An Investigation of Thermal Comfort by Autodesk CFD Simulation at Indoor Living Space in Urban Residential Building in Monsoon Climate

Md. Shahriar Hossain, Ananya Abdhu, Md. Shohol Ebna Shad

Abstract: The global warming creates overheating problems, solar heat gain, increasing use of mechanical means. Urban residential areas suffer much with these problems in monsoon climate. Without keeping spaces around the building as mentioned in the provision and insufficiency of proper ventilation system increase the inside temperature. This paper only concentrates on the existing thermal condition inside the building which is based on the case studies. Khulna region has been selected for this case studies as Khulna region is in Bangladesh and exposed to monsoon climate. The thermal condition of the building has been observed by Autodesk CFD software simulation process. Finally, from the simulation result, it is determined whether the existing building design is comfortable for living purposes or not according to American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). Manual calculation of determining Temperature Humidity Index is also conducted here to understand the status. It is noted that this experiment has been done only for summer season as the temperature of winter season is reasonably adoptable.

Keywords: auto desk CFD simulation, thermal comfort; monsoon climate, urban residential buildings

1. Introduction
In the era of climate change and global warming, it is quite challenging and very fundamental to provide comfort for the occupants of a building. This paper represents case studies on residential building located at Khulna in Bangladesh, as monsoon climate governs on Bangladesh. Bangladesh is over populated country. Urban areas are greatly affected for this excess pressure of population. For this, urban residential areas are mostly critical to ensuring thermal comfort. In commercial buildings, HVAC equipment are widely used for the favour of employees working conditions, building location, materials etc. But in the residential buildings, there has always demand of occupants for daylight and sufficient air supply. In the case of choosing a building, they always prefer to live in comfortable zone. Occupants are also reluctant to use mechanical means to save energy and cost. Besides, the comfortable zone badly varies from rural to urban areas. The main aim of this research is to measure the thermal comfort for natural conditioned space in urban residential building in monsoon climate.

Experiments on existing buildings are based on the climatic data of June 2018 of Khulna region. Figure 1 shows the graphical variation of temperature of Khulna from the year 2009 to 2018. Here the maximum, average and minimum temperature at June 2018 is 36°C, 32°C and 29°C respectively.

Figure 1: Air Temperature at June 2018 (Source: Khulna Weather Forecast [9]).

Figure 2 shows the cloud and humidity value at June 2018 of Khulna. Here the black vertical bars represent humidity. The average humidity at June 2018 is observed 65%.

Figure 2: Relative Humidity at June 2018 (Source: Khulna Weather Forecast [10]).
2. Thermal Comfort Parameters and Autodesk CFD simulation

According to American Society of Heating and Engineers [1], thermal comfort is the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation. As exterior temperature in summer is higher than the comfort level, solar radiation leads to overheating as soon as direct sunlight penetrates the façade. But in winter, in contrast, direct sunlight is actually desired in order to reduce heating loads and electric consumption caused by artificial lighting [2]. For this, the main concentration of this paper is summer season.

Figure 3: Psychometric Chart [3]

In this paper, attention is given only at air temperature and relative humidity. From psychometric chart-ASHRAE 55, the approximate range of thermal comfort and relative humidity for human body is assumed 23-26°C and 20-60% respectively which is shown in Figure 1. Temperature humidity index (THI) also known as discomfort index (DI) is one of the variants of effective temperature (ET), developed by Thom [4]. According to Emmanuel [5], it combines the wet and dry bulb temperatures into a scale that imitates the thermal sensation of a human being. Nieuwolt [6] modified the index using air temperature and relative humidity. The following equation is used to determine THI-

\[ \text{THI} = 0.8T_a + \frac{\text{RH} \times T_a}{500} \]

Where \( T_a \) is the air temperature (°C) and RH is the relative humidity (%). By empirically testing the THI values on human objects, the comfort limits are defined as-

21≤ THI≤ 24=100% of the subjects felt comfortable
24<THI≤ 26=50% of the subjects felt comfortable
THI>26=100% of the subjects felt uncomfortably hot [7]

Computational fluid dynamics (CFD) is a branch of fluid mechanics that uses numerical analysis and data structures to analyse and solve problems that involve fluid flows. Autodesk CFD software is a fluid flow and thermal simulation tool which helps to predict product performance, optimize designs, and validate product behavior including thermal prototyping, architectural and MEP tools, and flexible cloud solving options. It also minimizes reliance on costly physical prototypes. Besides, it enables users to easily explore and compare design alternatives for better understand the implications of design choices using an innovative Design Study Environment and automation tools. Autodesk CFD supports direct data exchange with most CAD software tools, including Autodesk Inventor software, Autodesk Revit software, PTC Creo, Siemens NX, and Solid Works.

