A WIND TUNNEL STUDY ON THE EXTERNAL PRESSURE DISTRIBUTION ON A TYPICAL BANGLADESHI RURAL HOME

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Introduction

During the last few years, engineers have increasingly realized the importance of wind loads for all types of structures. Some recent disasters (such as the 1991 tornado in the Bay of Bengal, 1993 Hurricane Emily, 1998 Hurricane Georges in USA) are vivid examples of what can happen if wind effects are not fully taken into account. Except by hurricanes and tornadoes, complete destruction of buildings by wind is rare. However, by local failures of roofs, claddings, and glass are both common and more costly in the aggregate than all the complete failures. Single-family houses in high-wind areas experience large, negative roof pressures that can lead to local failures. The shape of the roof seems to be a major factor in the extent of damage. Another major factor is the amount of the roof overhang. More information describing the wind loads on house roofs is needed so that roofs can be designed against such local damage. The purpose of this study is to determine the external pressure distribution over a typical gabled roof for different wind speeds and direction. The effect of roof pitch angle has also been studied.

Housing practice in Bangladesh

The majority of houses in the wind hazard zones of Bangladesh fall under the category of non-engineered structures. These are the traditional self-built housing for the poorest class of people. These structures, mostly with thatched roofs, are not covered in any code. They exhibit little or no resistance to extreme winds. Collapse of this category is responsible for the majority of loss of life and injury during cyclonic storms. An improvement in their wind resistance potential will significantly contribute to minimize loss of life and property.

During the last few years, a number of projects have been undertaken in different parts of the world aimed at developing techniques for reducing the vulnerability of non-engineered construction against extreme winds (NBS, 1977). Most of the houses of rural Bangladesh are designed and built by owners or artisans. Well documented literature regarding this type of housing is unavailable in Bangladesh. There is a necessity for bridging this gap by transferring technology to the people, mostly living in the rural areas, who are actually involved in non-engineered construction. Following steps are proposed by Choudhury (1996) which may be used: *Translate the guidelines by Bangla. Train the trainers by BUET, HBRI in association with NGOs. Training programmes for the artisans (masons, carpenters etc.). Use of mass media to demonstrate good practices. Experiences of other country shows that post-disaster reconstruction provides an excellent opportunity for introducing improvements in housing technology.*

Wind risk areas

Wind in the first 1000m of the atmosphere is of boundary layer nature. This means that shear forces within the wind flow are significant. Wind velocity can be considered as a low frequency velocity-time wave superposed with a higher frequency, velocity-time wave. These high frequency waves represent wind-gust, which is recorded as an average velocity for a particular time interval. Recently a comprehensive National Building Code has been formulated (BNBC, 1993) in Bangladesh. Figure 1 shows the basic wind speed map of the country as presented in BNBC.

Improved domestic construction

According to a recent ADB report (Lewis and Chisholm, 1996), 82% of dwellings in Bangladesh are in rural areas, 75% of rural areas are of kutcha construction (non-masonry; bamboo, woven bamboo, etc.), and that 23% of urban and more than 40% of rural dwellings are of a temporary nature.

Evidence from the field in cyclone-prone areas indicates that there is a socially perceived need for improved construction of domestic dwellings and that assistance to build stronger homes would be appropriate. Traditional materials for domestic construction include bamboo and jute poles, woven bamboo, mud, thatch, timber, very often in combination with cgi sheet, and in varying combinations and preferences overall according to region and material availability. Generally, floor is composed of mud plinth or raised timber, frame is made of bamboo poles or jute poles, walls are made of woven bamboo, mud or cgi sheet and roof is composed of thatch or cgi sheet.

Lewis and Chisholm (1996) proposed several improvements. Buildings should be sited with trees so as to protect each other. Clustering achieves a degree of mutual protection that linear layouts do not. Protection from normal wind and weather as well from cyclonic winds is also advantageously achieved. Frame will be improved with the inclusion of cross bracings as shown in Figure

