586: Energy Efficient garment factories in Bangladesh

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Abstract

Garment factories in Bangladesh have been heavily criticised over the last 30 years for the working conditions in which employees must labour. High internal gains from artificial lighting and equipment produce an intolerably hot work environment, which exacerbates the already uncomfortable climatic. This paper identifies the causes of this poor thermal environment through a detailed analysis of a garment factory in Dhaka. Two key spaces are selected: the ironing space and the sewing space. Through the evaluation of the building fabric, and the reduction of the artificial lighting demand, thermal comfort conditions within these spaces is improved relative to a defined comfort zone of the workers. The research identifies strategies that can be adopted as a basic design guidelines in the vital work spaces in a garment factory in order to attain a comfortable working environment.

Keywords: energy, thermal comfort, garment factory, hot and humid climate.

1. Introduction:

The context of the research and project is situated in Dhaka, the capital of Bangladesh. The apparel industry is the economic lifeline of the country, employing 10% of the total population. Bangladesh is the twelve largest apparel exporter in the world (fifth largest in EU), with a turnover of US$9.52 billion annually. This industry is not a textile oriented business, but more focused towards a mass tailoring industry, to support the clothing market of the western investors. Currently there are 8000 factories in the country and the British Bangladesh Chamber of Commerce (BBCC) has reported that 1000 more will be built by the end of 2008. This equates to 38 new factories each month.

Most of these factories are criticized for their over heated working conditions, causing a health hazard for the workers. The high density of people, equipment and artificial lighting are the reason for high internal temperatures. Extensive work hours (10-12 hours/day) become most intensive during summer, when production increases to meet the Christmas holiday deadline. The two main workspaces, sewing and ironing, are the most critical. Extensive usage of artificial lighting in sewing spaces and steam irons in the ironing space is the major cause of high internal temperatures.

The cooling solutions for such factories usually comprise ceiling and exhaust fans. The potential for natural ventilation is minimal with deep floor plans with low ceiling heights. The resulting lack of heat dissipation leads to an oven-like working environment, and is fast becoming a prime health and safety concern for the industry.

2. Design Research Hypothesis:

Fig 1: Left: a typical Vertical factory in Dhaka. Right: Interior of a sewing space in a Factory.

This paper focuses on how thermal comfort may be achieved within the two critical factory spaces: the sewing and ironing spaces. In the sewing space, the goal is to reduce artificial lighting demand through optimized window openings, designed to enhance natural day lighting in the spaces, whilst also reducing the solar gains. In the ironing space high internal temperature is mainly due to steam irons. Since these high internal gains cannot be reduced; building fabric modulation and convective cooling is investigated as means to achieving thermal comfort.

2.1.Structure of the Research and Paper:

This research focuses on two goals:

(1) Demand reduction through optimized day lighting design in work spaces.

(2) Attaining thermal comfort – through ventilation and building fabric modulation.

The paper is structured in two segments: Firstly, to identify comfort criteria, through field investigation,and reconnaissance survey. Secondly, to apply this information, to design a context-specific garment factory, with a particular focus on the sewing and ironing spaces.

3. Context:

3.1 Climate: Dhaka (20º34 N´ 92º41 E´) is 48 meters above sea level, has a hot and humid climate, with an average mean annual temperature of 26.5°C. The maximum summer temperature is 37°C and minimum winter temperature is 6°C, with a diurnal swing between 10°C–14°C throughout the year. Ground temperature can be assumed to be around 26.5°C (average annual outdoor air temperature), at depths over 10 meters below grade, which is not low enough to provide a powerful heat sink for cooling. Due to geographic location relative humidity ranges, between 50-90% throughout the year. During the summer (June – September) cloud cover averages above 40%. The sky illuminance in an overcast sky in Dhaka is 11,000 lux.

3.2 Climate Modification (UHI): Dhaka is a congested city with a population density of 1000 people and 100 garment factories, per sq. kilometre (approx). Most of the factories are located in the industrial area situated in the city, due to close proximity to airports. There is significant urban warming within these areas as a result of high congestion of people, traffic, heat gains from air conditioning equipment and a lack of greenery. High levels of solar radiation are absorbed by the buildings and road surfaces, and contribute to the microclimatic warming. The garment factories are therefore situated in a difficult climate, which is exacerbated by the heat gains from the factories themselves.

