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Thermal Experience of University Student Accommodation for Different Orientations and Materials in Chattogram, Bangladesh

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ABSTRACT

The building walls, which constitute the crucial component of the building envelope, thermally interact with the outdoor environment and impact the indoor thermal experience. Fire burnt mud bricks are commonly used for building envelopes in Bangladesh, including Chattogram, and the thermal behavior of a single layer of brick wall is well-known. However, the thermal performance of brick cavity walls is still unknown, though designers also use it as a solution to enhance the indoor thermal experience. This paper aims to assess the thermal experience (Air Temperature and Relative Humidity) of university student accommodations made of single brick walls and cavity walls in different orientations, affecting the indoor thermal environment of the buildings in tropical climates during the summer season. Chattogram University of Engineering and Technology is selected to conduct the field and simulation study for this research as it is one of the major governmental universities in Chattogram, and most of the students reside in hostels. In the first phase of this study, indoor temperature and humidity data from four rooms with four orientations from two hostels were collected with a Hobo data logger. In the second phase, a simulation and parametric study was conducted with EnergyPlus with Openstudio plugins to compare simulation results with the field data. The result shows that rooms built with cavity walls have around 2^{o}C less temperature than the rooms constructed with a single layer of brick. In terms of orientation, south-facing rooms perform best for indoor temperatures, whereas west-facing rooms perform the worst for both hostels.

INTRODUCTION

To meet the demand of huge economic activities and rapid urbanization, the use of energy in buildings has increased in recent years due to the growing demand for energy used for various operations in buildings (Santamouris, M, 2021). Thermal performance is the key factor for energy efficiency and is very much accountable for thermal experience. Thermal experience in an individual space is significant not only for good health but also affects the productivity of an individual or residential dweller (Ali, 2018; Šujanová P, 2019). Thermal experience is the foremost variable of indoor environment quality, and it is influenced by the design techniques and materials used in buildings (Jannat, 2020). According to how materials respond to the climate, the human settlement environment on earth can be categorized into the heat preservation priority and heat insulation priority climate zones. Heat insulation priority climate zones consist of the tropical and subtropical regions where high humidity, temperatures, and solar radiation are the major stresses. Therefore, materials in this area are mainly used for resolving the sun shading and heat insulation (Zhang, 2017; Gou, 2018). Fire burnt mud bricks have been used in Bangladesh for centuries, and numerous researches have been conducted to identify their thermal performance. Nowadays, designers are using different types of brick walls to minimize indoor temperature, such as cavity walls. However, comparative field investigation and simulation study of single brick walls and cavity walls are very limited for student accommodation for different orientations. This study aims at investigating the thermal experience of university hostel rooms of Chattogram made of single brick wall and cavity wall in different orientations. The study has been carried out by measuring the air temperature and relative humidity of these spaces.

LITERATURE REVIEW

A comfortable indoor environment is crucial for the human experience as it directly impacts occupants' health, well-being, and productivity (Ganesh, G. A. 2021; Chen, C. F., 2020; Fantozzi, F. 2020). Maintaining an optimal indoor temperature and humidity is essential for creating a conducive and pleasant environment for work, study, and engaging in daily activities comfortably (Mansor, R. 2020). Additionally, extremes in the indoor environment can adversely impact human health, productivity, and comfort (Zhang, S. 2021; Allen, J. G., & Macomber, J. D. 2020). Therefore, maintaining a comfortable indoor environment is necessary for promoting a positive and healthy human experience (Altomonte, S. 2020; Peters, T. 2021).

The building envelope is the interface between the interior of the building and the outdoor environment, including its physical components like the walls, roof, floor, doors, and windows (Horner, M 2007; Kumar, G 2016; Saleh, 2007). The building envelope, which acts as a thermal barrier, plays an important role in regulating indoor temperatures and helps to determine the amount of energy required in order to maintain thermal comfort (Saleh, 2007; Ochoa, 2008; Chou, 1996). Primary

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environmental factors to which the building envelope is exposed are air temperature, air velocity, solar radiation, and relative humidity, which have often been neglected in designing buildings in the context of tropical climate (Naz, 2008; Zohir, 2010; Tzempelikos, 2007). Most of the tropical developing countries are facing difficulties in achieving indoor thermal comfort without mechanical control because of inappropriate building design and limited access to energy resources (Kuik, 2011; Njiru, 2018; Nwalusi, D. M 2022). Indoor thermal comfort conditions can be controlled without a mechanical system if the indoor temperature remains within the range of adaptive comfort levels (Pathirana, 2019) and the building envelope can play a significant role in regulating indoor air temperature (Makaka, 2006; Mohammad, 2013). Hence, the application of appropriate materials for efficient building envelope design would be an effective alternative to attain standard indoor thermal comfort conditions due to the lack of energy supply in tropical developing countries. There are different wall materials used worldwide as building envelopes. Fire burnt mud bricks are the very common and popular material used as wall material (Almusaed, A 2023; Almssad, A 2022). These brick walls have high thermal mass, which allows them to absorb, store, and slowly release heat. This helps in stabilizing indoor temperatures, providing a more comfortable and consistent environment (Vijayan, D. S. 2021; Zhang, L. 2020).

On the other hand, cavity walls made of mud bricks are often proposed in the building envelope design as a solution for improving the thermal comfort of the occupants and reducing the adverse condensation effects on the building fabric (Fawaier, M 2022; Sadineni, S. B 2011). The presence of an air gap (cavity) between the inner and outer wall in a cavity wall increases its insulation capability and reduces indoor temperature (Stazi, F. 2020; Ling, Z. 2021). Additionally, the cavity in a cavity wall provides a buffer against moisture penetration and creates an optimum humid environment for the indoor area (Vanpachtenbeke, M 2020). However, comparison of indoor thermal performance of single brick wall and cavity wall is very limited. In this study, field investigation was made in eight hostel rooms of two newly constructed students halls of the CUET campus-Shekh Rasel Hall (Boys Hall) and Shamsen Nahar Khan Hall (Ladies Hall), as both halls are situated in the same geographical location and accommodate more than 500 students each and play a significant role in solving the accommodation problem of the university. Then the findings of the field investigation were verified using a simulation study with standard simulation software.

METHODOLOGY

For field investigation, the newly constructed Shekh Rasel Hall (Boys Hall) and Shamshen Nahar Khan Hall (Ladies Hall) of the CUET campus have been chosen. Shekh Rasel Hall is a five-storied hostel building located on the west side of the CUET campus (Figure 1). As this is a frame structure, the partition walls and outer walls of the room are constructed by 5" single-layer fire-burnt brick wall.

