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Windows for Evaluating the Impact on Human Comfort in Academic Studios in Bangladesh

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ABSTRACT

Despite the fact that windows have a vast scale sway on thermal environment bearing in mind window dimensions and alignments, more often than not, for naturally ventilated architectural design studios in Dhaka it ends up being troublesome to give the agreeable warm condition for educating and learning within the studios due to high temperature amid summer term. As a result, electrical means are required to make non-natural condition that puts mammoth weight on the complete national energy need. This examination intends to discover a compelling window classification from accessible window setups in existing architecture studios, situated in various open and private colleges in Dhaka through simulation readings for enhancing the thermal conditions, which can be seen as agreeable by a large portion of the inhabitants, as indicated by PMV-PPD. Field examination was done to distinguish the current windows, which are utilized in architecture studios with regards to Dhaka. At that point, the case design studio was chosen and simulation instrument EnergyPlus™ was utilized for estimating the execution of the accessible window arrangements as for thermal conditions. For the simulation study at the last stage, the test points and core test points of virtual 3D-case studio were established. In light of the investigation, for architecture design studios in Dhaka, 'segregated viewing windows' classification was deemed as best among the chosen window classes.

1. Introduction

Design studios in Architecture schools are generally used as workspace for the students to perform project related activities and often present the outcomes in front of course teachers, jurors and invited experts. Therefore, everyone in the studio rightfully expects to have a thermally comfortable environment for the avoidance of tiresome and exhausting conditions after a certain time period, which may create harm to individuals' body and mind (Trisha, 2015). During summer, direct solar radiation through windows can cause overheating in the room, resulting in thermal discomfort with increased cooling loads in the climatic context of Bangladesh (Shikder, 2010). Designed windows would successfully be used, to address this issue of balancing luminous and thermal comfort in architecture design studios.

This research focuses the potential of different window configurations in keeping occupants' satisfaction towards thermal comfort in architecture design studios. A passive trend of window category from available window configurations, that is only suitable for specific climatic regions, i.e. in tropical countries, such as Bangladesh, can be a significant building design element to satisfy human thermal comfort in architecture design studios. Strategies for ensuring a combination of thermal conditions in architecture design studios should be established in designing process. To achieve this aim, following objectives have been developed.

- To predict PMV-PPD for different available window configurations in the climatic context of Bangladesh in architecture design studios.
- To find out the best possible window category from the window configurations for ensuring human comfort during design studio works.

2. Human Comfort Factors

During warm periods in Dhaka, the 'neutral temperature' in design studio is 30.20ºc and acceptable temperature range is 29.89ºc to 30.54ºc. The range of relative humidity levels is 65% to 68% and 'neutral' relative humidity is 66.5% (Tariq, 2014). Summer cloth having a clo value of 0.35-0.5 is common in tropical environments (Auliciems, 2007). PPD of less than 20% is acceptable for proper thermal environment (Ahmed, 2012).

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3. Methodology

Universities were selected from the University Grants Commission (UGC), Bangladesh registered list for physical survey based on specific criteria. Thermal conditions, window details, material, window bottom and top level, shading devices, work plane height, aisle width, exterior-interior photographs, detail observations and related information were collected for these universities. From universities, the most suitable one was selected as 'case studio', for simulation analysis.Through field surveys in the universities, available window configurations under different categories were selected for thermal simulation by the Sketchup_OpenStudio-EnergyPlus™ software under the climatic context of Bangladesh.

3.1 *Case room selection*

The criteria for selection of the case studio was based on the following factors (Sharmin, 2011).

- Location of the university would be in the urban context of Dhaka.
- The case studio must be located on designed and planned campus.
- Year of completion of the building should be within last 10 years (2007-2017).
- The room should be designated and designed for minimum of 30 students.
- The activity pattern and internal layout of the studio should represent the current practice of architecture design studios of Bangladesh.

In Bangladesh, there are 22 universities with an architecture department and among these universities, 14 are located in Dhaka (Aman & Joarder, 2017). Considering the mentioned criteria, the design studio located at the Department of Architecture in Ahsanullah University of Science and Technology (AUST) was chosen as the case room. AUST premise is an example of contemporary Architecture, which was built in 2008. The University is a 10 storied building, located in the Tejgaon industrial area, Dhaka in a compact urban setting, having a front road of 8m in width and main entry from the west (figure 1).