3.3 Internal Climatic Condition: Reconnaissance Survey: In the early days, most garment factories developed in tin sheds, garages or converted verandas. With space and building cost as limiting factors, and density as a key concern, the architectural language of this typology became ‘adaptive’ rather than ‘definitive’. For the last 30 years a vertical factory building typology emerged, signifying the concept of multi-storey, open plan floor plates. These vertical factories consisted of 5-10 floors with a maximum building height of 20m–26m.

A base case factory situated within the city, was selected for further study. From the reconnaissance survey the following was identified :

1. Sewing requires a level of lighting between 800- 1200 lux, for 10-12 hours a day, which is met by artificial means. Within these spaces, 70% of the internal gains may be attributed to artificial lighting. The ironing space requires less light 100-300lux, and therefore less artificial lighting, however the use of steam irons results in internal temperatures as high as 39ºC, resulting in a significant cooling demand.
2. In the chosen garment factory, the ironing space and the sewing space are adjacent, resulting in heat transfer between these two spaces. Most buildings are made with sand lime brick which is not ideal in terms of dissipating heat.
3. The artificial lighting and lack of natural ventilation is due to the deep floor plan, and small windows which are not correctly orientated. Most windows are not shaded and in many cases are shut to prevent drafts.
4. Insufficient ventilation: Most factories have ceiling fans for interior circulation. Fan and exhaust fans are usually used for a 1-2ach per hour per person, but in many cases are randomly placed. As a result they are turned off to avoid creating strong breezes in the wrong direction, which may disrupt the work.

3.4 Field Investigation: The field investigation was performed in the urban factory. The goals were as follows :

1) To identify the internal thermal condition of an existing garment factory through data logging.
2) To perform a comfort survey, among the factory workers, in order to identify the human comfort adaptability for such a working environment.

3.4.1. Methodology:
Tiny Tag Temperature loggers were installed in both the sewing and ironing spaces. The temperature was logged during the week of August 7th to 27th 2007, when the average outdoor temperature was between 25 - 30ºC, RH between 70% - 80% with over 20% clear sky throughout the month. A structured questionnaire in the local language was issued for data collection. Spot measurements with hand held temperature loggers and anemometers were also taken. A random group of 40 workers was also chosen for an in-depth face to face interview. Their clo value were between 0.5 – 0.75, and the group was aged between 20- 35 years.

3.4.2. Existing Thermal Condition-Logged Results:
During the recorded occupied hours, the average mean temperature for the internal spaces ranged between 26°C to 34°C. At this time, the average external temperature was 30°C.

The ironing space showed the highest internal temperature, ranging between 27°C to 39°C, with a mean average daily swing between 3-5K.The rise of temperature in the work space was closely related to the external temperatures, with a time lag of 1-2 hours and reflected the effect of natural ventilation during some days.

The internal temperature increased every morning due to the presence of a natural gas boiler which is used for the steam irons but not

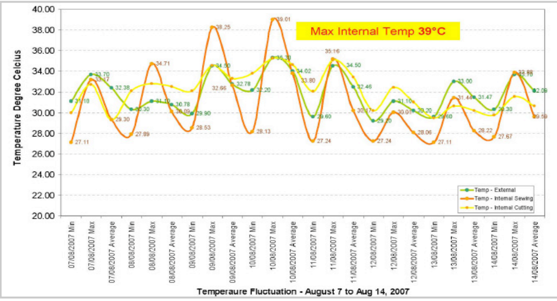


Fig 2:Logged Interior logged temperature of Sewing and Ironing Space of the Base Case

for any heating. This natural gas powered boiler is located between two sewing spaces in a closed room. During lunchtime between 12pm and 1pm, all the artificial lights were turned off, leading to an internal ambient temperature drop between 2-4°C.