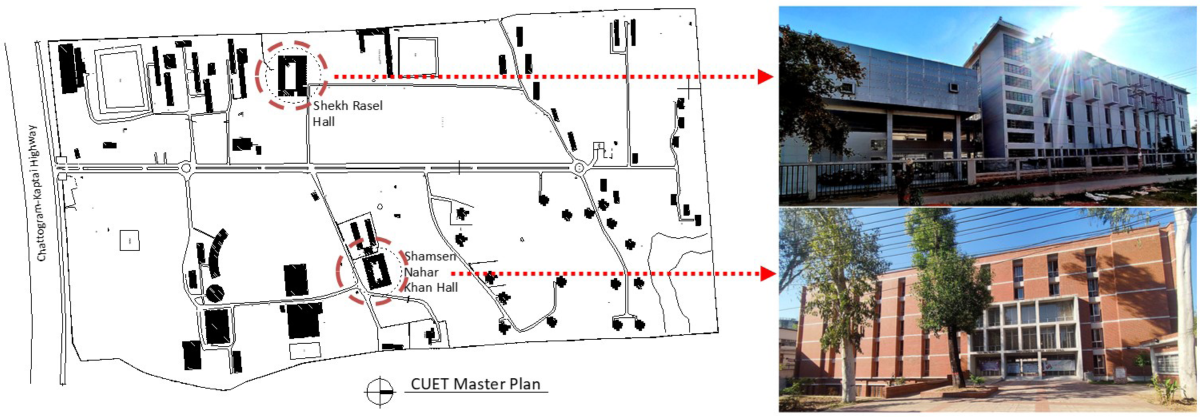

Figure 1: CUET Master Plan and location of study area (Shekh Rasel Hall and Shamsen Nahar Khan Hall)

Shamshen Nahar Khan Hall (Ladies Hall) is also a five-storied hostel building, located on the east side of the CUET campus (Figure 1). Though this is also a frame structure, most of the outer wall is constructed with brick cavity walls, and other partition walls are constructed with 5" single layer fire burnt brick. 4 rooms from each building in different orientations have been selected to investigate the thermal performance in terms of Air Temperature and Relative Humidity. This investigation was conducted by a renowned and worldwide accepted data logger-Hobo U30 NRC Weather Station (Figure 2). HOBO U30 NRC data logger has 10 smart sensor inputs that can measure different environmental variables like air temperature, relative humidity, wind speed and direction, solar radiation, etc. The HOBO data loggers were installed in the test rooms of the hostels at one point at a height of 2.1-3.0 m (which is the average minimum human height and ceiling height in our context) from the floor level of the test room. The HOBO U30 Station automatically recognizes Smart Sensors. We have connected to 4 Smart Sensors and combinations just by plugging them in before logging begins. No programming, wiring, or calibration is required to set them up. The connections between the Smart Sensors and the logger are digital.

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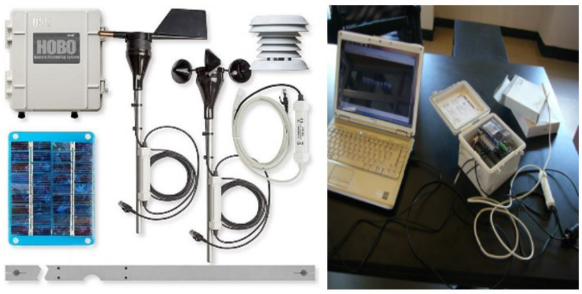

Figure 2: HOBO U30 NRC data logger and different sensors

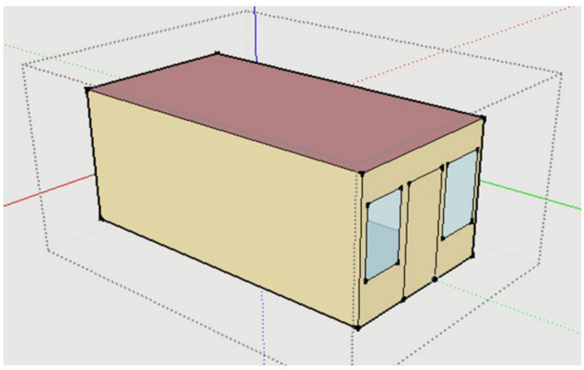

Figure 3: Sketch up model using Openstudio plugins for Energyplus simulation

The data collection was held on different dates in April 2022 as this is the hottest month of this research region (Chowdhury. S, 2015), and collect air temperature and relative humidity of both indoors and outdoors for 24 hours for each study room. After that, a simulation study was conducted on two different rooms of each hostel building of the same orientation (Outdoor-South facing) by an environmental simulation program- Energyplus with Openstudio plugins (Figure 3). The simulation results have been discussed and compared with the data of field investigation. The results indicate the thermal performance of the study rooms of the hostels.

Field Investigation

For student accommodation, currently, CUET has 5 boy's halls and 2 ladies halls, including the newly constructed Shekh Rasel Hall (Boys Hall) and Shamshen Nahar Khan Hall (Ladies Hall). Shekh Rasel Hall is a five-storied hostel building that accommodates more than 500 male students at the university. This is a courtyard building, and rooms are designed on all four sides of the courtyard. There are 31 same size rooms on a typical floor (Figure 4) and maximum 4 students can stay in a room (Figure 7 - Figure 10). The room dimensions are 23'x 12'.