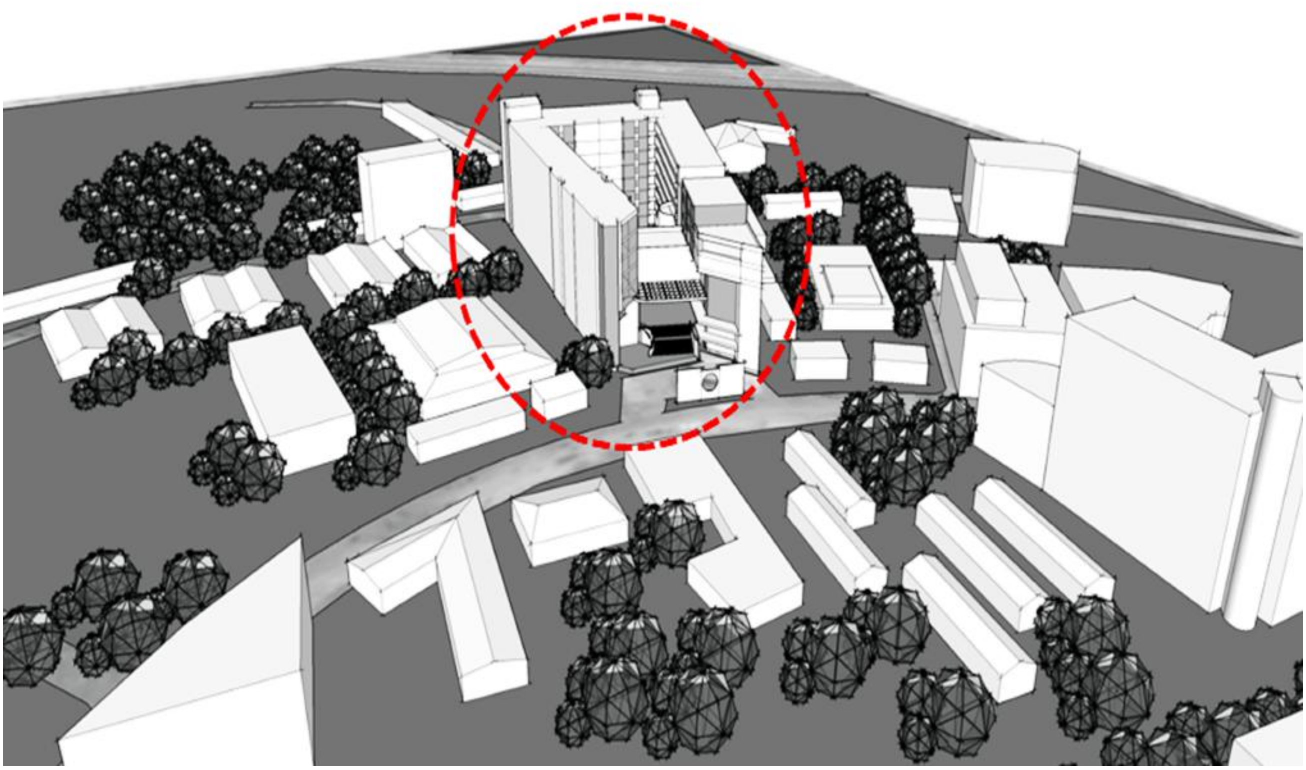


Figure 1. Surrounding Context of AUST campus in Tejgaon, Dhaka (*Source:* Begum, 2016)

Case studio is located on the second floor, designated for 1st year 1st semester (Figure 2). It is a rectangular room with the following characteristics (Table1). Figure 3 & Figure 4 present the plan and interior views of the case studio.

