Improving Ventilation Condition of Labour-intensive Garment Factories in Bangladesh

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ABSTRACT

The ready-made garment (RMG) sector of Bangladesh is based on the productions from the garment factories where workers are engaged in textile sewing activities, ironing and operating machines. Due to the generally poor quality working environment, these factory workers suffer discomfort and a range of health problems. It is widely known that the thermal environment of workspaces has a direct impact on physical comfort and hence productivity. In the context of a tropical climate, flushing-out the unwanted heat in these deep-planned production spaces is always a major challenge. Mechanical means that annually consume significant amount of energy are usually applied to resolve the ventilation issue. Potentially, passive ventilation strategies within the garment factory buildings may not only enrich the indoor working environment but also reduce carbon emissions. However, research has not yet demonstrated that passive ventilation strategies are viable in this sector. This paper describes an approach that may passively improve ventilation conditions in the existing garment factories of Bangladesh in terms of indoor air quality, thermal comfort; and, potentially, emergency smoke removal. These studies suggest that a methodology to develop passive ventilation strategies within existing garment factories is feasible in this tropical climatic context.

INTRODUCTION

RMG sector plays an essential role in the economy of Bangladesh, accounting for more than 80% of the total export earnings (Rahman et al, 2008) and nearly 10% of GDP (IFC, 2007). The production space (cutting, sewing and finishing sections) of this sector is usually human labour intensive. The workers’ health, comfort and performance can be influenced by the quality of the production space (NAP, 2010). Hence, optimal working environment is necessary to maximise productivity (Prokaushali Sangsad Limited, 2007). Poor indoor environment has harmful impacts on workers’ health (Wilson and Corlett, 2005) resulting in a high incidence of illness (Zohir and Paul-Majumder, 2008). The most frequent incidences are headache (98%), respiratory problem (36%), vomiting (28%), fatigue (28%) and fainting (18%) (Mridula et al., 2009). These are likely to result from the humid indoor conditions and lack of ventilation of the factories. After the ‘Rana Plaza tragedy’ in April 2013, new ‘Alliance’ and ‘Accord’ between RMG factories in Bangladesh and International organisations have been formed to ensure fire and structural safety in the buildings. However, improving the indoor workspace environments for workers’ safety and comfort is also important. There is a significant amount of heat gain inside the building from the artificial luminaires, workers’ body temperature and constantly in-use equipment (e.g. sewing machines, iron machines, etc.) (Hossain, 2011; Naz, 2008). The resultant gained heat is usually trapped at indoor due to lack of air changes. The factory owners use mechanical means to keep the indoor environment comfortable consuming a significant portion of energy. Local regulatory frameworks (e.g. ‘Bangladesh National Building Code 2006’) generally guide about
window-floor areas for buildings which may not apply to the deep-planned one and need contextualisation (Ahmed, 2011). About 414 garment workers were killed in 213 factory fires between 2006 and 2009; and workers lost their lives in 2010 (Clean Clothes Campaign, 2012). During fire incidents, indoor trapped smoke is one of the main issues of fatalities (Akther et al., 2010) that correlated to ventilation efficiency.

In 2005, Ali showed that workspaces with light-wells of ‘National Assembly Building’ in Dhaka had optimum ventilation performance. Courtyards buildings also have advantages of increased incidence of natural ventilation (Ali, 2007). Increasing openings, soft surfaces and vegetation on facades were indicated as the possible solutions in Ahmed and Roy’s study of 2007, while adding ventilation shafts in residential apartment buildings is a common practice. Even in a still outside air condition, required air flow rate can be achieved by changing opening size and location (Ahmed et al., 2006). Though cross ventilation is suggested in fully humid tropical context (Bay & Ong, 2006), these deep-planned buildings have no provisions of cross-ventilation. Hence, to get a passive solution in existing buildings, main possible solutions are to alter the fabric of the building, to add shaft or atria, to optimise space utilisation and to install control systems (Lush and Meikle, 1988). However, no research has been done prescribing any passive design solution for improving the existing RMG factory buildings in the tropical climatic context of Bangladesh.

**OBJECTIVE**

The main objective of the paper is to propose a feasible design approach that may passively improve ventilation conditions in the existing multi-storied RMG factories in context of Bangladesh in terms of indoor air quality, thermal comfort and potentially emergency smoke removal.

