive comfort during the hot-dry season; while airspeed affected that during the warm-humid season (Toe and Kubota, 2013).

3.3. Personalised Control and Adaptive Behaviour

In terms of personal behavioural adaptation (Schweiker and Wagner, 2015, Gunay et al., 2013, Brager et al., 2004), increasing Fan speed or on-off (46%), opening-closing the windows (31%), reducing activity (13%), Tying up hair (5%), changing the dress (2%) and the body posture (3%) were the common activities as found from the questionnaire survey. While 'opening windows' was found as a widespread activity in a research by Mishra and Ramgopal (2013), 'drinking water' (including saline water), freshen up with cold water in the toilet, standing near to the inlet windows and fans were also counted as adaptive and cultural traits to cope with these workspaces with high AT. They also highlighted their limitations to operate the windows and fans due to long distances from their workstations. Hence, ensuring the personalised control for workers may not only improve thermal comfort perception by psychological influence but also give a paradigm shift from the conventional centralised ventilation control (Brager et al., 2004, Brager et al., 2015, Luo et al., 2016, Raja et al., 2001).

Since, in this study, RH and GT range vary with the types of season and production section, AV is the parameter which is closely associated with the ventilation and personalised controlling system (Brager et al., 2015, Rupp et al., 2015, Brager et al., 2004) confirming workers' higher acceptability, e.g. from the airspeed above 0.2m/s workers may have a chilling effect, and reduction of energy consumptions (Veselý and Zeiler, 2014).

3.4. Preferred Air Flow Directions and Airspeed Ranges

3.4.1. Preferred directions for airflow

The warm-humid season was considered as the 'worst-case' scenario with a consistent AVFR in each case study building and 197 subjects with their workspace conditions were examined. The histogram of the mean AV (n/s) in terms of overall acceptability vote indicated that mean AV (n/s) increased with the acceptability vote (up to 0.85m/s from the south). On the other hand, mean AV (u/d) decreased against the same vote (as low as 0.7m/s).

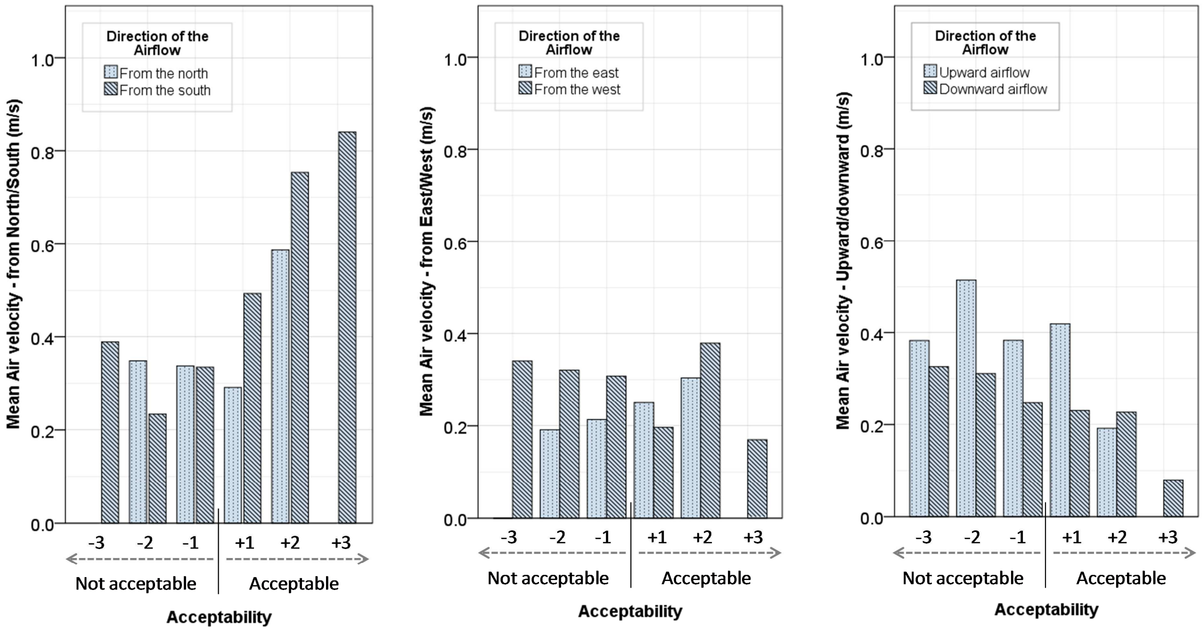


Figure 11: Acceptable mean airspeeds from different directions during the warm-humid season

For further investigation, 'Spearman' non-parametric correlation analyses were executed among the environmental data, airspeeds from different directions, AT and subjective votes. The correlation analysis was held for each case study building's workspaces separately. Since similar results were found for individual cases, Table 3 illustrates that AV (n/s) has positive correlations of 0.322, 0.260 and 0.369 (significant at the 0.01 level, p-value <0.0001) with the overall acceptability vote, preference vote (air flow) and comfort vote (air flow) respectively. It implied that AV (n/s) was more acceptable and desirable to workers at their workstation. It is also consistent with the generalised suggestion from ILO (1998) of designing airflow pattern from the side windows in textile factories. It also supports the research by Chowdhury al el. (2017a) predicting RMG production zones with openings toward N-S orientation were high in the thermal performance matrix (i.e. average AT 32.4°C, SD 0.98–1.84°C). In contrast, AV (u/d) had a negative correlation of 0.180 with the preference vote. It also implied that the increase of upward and downward airspeed was not preferable to the workers at their workstations.

Table 3: Nonparametric correlations (Spearman's rho) between AV (from different directions), AT and subjective votes on air flow

Variable	AV (n/s)	AV (e/w)	AV (u/d)	AT	Overall Acceptability	Preference vote (Air flow)	Comfort vote (Air flow)
AV (n/s)	1	0.559** *(p = 1.5 x 10^{-17})*	0.483** *(p=6.3 x 10^{-13})*	-0.102 *(p=0.153)*	**0.322**** *(p=4 x 10^{-6})*	**0.260**** *(p=2.3 x 10^{-6})*	**0.369**** *(p=9.6 x 10^{-8})*
AV (e/w)	0.559** *(p=1.5 x 10^{-17})*	1	0.565** *(p=4.9 x 10^{-18})*	0.113 *(p=0.113)*	0.061 *(p=0.394)*	0.002 *(p=0.973)*	0.055 *(p=0.444)*
AV (u/d)	0.483** *(p=6.3 x 10^{-13})*	0.565** *(p=4.9 x 10^{-18})*	1	**0.455**** *(p=4.9 x 10^{-18})*	-0.119 *(p=0.096)*	**-0.180*** *(p=0.011)*	-0.112 *(p=0.117)*
AT	-0.102 *(p=0.153)*	0.113 *(p=0.113)*	0.455** *(p=1.8 x 10^{-11})*	1	**-0.590**** *(p=7.0 x 10^{-20})*	**-0.644**** *(p=1.8 x 10^{-24})*	**-0.601**** *(p=1.1 x 10^{-20})*
Overall Acceptability	0.322**	0.061 *(p=0.394)*	-0.119 *(p=0.096)*	-0.590** *(p=7.0 x 10^{-20})*	1	**0.840**** *(p=8.6 x 10^{-54})*	**0.821**** *(p=2.9 x 10^{-49})*
Preference vote (Air flow)	0.260** *(p=0.0002)*	0.002 *(p=0.972)*	-0.180* *(p=0.011)*	-0.644** *(p=1.8 x 10^{-24})*	0.840** *(p=8.6 x 10^{54})*	1	0.854** *(p=3.3 x 10^{-57})*
Comfort vote (Air flow)	0.369** *(p=9.6 x 10^{-8})*	0.055 *(p=0.444)*	-0.112 *(p=0.117)*	-0.601** *(p=1.1 x 10^{-20})*	0.821** *(p=2.9 x 10^{-49})*	0.854** *(3.3. x 10^{-57})*	1

***Correlation is significant at the 0.01 level (where, significance p-value < 0.0001 unless otherwise stated).*

**Correlation is significant at the 0.05 level.*

During the survey, the workers significantly reported that they experienced air flow of hot air from both from ceiling fans and floor areas at their workstations. Hence, this study also exploited the correlations between AV and AT to justify workers' above feedback. The correlation between AV (u/d) and AT was also found as significant as +0.455. It indicated that upward and downward air flow might increase the AT within their workspaces and reduced their acceptability and comfort (with significant correlations -0.591 and -0.601), as shown in Table 3. It indicated that ceiling fans rather caused discomfort to the workers blowing warmer air to their workstations. Additionally, it was observed that overall acceptability vote on the thermal environment had significant positive correlations of 0.840 and 0.821 with the preference and comfort vote of air flows respectively.