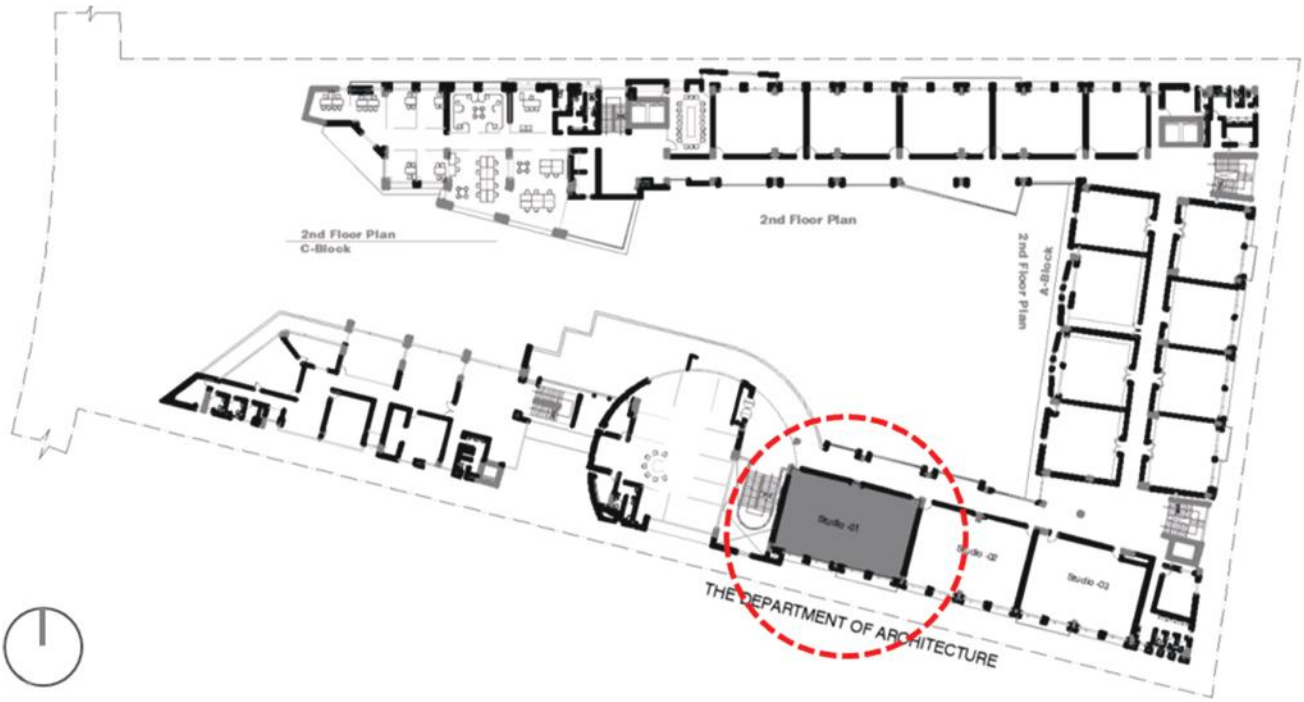


Figure 2. Design studio location at AUST (*Source:* AUST Authority, drawn by Riddhi Architects).

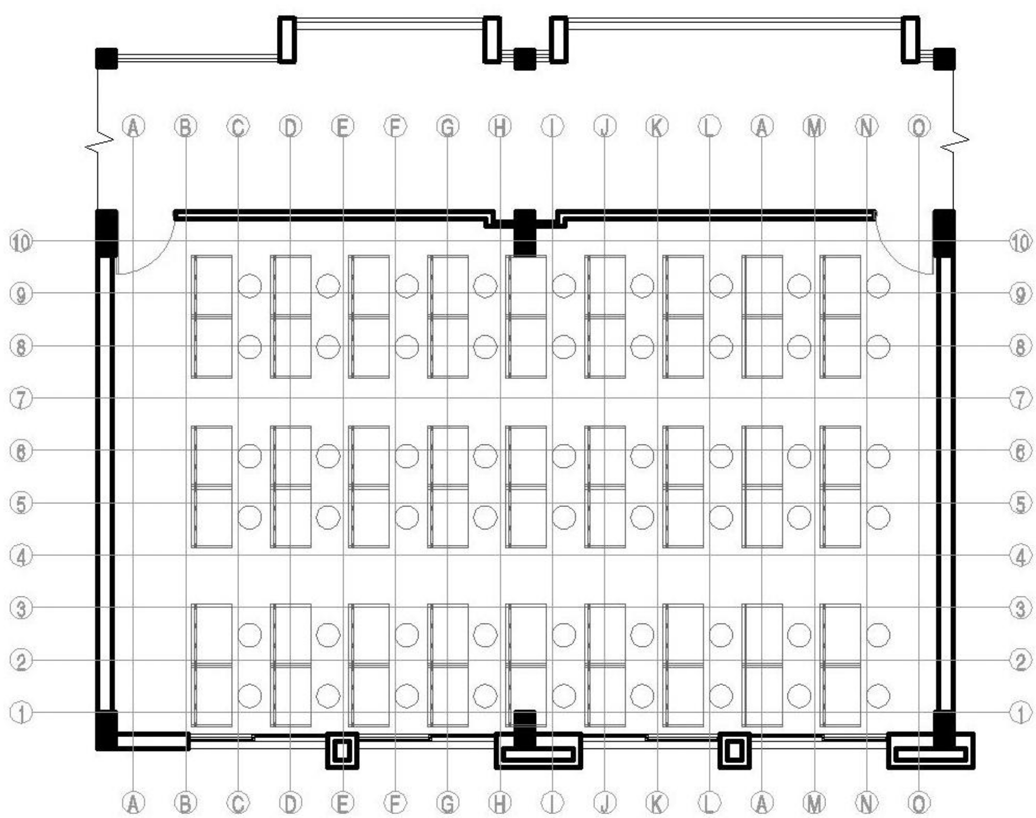


Figure 3. Case Studio plan (*Source:* Author)

Figure 4. Perspective views of Case Studio (*Source:* Author)