**METHODOLOGY**

**Building selection method**

As per recent database (May 2014) of the Bangladesh Garment Manufacturers and Exporters Association (BGMEA), a total of 5708 member garment factories are located in Dhaka region: Dhaka, Savar and Gazipur (74.7%), Narayanganj (17.9%) and Chittagong (10.8%). Approximately above 80% of the factory buildings, listed under the recently developed alliance and accord, are multi-storied. Hence, considering the existing building stock scenario, it was justified to choose a multi-storied RMG building within Dhaka region to establish a tangible and replicable outcome. In reference to previous studies (Naz, 2008; Hossain, 2011 and Fatemi, 2012), the major archetype of multi-storied RMG buildings was of ‘shoe-box’ shape (either rectangular-oblong or tapered). Hence, after getting shortlisted buildings according to selection criteria, a typical shoe-box shape building within Dhaka region has been selected for the pilot study.

**Empirical data and physical viability testing method**

In the site-micro climate analysis, the local meteorological data and updated weather file of Dhaka region along with computer aided tools (i.e. ‘Autodesk weather tool, 2011’ and ‘Climate consultant 4’) have been utilised. ‘Ecotect Analysis 2011’, an established validated tool in previous academic M.Arch and PhD research, has been used for the shadow and solar radiation study only. As a part of Hossain’s research in 2011, a HOBO scientific ‘data logger’ with Dry Bulb Temperature (DBT), Relative Humidity (RH) and Air Velocity sensors (placed in the centre of the 1st floor at 2.1 m height level) was moderately used. Other Information (i.e. numbers of workers, activity types, equipment etc.) have been collected during Hossain’s previous field study in 2011. A calculation tool ‘Opti-VENT’ (developed by Brian Ford & Associates), with contextualising the input data (e.g. deploying the solar radiation data from the Ecotect analysis, design DBT target from Fatemi’s study, 2012), was accomplished to test the physical viability. ‘Bentley Tas Simulator V8i’ has been applied to validate the logged-data and evident the thermal improvement of the workspace.

**Questionnaire survey and practical viability testing method**

An online questionnaire survey was conducted to get feedback from the owners and directors of RMG (18 respondents) factories in Bangladesh. The 11 structured questions were formulated to understand their perception on natural ventilation and energy cost, refurbishments and to identify possible constraints.
PROPOSING A PASSIVE VENTILATION APPROACH

Site and Micro-climate Analysis

The impact of local climate: Plotting the local climatic data reveals that the local DBT varies between 6-37°C within different periods of the year. Hence, the local seasons can be classified into major three categories (figure 1a): warm-dry (DBT 28.08°C), warm-humid: monsoon and post-monsoon (28.08°C and 26.6°C) and cool-dry (19.9°C). During the occupied period of the factories, both outside DBT and solar radiation are relatively high (figure 2b) which can be utilised or controlled for passive ventilation.

Figure 1: a) Seasonal variation of DBT b) Daily DBT profile c) Psychometric charts showing boundary of natural ventilation (Source: Climate Consultant 4 and Autodesk weather tool 2011)

Figure 2: Location of the building, local wind regime with future development and shadow pattern analysis (source: Google map, Ecotect analysis 2011 and Autodesk weather tool 2011)

Phychrometric chart analysis: According to ASHRAE comfort range, comfort can be achieved in at least 9.3% period of the year utilising the natural wind speed (figure 1c). It can be extended by reducing RH or increasing air flow. However, in 2012, Fatemi proposed the garment workers’ higher comfort range of 28.5-33°C BDT and 56-72% RH if the air velocity is 0.8-1.5 ms-1. Hence, passive ventilation in the studied building may still deliver comfortable air temperature for the workers covering more period of the year.

Physical context and wind regime: Heavy traffic road at west side (Figure 2) is a source of polluted air and noise. Wind with higher velocity usually approaches from the south, south-east and north side towards the building site during the warm-dry and cool-dry periods. However, considering the future development, wind of reduced velocity may be able to reach to south and north building-facades where major operable openings are also located. Considering sun-path and shadow analysis (Figure 2), the north facade’s wind regime, usually shaded, can be the source of cooler air during daytime working hours (Ford, 2010). Figure 3 also illustrates that the north façade and the ground level area adjacent to a five storied building can potentially deliver cooler air. In contrast, the south façade and roof have higher solar radiations. Hence, these facades require solar control (Akbari, 2007) to avoid external heat gain (e.g. 1000-1800Wh solar radiations).