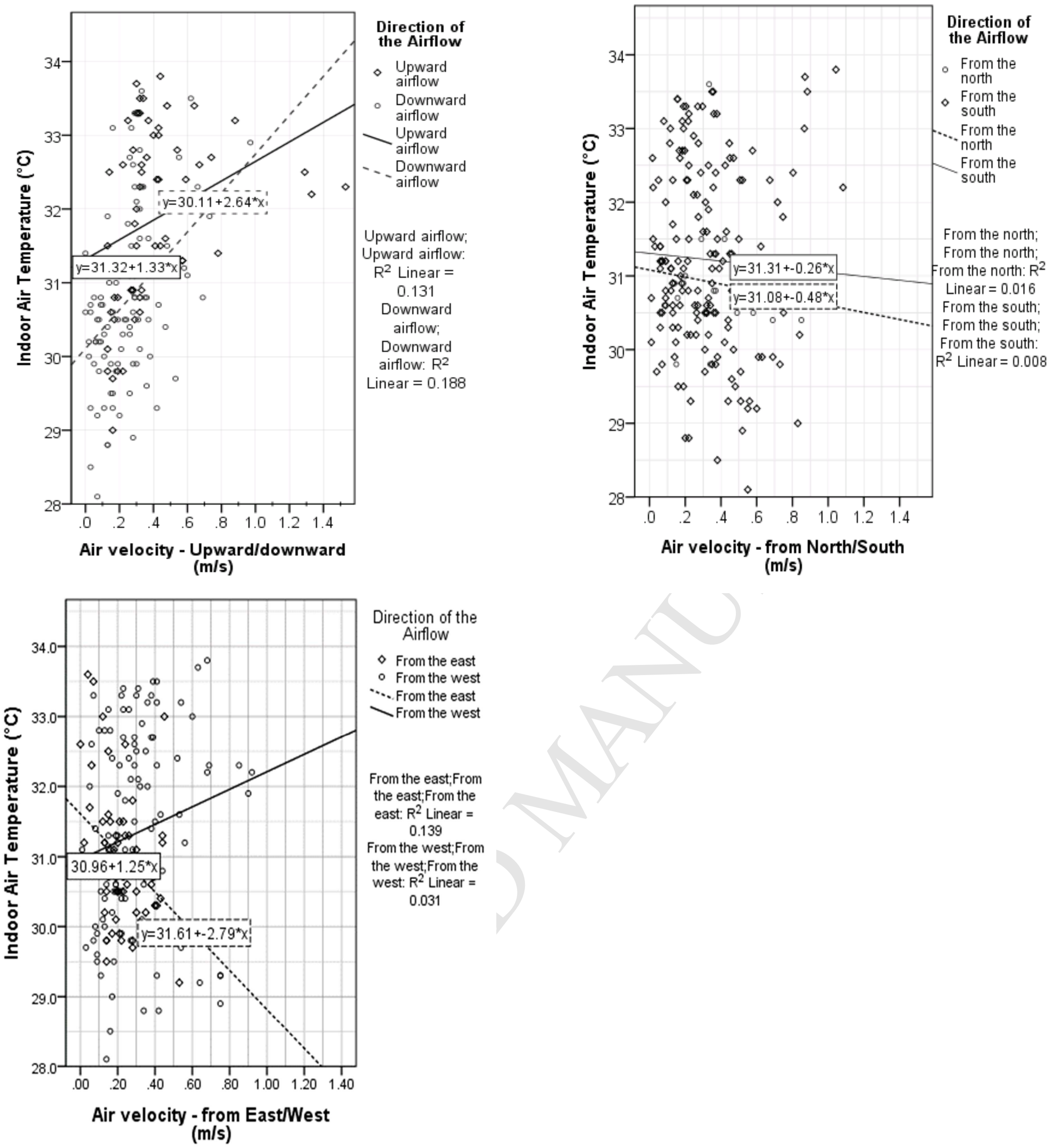


Figure 12: Regression analyses between AV (from different directions) and Indoor AT

Further linear regression analyses (Figure 12) between AV and Indoor AT revealed that AT increased with both upward and downward airflows with positive slopes of 1.33 and 2.64 of the regression lines (where R^2=0.131 and 0.188). It indicated that for every 1m/s increase of airspeed towards up and down could increase 1.3°C and 2.6°C of AT within their workstations. Similarly, positive slope of 1.25 of the regression lines (R^2=0.031) with AV (from the west) revealed that for every 1m/s rise of airspeed from west side would increase 1.2°C of AT within their workstations. In contrast, the inverse slopes (-0.26, -0.48 and -2.79) of the regression lines between AT and AV from south, north and east sides determined that increase of airspeeds from these directions significantly helped to reduce the workspaces' AT. The relationship of increasing AT with the airspeeds from up, down and west might be result of heat sources (e.g. sewing machine motor at the bottom of the desk, lighting equipment and convective hot air near the ceiling) and additional radiative heat from the exposed west façade of the buildings, which also correlated with results from previous studies of Hossain et al. (2016) and Chowdhury et al. (2017a).

3.4.2. Preferred airspeed ranges

Table 4 illustrates the mean and acceptable ranges of airspeed (i.e. 90% acceptability range, -0.5 to +0.5) for the workers to execute the production work at different kind of workstations comfortably.

Table 4: Preferred air velocity at different workstations*

	Work section	**Comfortable Airspeed, m/s (Bedford sensation scale)**		**Preferred Airspeed, m/s (McIntyre preference scale)**	
		'Perfect' vote Mean (SD)	Comfortable airspeed range	'no change' vote Mean (SD)	Preferred airspeed range
Average air flow (from all direction)	CS	0.3 (0.13)	0 – 0.6	0.3 (0.12)	0.4 – 1.6
	SS	0.3 (0.14)	0.4 – 1.2	0.3. (0.10)	1.6- 3.8
	FS	0.3 (0.26)	1.2 – 3.0	0.3 (0.14)	Undefined**
From the east side	CS	0.4 (0.14)	0 – 0.7	0.5 (0.04)	0.5 – 0.9
	SS	0.3 (0.08)	2.5 – 0.8	0.3 (0.08)	0.3 – 0.6
	FS	0.3 (0.12)	Undefined**	0.3 (0.12)	0.4 – 0.8
From the north/south side	CS	0.4 (0.20)	0 – 1.2	0.5 (0.18)	0.4 – 1.1
	SS	0.5 (0.25)	0.7 – 1.8	0.5 (0.23)	**1.2 - 2.8**
	FS	0.4 (0.22)	1.2 – 2.5	0.3 (0.17)	**2.8 – 5.8**

* AT, GT and RH were within the fixed range found in the different type of workstations during the warm-humid season (Appendix G)

**the slope of the regression line was not high enough to define the airspeed range.

Table 4 reveals that they preferred higher ranges of airspeed at the SS and FS, especially from the north/south side (e.g. 1.2 -2.8m/s, higher than 0.7-1.8). In all production sections, the mean air velocities were minimum 0.3m/s while the preferred ranges were also suggested above 0.3m/s. It indicated that to airspeed should be maintained as minimum as 0.4m/s in all section with the highest airspeed of 1.1m/s, 2.8m/s and 5.8m/s for cutting, sewing and finishing (e.g. maximum 5.8m/s for ironing only) works respectively in RMG factories. The maximum airspeed range also reflected allowable airspeed to conduct the certain nature of work, such as the CS involved in cutting small pieces of clothes and desired less airspeed. It was inclusive to less AT and GT of the CS.