3.4.3 Discussion: Comfort votes vs logged temperature:

When the logged internal temperatures were between 28º and 34º C, with a wind speed above 0.50 m/sec, 55% of the surveyed people said they were in acceptable conditions. As the wind speed decreased their acceptability of higher

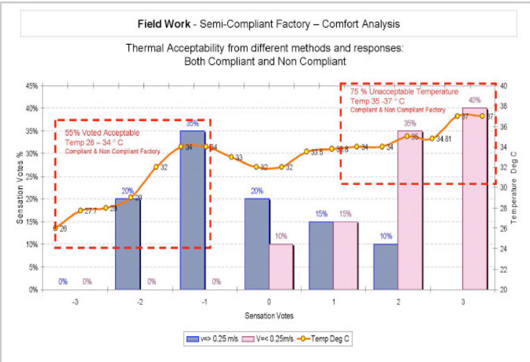


Fig 3: Comparative Analysis of logged temperatures with the comfort votes.

temperatures decreased as well. When the temperatures reached between 35º – 37ºC, and the wind velocity was less than 0.50 m/sec, 75% people reported unacceptable conditions. This data corresponded with research by Giovani (1980), Shabbir (1995), where it is stated that in hot climates people are more adaptable to higher temperatures. So it can be deduced that the workers had an acceptability of higher temperatures and increased wind speed made a difference in their comfort perception. They also used different adaptive measures to habituate themselves to their work environment including opening windows, sitting under fans, drinking water / potassium based snacks and listening to music. Based on the data collected a design research hypothesis was formed to propose a design solution for the garment factory.

3.4.4. Thermal Comfort:

Calculation of PMV and PPD values suggests that comfort conditions (as identified by ISO 7730 and the ASHRAE standard 55 -92) can be achieved when the air and mean radiant temperature is, within the range of 19º - 30º C, when the other variables are suitably adjusted to reflect common human adaptive behaviour (Yannas 2007). Similarly calculating monthly neutral temperature for Dhaka, using Auliciems' empirical equation (Tn=17.6+0.31*) for the factory occupied hours, (8-18 hrs) shows that the comfort temperature ranges between 20º to 30º C. (Auliciems and Szokolay 1997).This reflects that the comfort zones can be extended by +/- 2K, which gives an adaptive comfort range between 20-30° C over the annual cycle. There is no fundamental difference observed between the results obtained using the Auliciems' empirical equation or the PMV/PPD calculation.

3.4.5. Environmental Performance Criteria: Thermal Requirement:

The hypothetical design temperature based on Auliciems' empirical theory was identified, adaptive comfort range was hypothesized as being between 24°C and 30°C for summer and between 11°C and 20°C for winter. However, the field work comfort survey indicated that the comfort temperatures for summer can be redefined and extended to 34º C.

Areas with a reduced amount of occupied time and density, like circulation spaces, storage and packaging, can have a higher or lower temperatures. Sewing and ironing spaces should maintain a comfort temperature, between 20º to 32º C, with upper limits of 34º C if needed.

4. Design Proposal:

After identifying the comfort criteria for the work spaces, the next part of this paper focuses on how to apply the information to design a context specific garment factory.

4.1. Site: The location of the site is a hypothetical urban site, situated in Dhaka city, close to the airport, in a future industrial site designated by the government. The height limitation is 21 meters, with an H/W ratio of 2. Total building foot print, will be 600m², comprising in total a 3000 m² floor space, within 5 floors. The focus of the design is to maximise floor space whilst at the same time maximise the opportunities for passive design strategies appropriate to that climate. Building massing studies were performed to identify the optimal shape for daylighting, minimisation of solar radiation and self shading overshadowing of a 21 meter building block.

4.2. Spatial Requirement: The spatial requirements of a factory are primarily activity based and secondarily time sensitive. The thermal conditions will vary according to the function of a space, the density of people and the occupancy hours. In a garment factory, the required activity spaces are: sewing, ironing, packaging, storage, administration and cafeteria, day care and medical room. The work flow of a factory is usually from the top to the bottom floors. Fabric is stored at the top and then the raw goods work their way through the different stages and different floors, emerging from the ground floor where packaging area is situated, ready to be shipped out. These spatial requirements are based on the document 'Improving Working Conditions and Productivity in garment Industry – An Action Manual' by Juan Carlos Hiba, certified by ILO as a guide for setting up the basic layout for most garment factories.

Table1: Spatial Organization of a Vertical factory.

Area name	Space Ratio	Met Rate	Existing Temp	Suggested Design Temp	Hours/ Day Occupied
Sewing (s)	S = X	1-1.5	26-35 ° C	20-32 ° C	12
Ironing	S: I= X: 2X	2- 2.5	26-40 ° C	20-32 ° C	12

4.3. Building Design Strategies: In embarking on a design solution, following passive strategies were identified as key design considerations:

Architectural:

- The floor plates and height of a vertical factory can be varied depending on the lighting levels required, occupancy and activity requirements. Based on the internal heat gain, space layout can be adjusted. Massing studies informed the ideal position for windows, to minimise solar gain but maximise day lighting.