Effect of Street pattern, Vegetation and Urban Heat Island (UHI): The existing street pattern and vegetation reveals that west-side air must be avoided, while south and south-east vegetation is the source of fresh air. Since the site is 26km far from Dhaka city, local temperature can be less affected by UHI effect.
Based on the finding in the microclimate analysis and literature review on ventilation principles (table 1), it can be proposed that free running ‘natural ventilation’ can be applicable in cool dry and partially hot-dry seasons (40% of the year), while night ventilation and evaporative cooling is also partially applicable in these seasons. Other seasons may need dehumidification due to high level of RH.

**Table 1: Summary proposal from the findings of micro climate analysis**

<table>
<thead>
<tr>
<th>Climatic seasons</th>
<th>Months</th>
<th>Potential natural ventilation approaches (options)</th>
<th>Ventilation principal</th>
<th>Exploitation of fresh air and wind regime</th>
<th>Required Solar Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot-dry</td>
<td>Mar-May</td>
<td>Natural ventilation</td>
<td>Wind forces</td>
<td>Wind from the south</td>
<td>West and South façade</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Night ventilation (Thermal mass)</td>
<td>Thermal forces</td>
<td>Wind from any direction (except the west side)</td>
<td>West façade and South façades</td>
</tr>
<tr>
<td>Warm-humid:</td>
<td>Jun-Sep</td>
<td>Dehumidified cooling</td>
<td>Thermal forces</td>
<td>Wind from any direction (except the west side)</td>
<td>West and South façades</td>
</tr>
<tr>
<td>Monsoon</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Warm-humid:</td>
<td>Oct-Nov</td>
<td>Dehumidified cooling</td>
<td>Thermal forces</td>
<td>Wind from any direction (except the west side)</td>
<td>West and South façades</td>
</tr>
<tr>
<td>Post monsoon</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cool dry</td>
<td>Dec-Feb</td>
<td>Natural ventilation (with control)</td>
<td>Wind forces</td>
<td>Wind from the north (with control strategy)</td>
<td>West and South façades</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Evaporative cooling (Limited)</td>
<td>Thermal forces</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Building baseline condition and environmental aspect analysis**

Considering the work-type, workers’ number, equipment and above all the artificial lighting configuration, it reveals that 1st and 3rd floors have higher heat gain and 4th floors have high density (figure 4). Moreover, the top floor has higher conductive external gain from roof. To resolve the ventilation issue, ceiling fans and extractors are partially added. The logged-data (figure 5a) clearly reveals that even after having mechanical ventilation, the internal DBT is high during occupied period. Moreover, plotting the field measured DBT in compare to local meteorological data (figure 5b); it can be observed that the heat was trapped inside the production space with a maximum 11degC of indoor-outdoor temperature difference (ΔT).
The trapped heat also implies that there was not enough air change rate available in the workspace during the cool-dry season (namely the month of December). An empirical data of Naz (2008) showed that sewing and ironing section could have high DBT of 35°C-39°C with minimum ∆T of 3-5 degC in warm-humid season.

To sum up, the micro climate analysis and existing empirical evidence shows that thermal principles (considering ∆T and cooler air sources) may be utilised and ‘stack induced ventilation’ can be proposed as a robust solution in this pilot surveyed building.

TESTING THE PHYSICAL VIABILITY OF THE PROPOSED APPROACH

For effective stack ventilation, three concerned variables are: effective area of the inlets and outlets (A), ∆T and stack height (H), where indoor air flow rate is directly proportional to these variables. Estimated air flow rates can be compared with target design flow rates required for fresh air and comfort cooling; while required air changes are 1~2 ACH and 12~15 ACH respectively (Baker, 2013). For more flow rate, the outlet size and/or the stack height need to be higher. For calculating solar gain, roof surface absorbance, roof U-Value, roof external surface conductance are assumed as 0.65, 1.15 W/m²K and 8.5 W/m²K respectively.