Chowdhury et al. (2015) and Fatemi (2014) proposed 0.6m/s as a mean comfortable airspeed which was too generalised to apply within all type of production workstations at RMG factories. The FS accepted a higher airspeed range supporting the findings from Cândido et al. (2010). Thus, this research outcome specified the mean and allowable range of the airspeed for certain production section which would be useful for enhancing the existing ventilation or designing more personalised airflow system (Brager et al., 2015, Brager et al., 2004).

3.5. Threshold Distance from Inlets or Workspace Width

Figure 13 provided an insight into the distribution of AT for forced cross-ventilation, from air-inlet windows to air-outlet, in different time of the day inside the *RMG Factory 1* and *RMG Factory 3* buildings, i.e. inside the SS only to keep the other variables constant. It was found that the indoor AT rose above the comfortable AT range (Table 2) from the centre-M point of the building floor, especially after 11 am. Hence, reducing AT and ensuring preferred airspeed were required to ensure the worker's comfort, as recommended by Toe and Kubota (2013).

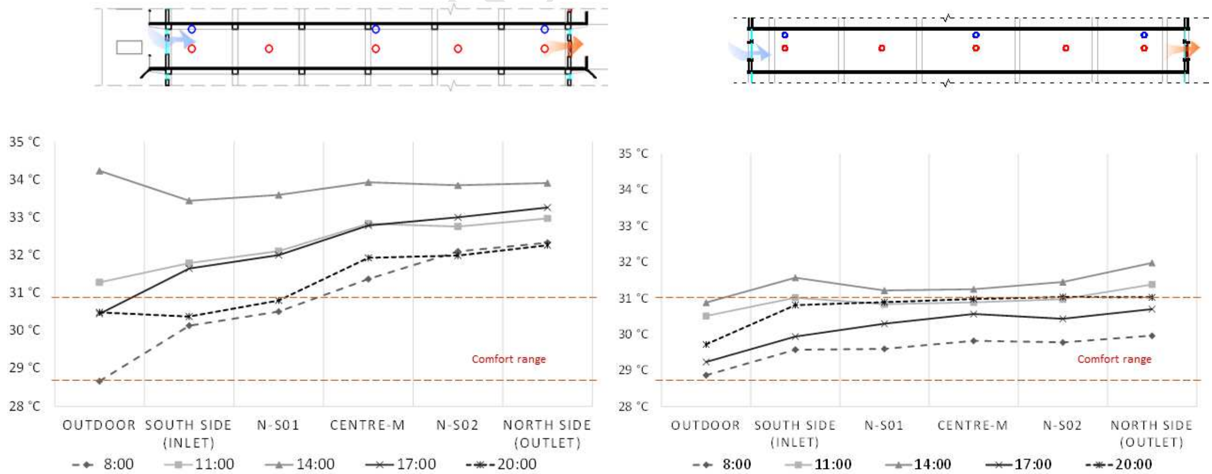


Figure 13: AT profile* along the inlets to outlets axis at the 1st floor (SS) - RMG factory 1 and the 4th floor (SS) - RMG factory 3

*During working hours of the hottest day at sewing floor during the warm-humid season (8 and 26 August 2015)

To observe the effect of 'distance of inlet' on TSV, Figure 14 revealed that all the 'warm' and 'hot' votes were gathered between 20-30m distances, while neutral votes were gained within a maximum of 16m distance (*RMG factory 3* only).

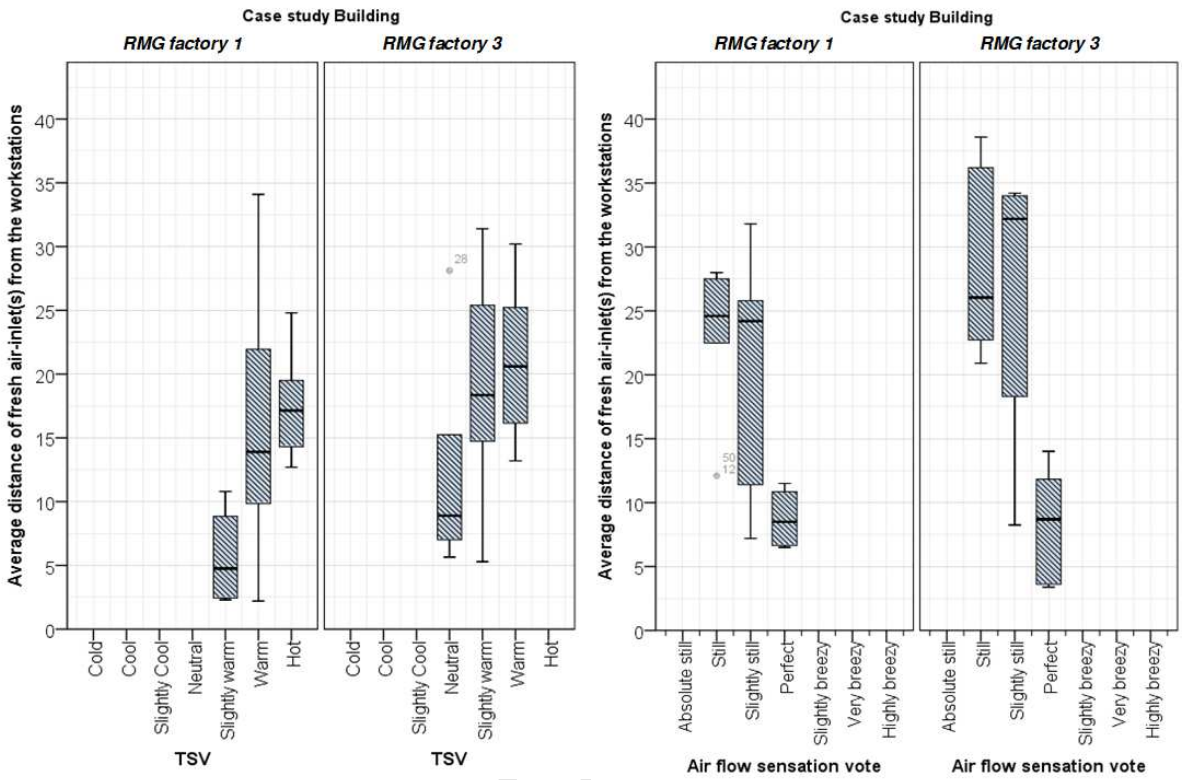


Figure 14: Subjective vote distributions in terms of workers' location within the SS

To identify whether there were correlations between 'distances of the inlets' and 'sensation votes', Spearman's non-parametric correlation analyses were executed (Table 5). Significant correlations of -0.5 and -0.324 were found with TSV and 'airflow sensation vote' respectively. It implied that workers comfort declined with the rise of distance from ventilation-inlets. Correlations between AV and distance of inlets reveals that AV also decreased with the significant correlation coefficients of -0.325 and -0.261. These correlations are also reliable with the statement that air loses the velocity by the distance it travels from the inlet windows (Heiselberg et al., 2001).

Table 5: Non-parametric correlations between 'distance from ventilation inlets', 'thermal parameters' and 'votes'

Variables	Average distance from ventilation inlet(s)	OT	AT	TSV	AV (from N/S)	AV (Average)	Air flow sensation vote
Average distance from ventilation inlet(s)	1	**0.320**** *(p=4.0 x 10^{-6})*	**0.390**** *(p=1.5 x 10^{-8})*	**0.500**** *(p=7.2 x 10^{-14})*	**-0.325**** *(p=3 x 10^{-6})*	**-0.261**** *(p=0.0002)*	**-0.324**** *(p=3 x 10^{-6})*
OT	0.320** *(p=4 x 10^{-6})*	1	0.569** *(p=2.8 x 10^{-18})*	0.306** *(p=1.2 x 10^{-5})*	-0.099 *(p=0.165)*	-0.096 *(p=0.180)*	-0.093 *(p=0.194)*
AT	0.390** *(p=1.5 x 10^{-8})*	0.569** *(p=2.8 x 10^{-18})*	1	0.678** *(p=7.2 x 10^{-28})*	-0.102 *(p=0.153)*	0.139* *(p=0.051)*	-0.251** *(p=0.0004)*
TSV	0.500** *(p=7.2 x 10^{-14})*	0.306** *(p=1.2 x 10^{-5})*	0.678** *(p=7.2 x 10^{-28})*	1	-0.255** *(p=0.0003)*	-0.038 *(p=0.600)*	-0.540** *(p=2.7 x 10^{-16})*
AV (from N/S)	-0.325** *(p=3 x 10^{-6})*	-0.099 *(p=0.165)*	-0.102 *(p=0.153)*	-0.255** *(p=0.0003)*	1	0.829** *(p=4.9 x 10^{-51})*	0.464** *(p=6.7 x 10^{-12})*
AV (Average)	-0.261** *(p=.0002)*	-0.096 *(p=0.180)*	0.139* *(p=0.051)*	-0.038 *(p=0.600)*	0.829** *(p=4.9 x 10^{-51})*	1	0.339** *(p=1 x 10^{-6})*
Air flow sensation vote	-0.324** *(p=3 x 10^{-6})*	-0.093 *(p=0.194)*	-0.251** *(p=0.0004)*	-0.540** *(p=2.7 x 10^{-16})*	0.464** *(p=6.7 x 10^{-12})*	0.339** *(p=1 x 10^{-6})*	1