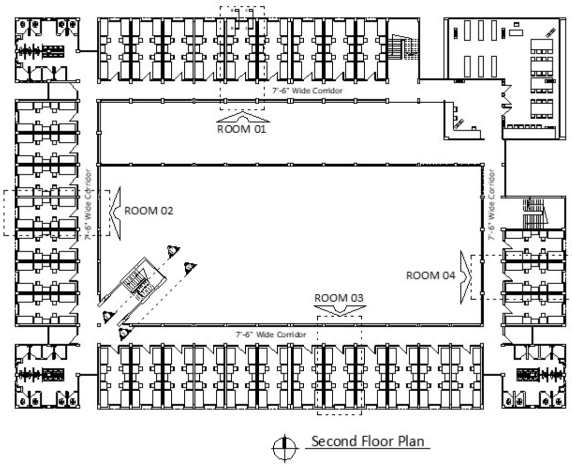

Figure 4: 2nd floor plan of Shekh Rasel Hall

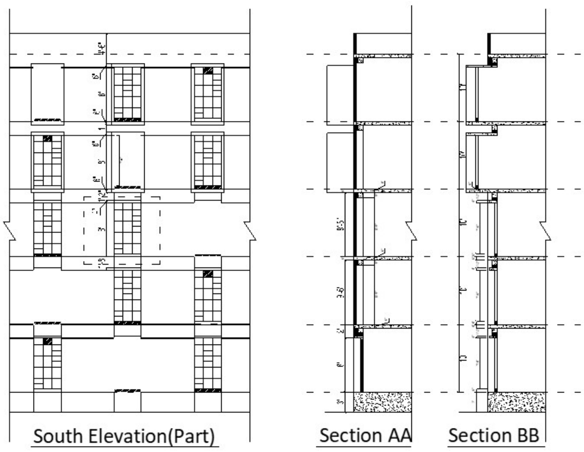

Figure 5: Section and elevations of Shekh Rasel Hall

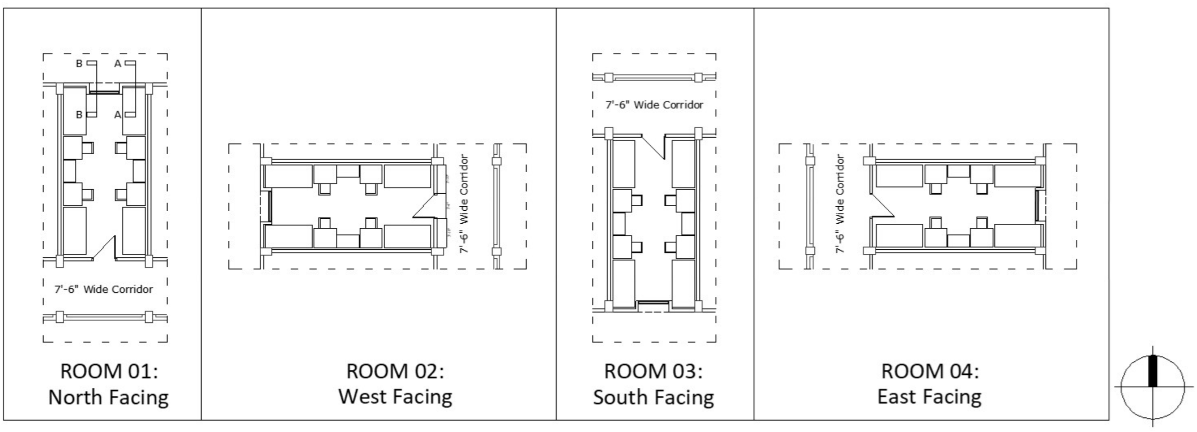

Figure 6: Study rooms of Shekh Rasel Hall

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Figure 7: South facing study room of Shekh Rasel Hall

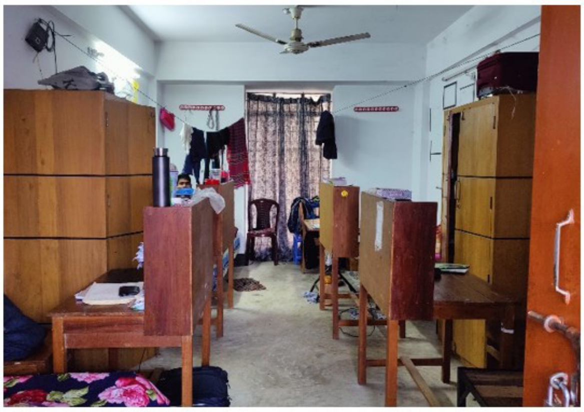

Figure 8: North facing study room of Shekh Rasel Hall

Figure 9: East facing study room of Shekh Rasel Hall

Figure 10: West facing study room of Shekh Rasel Hall

On the outer wall there is a full-size window (width--4', height-7'-6") (Figure 5) and two other window and one entry door at 7'-6" wide corridor of the room (Figure 6). As this is a frame structure, the partition walls and outer walls of the room is constructed by 5" single layer fire burnt brick wall.

On the other hand, Shamshen Nahar Khan Hall (S.N.K. Hall) is also a five-storied hostel building located on the east side of the CUET campus and accommodates more than 500 female students of the university (Figure 11). The building has a central courtyard and rooms are designed at all four sides of the courtyard. There are 20 same-size rooms on the north and south sides of the courtyard and 4 different size rooms on the east and west sides in a typical floor. A maximum of 4 students can stay in a regular room with dimensions of 23'-6"x 13'-9" (Figure 14-Figure 17).

Most of the outer wall is constructed with brick cavity walls (Outer wall ceramic brick and Inner wall-fire burnt brick), and other partition walls are constructed with 5" single layer fire burnt brick. While investigating, two sensors for measuring air temperature and two sensors for measuring relative humidity were set in 8 study rooms-one for indoor and one for outdoor for 24 hours in similar weather of the month of April. A typical section and south elevation are presented in Figure 12 and Figure 13 illustrates the study rooms of the Shamshen Nahar Khan Hall