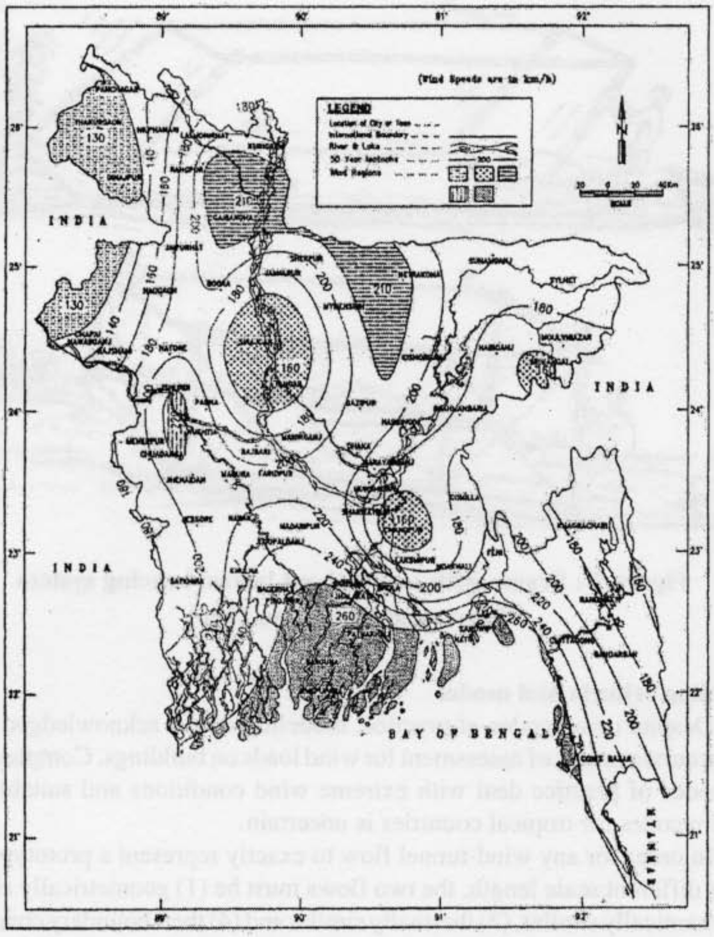

Figure 1 : Basic wind speed map of Bangladesh (BNBC,1993)

2. Frame members are normally lashed together with jute rope, which can be substituted with galvanized wires. Walls and openings can be improved by placing door in the center of the wall and placing a small window opening in the rear. Roof system can be improved by increasing the pitch of the roofs to between 30 to 40 degrees, tying down the thatch, improved fixings for cgi sheet.

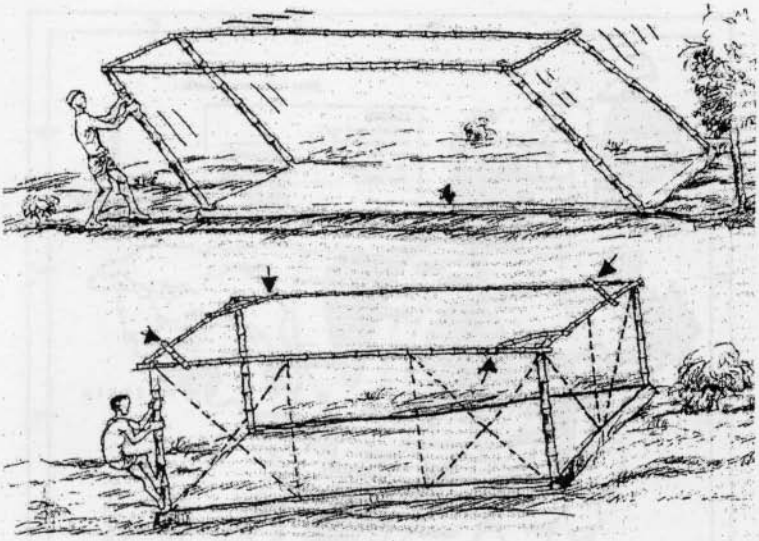

Figure 2 : Frame with and without lateral bracing system (Lewis and Chisholm, 1996)

Modeling criteria and model

Despite many codes of practice, modeling is still acknowledged as the only accurate means of assessment for wind loads on buildings. Comparatively few codes of practice deal with extreme wind conditions and suitability of western codes for tropical countries is uncertain.

In order for any wind-tunnel flow to exactly represent a prototype flow with a different scale length, the two flows must be (1) geometrically similar, (2) dynamically similar, (3) thermally similar and (4) their boundary conditions must be similar. These similarity conditions are described by performing an inspectional analysis of the governing equations of motions (continuity, momentum and energy). Unfortunately, exact simulation of the atmospheric boundary layer in a wind-tunnel is not presently possible. As a result, approximate or partial similarity is achieved by requiring exact equality for the most important factors while those of lesser importance are approximated.

The wind-tunnel used to simulate flow conditions in these experimental investigations was a low-speed wind-tunnel at the Fluid Dynamics Laboratory, School of Engineering, the University of Exeter, UK. The wind-tunnel used for this project is a closed jet tunnel with working section approximately 0.5m high by 0.75m breadth and 1.5m in length. Traditionally, the velocity in the tunnel was measured by an inclined water-column pressure system. In addition to that a Pitot-static tube connected to a micromanometer system was used to calibrate the tunnel velocity. Figure 3 shows the wind tunnel used in this study.