**All correlations are significant at the 0.01 level, p-value < 0.0001.

To define the acceptable distance of ventilation-inlet, the data of OT and airspeed (from north or south directions) groups were assumed as the independent variable while the distance was the dependent variable. Linear regression models were carried out to measure the relationship between them. In Figure 15, the linear regression equations (slopes: +1.79 and +4.71) revealed that distance of the ventilation inlet should be 13m and 17m (*RMG factory 1* and *RMG factory 3* respectively) from the workers to keep them within the comfortable OT threshold of 30.9°C for the SS (Table 2). Additionally, the regression equation (slopes: -13.95 and -3.28) revealed the distance should not exceed 12m and 18m (*RMG factory 1* and *RMG factory 3* respectively) to maintain the minimum airspeed (north or south) of 0.7m/s suitable for the SS (Table 4) for sewing workers' workspace.

It also can be observed that the threshold distance was relatively high (17-18m) for workspaces without ceiling fans (*RMG factory 1*), while that was relatively low (12-13m) for workspaces with ceiling fans (*RMG factory 3*). It might indicate that building can be designed for cross ventilation with wider floor plates when there are no ceiling fans ensuring thermal comfort for the workers. This ceiling height to floor-plate width ratio (maximum 1:5) can be reconsidered while designing the SS of RMG factories with a similar ventilation system. It is also explicit that cross ventilation would be needed while considering the range of

12-18m width in designing an RMG factory and the single-sided ventilation would not suffice to improve thermal comfort condition.

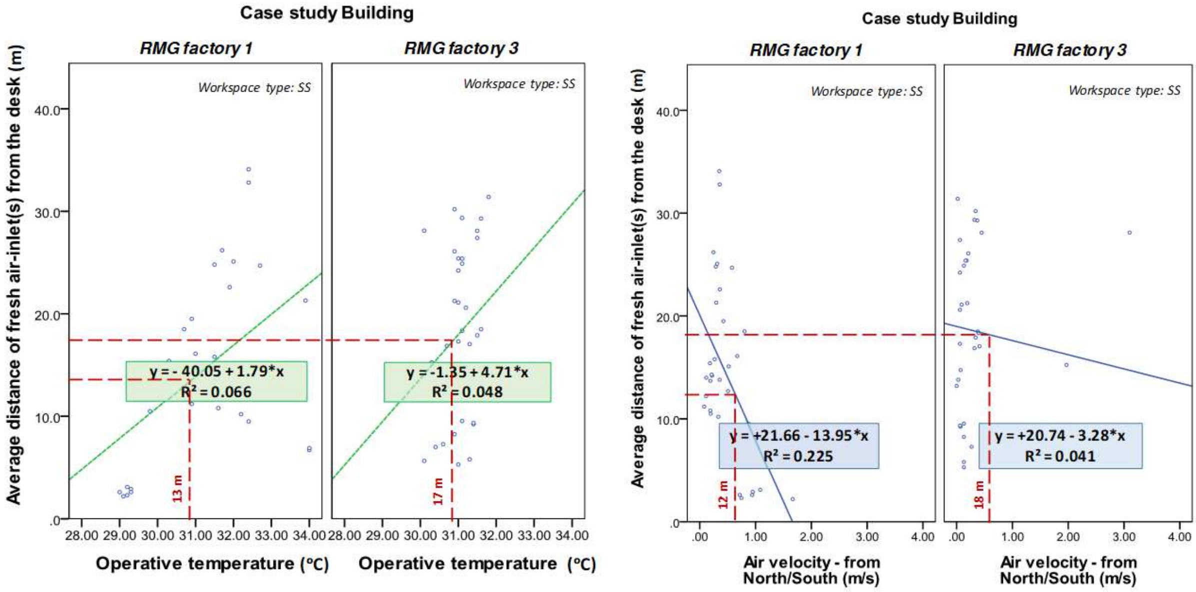


Figure 15: Scatter plot diagrams with regression lines of the distance of air-inlets against OT and AV from the north/south side

3.6. Integrated thermal comfort guidelines

Based on the studied objects within a given time, the overall findings of this section were summarised within an adaptive chart where the airspeed was assumed up to 0.6 m/s (Figure 16). While the comfort ranges with neutral OTs were shown in reference to the mean outdoor ATs from the field studies (Appendix E), the suggested airspeeds, the width of space and cross ventilation are more applicable to the warm-humid season.

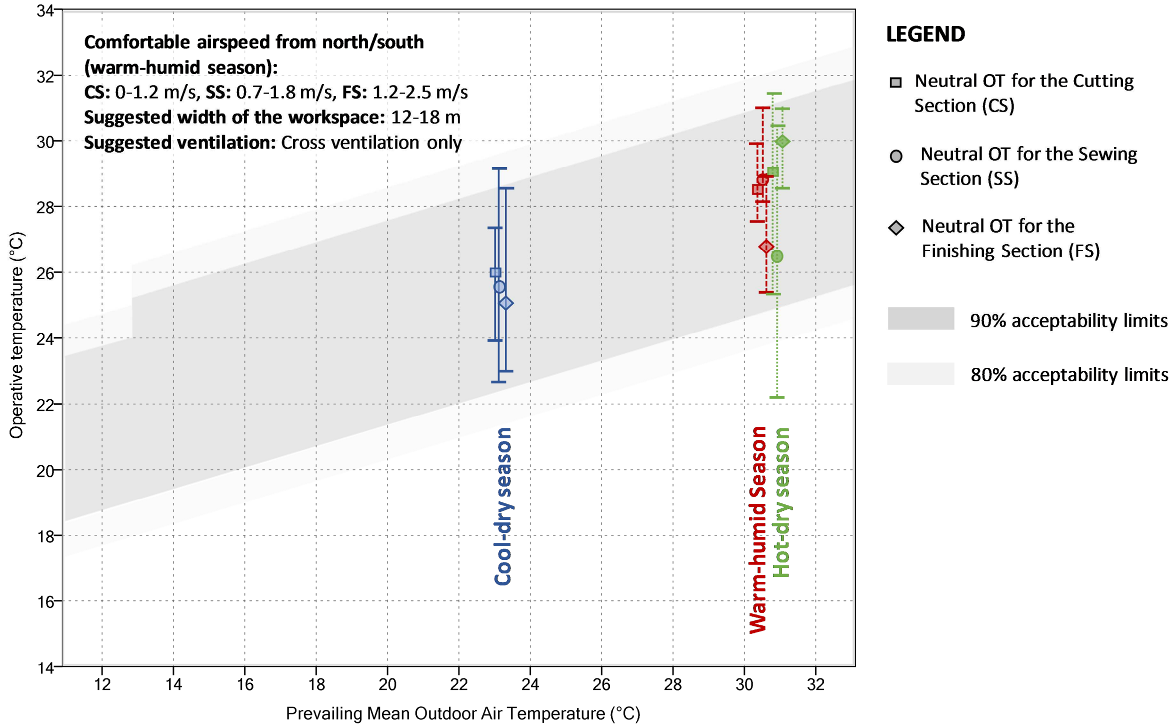


Figure 16: Proposed thermal comfort guidelines integrating with Adaptive Comfort Chart

4. Conclusion

The following conclusions can be drawn based on the field data and analyses made in this paper:

- Variations in internal heat gains and resultant indoor thermal condition, such as AT, GT and MRT, within three types of production sections indicated the considerations of different thermal comfort targets (i.e. preferred AT and airspeed) for the workers in existing multi-storied RMG factories.
- NT and thermal comfort ranges vary by the production space and season.
- The preferred neutral OT for the workers allowing adaptive behaviour in the CS, SS and FS were found between 25.2°C and 26°C during the cool-dry season, while those ranges were higher during the hot-dry and warm humid seasons (26.5°C - 30°C and 26.9°C - 28.9°C respectively) (Table 2). It was revealed that during the cool-dry and hot-dry seasons, the workers coped with wider OT ranges (e.g. 22.7°C-29.1°C and 22.3°C -30.4°C respectively in the SS) than the warm-humid season (e.g. 28.7°C -30.9°C).