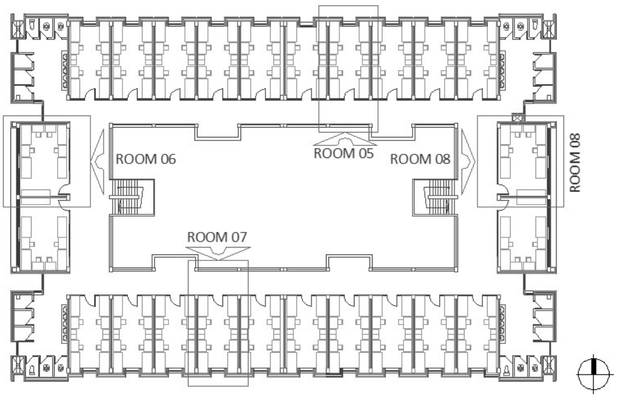

Figure 11: 2nd floor plan of S.N.K. Hall

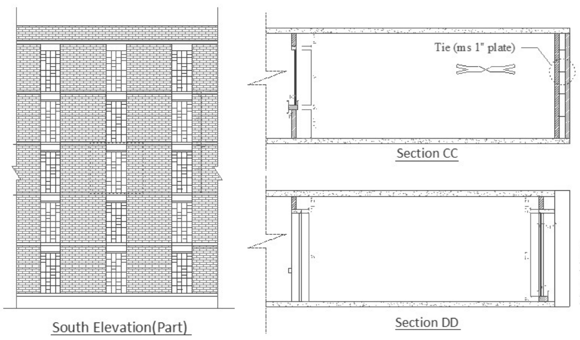

Figure 12: Elevation and Section of S.N.K. Hall

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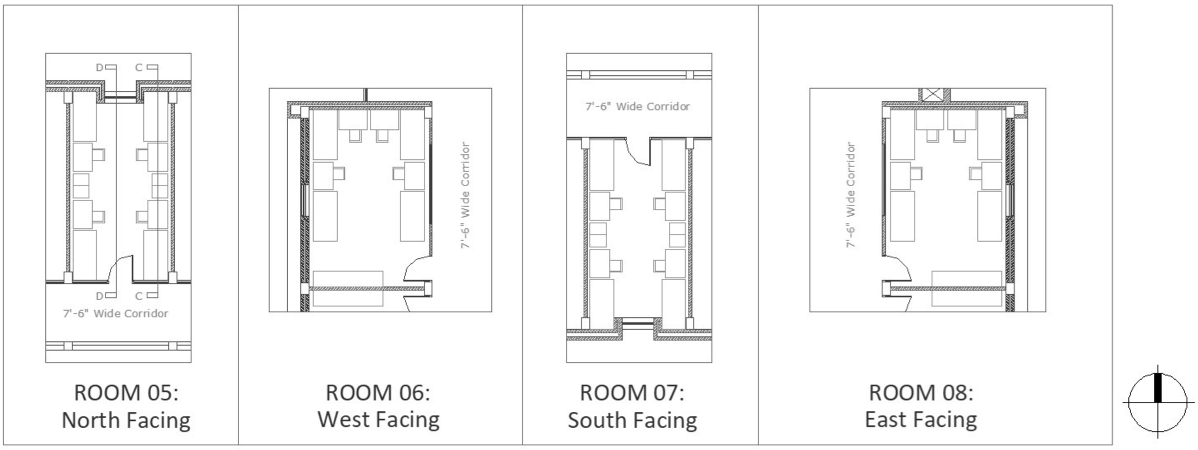

Figure 13: Study rooms of Shamshen Nahar Khan Hall

Figure 14: North facing study room of Shamshen Nahar Khan Hall

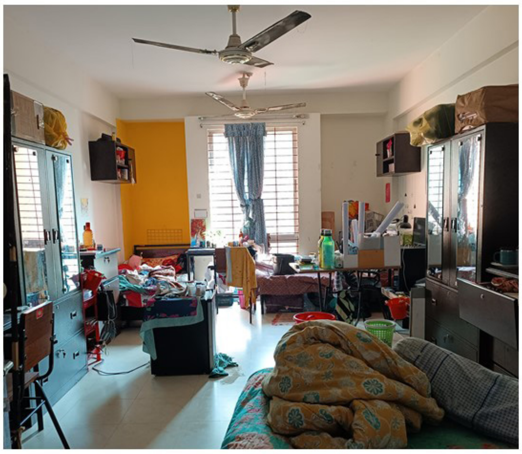

Figure 15: South facing study room of Shamshen Nahar Khan Hall

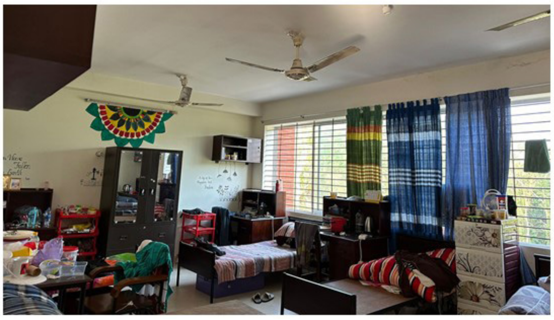

Figure 16: East facing study room of Shamshen Nahar Khan Hall

Figure 17: West facing study room of Shamshen Nahar Khan Hall

Simulation and Parametric Study

It is possible to identify the performance of the building envelope due to the heat gain factor from the outdoor environment. These include Mean Radiant Temperature, Air Temperature, Operative Temperature, Solar Radiation etc. It is possible to analyze the thermal performance of a building envelope for any period of the year simply by assigning simulation parameters (temperature, radiation, wind speed, and direct relative humidity). In this study, the thermal performance of two study rooms was analyzed by a dynamic computer simulation program developed by the U.S. Department of Energy named Energy Plus (Energy+) Version 8.1.0 with the Open studio Plug-in 1.3.0 integrated with Google Sketch-Up 8 for this simulation study. The energy tools listed in this directory include databases, spreadsheets, component and systems analyses, and whole-building energy performance simulation programs.

Outdoor variables are shown in Figure 18. Open Studio Plug-in for Google Sketch Up 8 is another front end to

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Energy Plus that was created by the National Renewable Energy Laboratory for the U.S. Department of Energy, that allows users to create and edit the building geometry for the Energy Plus input files.

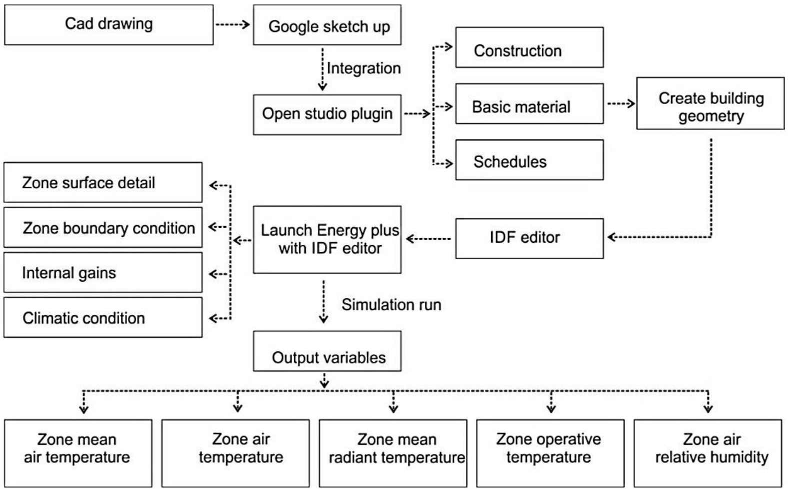
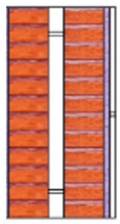


Figure 18: Simulation and evaluation process of Energy + parametric studies

Categorization of Conventional Envelope Types for Parametric Studies

In this parametric study, floor, window pattern, and roof construction techniques are constant in the whole simulation process. Only exterior wall construction techniques are considered for the simulations. Table 1 presents the types of walls used for parametric study.