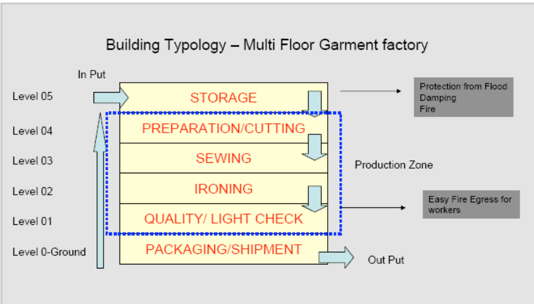


Fig 4: Workflow of a Vertical factory.

- A vertical factory workflow from top floor to bottom floor is as follows: Storage, (level 5), preparation/cutting (level-4), sewing (level-3), ironing (level 2), quality check (level1), shipping and packaging(level-0).
- Sewing / ironing spaces separated.
- Linear floor plates (10m) with windows, depending on the lighting level required.
- Roof (level 5) is a double roof, at elevation 19m from ground with storage between the double roof, protected from rain by a permeable façade.
- Sewing spaces are arranged in an L shaped linear block, situated at elevation 12m and elevation 9.5m from ground level, with a split floor plan and internal opening to induce air flow.
- Roof garden is situated at elevation 9m, separating the sewing space from the ironing, creating a social space.
- Ironing space is situated at 2.5m elevation level, overshadowed by other building and with indirect window openings to avoid direct sun.

Table2: Shading Analysis of the Openings.

Building height (m)	Season	South	North	Annual Average Shading %
0-5m	All Season	All orientation		78.9
5-15m	Summer (Mar-Aug)	30-46.5%		
	Winter	67-75%		
15-21m	Summer	10-30%	30-45%	

Solar Control:

- Solar shading is needed and reduction of solar gains on interior spaces, to reduce overheating.
- Permeable openings that provide security and privacy as well as adequate day lighting is the key design goal.

Comfort Cooling:

- Thermal Mass for the structure to keep the structure cooler.
- Controlled natural Ventilation with high and low level windows. Ceiling fan to maintain a constant air flow and extractor fan to exhaust hot air during stagnant conditions.
- Glazing can be sized and placed based on the activity and the hours of operation of different factory spaces. It is not essential for all the windows to have glazing. If glazing is to be used Low E or Solar Glass equivalent can be utilized.
- *Radiative Cooling* has potential along with night cooling.
- *Evaporative Cooling* has limited potential due to high humidity and in many cases the humidity reduces the needle longevity.
- *Adaptive measures for thermal comfort* can give the users a control over their environment.

4.4 Day lighting Study- Sewing:

The day lighting study was performed with Ecotect V 5.1. The illumination level in Dhaka, with a CIE overcast sky is 11,000 lux. Frequency of occurrence of diffuse illumination shows over 4500 hours, more than 1500lux, during the occupied hours (8-18hrs). The illuminance value used for the study is 11,500 lux, which corresponds to 75% of the working hours (8-18hrs).Sewing space has a lighting requirement between 800-1200lux and ironing between 100-300lux. From the day lighting study following conclusion was reached:

- Sewing space orientated north south requires a W/F ratio of 14%, for East west orientation 12.6% and ironing space needs 5.5% to meet the daylight requirements.
- Floor depth 10 m, height can vary between 3.5 to 5 meters.
- The double roof provides shading 78% of the year to most of the windows. Table 2 shows the shading data from the windows.
- North south facing sewing block requires high and low level horizontal windows with an overhang of 1.5 meter deep. In comparison with ribbon window, tall vertical windows provide

better light penetration as part of their opening is located higher up and the variation from front to back of the room is much less compared to a ribbed horizontal windows (Baker,Steemers 2002). East-west blocks works better with vertical openings.

- The day lighting results are reported in the following Table 3. From the study it was seen that the lighting levels in the sewing space had an average DF 5, and 52% of the work hours throughout the year the lights switches can be turned off.In the same way in the ironing space, the average DF was 2.2, and 55% of the work hours the switches can be turned off. This 50% reduction of artificial lighting usage will minimize the internal heat gain of the work spaces.