- The neutral temperatures and comfort range determined by actual subjective votes were higher than that calculated by predicted mean votes during cool-dry and hot-dry seasons. However, during the warm-humid season, the actual and predicted comfort ranges were similar.
- During the warm-humid season, comfort condition in a workspace with high AT may only be improved by reducing GT which may depend on elevating airspeed.
- Workers preferred airflow from north, south and east facades. They did not prefer upward and downward airflows that increased AT, such as airflow from ceiling fans.
- Though the mean values of preferred airspeed for all production works were found between 0.3 and 0.5m/s, the airspeed ranges in the CS, SS and FS were preferred as 0.4 –1.1m/s, 1.2-2.8m/s and 2.8–5.8m/s respectively (Table 4) to execute the specific production works comfortably.
- Personalised control over the ventilation and airflow at their workstations, including control over fans and windows, can be considered as a workable improvement strategy.
- Correlation and regression analyses suggested that the maximum distance from workstations to inlets should be maintained between 12m and 18m to enhance the indoor thermal comfort within the threshold points of preferred OT and airspeed in the SS. This also recommends the width of a multi-storey RMG factory space within 12-18 m where cross ventilation would be required, and the single-sided ventilation would not suffice the comfort condition.

5. Limitations of the study

The environmental data monitoring and spot measurements were undertaken for around 10 days for each of three case study buildings during each season assuming that the data represent a whole year's performance. Therefore, the thermal comfort guidelines, based on these data, presented in this paper may not be representative for a whole year of thermal comfort and may need further study to apply them to other RMG factory buildings in Bangladesh. While accepting the existing thermal condition by the workers, their productivity level may not be at their highest levels. Hence, it may be a drawback of this study and it can be overcome by further assessment of productivity of the subjects across a range of temperatures in the future.

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Appendices

Appendix A*: Schedule of field data collection for three case study buildings for the year of 2015*

Field study no.	Main Seasons	Scheduled field visits	Case study building	Environmental data collection		Subjective Response collection
				Continuous data monitoring	Onsite spot measurement	questionnaire interviews with workers
		Dates (duration)		Dates (duration: working days*)	Dates (duration: working days*)	Dates (duration: working days*)
One	Cool-dry (Dec-Feb)	4 January - 5 February (33 days)	1	4 - 13 January (10 days)	4 - 13 January (9 days)	4 - 13 January (9 days)
			2	15- 24 January (10 days)	15- 24 January (8 days)	15- 24 January (8 days)
			3	26 January – 5 February (11 days)	26 January – 5 February (10 days)	26 January – 5 February (10 days)
Two	Hot-dry (Mar-May)	4 April - 5 May (32 days)	1	4-13 Apr (10 days)	4-13 April (9 days)	4-13 April (9 days)
			2	15-27 April (13 days)	15-27 April (11 working days)	15-27 April (11 working days
			3	23 April – 5 May (13 days)	23 April – 5 May (11 days)	23 April – 5 May (11 days)
Three	Warm-humid (Jan-Nov)	5 August – 2 September (29 days)	1	5-12 Aug (08 days)	5-12 August (7 days)	5-12 August (7 days)
			2	13-19 August (7 days)	13-19 August (6 days)	13-19 August (6 days)
			3	21 August – 1 September (12 days)	21 August – 1 September (11 days)	21 August – 1 September (11 days)

**Working days are usually from Saturday to Thursday. Working hours are 08:00-20:00 (RMG factory 1) and 08:00-19:00 (RMG factory 2 and RMG factory 3) with an hour of lunch break between 13:00-14:00.*

***Appendix B**: Name, measuring range and accuracy of the instruments used during the field studies (sources: Specifications and official data sheets)*

Model number and name of the instruments	**Number of instruments used**	**Illustration**	**Range of the instrument**	**Accuracy of the instrument**
Tinytag Ultra 2: TGU-4500 (Indoor temperature data logger)	20		-25 to +85°C / 0 to 95% RH	Better than ±0.5°C / Better than 0.3% RH
Tinytag Ultra 2: TGU 4510 (Internal and external temperature data logger with PB-5001-1M5 probe)	2		-40 to +85°C (internally mounted)/ -40 to +125°C (external probe)	Better than ±0.4°C (internally mounted)/ Better than ±0.35° when used with PB-5001
Tinytag View 2: TV-4505 (Temperature and Relative Humidity logger with display and accompanying probe)	3		-25 to +85°C / 0 to 100% RH	Better than ±0.35°C with probe/ Better than 0.3% RH (±3.0% RH at 25°C)
Kestrel® 4600 pocket heat stress tracker with compass and (KVANE – 0791 Kestrel® portable vane mount)	1+(2)		AV: 0.6 to 60 m/s, Direction: 0 to 360°, Crosswind, headwind, tailwind: 0.6 to 60 m/s, T: -45 to +125°C, GT: -10 to +55°C, 0.1 RH: 0 to 100%	AV: ±3% of reading or ±0.1m/s, Direction: ±5°, Crosswind, headwind, tailwind: ±5%, T: ±1°C, GT: ±1.4°C, WBT: ±0.8 °C, RH: ±3%
Testo 417 - Vane Anemometer With integrated 100 mm vane	1		0 to +50 °C / +0.3 to +20 m/s	±0.5 °C/ ± (0.1 m/s +1.5% of mv)
Testo 315-3 - CO/CO2 monitor	1		-10 to +60 °C/ CO: 0 to 100 ppm/ CO_2: 0 to 10.000 ppm	±0.5 °C/ CO: ±3 ppm (0 to 20 ppm), ±5 ppm (>20 ppm) CO_2: ±300 ppm (0 to 4.000 ppm), ±8% of mv (4.000 to 6.000 ppm)
Raytek minitemp MT4: Infrared Thermometer	1		T: -18 to 400°C (Distance to target up to 1.5m)	±2%, or ±2°C whichever is greater
FLIR E60bx: FLIR Thermal Imaging Camera	1		T: -20°C to +120°C	±2°C or ±2% of reading
Stanley TLM165 Distance Measurer: Laser Distance measuring instrument (for distance/area/volume calculation)	1		0.1m to 50m	± 1.5mm

***Appendix C:** Questionnaire survey, spot measurement forms and a sample document*

Thermal Comfort Study (Part 1: measured and observed data)

Building case no.		**Building Floor**		**Date**	
Survey Time	Start time:		End time:		
Location of the participant	*(number of the respondent is located in the floor plan)*				
Distance from the nearby window(s)		**Distance from the ceiling fan (if running)**		**Distance from the fan switch**	
Main Activity name	Cutting ☐	Sewing ☐	Finishing ☐	Other ☐	

Participant Information

Participant ID *[assigned by the researcher]*				
Gender	Male ☐	Female ☐	**Age**	
Height			**Weight**	
Work experience in this factory	1-6 Months ☐	7-12 months ☐	> 12 months ☐	---------- months

Environmental Data (onsite spot measurement)

Position from floor	**0.1 m**	**0.6 m**	**1.1 m**	**Position from floor**		**0.1 m**	**0.6 m**	**1.1 m**
AT (°C)				RH (%)				
GT (°C)				WBT (°C)				
CO_2 level (ppm)				Air velocity (m/s) Direction from (+/-)	South/North			
CO level (ppm)					West/East			
Other parameter (if relevant):					Down/Up			
Light level (lux) at work plane				Volumetric flow rate (m³/h) (if relevant)				
Outdoor AT (°C)				Outdoor RH (%)				

Observations

Clothing type

Short sleeve T-shirt	Full Sleeve Short T-shirt	Full pant	Cotton Fotua	Other:
Cotton Salwar Kameez	Sharee	Sandal	Shoe-socks	

Colour and material of the cloth

Cloth Material	1.	2.	3.	4.
Colour of the cloth	1.	2.	3.	4.