Table 1: Two types of wall construction of study space for parametric studies

Wall Type	Wall reference and type	Construction materials	Detail
01.	Conventional 127mm. Brick Wall Construction	Internal Plaster lining (6.35mm)	
		(With Plaster)	
		Sand & cement mortar (6.35mm)	
		External Plaster lining (6.35mm)	
02.	Conventional cavity Wall Construction (With one side plaster)	Internal Plaster lining (6.35mm)	
		Brick outdoor-Ceramic (127mm)	
		Brick indoor-1st Class (127mm)	
		Sand & cement mortar (6.35mm)	
		Plaster (Cement: Sand=1:5)	
		Internal air gap:15cm	

Simulation and Evaluation Process

To model the building in Energy Plus, initially, Google Sketch-Up with Open studio plug-in software, which is the most popular front end for Energy Plus was used. To visualize the file and edit the building geometry, Google Sketch Up with an Open Studio plug-in was used. This free plug-in allows us to launch Energy Plus simulations, assign some attributes, and view the results without leaving the Google Sketch Up 3D drawing program. Open Studio allows us to import the IDF file and edit surfaces and zones in the file. Using open studio one can match interzone surface boundary conditions, add internal gains and simple outdoor air for load calculations, and can set and change default constructions and assign daylighting controls. Simulation parameters for Energy Plus are presented in Tables 2, 3, and 4

Simulation Run Period

Table 2: Simulation run period parameters of test production zone for Energy + simulation

Name	Weather File Days
Begin Month	April
Begin Day of Month	16
End Month	April

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End Day of Month	17
Day of Week for Start Day	Saturday
Use Weather File Daylight Saving Period	no
Use Weather File Rain and Snow Indicators	no
Period Selection	Tropical Hot

Table 3: Simulation parameters of study model for Energy + simulation

Parameters	**Specifications**
Location	Within the greater Chattogram region, Bangladesh
Geographical Location:	
i) Longitude	91.82° (North)
ii) Latitude	22.27° (East)
Time Zone	+6 GMT
Time	12:30 p.m.
Date	April-July 2014 (Condition: High Temperature & Humidity)
Sky Model	Clear sky
Calculation option	Standard
Units of Dimensions (Length, areas, etc.)	Metric (SI) (m, cm, etc.)
Units of Photometric Dimension	European (SI) (lux, cd/m^2, etc.)
Elevation	9m
Orientation	Front Elevation facing South
Plan Shape	Rectangular
Number of floors	1
Floor to Floor Height	3.5 m (7.0 m for the two floors)
Floor Area	3600 ft^2 (330 m^2)
Floor Dimension	45ft x 80ft (13.71m x 24.39m)
Window Area	20% of the gross wall area (98 m^2), Uniformly Distributed
Solar Absorbance (for	0.55 for external walls (Light color)
Exterior Surfaces)	0.35 for the roof (light color)
Occupancy Density	General commercial industrial work precision people/area
Glazing	Single panel of glass with aluminum frame (refl. 0.92)
Building Construction Type	ASHRAE 90.1 non-Res.
Natural Ventilation	Simple (Operable simple window) (One Array)
Electrical Equipment Load	General commercial industrial work precision equipment
Lighting	General industrial simple lighting
Room Air Distribution Model	General cross ventilation
Ventilation Control Mode	Temperature
Design Flow Rate Calculation Method	Air Changes/Hour
Leakage Component Name	Surface Object

Table 4: Simulation engine detail parameters of test production zone for Energy + simulation

Parameters	**Specifications**
Simulation Engine	Energy Plus
Version Identifier	8.1.0
Run Simulation for Weather File Run Periods	Yes
Run Simulation for Sizing Periods	Yes
Terrain	City
Loads Convergence Tolerance Value	0.04

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Temperature Convergence Tolerance Value {deltaC}	0.4
Solar Distribution	Full Interior and Exterior
Calculation Method	Average Over Days in Frequency
Calculation Frequency	20
Sky Diffuse Modeling Algorithm	Detailed Sky Modeling
Algorithm	TARP & DOE-2
Number of Time steps per Hour	4

RESULTS AND DISCUSSION

Data of Hobo Data Logger

By using Hobo data logger, the air temperature of indoor and outdoor and relative humidity of indoor and outdoor were recorded for a long span of time. For convenience, the data from 12.00 PM to 01.00 PM have been compared and shown in table 6.

The indoor temperature of North and East facing rooms of Sheikh Rasel Hall is higher than the indoor temperature of west and south-facing rooms. For the west-facing rooms of this hostel, indoor temperature is found the highest, which is around 31.5ºC. It is also approximately 2ºC less than the outdoor temperature. All the other rooms of the Sheikh Rasel Hall have an indoor temperature of around 30ºC.

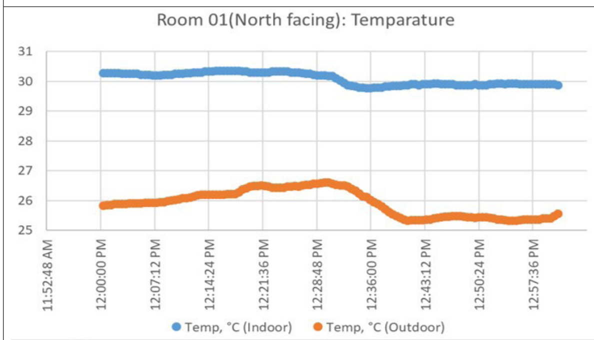
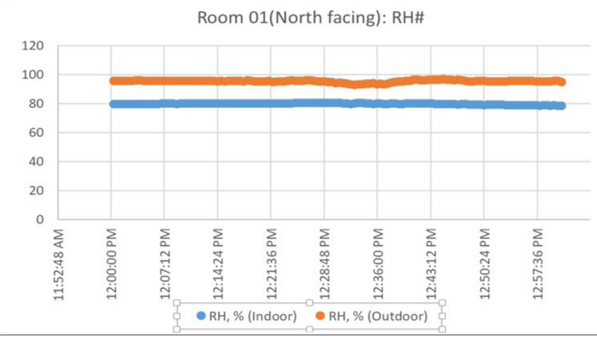
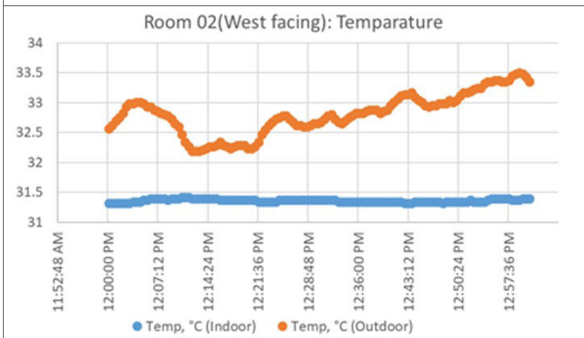
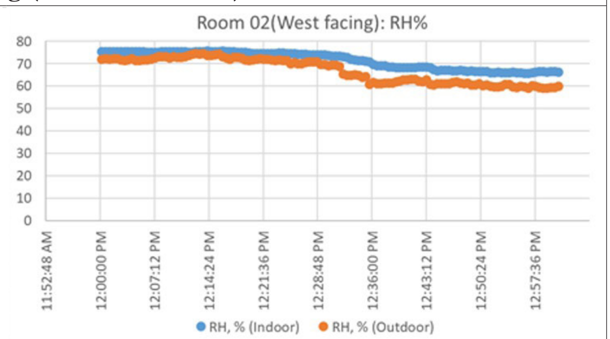
In terms of humidity, north and east-facing rooms have lower humidity than the outdoor area. For the rooms on the west and south sides, indoor humidity is higher compared to outdoor humidity. For the east room, the humidity is the lowest, which is around 74%, while the outdoor humidity is about 84%. For all the other sides of the rooms of the Sheikh Rasel Hall, indoor humidity is around 80%.