Table3: Results of the different options

Activity Space	DF Avg	>850 lux	> 1200lux	Artificial Lights off
Sewing Space	4	2250 hrs	1600hrs	52% of the working hours
		>100 lux	>300 lux	
Ironing Space	2.2	2000hrs	4000hrs	55% of the working

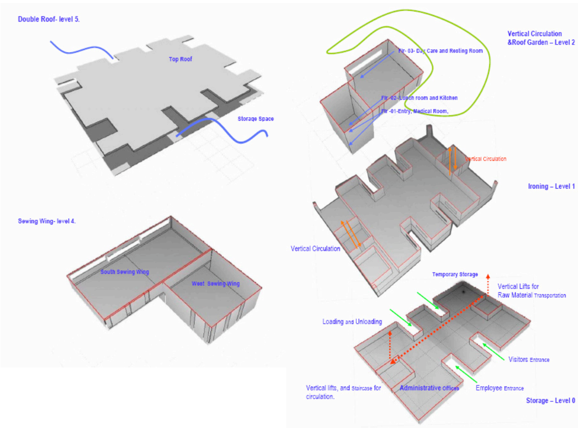
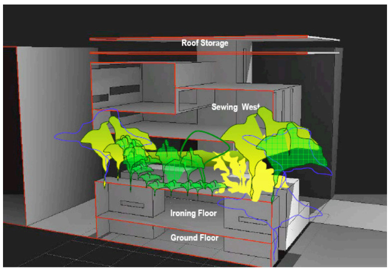


Fig 5. Proposed Vertical factory design.



Thermal Analysis:

Building surfaces especially the roof, wall and floor are critical in terms of minimising heat flow from outside. The three main factors that affect the heat transfer through the building surfaces are thermal transmittance, thermal resistance and thermal time constant. A parametric analysis was undertaken in order to identify the most suitable material and construction method capable of stabilizing the internal resultant temperature within the defined comfort range, without adding additional cost or high technology. Traditionally a material with low U value is used, providing high thermal resistance and providing constant temperature during the day time. For this building typology higher internal temperatures are problematic, and heat dissipation through the material is therefore critical. As a result, a material with a higher U value and heat transmissivity is desired.

Ventilation: Bangladesh factory Law 1965 suggests a ventilation of 10m³/person and the ILO factory regulations suggests 8-12 l/sec/person. According the BSI, standards the minimum ventilation required for factories is 0.75 ach, which does not specify the type of factory. In a garment factory there is people, equipment and light which constitutes majority of the high internal gain. Keeping the ventilation rate as a constant parameter 0.75 ach, construction material and methods were targeted as a way to achieve comfort temperature.

4.5 Parameter Setting- Material and Construction variants:

Three materials were chosen for the study:
1) Sandlime Brick (traditional construction material), 2) Concrete Plaster (most conventional material) and 3) Hollow core concrete slabs. These three construction materials were formed in six different construction methods by varying the position of the materials in three surfaces: the roof, wall and the floor. The impact of changing the construction materials in different surface were observed and the resultant temperature of all the six combinations were compared, to identify which construction combination would keep the internal temperatures within the comfort range 20 - 32° C (Ach: 0.75, Spatial Density: 8m²/ person)

Table 4: Six materials variants.

MATERIAL CONFIGURATION	SURFACE	MATERIAL	U= VALUE
Option 01	ROOF	SAND LIME BRICK	1.072
	WALL	SAND LIME BRICK	1.072
	FLOOR	SAND LIME BRICK	1.072
Option 02	ROOF	SAND LIME BRICK	1.072
	WALL	CONCRETE PLASTER	2.038
	FLOOR	THERMADECK HOLLOW CORE	1.036
Option 03	WALL	THERMADECK HOLLOW CORE	1.036
	ROOF	THERMADECK HOLLOW CORE	1.036
	FLOOR	THERMADECK HOLLOW CORE	1.036
Option 04	ROOF	SAND LIME BRICK	1.072
	WALL	CONCRETE PLASTER	2.038
	FLOOR	SAND LIME BRICK	1.072
Option 05	ROOF	DOUBLE ROOF – CONCRETE PLASTER	1.072
	WALL	*THERMADECK HOLLOW CORE*	1.036
	FLOOR	*THERMADECK HOLLOW CORE*	1.036
Option 06	ROOF	*DOUBLE ROOF – CONCRETE PLASTER*	1.072
	WALL	*THERMADECK HOLLOW CORE*	1.036
	FLOOR	THERMADECK HOLLOW CORE	1.036