Table 1. The Universities in Dhaka with Architecture Department

Sl.	Parameters	Specification
01	Studio floor dimension	14.9m x 9.2m (137 sqm)
02	Window-floor area ratio	0.11%
03	Window size	3.78m^2
04	Number of windows	4 nos.
05	Window top level	2.2m
06	Window bottom height	0.55m
07	Ceiling	Height: 3.45m, Concrete, White Painted
08	Average work plane height	0.75m
09	Floor	600mm x 600mm glazed tiles
10	Wall	North and East: Yellow, painted Particle board South: White painted on plaster West: White painted on Particle board
11	Window glazing	Single panel glass with aluminum frame

3.2 *Evaluation Process*

Window categories

The studio window configurations were organized in four categories and coded as follows (table 2):

Segregated Viewing Windows (SVW), Segregated Full Height Windows (SFW), Continuous Viewing Windows (CVW), Continuous Full Height Windows (CFW).

Table 2. Window categories with dimensions

Category of Windows	Code	Window dimension	Shading dimension	Window-Wall ratio (WWR) [%]
Segregated Viewing Windows	SVW1	4 no. 2400mm x 1200mm	4 no. 2400mm x 450mm	22.4
	SVW2	4 no. 2400mm x 1350mm	4 no. 2400mm x 450mm	25.2
	SVW3	4 no. 2400mm x 1500mm	4 no. 2400mm x 300mm	28.0
	SVW4	4 no. 2400mm x 1500mm	4 no. 2400mm x 300mm	28.0
	SVW5	4 no. 2400mm x 1650mm	4 no. 2400mm x 450mm	30.8
	SVW6	4 no. 2400mm x 1650mm	4 no. 2400mm x 300mm	30.8

Segregated Full-height Windows	SFW1	4 no. 2400mm x 2550mm	4 no. 2400mm x 300mm	47.6
	SFW2	4 no. 2400mm x 3000mm	4 no. 2400mm x 250mm	56.0
	SFW3	4 no. 2400mm x 3000mm	4 no. 2400mm x 125mm	56.0
Continuous Viewing Windows	CVW1	1 no. 12000mm x 1200mm	1 no. 12000mm x 250mm	28.0
	CVW2	1 no. 12000mm x 1350mm	1 no. 12000mm x 250mm	31.5
	CVW3	1 no. 12000mm x 1500mm	1 no. 12000mm x 500mm	35.0
Continuous Full-height Windows	CFW1	1 no. 12000mm x 2550mm	1 no. 12000mm x 300mm	59.5
	CFW2	1 no. 12000mm x 3000mm	1 no. 12000mm x 50mm	70.0

3.3 *Simulation perimeters*

Considering human comfort in a room, the hottest and the coldest day are the extreme conditions in a year. The most dominant factor for comfort/discomfort in the winter is the outdoor air temperature, while solar radiation is for summer (Huizenga, 2006). Therefore, the hottest day (24 April, 2016) was considered in analyzing the impact of windows for daylighting on thermal comfort in this research. Finally, the thermal comfort condition for the configurations have been evaluated according to the following criteria:

- PMV-PPD of the room by calculating simulation results of Air temperature, Mean radiant temperature, Relative humidity and Wind speed.

The entire room was considered for thermal simulation, where each point gives data from 8:00 AM to 5:00 PM in 5 days a week.

3.4 *Simulation tools and PMV-PPD prediction*

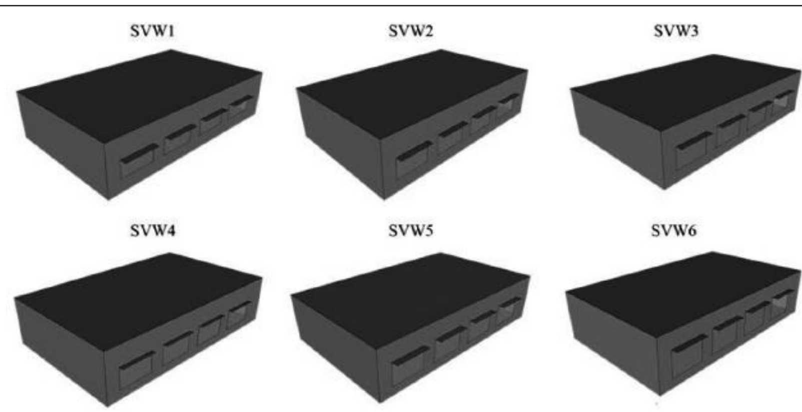
EnergyPlus^{TM} Version 7.2.0 with OpenStudio Plug-in 1.0.1 integrated with Google Sketch-Up 8 have been used for this simulation study. The PMV-PPD spreadsheet (Silva, 2013), according to the formulas was used to determine PMV and PPD by measuring metabolic activity (met), clothing insulation (clo), air temperature (°C), mean radiant temperature (°C), wind speed (m/s) and relative humidity (%) with the assistance of simulation tools.