For the Shamshen Nahar Khan Hall, north-facing room has a higher indoor temperature compared to the outdoor area. For the remaining three side rooms, indoor temperature is lower than the outside. In this hostel, west-facing rooms have the lowest indoor temperature (around 25ºC), which is around 5ºC less than the outdoor area. South-facing rooms have the highest indoor temperature of this hostel, which is approximately 30ºC. For east-facing rooms, indoor temperature is around 27ºC, whereas the outdoor temperature is around 32ºC. For north-facing room, the indoor temperature is approximately 27.5ºC, whereas the outdoor temperature was, on average, 26ºC.

In terms of humidity, all indoor rooms of Shamshen Nahar Khan Hall have a higher humidity percentage compared to outdoor areas.

The highest humidity is recorded in north-facing rooms of Shamshen Nahar Khan Hall, which is around 65%, about 15% higher than the outdoor area. The lowest humidity is recorded in the west-facing room, which is approximately 40%, which is an average 10% higher than that of outdoor area. For the other two sides, 55% and 50% humidity are found in the south and east-facing rooms of the hostel respectively.

Table 6: Comparison of Temperature and Relative humidity of study rooms (Indoor vs Outdoor)

Temperature (Indoor vs Outdoor)	**Relative Humidity (Indoor vs Outdoor)**
Room 01: North Facing (Shekh Rasel Hall)	
	
Room 02. West Facing (Shekh Rasel Hall)	
	

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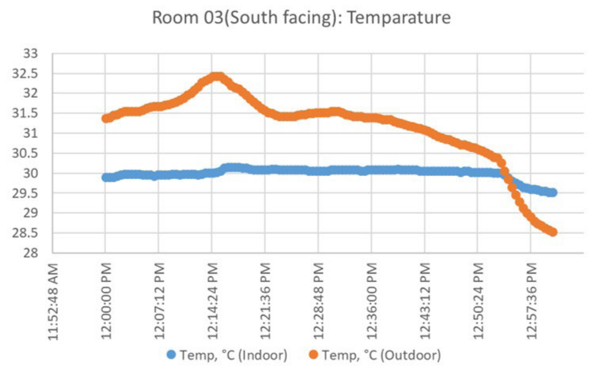
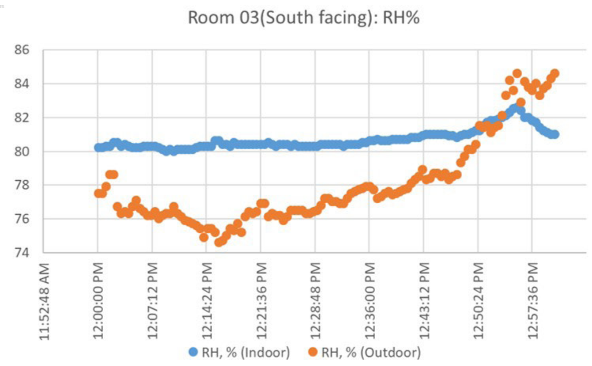
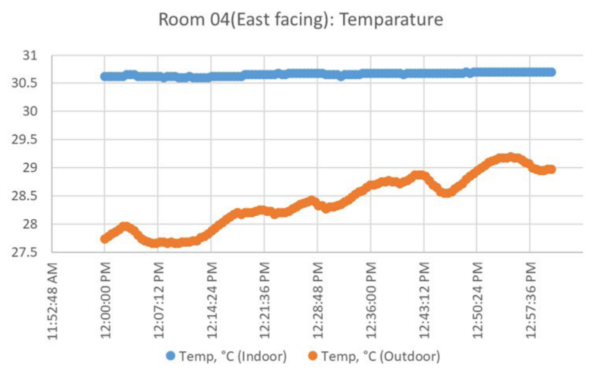
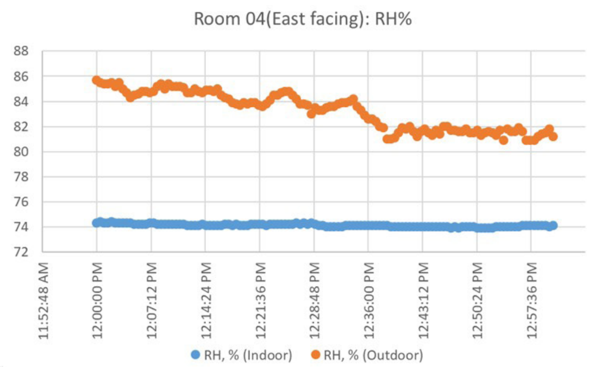
Room 03. South Facing (Shekh Rasel Hall)



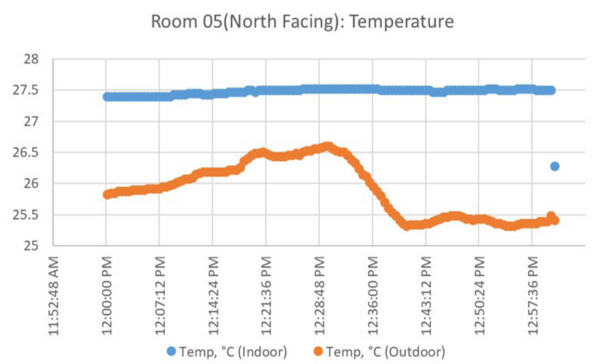


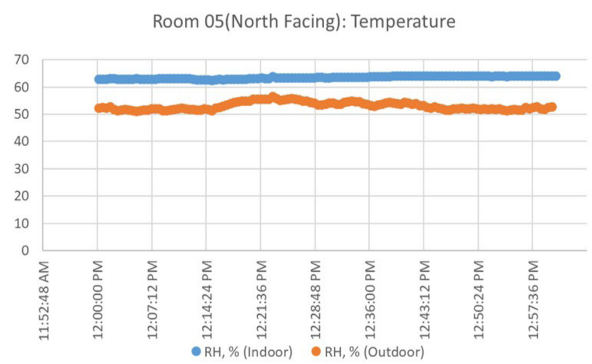
Room 04. East Facing (Shekh Rasel Hall)