FIGURE 5: a) field logged data of the 1st floor and b) comparative diagram of DBT in 1st floor (Source: Hossain 2011, previous field survey, weather tool generated data and TAS output data)

To testing by a preliminary shaft design: The outlet sizes can be determined from the ‘required air flow rates’. However, to keep it simple in preliminary design, initial ventilation shaft’s size was determined following the existing beam-column layout (Lomas, 2007). In the preliminary design step, a modular size of
9.2mx7.4m (3.78% of each floor area and 7.4mx2m each of four modules) has been selected and located centrally within the building (figure 6a) believing it may help to equally remove the warm air from all surrounding indoor area. Thus the maximum allowable area of the shaft in each floor is 9.2X7.4=68.08m² and maximum perimeter is 2X9.2+2X7.4=33.2m. The inlet sizes are determined from the existing opening (35% effective). Considering average outdoor BDT in three seasons (figure 1); three cases were preliminarily considered where assumed ΔT were 5.2, 5.6 and 13.4 degC. An initial shaft height was also assumed (figure 6a) with a stack height of maximum 25.3m in the ground floor and minimum 6m in the top floor. Figure 6b shows that the proposed shaft has met the fresh air flow targets in all seasonal cases. However, the 3rd and 4th floors have not met the cooling targets in warm-dry season so as the 4th floor in the warm-humid case. In cool-dry case, it has been gained in all floors. Increasing stack height may improve the condition.

Table 2: Estimation of structural and effective outlets size to test physical viability

<table>
<thead>
<tr>
<th>Floor</th>
<th>Structural inlet (existing window in N°S sides) m²</th>
<th>Case 1: Hot seasons while average ΔT=5 degC. (represents warm-dry and warm-humid seasons)</th>
<th>Case 2: Cool seasons while average ΔT=11 degC. (represents cool-dry season)</th>
<th>Required max. shaft outlet (outlet-height is 1.2 m) m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>4th</td>
<td>97</td>
<td>Required structural outlet for cooling m²</td>
<td>Effective outlet at shaft-top (50% structural) m²</td>
<td>Effective outlet at shaft-top (50% structural) m²</td>
</tr>
<tr>
<td></td>
<td></td>
<td>152.4*</td>
<td>76.20*</td>
<td>125.6*</td>
</tr>
<tr>
<td>3rd</td>
<td>97</td>
<td>37.7</td>
<td>18.85</td>
<td>9.8</td>
</tr>
<tr>
<td>2nd</td>
<td>97</td>
<td>17.2</td>
<td>8.60</td>
<td>5.1</td>
</tr>
<tr>
<td>1st</td>
<td>97</td>
<td>29.2</td>
<td>14.60</td>
<td>8.2</td>
</tr>
<tr>
<td>Geo+Mez</td>
<td>49</td>
<td>14.7**</td>
<td>7.35</td>
<td>4.1</td>
</tr>
</tbody>
</table>

*In 4th floor, the required effective outlet area and shaft perimeter are not feasible to achieve due to high shaft perimeter requirement.
**In Ground Mezzanine floor, the outlet would be a horizontal opening in the ceiling (figure 7). Hence, perimeter has been calculated directly from required structural area (14.7m²) assuming area 14.7m²=4mx3.68m and perimeter 15.35m=2x4m+2x3.68m. Hence, 1.2m height of outlet is not applicable here.

Figure 7: a) Proposed passive ventilation approach to improve ventilation condition b) Improvement of Thermal performance with proposed shaft (source: TAS simulation)

Testing by effective area (A) of outlet: An increased stack height has been assumed where maximum stack height is 30.3m in the ground-mezzanine level and minimum 11m in the top floor. The effective outlets of the shaft (50% of the structural openings in each floor and at the top of the shaft) were actually the free areas to drain warm and stale air. Required cooling flow during warm seasonal conditions always determines the effective free area of opening required (Lomas, 2007). Hence, at this stage, only two cases have been considered, where case 1 and case 2 represent the hotter (ΔT = 5 degC) and cooler (ΔT = 11 degC) seasons respectively. As the area for the outlet available in the perimeter, rather than the cross sectional area of the shaft, determines its effective area (Thomas, 2007); for variability the maximum effective outlets need to meet two criteria: to achieve cooling flow target in case-1 (38.14~13.39m³/s) and perimeter of the shaft