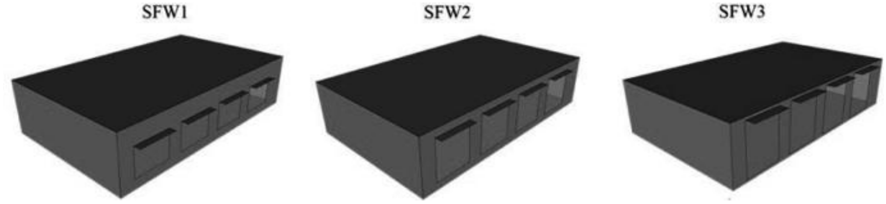
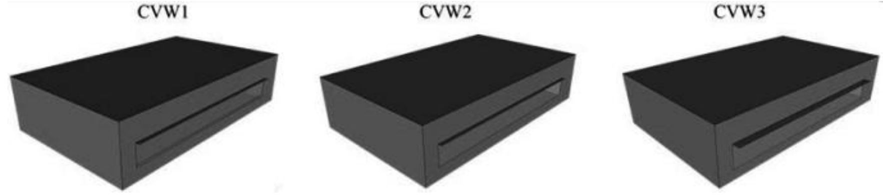
4. Results

4.1 *Thermal Simulation Findings*

South façade of the case studio with fourteen configurations of windows, coded as SVW1 to SVW6 for segregated viewing windows; SFW1 to SFW3 for segregated full-height windows; CVW1 to CVW3 for continuous viewing windows; and lastly, CFW1 and CFW2 for continuous full-height windows (Table 3) and simulated in consideration of PMV-PPD matrix. Figure 5 shows a comparison of performance for different window configurations with respect to different thermal metrics.

Table 3. Sketch up-OpenStudio modelling with window configurations

Window Categories	**Sketch up-OpenStudio modelling**
Segregated Viewing Windows	

Window Categories	Sketch up-OpenStudio modelling
Segregated Full-height Windows	
Continuous Viewing Windows	
Continuous Full-height Windows	

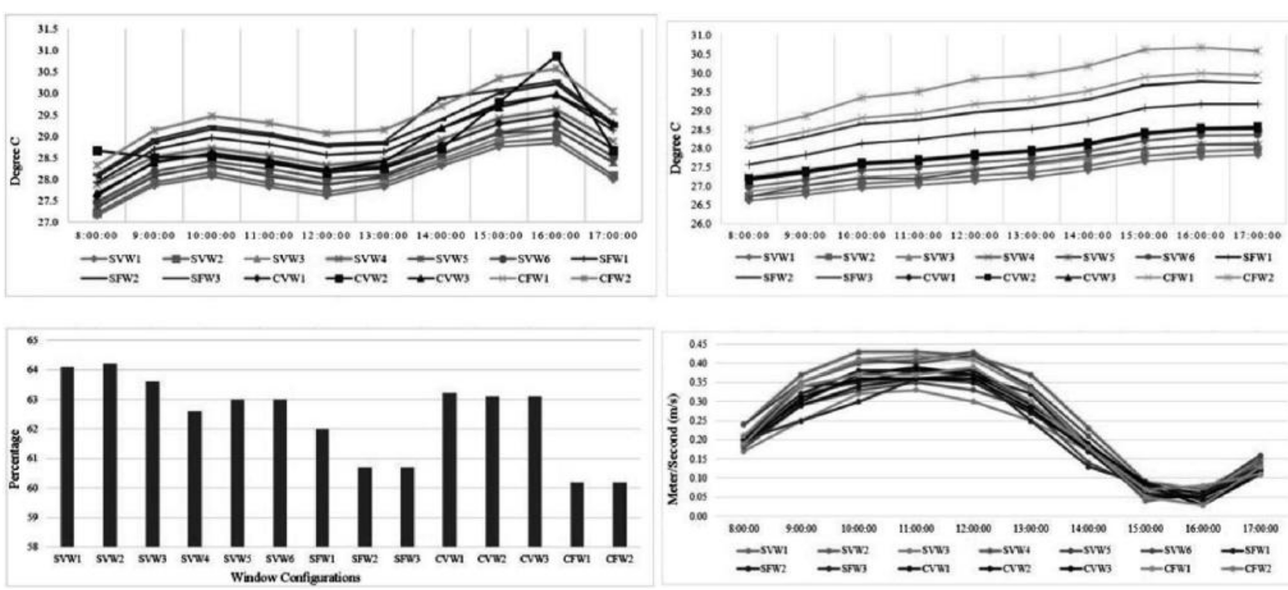


Figure 5. Simulation results of Air temperature (left upper panel), Mean radiant temperature (right upper panel), Relative humidity (left lower panel), wind speed (right lower panel) (*Source:* Author)