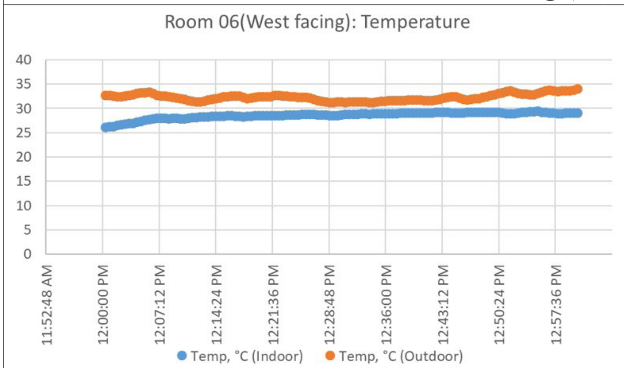


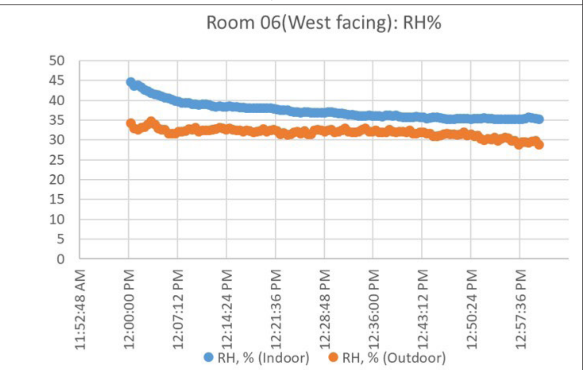
Room 05: North Facing (Shamshen Nahar Khan Hall)





Room 06. West Facing (Shamshen Nahar Khan Hall)





Room 07. South Facing (Shamshen Nahar Khan Hall)

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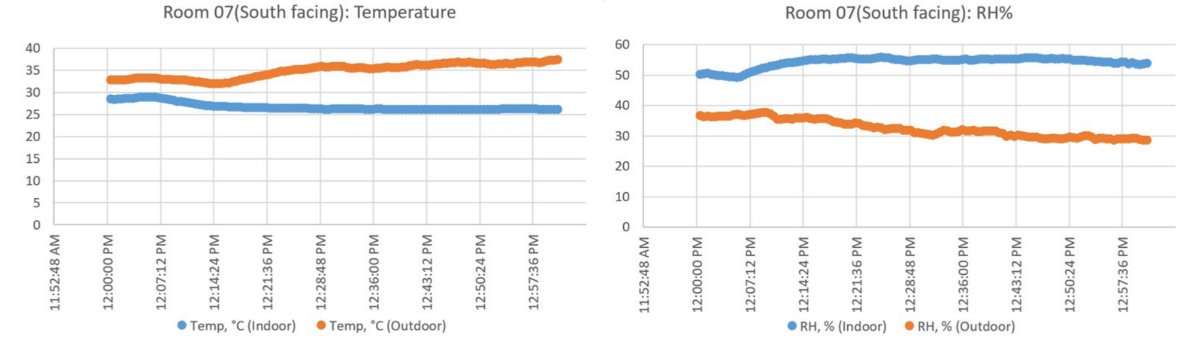
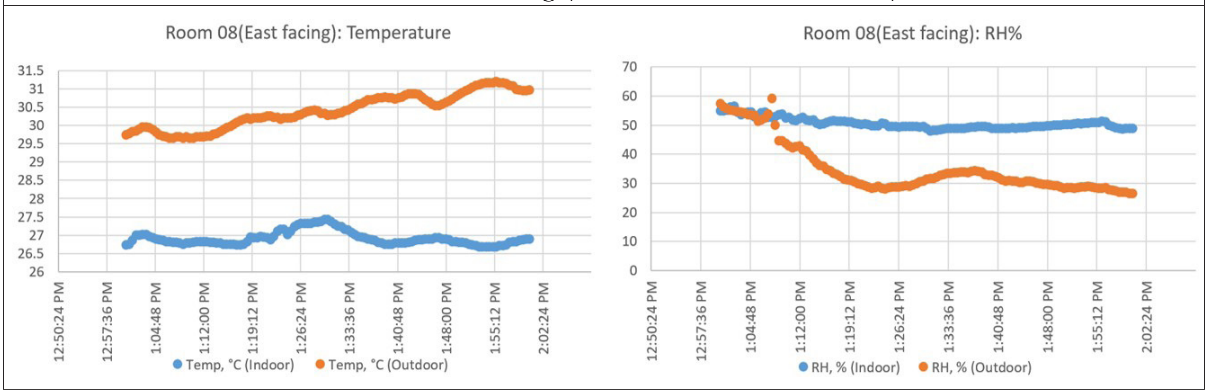


Room 08. East Facing (Shamshen Nahar Khan Hall)



Indoor Temperature Comparison of All Sides

Figures 19 and 20 show that indoor temperature of west-facing room made of single brick wall of Shekh Rasel Hall gain 31.5°C which is the highest temperature from 12 PM to 01 PM among all study rooms, whereas south and north-facing rooms are more comfortable as it achieves less temperature at that time (29.5°C to 30.5°C).

Indoor temperature of west-facing room made of cavity wall of Shamshen Nahar Khan Hall also gains 29.5oC, which is the highest temperature from 12 PM to 01 PM among all study rooms of this hall, whereas south-facing rooms are more comfortable as it gains less temperature at that time (26°C to 29°C).