Activity level

Immediate last Activity before the survey	Walking	Running	Eating	Sewing	Ironing	Cutting	Other (specify)
Occupant's activity level (during the survey)	Sewing	Ironing	Cutting	Seated	Standing	Reclining	Other (specify)

Provision of control

Provision of regulating window	Yes ☐	No ☐	Ceiling fan (On/Off)	On ☐	Off ☐
Provision of regulating fan(s)	Yes ☐	No ☐	Windows with a curtain or without a curtain?	Yes ☐	No ☐
Window open (Approximate %)			Curtain open (approximate % of opening)		

Thermal Comfort Study (Part 2: workers' subjective feedback)

Questionnaire survey on thermal comfort

How are you feeling with your workspace environment at the moment?							
Thermal sensation (ASHRAE scale)	Cold -3	Cool -2	Slightly cool -1	Neutral 0	Slightly warm +1	Warm +2	Hot +3
Humidity	Very dry -3	Dry -2	Slightly dry -1	Perfect 0	Slightly humid +1	Humid +2	Very humid +3
Air flow sensation	Very low -3	low -2	Slightly low -1	Perfect 0	Slightly high +1	High +2	very high +3
Freshness of air (Bedford scale)	Absolute stale -3	Very stale -2	slightly stale -1	Neutral 0	Quite fresh +1	Very fresh +2	Absolute fresh +3

How comfortable are you feeling with your workspace environment at the moment?							
General comfort scale	Uncomfortable			Not sure*	Comfortable		
Thermal sensation	-3	-2	-1	-	+1	+2	+3
Humidity	-3	-2	-1	-	+1	+2	+3
Airflow	-3	-2	-1	-	+1	+2	+3
Freshness of air	-3	-2	-1	-	+1	+2	+3

What kind of improvement do you suggest at your workspace at the moment?							
Thermal preference: Change in the temperature (McIntyre scale)	Prefer cooler	Much cooler +2	Slightly cooler +1	Prefer no change 0	Prefer warmer Slightly warmer -1	Much warmer -2	
Change of humidity	Prefer drier	Much drier +2	Slightly drier +1	Prefer no change 0	Prefer more humid Slightly humid -1	Much humid -2	
Change of Airflow	More Ventilation	Much less air flow +2	A bit less air flow +1	No change 0	Less ventilation A bit more air flow -1	Much more air flow -2	

What do think of the overall acceptability of the existing thermal environment?							
Overall thermal acceptability assessment **	**Not Acceptable** -3	-2	-1	Not sure* -	**Acceptable** +1	+2	+3

What action do you undertake while feeling uncomfortable in terms of thermal sensation?							
Increasing the speed of the fan (or on/off)	Opening the window	Closing the window /curtain	Reducing activity	Tying up hair	Changing the dress	Changing posture	Other (specify)

** 'Not sure' is only added to these answer sheets to provide workers with having the flexibility of choice to say 'not sure' vote if they are actually not sure about experience. This will also be used crosscheck with other set in the future.*

***Though the answer is originally sought to vote either 'not acceptable' or 'acceptable', the additional divisions (i.e. '-3, -2, and -1' or +'1, +2 and +3') in each side are provided for statistical cross-tabulation purpose.*

IMPROVING VENTILATION CONDITION OF THE WORK-SPACE ENVIRONMENT WITH SPECIAL REFERENCE TO EXISTING GARMENT FACTORIES IN BANGLADESH

The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

Thermal Comfort Study (Part 1: measured and observed data)

3rd Warm-humid Season

Building case no.	03	Building Floor	8th (9)	Date	22.08.2015		
Survey Time	Start time: 08:38			End time: 08:56			
Location of the participant	*(number of the respondent is located in the floor plan)* (1)						
Distance from the nearby window(s)	7.97	Distance from the ceiling fan (if running)	28.86	Distance from the fan switch	29.02		
Main Activity name	Cutting ☑	Sewing ☐	Finishing ☐	Other ☐			

Participant Information

Participant ID *[assigned by the researcher]*	C 3001			
Gender	Male ☑	Female ☐	Age	25 years.
Height	5'-7" (67 in)	1.7 m	Weight	67 kg
Work experience in this factory	1-6 Months ☐	7-12 months ☐	> 12 months ☑	61 months

Environmental Data (onsite spot measurement)

Position from floor	0.1 m	0.6 m	1.1 m	Position from floor		0.1 m	0.6 m	1.1 m
AT (°C)	28.2	28.1	27.9	RH (%)		83.7	83.8	83.5
GT (°C)	28.8	28.8	28.8	WBT (°C)		25.8	25.8	25.6
CO_2 level (ppm)	600	610	560	Air velocity (m/s) Direction from (+/-)	(South)/North	0.62	0.48	0.56
CO level (ppm)	0	0	0		(West)/East	0.11	0.12	0.18
Other parameter (if relevant):					(Down)/Up	0	0.1	0.1
Light level (lux) at work plane	987			Volumetric flow rate (m³/h) (if relevant)		–		
Outdoor AT (°C)	28.4			Outdoor RH (%)		91.2		

Observations

Clothing type

✓Short sleeve T-shirt	Full Sleeve Short T-shirt	✓Full pant	Cotton Fotua	Other:
Cotton Salwar Kameez	Sharee	Sandal	Shoe-socks	

Colour and material of the cloth

Cloth Material	1. Cotton	2. Denim.	3.	4.
Colour of the cloth	1. Pink	2. Black	3.	4.

Activity level

Immediate last Activity before the survey	Walking	Running	Eating	Sewing	Ironing	Cutting	Other (specify)
						✓	
Occupant's activity level (during the survey)	Sewing	Ironing	Cutting	Seated	Standing	Reclining	Other (specify)
			✓				

Provision of control

Provision of regulating window	Yes ☑	No ☐	Ceiling fan (On/Off) N/A	On ☐	Off ☐
Provision of regulating fan(s)	Yes ☐	No ☑	Windows with a curtain or without a curtain?	Yes ☐	No ☑
Window open (Approximate %)	30%		Curtain open (approximate % of opening)	N/A	

IMPROVING VENTILATION CONDITION OF THE WORK-SPACE ENVIRONMENT WITH SPECIAL REFERENCE TO EXISTING GARMENT FACTORIES IN BANGLADESH

The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

Thermal Comfort Study (Part 2: workers' subjective feedback)

Questionnaire survey on thermal comfort

How are you feeling with your workspace environment at the moment?

Thermal sensation (ASHRAE scale)	Cold -3	Cool -2	Slightly cool -1	Neutral 0 ✓	Slightly warm +1	Warm +2	Hot +3
Humidity	Very dry -3	Dry -2	Slightly dry -1	Perfect 0 ✓	Slightly humid +1	Humid +2	Very humid +3
Air flow sensation	Very low -3	low -2	Slightly low -1	Perfect 0 ✓	Slightly high +1	High +2	very high +3
Freshness of air (Bedford scale)	Absolute stale -3	Very stale -2	slightly stale -1	Neutral 0	Quite fresh +1 ✓	Very fresh +2	Absolute fresh +3

How comfortable are you feeling with your workspace environment at the moment?

General comfort scale	Uncomfortable			Not sure*	Comfortable		
Thermal sensation	-3	-2	-1	-	+1 ✓	+2	+3
Humidity	-3	-2	-1	-	+1 ✓	+2	+3
Airflow	-3	-2	-1	-	+1	+2 ✓	+3
Freshness of air	-3	-2	-1	-	+1 ✓	+2	+3

What kind of improvement do you suggest at your workspace at the moment?