Table 4 presents the summary results of the thermal performance process for architecture design studios provided with window configurations of four categories. Indoor air temperature gradually rose with the increase of window size during the class time. Viewing windows provided the temperature range of 28.0°C to 28.9°C, while full-height windows provided an increased temperature range of 29.0°C to 29.5°C. The maximum air temperature was found as 29.5°C for continuous full-height windows, which is in comfortability range. On the other hand, relative humidity decreased according to window size changes.

Table 4. Summery result of thermal simulation for available window configurations for architecture design studios.

Category of Windows	Code of Windows	Hottest day (24th April, 2016)			
		Air Temperature [°C]	Mean Radiant Temperature [°C]	Relative Humidity [%]	Wind Speed [m/s]
SVW	SVW1	28.0	27.2	64.1	0.23
	SVW2	28.1	27.4	64.2	0.25
	SVW3	28.3	27.5	63.6	0.20
	SVW4	28.7	27.9	62.6	0.28
	SVW5	28.3	27.5	63	0.27
	SVW6	28.4	27.7	63.0	0.21
SFW	SFW1	29.0	28.5	62	0.24
	SFW2	29.2	29.0	60.7	0.22
	SFW3	29.3	29.0	60.7	0.21
CVW	CVW1	28.6	27.9	63.2	0.24
	CVW2	28.9	27.9	63.1	0.22
	CVW3	28.8	27.9	63.1	0.23
CFW	CFW1	29.5	29.2	60.2	0.24
	CFW2	29.5	29.8	60.2	0.25

Using viewing windows provides the sensation of the higher relative humidity range of 62.6% to 64.2%, while continuous windows had the lower humidity range of 60.2% to 62%. According to the average subjective reaction to wind speed in the studio, simulated results showed that, wind speed remained unnoticed with changes of window size.

4.2 *PMV-PPD Results*

Results of thermal simulation (air temperature, mean radiant temperature, relative humidity, and wind speed) were placed on spreadsheet to calculate PMV-PPD (Appendix A). Table 5 explains the PMV-PPD result of thermal simulation for available window configurations of four categories for architecture design studios. Moreover, the rating between the categories was presented. From 1st to 14th place rating points were considered as 13 points to 0 point respectively.

According to the PMV result, case studio by providing viewing windows was found to be 'neutral' to 'slightly warm' by having PMV range from +0.80 to +1.08. However, continuous full-height windows created the studio 'slightly warm' to 'warm' having PMV range of +1.16 to +1.42, which failed to satisfy more than 40% of occupants. The mean value of segregated viewing windows was found better than the other three categories. Therefore, more students would be satisfied with respect to the thermal sensation in the architecture design studios, if the studio is provided with segregated viewing windows.

The rating was done by PPD results for the case studio for each available window configurations of architecture design studios in Dhaka (Table 5). After summing the rating points achieved by the available window configurations, windows of segregated viewing windows were found as superior with rating points range of 8 to 13 and the average point of 10.5, from other window configurations. Here, most of the window configurations under the viewing and full-height window categories failed to achieve the acceptable range of 20%. On the other hand, windows of continuous full-height windows category were found as the lowest. This category achieved the rating point range of 0-1 and the average point of 0.5, creating thermal discomfort of a maximum number of occupants by allowing excessive solar radiation through large openings in the interior.

Considering the thermal simulation, SVW1 was rated as the most feasible window configuration, while segregated viewing windows yielded the first position.

Table 5. PMV-PPD result and distribution of thermal simulation rating points for available window configurations for architecture design studios.

Category of Windows	Code of Windows	Hottest day (24th April, 2016)					
		Predicted Mean Vote (PMV)	Predicted Percentage of Dissatisfied (PPD) [%]	Rating points for PPD	Ranking with rating points	Average rating points of category	Place
SVW	SVW1	(+) 0.80	18.3 ≈ 18	13	**1st (13)**	10.5	**1st**
	SVW2	(+) 0.82	19.3 ≈ 19	12	**2nd (12)**		
	SVW3	(+) 0.93	23.2 ≈ 23	10	**4th (10)**		
	SVW4	(+) 0.98	25.3 ≈ 25	8	**6th (8)**		
	SVW5	(+) 0.85	20.3 ≈ 20	11	**3rd (11)**		
	SVW6	(+) 0.96	24.5 ≈ 25	9	**5th (9)**		
SFW	SFW1	(+) 1.16	33.2 ≈ 33	4	**10th (4)**	3	**3rd**
	SFW2	(+) 1.27	38.9 ≈ 39	3	**11th (3)**		
	SFW3	(+) 1.30	40.0 ≈ 40	2	**12th (2)**		
CVW	CVW1	(+) 1.00	26.1 ≈ 26	7	**7th (7)**	6	**2nd**
	CVW2	(+) 1.08	29.8 ≈ 30	5	**9th (5)**		
	CVW3	(+) 1.05	28.4 ≈ 28	6	**8th (6)**		
CFW	CFW1	(+) 1.34	42.5 ≈ 43	1	**13th (1)**	0.5	**4th**
	CFW2	(+) 1.42	46.3 ≈ 46	0	**14th (0)**		