3. Methodology

3.1 Questionnaire Survey

Figure 4 show the questionnaire survey form used for this research. For more details, please see the Appendix A. It contains project details, number of ventilations, thermal comfort level both at summer and winter, adequacy of daylight and finally building plan. Project detailing section includes information of plot and building area and dwellers. There has also an enquiry about the implementation of internal shading device and the surrounding obstacles which are important issue to measure thermal comfort level inside the building.

Figure 4: Questionnaire Survey form

3.2 Simulation Steps

Step 1 - 3D Modeling of Existing Building in Autodesk Revit for Simulation

From the field survey, the existing buildings are modelled in Autodesk Revit for simulation process. Here sample for one project has been shown below in figure 5 and 6.

Figure 5: Typical floor plan of surveyed building
Step 2 - 3D Modeling of Existing Building in Autodesk Revit for Simulation
To import the existing 3D model of Autodesk Revit into Autodesk CFD, the active model in CFD add-ins has been launched in Revit. Then inside CFD, the step mentioned below has been performed. (Setup → Geometry Tools → Ext. Volume)
- Creating Virtual Volume Environment for the Simulation case

Step 3- Assigning Building Materials Properties in the model
The required properties of materials such as bricks, concrete, air etc. have been defined here to use for the simulation.

Step 5- Meshing Model for Simulation Solver
For the accuracy of simulation process, meshing of model is necessary. The approximate number of meshing element is 440k for the model.

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Step 7- Solve Simulation Process
At last, simulation process has been solved as per the following methods.
- Defining Solar Heating Factors for Khulna
- Define Thermal Comfort Factors as per ASHRAE

4. Result and Discussion
From the questionnaire survey report, it is seen that maximum buildings is exposed to extremely hot temperature and to prevent the penetration of solar heat, there is no arrangement of shading device. It is also observed that there is insufficiency of daylight because of the surrounding building block. It affects the work efficiency and mental and physical health.

<table>
<thead>
<tr>
<th>Project No.</th>
<th>Level of Thermal Comfort at Summer</th>
<th>Level of Thermal Comfort at Winter</th>
<th>Arrangement of Shading Device</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hot</td>
<td>Cold</td>
<td>No</td>
</tr>
<tr>
<td>2</td>
<td>Extremely hot</td>
<td>Cold</td>
<td>No</td>
</tr>
<tr>
<td>3</td>
<td>Extremely hot</td>
<td>Cold</td>
<td>Yes</td>
</tr>
</tbody>
</table>

4.1 Temperature Humidity Index
From the study about air temperature and relative humidity at June 2018 of Khulna region, the maximum temperature is 36°C and relative humidity is 65°C. According to the equation, the determined THI value is 33.48 which is greater than 26. This means it is 100% felt uncomfortably hot in Khulna region.

\[
THI = 0.8T_a + RH \times T_a ÷ 500 \\
= 0.8 \times 36 + 65 \times 36 ÷ 500 \\
= 33.48 > 26
\]

Likewise the average temperature at that month is 32°C. After calculation, the value of THI is approximately 30 which means the subjects are felt 100% comfortable as per Kakon et al. (2009) [7].

\[
THI = 0.8T_a + RH \times T_a ÷ 500 \\
= 0.8 \times 32 + 65 \times 32 ÷ 500 \\
= 29.76 > 26
\]

Again the minimum temperature at the same month is 29°C. Then the value of THI is almost 27°C. If the temperature can be reduced around 1°C to 2°C, the THI value can be within 24 and 26 which depicts occupants can feel 50% comfortable. It satisfies the research objectives to some extent as thermal comfort is a psychological matter stated before. So, if the temperature can be minimized into 27°C to 28°C, the research purpose can be satisfied.