Thermal preference: Change in the temperature (McIntyre scale)	Prefer cooler	Much cooler +2	Slightly cooler +1	Prefer no change 0 ✓	Prefer warmer Slightly warmer -1	Much warmer -2	
Change of humidity	Prefer drier	Much drier +2	Slightly drier +1	Prefer no change 0 ✓	Prefer more humid Slightly humid -1	Much humid -2	
Change of Airflow	More Ventilation	Much less air flow +2	A bit less air flow +1	No change 0 ✓	Less ventilation A bit more air flow -1	Much more air flow -2	

What do think of the overall acceptability of the existing thermal environment?

Overall thermal acceptability assessment **	Not Acceptable -3	-2	-1	Not sure* -	Acceptable +1 ✓	+2	+3

What action do you undertake while feeling uncomfortable in terms of thermal sensation?

Increasing the speed of the fan (or on/off)	Opening the window	Closing the window /curtain	Reducing activity	Tying up hair	Changing the dress	Changing posture	Other (specify)
			✓				Drinking water

***Appendix D**: Profile of the subjects who participated in the field studies*

Case study building	Field visit no.	Season	Subject(Nos.)	Sex	Nos. (%) of subjects	Mean age (years)	Mean weight (kg)	Mean height (m)	Mean Clo value
RMG factory 1	One	Cool-dry	80	M	28 (35%)	26	59	1.7	0.67
				F	52 (65%)	25	53	1.5	0.50
	Two	Hot-dry	115	M	49 (43%)	26	60	1.7	0.60
				F	66 (57%)	25	53	1.5	0.51
	Three	Warm-humid	61	M	27 (44%)	28	69	1.7	0.53
				F	34 (56%)	26	58	1.5	0.52
	Total (three seasons)		**256**	**M**	**104 (41%)**	-	-	-	-
				F	**152 (59%)**	-	-	-	-
RMG factory 2	One	Cool-dry	150	M	26 (17%)	25	56	1.7	0.66
				F	124 (83%)	25	49	1.5	0.53
	Two	Hot-dry	100	M	15 (15%)	24	61	1.7	0.62
				F	85 (85%)	24	53	1.5	0.51
	Three	Warm-humid	66	M	17 (26%)	26	67	1.7	0.50
				F	49 (74%)	26	60	1.5	0.51
	Total (three seasons)		**316**	**M**	**58 (18%)**	-	-	-	-
				F	**258 (82%)**	-	-	-	-
RMG factory 3	One	Cool-dry	154	M	52 (34%)	26	56	1.7	0.71
				F	102 (66%)	24	49	1.5	0.50
	Two	Hot-dry	112	M	52 (46%)	28	62	1.7	0.62
				F	60 (54%)	27	54	1.5	0.55
	Three	Warm-humid	70	M	25 (36%)	27	68	1.7	0.50
				F	45 (64%)	26	56	1.5	0.50
	Total (three seasons)		**336**	**M**	**129 (38%)**	-	-	-	-
				F	**207 (62%)**	-	-	-	-
Total (three field visits and three case study buildings)			**908**	**M**	**291 (32%)**	**25.7**	**55.4**	**1.56**	**0.54**
				F	**617 (68%)**				

Here, M=Male, F=Female

Appendix E: *Descriptive statistics of the continuously recorded indoor and outdoor environmental data**

(source: field studies in the year 2015)

Season	Case study	Work section	Avg. AT_in (°C) Min - Max	Avg. AT_in (°C) Mean (SD)	Avg. AT_out (°C) Min-Max	Avg. AT_out (°C) Mean (SD)	Avg. RH_in (%) Min - Max	Avg. RH_in (%) Mean (SD)	Avg. RH_out (%) Min - Max	Avg. RH_out (%) Mean (SD)
Cool-dry	*RMG Factory 1*	CS	21.0 - 28.1	24.3 (1.3)	11.8 - 32.3	**19.3** (5.2)	41.1 - 69.1	51.7 (4.4)	26.1 - 94.6	**71.2** (19.6)
		SS	21.2 - 30.7	26.6 (1.7)			34.9 - 67.3	45.7 (4.3)		
		FS	23.5 - 28.1	25.9 (0.8)			37.7 - 67.0	51.3 (5.3)		
	RMG Factory 2	CS	22.9 - 27.7	25.0 (1.1)	12.7 - 28.7	**19.3** (3.7)	43.6 - 68.0	56.2 (4.5)	43.9 – 96.1	**73.6** (13.9)
		SS	23.1 - 31.6	26.9 (1.8)			41.3 - 69.6	52.3 (4.8)		
		FS	20.3 - 30.0	24.5 (2.0)			43.0 - 73.9	60.5 (5.2)		
	RMG Factory 3	CS	20.6 - 28.2	24.7 (1.6)	13.2 - 33.9	**21.4** (4.6)	30.5 - 59.4	46.6 (5.6)	20.2 - 86.3	**59.0** (17.6)
		SS	21.3 - 29.3	27.4 (0.9)			31.4 - 52.4	41.5 (4.4)		
		FS	20.9 - 31.5	28.0 (1.8)			25.8 - 54.4	40.6 (5.2)		
Hot-dry	*RMG Factory 1*	CS	26.2 - 33.9	30.0 (1.5)	20.9 - 37.9	**27.4** (4.3)	44.9 - 75.6	60.9 (4.9)	27.1 - 97.5	**74.2** (15.8)
		SS	26.5 - 34.3	30.2 (1.7)			40.8 - 77.5	60.5 (6.2)		
		FS	26.2 - 34.2	30.3 (1.5)			43.3 - 75.4	61.7 (5.1)		
	RMG Factory 2	CS	25.8 - 32.8	30.0 (1.5)	20.9 - 36.3	**28.8** (3.5)	46.5 - 78.7	67.2 (6.0)	38.2 - 99.9	**74.0** (13.8)
		SS	26.2 - 33.7	31.1 (1.7)			43.4 - 85.8	63.4 (5.9)		
		FS	25.6 - 34.9	31.2 (2.1)			43.3 - 81.5	62.9 (6.5)		
	RMG Factory 3	CS	25.1 - 33.8	29.7 (1.9)	20.9 - 35.9	**27.4** (3.4)	51.8 - 81.9	66.0 (5.4)	45.0 - 99.3	**76.5** (13.4)
		SS	26.7 - 32.8	29.9 (1.1)			52.5 - 81.6	66.1 (4.9)		
		FS	26.8 - 34.9	31.3 (1.5)			46.1 - 75.9	59.8 (5.2)		
Warm-humid	*RMG Factory 1*	CS	30.7 - 34.7	33.2 (0.7)	25.7 - 36.9	**30.1** (2.6)	58.7 - 79.8	68.7 (3.5)	51.8 - 100	**84.2** (12.8)
		SS	29.8 - 35.0	32.8 (0.9)			56.7 - 82.3	69.0 (4.4)		
		FS	29.7 - 34.9	32.3 (1.1)			58.6 - 87.2	71.7 (5.5)		
	RMG Factory 2	CS	27.1 - 32.0	29.5 (0.9)	25.1 - 33.2	**28.1** (2.0)	70.4 - 90.4	79.8 (4.2)	70.8 - 100	**92.8** (8.5)
		SS	28.9 - 33.3	30.9 (1.1)			67.1 - 88.1	74.5 (4.6)		
		FS	28.3 - 34.3	30.9 (1.5)			65.6 - 89.9	75.2 (6.3)		
	RMG Factory 3	CS	26.3 - 32.0	29.8 (1.3)	24.3 - 35.5	**28.4** (1.8)	65.4 - 91.9	79.4 (5.5)	63.8 - 100	**95.0** (7.8)
		SS	27.2 - 31.8	30.1 (0.8)			65.8 - 88.9	79.0 (3.7)		
		FS	27.0 - 33.5	31.0 (1.0)			60.1 - 84.4	75.9 (3.9)		

**measured from the typical production floor (SS) including the unoccupied hours (i.e. out of production hours and the hours during weekends)*