5. Conclusion

This research was conducted to find out the human comfort of the occupants in academic studios in the architecture departments, Dhaka according to available window configurations. The following specific as well as some general recommendations can be drawn from this study for window designing of architecture design studios in order to improve the thermal conditions by integrating appropriate window design, in the climatic context of Dhaka.

- Use segregated windows rather than continuous windows for architecture design studios, as it was found in this research as the most feasible window category among available fourteen window configurations for human comfort in the studios.
- To satisfy thermal conditions in the studios, positioningthe window bottom level at 1200mm will result avoiding the unwanted heat in the room.
- Use windows of lower WWR of 22%-31% rather than windows of higher WWR of 60%-70% to avoid overheating during the summer period.
- Horizontal shading device of 450mm performs better with south facing segregated viewing windows to improve daylight penetration and to avoid overheating in architecture design studios.

According to this study, it is a clear indication that, occupants' comfort largely depends on the building openings, i.e. windows. Though, the simulation study of PMV-PPD was based on the climatic context of Dhaka, this research can be generalized for architecture design studios in similar climates and cultures, in Bangladesh and elsewhere in the world. It is expected that, Architects and Engineers will get a guidance in designing building openings in consideration of thermal comfort in architecture design studios in tropical climate.

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Appendix A: Thermal simulationfindings of the case studio

Time Period (24th April)	Output Variables	SVW1	SVW2	SVW3	SVW4	SVW5	SVW6	SFW1	SFW2	SFW3	CVW1	CVW2	CVW3	CFW1	CFW2
08:00:00	A.T. [°c]	27.2	27.2	27.4	27.9	27.4	27.5	27.9	28.1	28.1	27.6	28.7	27.7	28.3	28.3
	M.R.T. [°c]	26.6	26.7	26.8	27.2	26.7	27.0	27.6	28.0	28.0	27.1	27.2	27.1	28.1	28.5
	R.H. [%]	66.6	66.4	66.4	64.9	66	66.0	65	64.1	64.1	66.1	66.0	66.1	63.7	63.7
	W.S. [m/s]	0.20	0.21	0.17	0.24	0.24	0.18	0.20	0.19	0.20	0.20	0.19	0.20	0.19	0.21
09:00:00	A.T. [°c]	27.9	27.9	28.1	28.5	28.1	28.2	28.7	28.9	28.9	28.4	28.5	28.4	29.1	29.1
	M.R.T. [°c]	26.8	26.9	27.0	27.4	27.0	27.2	27.8	28.3	28.3	27.3	27.4	27.4	28.4	28.9
	R.H. [%]	65.7	65.5	65.9	64.7	65	65.3	64	63.2	63.2	65.5	65.3	65.4	62.8	62.8
	W.S. [m/s]	0.32	0.35	0.25	0.37	0.35	0.29	0.32	0.29	0.25	0.34	0.31	0.30	0.34	0.35
10:00:00	A.T. [°c]	28.1	28.2	28.3	28.7	28.3	28.4	29.0	29.2	29.2	28.6	28.5	28.6	29.5	29.5
	M.R.T. [°c]	26.9	27.1	27.2	27.6	27.2	27.4	28.1	28.6	28.6	27.6	27.6	27.6	28.8	29.3
	R.H. [%]	66.6	68.2	65.9	65.0	66	65.3	64	63.0	62.9	65.5	65.4	65.5	62.4	62.4
	W.S. [m/s]	0.32	0.35	0.25	0.37	0.35	0.29	0.32	0.29	0.25	0.34	0.31	0.30	0.34	0.35
11:00:00	A.T. [°c]	27.8	27.9	28.1	28.6	28.1	28.2	28.8	29.0	29.1	28.4	28.4	28.4	29.3	29.3
	M.R.T. [°c]	27.0	27.1	27.3	27.7	27.2	27.5	28.2	28.8	28.8	27.7	27.7	27.7	28.9	29.5
	R.H. [%]	67.3	67.0	66.4	65.4	66	65.8	64	63.4	63.4	65.9	65.8	65.9	62.9	62.9
	W.S. [m/s]	0.36	0.41	0.33	0.43	0.40	0.35	0.38	0.36	0.36	0.38	0.36	0.39	0.37	0.42
12:00:00	A.T. [°c]	27.6	27.7	27.9	28.3	27.9	28.0	28.6	28.8	28.8	28.2	28.2	28.2	29.1	29.1
	M.R.T. [°c]	27.1	27.3	27.4	27.8	27.4	27.6	28.4	29.0	28.9	27.8	27.8	27.8	29.2	29.8
	R.H. [%]	67.1	66.7	66.2	65.2	66	65.6	64	63.2	63.3	65.7	65.6	65.7	62.7	62.7
	W.S. [m/s]	0.36	0.43	0.30	0.42	0.42	0.33	0.38	0.35	0.37	0.37	0.36	0.37	0.39	0.41
13:00:00	A.T. [°c]	27.8	27.9	28.0	28.4	28.1	28.1	28.6	28.8	28.9	28.3	28.3	28.4	29.2	29.2
	M.R.T. [°c]	27.2	27.4	27.5	27.9	27.6	27.7	28.5	29.1	29.1	27.9	27.9	27.9	29.3	29.9
	R.H. [%]	65.4	65.1	65.2	64.1	64	64.6	63	62.4	62.4	64.7	64.6	64.7	61.8	61.8
	W.S. [m/s]	0.28	0.33	0.25	0.37	0.34	0.28	0.30	0.27	0.25	0.32	0.28	0.29	0.30	0.33