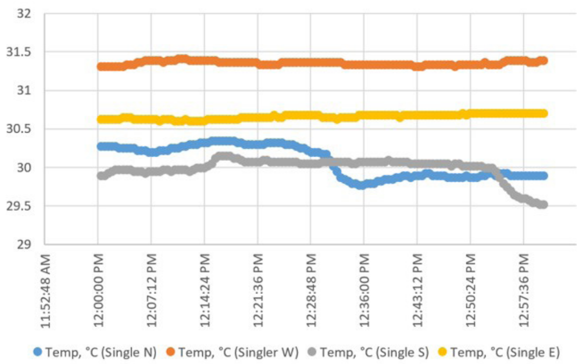


Figure 19: Indoor Temperature Comparison of rooms made of Single brick wall

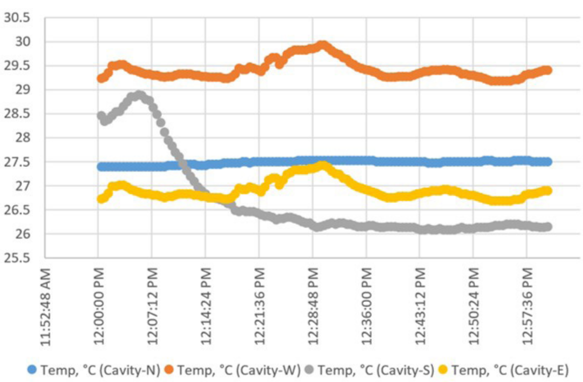


Figure 20: Indoor Temperature Comparison of rooms made of Cavity wall

Indoor Temperature Comparison for West Side (single wall vs cavity wall)

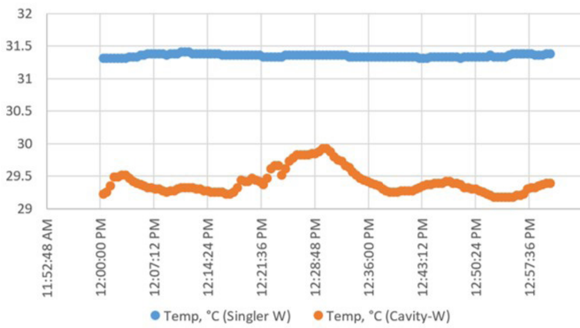


Figure 21: Indoor Temperature Comparison of the west-facing room made of single brick wall and Cavity wall

Figure 21 shows that indoor temperature of west facing room made of single brick wall of Shekh Rasel Hall gained the highest temperature of 31.5°C from 12 PM to 01 PM than that of Cavity wall (29.5°C). The indoor temperature is less than 2°C for the room made of cavity

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wall of Shamshen Nahar Khan Hall. So, the thermal performance of west-facing rooms made of Cavity wall is better than the west-facing rooms of single brick wall, and the temperature difference is around 2ºC.

Indoor Temperature Comparison by Energy Plus (single wall vs cavity wall)

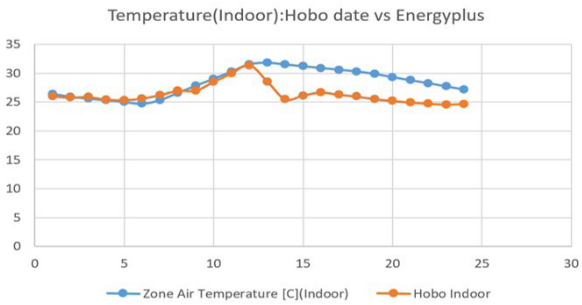
As the room configuration of East and West of Shamsen Nahar Khan Hall is a little different from other study area, the room 03(South Facing-Single wall) has been considered for Energy plus simulation (Table 7).

The maximum Zone Air Temperature is 32.2ºC and minimum Zone Air Temperature is 24.6ºC. Outdoor Air Dry blub Maximum Temperature is 37.46oC and Minimum Temperature is 34.07ºC. Indoor Air Relative Humidity is maximum 52.59 % and minimum 43.74%. Outdoor Air Relative Humidity is maximum 91% and minimum 58%.

Table 7: Summery result of Energyplus simulation for South facing room (single wall)

	Zone Air Temperature	Zone Air Relative Humidity	Site Outdoor Air Dry blub Temp	Site Outdoor Air Relative Humidity
Minimum	24.60	43.74	34.07	58.00
Mean minus two standard deviations	24.31	42.39	33.66	57.49
Mean	28.74	47.98	35.78	74.98
Mean plus two standard deviations	33.18	53.56	37.91	92.48
Maximum	32.20	52.59	37.46	91.00
Standard deviation	2.22	2.79	1.06	8.75

Figure 22 shows Temperature Comparison between Hobo data and Energyplus of the south-facing room made of Single brick wall. Graph shows few differences of the data of field investigation with the data of Energyplus for indoor temperature. Indoor temperature measured by Hobo data logger is 25ºC to 32ºC and the same temperature measured by Energyplus simulation is 26ºC to 33ºC. But it shows much difference for outdoor temperature. Outdoor temperature measured by Hobo data logger is 29ºC to 30ºC and the same temperature measured by Energyplus simulation is 35ºC to 37ºC. It may happen for the data analysis system of Energyplus, which analyzes the whole environment, but data logger analyzes the outdoor temperature of micro climate.



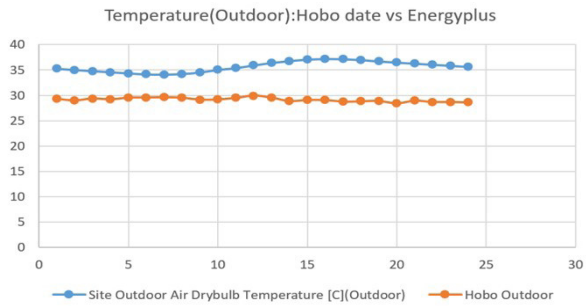


Figure 22: Temperature Comparison between Hobo data and Energyplus of the south-facing room made of Single brick wall

CONCLUSION

In this study, the thermal performance of the hostel rooms made of single brick walls and cavity walls for different orientations was investigated by field investigation and simulation study. Results show a significantly better result for the thermal performance (nearly 2ºC less temperature) of the room made with cavity wall, which was constructed with one-layer ceramic brick and one-layer fire burnt mud brick with plaster along with 15cm air gap. In case of orientation, South-facing rooms show the best results for both types of wall material.

The rooms of North and East show moderate performance while the room of west show poorest performance in terms of thermal performance. To verify the data found by Hobo data logger, Energyplus simulation was conducted for one study room of single brick wall. Results show little difference in some hour's data with the data of the same period investigated by Hobo data logger. This error might be solved by simulating more rooms selected for investigation. So, the key findings of the research are:

- Indoor temperature of west-facing room made of single brick wall of Shekh Rasel Hall gain 31.5ºC which is the highest temperature at 12 PM to 01 PM among all study rooms.
- Indoor temperature of south-facing rooms of Shamshen Nahar Khan Hall is more comfortable as it gains less temperature at that time (26ºC to 29ºC).

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• Thermal performance of west-facing rooms made of Cavity wall is better than the west-facing rooms of single brick wall, and temperature difference is around 2°C.

Considering time and resource constraints for the research, thermal performance of other materials was, however, beyond the scope of this study. The present work focuses mainly on performance of wall material used in two study buildings and finds out the best combination with specific orientation of the building in the context of Chattogram.

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