***AT and RH were the average values logged at two different levels (e.g. 1.2m and 2.5m heights from the floor level)*

***Appendix F**: Seasonal variations of the spot measured database* in three case study buildings*

Season	Case study	Value type	AT (°C)	GT (°C)	RH (%)	Air speed (m/s)	WBGT (°C)	MRT (°C)	OT (°C)**	AT_{out} (°C)	RH_{out} (%)
Cool-dry	*RMG Factory 1*	Mean (SD)	26.7 (1.9)	26.8 (1.2)	52.2 (7.0)	0.5 (0.7)	21.8 (1.4)	27.1 (1.8)	26.8 (1.3)	23.2 (2.5)	55.4 (10.7)
	RMG Factory 2		27.0 (1.4)	26.8 (1.6)	60.0 (5.6)	0.3 (0.3)	23.1 (2.2)	26.7 (2.0)	26.9 (1.6)	20.8 (3.6)	73.5 (13.0)
	RMG Factory 3		27.5 (1.4)	27.3 (1.4)	41.6 (5.4)	0.1 (0.2)	21.6 (1.2)	27.3 (1.5)	27.3 (1.4)	25.2 (4.6)	38.2 (13.6)
	All cases	Min - Max	20.2 - 30.0	20.2- 31.0	29.7 - 73.7	0.0 - 3.5	18.1-25.6	20.7 - 33.6	21.1 - 30.8	14.1 - 33.9	17.1 - 98.0
		Mean (SD)	**27.1** (1.5)	**27.0** (1.5)	**51.0** (10.1)	**0.3** (0.4)	**22.0** (1.9)	**27.0** (1.8)	**27.0** (1.5)	**23.1** (4.3)	**55.6** (20.2)
Hot-dry	*RMG Factory 1*	Mean (SD)	30.0 (1.7)	29.9 (1.7)	66.0 (6.5)	0.5 (0.2)	26.3 (1.3)	29.8 (1.9)	29.9 (1.7)	29.0 (3.9)	66.3 (14.3)
	RMG Factory 2		32.0 (1.0)	32.0 (1.0)	64.9 (5.8)	0.3 (0.3)	28.1 (1.0)	31.9 (1.1)	32.0 (1.0)	32.9 (1.8)	60.2 (6.4)
	RMG Factory 3		31.3 (1.4)	31.3 (1.4)	66.2 (5.9)	0.2 (0.2)	27.6 (1.1)	31.3 (1.5)	31.3 (1.4)	31.1 (3.9)	65.7 **(**11.2)
	All cases	Min - Max	26.4 - 34.4	26.4 - 34.4	46.4 - 82.4	0.0 - 2.5	23.2-30.2	24.8 - 34.8	26.2 - 34.3	15.3 - 36.0	35.3 - 92.5
		Mean (SD)	**31.1** (1.7)	**31.0** (1.6)	**65.7** (6.1)	**0.4** (0.3)	**27.3** (1.4)	**30.9** (1.8)	**31.0** (1.6)	**30.9** (3.7)	**64.3** (11.6)
Warm-humid	*RMG Factory 1*	Mean (SD)	32.5 (0.7)	33.9 (1.5)	72.8 (3.4)	0.4 (0.2)	30.0 (0.7)	35.6 (2.6)	33.6 (1.3)	33.6 (1.6)	69.0 (8.8)
	RMG Factory 2		30.4 (0.7)	31.6 (1.4)	79.6 (3.4)	0.3 (0.1)	28.7 (0.6)	32.7 (2.2)	31.3 (1.2)	28.6 (1.9)	91.3 (9.3)
	RMG Factory 3		30.7 (0.8)	31.4 (1.3)	78.2 (2.8)	0.2 (0.3)	28.6 (0.6)	31.8 (1.7)	31.3 (1.1)	30.3 (1.3)	85.0 (8.6)
	All cases	Min - Max	28.1 - 33.8	28.1 – 35.7	68.4 - 85.9	0.0 - 1.3	26.7-31.3	27.1 – 38.8	28.6 – 35.3	25.1 - 36.9	51.7 - 100
		Mean (SD)	**31.2** (1.2)	**32.7** (1.8)	**77.0** (4.3)	**0.3** (0.2)	**29.1** (0.9)	**33.3** (2.7)	**32.0** (1.6)	**30.8** (2.6)	**82.2 (12.8)**

**During the working hours (i.e. 8 am to 8 pm) only*

***OT was only considered for those 'workspace cases' where the workers have the flexibility to operate window and/or fans, their Met values were close to 1.0 to 1.3, from resting (1.0) to working (1.4) condition and they have the freedom to change their clothes within the Clo values of 0.5 - 1.0.*

****Unless mentioned as '_out' (e.g. AT_{out}), all the data are in the indoor environment.*

Appendix G: Variations of mean values and SDs in three different production workspaces*

	Seasons	Work section*	AT *(°C)*	GT *(°C)*	RH *(%)*	Air speed *(m/s)*	WBGT (°C)	MRT *(°C)*	OT *(°C) ***	AT_{out} *(°C) ****	RH_{out} *(%)****
Mean (SD*)	Cool-dry	CS	**26.0** (1.3)	**25.8** (1.1)	**48.9** (12.2)	**0.2** (0.2)	**20.7** (1.9)	**25.7** (1.5)	**25.8** (1.0)	**23.1** (4.3)	**55.6** (20.2)
		SS	**27.4** (1.6)	**27.3** (1.5)	**53.0** (9.5)	**0.2** (0.3)	**22.5** (2.0)	**27.3** (1.8)	**27.3** (1.5)		
		FS	**27.1** (1.3)	**26.9** (1.3)	**46.6** (9.2)	**0.4** (0.7)	**21.5** (1.1)	**26.9** (1.5)	**26.9** (1.3)		
	Hot-dry	CS	**30.0** (1.6)	**30.0** (1.6)	**66.2** (3.5)	**0.3** (0.3)	**26.4** (1.5)	**30.0** (1.8)	**30.0** (1.6)	**30.9** (3.7)	**64.3** (11.6)
		SS	**31.0** (1.6)	**31.0** (1.6)	**66.8** (6.7)	**0.4** (0.3)	**27.4** (1.2)	**30.8** (1.8)	**31.0** (1.6)		
		FS	31.8 (1.4)	**31.8** (1.3)	**62.3** (3.7)	**0.3** (0.2)	**27.7** (1.4)	**31.9** (1.3)	**31.8** (1.3)		
	Warm-humid	CS	**30.3** (1.2)	**30.0** (1.0)	**79.5** (3.9)	**0.3** (0.1)	**28.1** (0.7)	**29.7** (1.4)	**30.1** (1.0)	**30.8** (2.6)	**82.2** (12.8)
		SS	**31.3** (1.0)	**32.5** (1.4)	**76.7** (4.1)	**0.3** (0.2)	**29.2** (0.6)	**33.9** (2.1)	**32.3** (1.3)		
		FS	**31.4** (1.4)	**32.9 (1.9)**	**76.3** (4.5)	**0.3** (0.2)	**29.4** (1.1)	**34.0** (2.9)	**32.6** (1.6)		

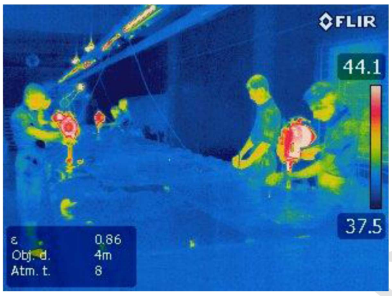
**working sections or production sections in RMG factories, i.e. CS = Cutting Section, SS=Sewing section and FS=Finishing section.*

***SD= Standard Deviation.*

****The Operative temperature at those workspaces where workers have the flexibility to operate windows and change the fans' speed etc.*

*****Unless mentioned as _out, all data are of the indoor environment.*

Appendix H: *Thermal images of workspaces in the cutting, sewing and finishing sections in RMG factory 1 (source: field studies in the year of 2015)*



Cutting section (CS)

Sewing section (SS)

Finishing section (FS)

Highlights

- Workers adapt with wider comfort range during the cool-dry and hot-dry seasons.
- Favoured air temperature and speed ranges for production activities were determined.
- Upward and downward airflow increase air temperature and thermal discomfort.
- Workers prefer airflow from the inlets located in north and south facades.
- The width of workspaces should be between 12-18m to enhance thermal comfort.