30th INTERNATIONAL PLEA CONFERENCE
16-18 December 2014, CEPT University, Ahmedabad
would not exceed 33.2m per floor. From Table 2, it can be noted that the outlet size of the 4th floor does not meet the criteria. The primary reasons behind this situation are excessive heat gain (12.9 W/m²), worker-density (5.6 m²/person) and lower stack height (11m). Apart from the top floor in case-1, the calculations clearly demonstrate that the sizes of the effective outlets are easily achievable to incorporate in the existing building with minimum shaft perimeters between 15.35m and 31.4m (as shown in table 2 and figure 7b).

**Thermal analysis with ‘TAS’ simulator:** Figure 6b reveals that ‘TAS dynamic thermal modelling’ output data has acceptable deviations (maximum 2°C) with the logged-data, which also establishes its validity. Incorporating the effective outlet shafts and achieved air change rate in the pilot studied building (figure 7a), it is revealed that this passive design approach can reduce 2~5°C and 2~7°C DBT (figure 7b) in Cases 1 and 2 (table 2) respectively in the studied first floor.

Considering all analyses, it is evident that it is physically feasible to design a central supply route as a shaft of sufficient cross-sectional area to achieve a presumed design air flow rate and reduce indoor temperature as an improvement of the indoor workspace environment within this existing studied building.

**VIABILITY OF IMPLEMENTING THE PROPOSED STRATEGY**

From the questionnaire survey, it has been found that the majority of the factories consume 1000-2000KWh (33%) and above 2000KWh (61%) of electrical energy with an annual average expenditure of US$2500-6250 (39%) and above US$6250 (56%). All the factories are using mechanical ventilation system, though they know it consumes significant amount of electricity. 50% of the stakeholders claimed that they have emergency smoke removal system. The other results (figure 8) reveal that about 72% of stakeholders are inclined to adopt a passive ventilation strategy and 78% would like to undertake refurbishments to improve ventilation condition. 72% may invest US$6250-12500 to implement the strategy subject to an assured return on investment within 5 years. Survey result deployed that the possible challenging issues of execution are construction, disruption of production, existing functional layout and reduction of floor area.

**CONCLUDING REMARKS**

Stack driven ventilation and night cooling can be utilised to improve the air flow rate in all seasons, with a free running period of about 40% of the year, in the studied building in Bangladesh and to save a significant energy cost. A common shaft can be incorporated at every floor to naturally remove the trapped hot air from the production floors. Effective outlet for cooling may always meet the target of air quality. However, improved thermal condition at the top floor is difficult to achieve in warm seasons due to conductive heat gains of roof. Relocating functional zones with less internal gains towards top floor within a building may potentially optimise ventilation performance and shaft-outlet size. Moreover, the inlets may need dehumidified cooling and bio-climatic solar control to ensure cool air inflow in warm seasons. Preliminary shaft size should be determined from the modular structural layout and strength, equipment and work-lane dimension, etc. for efficient space usage. Based on relationship between ΔT and air flow rate, during any fire hazard, the temperature of that floor automatically increases which eventually increase air volume flow speed of the stack ventilation due to the raised ΔT. Furthermore, the hot air containing smoke will naturally travel through the shaft subject to effective air back flow control. This may reduce indoor trapped smoke and workers may, therefore, get an additional time to evacuate from the fire incident floor.

RMG factory owners and directors are affirmative about adopting passive strategies and refurbishments to improve ventilation condition. Hence, methodology of implementing proposed passive strategy may be practically viable subject to it is within owners’ budget and payback plan (i.e. cost-benefit analysis) through energy saving and increased productivity with minimum disruption during execution of the refurbishment. An extended field investigation can be developed to observe workers’ adaptive comfort strategy. Emerging passive design cases and associate cost estimations can be part of the extended research with some
extended questionnaire survey and interviews. This paper has attempted to demonstrate a feasible passive design approach to improve the ventilation condition in existing RMG factories. The authors look forward to pursuing further extended research with more field evidences, sophisticated analyses and larger samples.

ACKNOWLEDGEMENTS

The authors acknowledge the Commonwealth Scholarship Commission, UK and the University of Nottingham for their continued support.

REFERENCE