\[
THI = 0.8T_a + RH \times T_a ÷ 500 \\
= 0.8 \times 29 + 65 \times 29 ÷ 500 \\
= 26.97 > 26
\]

4.2 Simulation Result
Figure 7 represents the simulated temperature of whole building block including the surrounding area. Temperature gradient is shown at the left side of the display and the range of temperature gradient is 19°C to 35°C. Here 19°C denotes the coldest temperature for this experiment and 35°C denotes the hottest temperature. The temperature inside the building varies from 25°C to 35°C. The dominant temperature of maximum coverage is between 28°C to 30°C. The maximum temperature is seen at the west side which is marked with red colour fill. The rest portion of the building is seen quite tolerable compared to west zone.
The hottest zone of the building has been focused in figure 8. It shows that the maximum temperature inside the building governs at the west side which is indicated with a plane of blue colour.

The temperature gradient for comfort temperature has been shown below of the temperature gradient. From this scenario, decision has been taken that the proposed solution has to be implemented at west zone of the building.

Figure 10 shows the convergence plot where the performing number of iteration or step is 100. The convergence plot can be defined as a graphical representation of information listed within the analysis log file. Here the red line shows the temperature curve which the main concentration of this research. The blue, green, magenta and black colour line represents velocity at X axis, velocity at Y axis, velocity at Z axis and pressure curves respectively. From the temperature curve, it is seen that after a certain period temperature suddenly rises up at a maximum value and it is decreasing very slowly. The rising temperature belongs at west side of the building.

Figure 11 exhibits the velocity magnitude in m/s where it illustrates that the air flows from south to north and enters into the window of south direction. Here the range of velocity magnitude gradient varies from 0 to 6.38 m/s. The value of velocity for the hottest temperature for this research is 6.38 m/s which is indicated with red colour. From the figure, it is seen that hot air is entered inside the building from the surrounding and it then spreads among the rooms and increases the inside temperature of the building.

Figure 12 depicts the temperature graph of west side rooms from south to north at summer, June 2018. The parametric distance of west side is 406.2 inch and the highest temperature at that side is approximately 34.5°C.
5. Conclusion and Recommendation

From the study it has been seen, the temperature of Khulna region is very critical. Maximum buildings are exposed to extremely hot condition according to questionnaire survey. The surrounding environment that is building block, narrow spaces affect the internal environment and thus the temperature inside the building rises up. It prohibits dwellers to work with efficiency and also create psychological problems.

However this solar heat gain problems can be minimized through various solutions like using insulating material, shading devices, design tools and techniques etc. Further research is suggested to apply these design solutions and optimize the comfort level.

Appendix A

Questionnaire Survey form on Thermal Comfort in Khulna

Project location:
Plot area:
Maximum Ground Coverage (MGC):
Building Setback:
Flat Area:
Building Orientation:
Number of Rooms and Occupants

<table>
<thead>
<tr>
<th>rooms</th>
<th>occupants</th>
</tr>
</thead>
</table>

Number of windows and ventilation systems inside the apartment:

<table>
<thead>
<tr>
<th>windows</th>
<th>ventilations</th>
</tr>
</thead>
</table>

How do you describe the typical level of thermal comfort at summer?

<table>
<thead>
<tr>
<th>Extremely hot</th>
<th>Hot</th>
<th>Warm</th>
<th>Slightly Warm</th>
</tr>
</thead>
</table>

How do you describe the typical level of thermal comfort at winter?

<table>
<thead>
<tr>
<th>Extremely Cold</th>
<th>Cold</th>
<th>Slightly Cold</th>
</tr>
</thead>
</table>

Is there any shading devices?
Yes ☐ No ☐

Are there any obstacles around the building which hinders air flow and sun light from entering into the room?
Yes ☐ No ☐

If your answer is yes, what they are?

Drawings of building floor plan:

References


Author Profile

Author 1 received the B.S. degree in Architecture from Khulna University in 2016. In 2017, he joined in Khulna University of Engineering and Technology. He is now lecturer of Department of Building Engineering and Construction Management, Khulna University of Engineering and Technology.