4.6 Result : Sewing Space & Ironing Space:

The result indicates the following:

The lowest internal resultant temperature is observed between 29 ºC to 30 ºC for both Option 4 and Option 6, where hollow core is placed on all three surfaces and two surfaces (with a double roof) respectively. Likewise in the ironing space resultant temperatures within 29 ºC to 31ºC, a 6ºC lower than the conventional construction option 01 and 4ºC lower than the external temperature. - sandlime brick on three surfaces (the conventional construction method), has the highest internal resultant temperature, ranging between 30 ºC to 34 ºC, is 4ºC higher than external.

Table5: Results of Six variants.

Variants	Sewing (Summer comfort temp)	Ironing (Summer comfort temp)	Notes:
Option 1	30 ºC to 34 ºC	29 ºC to 36 ºC	conventional material
Option 4	29 ºC to 30 ºC	29 ºC to 31ºC	Hollow core on 3 surfaces
Option 6	29 ºC to 30 ºC	30 ºC to 32 ºC	Hollow core on 2 surfaces
Option 2	30 ºC to 33 ºC	31 ºC to 32.5 ºC	conventional material
Option 3	30 ºC to 32 ºC	31 ºC to 32 ºC	conventional material

4.7 Comparative Analysis:

In the sewing space, the hollow core slabs maintains a stable temperature between 25º-30ºC for more than 3000 hours, and performs 10% better than sand lime brick. Lime brick was also found to achieve temperatures between 32º-34ºC for 1400 hours, compared to hollow core which achieved 240 hours, (83% better than the conventional material). This proves that hollow core plays a significant role in maintaining a lower temperature in comparison with the traditional construction material in such high internal gain spaces.

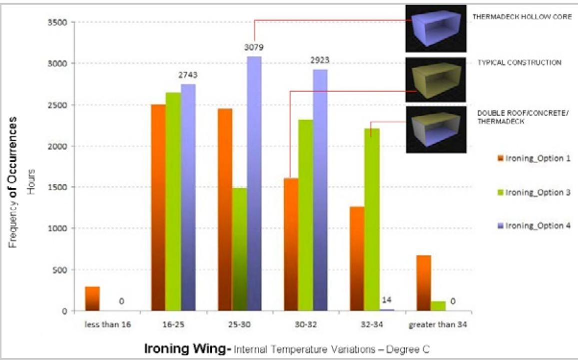


Fig 6: Frequency of occurrences of the internal temperatures of the material variants.

The same pattern is observed in the ironing space, where the temperature is between 25º-30ºC, the hollow core construction has a frequency of occurrence of 3079 hours, which is 24% better compared to sand lime brick. In the upper limit with temperatures above 30ºC, hollow core performs 20% less hours of occurrences than sand lime brick. Above 34ºC the hollow core has 0 hours of frequency of occurrences. For both sewing and ironing space, hollow core works efficiently bring the temperature within the comfort zone.

5. Conclusion:

The focus of this dissertation was to reduce demand in sewing spaces and secondly to attain comfort temperatures through passive means. The analysis proves that natural daylight can be utilized by using optimized window design in high lighting demand spaces like sewing. 50% of the working hours the artificial lights can be turned off, which will reduce the lighting demand, thus the internal gains within the space. Introducing high and low level windows will increase cross ventilation. Conventional construction materials like sand lime brick or concrete on all the surfaces or even with a double ventilated floor, does not really contribute to lower internal temperature for either the sewing or ironing spaces. The ironing spaces in particular, with considerable internal heat gains benefit from careful selection of the fabric construction, with hollow deck proving especially effective. Overshadowing will occur and is desirable; with a concrete double roof the internal temperature within the ironing space can be lowered close to the comfort range (and still 4ºC lower than the conventional construction types. Finally having a linear floor plan with higher ceiling height, shaded windows, separation between high internal gain spaces, in addition to the creation of voids between the vertical floor plates, thermal comfort may be significantly improved.

Additional experimentation of the thermal and day lighting should be carried out in-depth which can form a guideline for industrial building typology in the context of Dhaka.

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2. Giles Bruce 3. Dr. M.A. Alam

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