Appendix A: continued

Time Period (24th April)	Output Variables	SVW1	SVW2	SVW3	SVW4	SVW5	SVW6	SFW1	SFW2	SFW3	CVW1	CVW2	CVW3	CFW1	CFW2
14:00:00	A.T. [°c]	28.3	28.4	28.5	28.9	28.6	28.6	29.2	29.4	29.9	28.8	28.7	29.2	29.7	29.7
	M.R.T. [°c]	27.4	27.5	27.7	28.1	27.8	27.9	28.7	29.3	29.3	28.1	28.1	28.1	29.5	30.2
	R.H. [%]	62.7	62.4	62.7	61.7	62	62.0	61	59.7	59.7	62.2	62.1	62.2	59.2	59.2
	W.S. [m/s]	0.18	0.19	0.17	0.23	0.21	0.14	0.18	0.18	0.13	0.17	0.17	0.19	0.18	0.18
15:00:00	A.T. [°c]	28.8	28.9	29.0	29.4	29.1	29.1	29.8	30.0	30.1	29.3	29.8	29.7	30.4	30.4
	M.R.T. [°c]	27.6	27.8	28.0	28.4	28.0	28.2	29.1	29.7	29.7	28.4	28.4	28.4	29.9	30.6
	R.H. [%]	59.8	61.5	59.6	58.9	59	59.0	57	56.4	56.4	59.1	59.0	59.1	55.8	55.8
	W.S. [m/s]	0.06	0.04	0.05	0.09	0.08	0.07	0.06	0.09	0.08	0.08	0.05	0.08	0.07	0.05
16:00:00	A.T. [°c]	28.8	29.0	29.2	29.6	29.2	29.3	30.0	30.2	30.3	29.5	30.9	30.0	30.6	30.6
	M.R.T. [°c]	27.8	27.9	28.1	28.5	28.1	28.3	29.2	29.8	29.8	28.5	28.5	28.5	30.0	30.7
	R.H. [%]	58.8	58.5	58.1	57.5	58	57.5	56	55.0	55.0	57.7	57.5	57.6	54.4	54.4
	W.S. [m/s]	0.05	0.06	0.05	0.07	0.06	0.05	0.05	0.04	0.06	0.06	0.05	0.03	0.08	0.03
17:00:00	A.T. [°c]	28.0	28.1	28.4	28.9	28.4	28.5	29.1	29.2	29.3	28.7	28.7	29.3	29.6	29.6
	M.R.T. [°c]	27.8	28.0	28.1	28.5	28.1	28.3	29.2	29.7	29.7	28.5	28.6	28.5	29.9	30.6
	R.H. [%]	60.9	60.6	59.9	59.0	60	59.2	58	57.0	57.0	59.4	59.3	59.4	56.5	56.5
	W.S. [m/s]	0.12	0.14	0.13	0.15	0.16	0.12	0.13	0.11	0.13	0.13	0.12	0.11	0.11	0.13

* **A.T..: Air Temperature, R.H.: Relative Humidity, W.S.: Wind Velocity.**