Figure 3 : Wind tunnel used in the present study

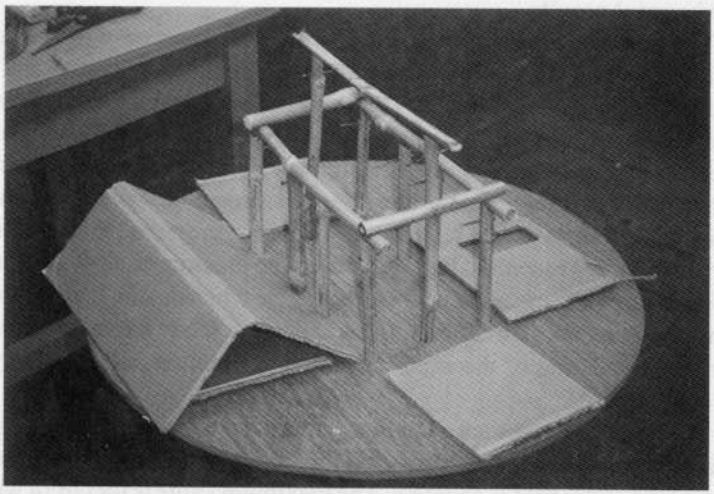

Figure 4 : Model of rural hut (1:20 scale)

The 1:20 scale model house as shown in Fig. 4 was constructed by the researchers using cardboard boxes and bamboo shoots. Fourteen pressure taps were located where wind-induced pressures were expected to be the largest. The pressure taps were made by drilling 2 mm holes on the roof and the walls. Figure 5 presents the pressure tap arrangements in the rigid base model and Fig. 6 shows the pressure tap arrangements in the flexible base model. Table 1 presents the total test scheme on the 1:20 scale model hut in the wind-tunnel.

Table 1. Information of one-twentieth scale rural hut

Height = 0.125m, breadth = 0.15m and length = 0.25m	
Types of structure	Rigid and Flexible base
Velocity (m/s)	10, 15, 20, 25, 30 and 35
Variation of roof pitch (degree)	30, 35, 40 & 45
Angle of model's front from the incident wind in degrees	0, 30, 60, 90, 120, 150, 180, 210, 240, 270, 300 & 330
Variations	Door, door+tree and door+window
Pressure measurements	14 locations for rigid base (see Figure 5) 14 locations for flexible base (see Figure 6)

Experimental results

The instantaneous peak pressure was measured at each of the 14 pressure taps shown in Figures 5 and 6, for 12 wind directions, 7 velocities and 4 roof pitches as mentioned in Table 1. The wind is blowing from a fixed direction within the wind tunnel. The model hut was rotated using a circular base connected with the bottom of the wind tunnel. Figure 7 shows model rural hut together with the rotating base. The interval of rotation was 30^0. At each 30^0 rotation of the hut, pressure tap readings from the pressure bank system were read manually and recorded. Figure 8 shows the pressure bank system, and the velocity control and measurement system in the wind-tunnel. It also shows the micromanometer used for calibrating the existing velocity measurement device. Before the beginning of the experiments, the velocity measurement systems were calibrated.

The peak pressures are plotted as a function of wind direction in Fig 9. This is only for a velocity of 20 m/s and for a rigid base model. The pressure on the top of the entire roof is negative. The maximum value is for tap 14 when the hut was rotated 60^0 from the wind direction. Figure 10 shows the relationship between wind tunnel velocity and pressure distribution for various angle of model's front from the incident wind. Tap 2 was located

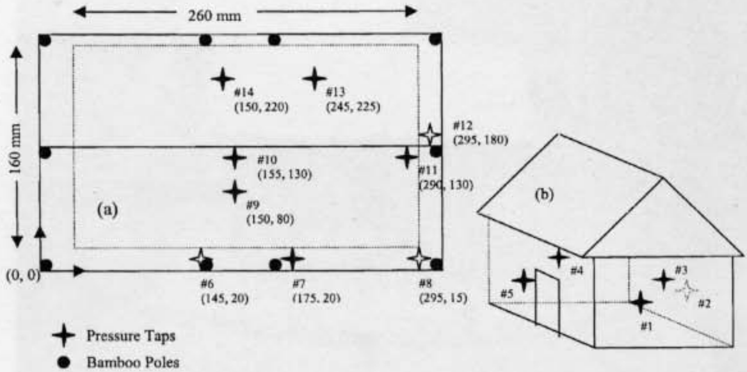

Figure 5 : Dimensions shown are for 1/20th scale model with rigid base (a) top view and (b) side view of model hut showing location and numbering of pressure taps (Hollow taps are placed inside the roof and wall)

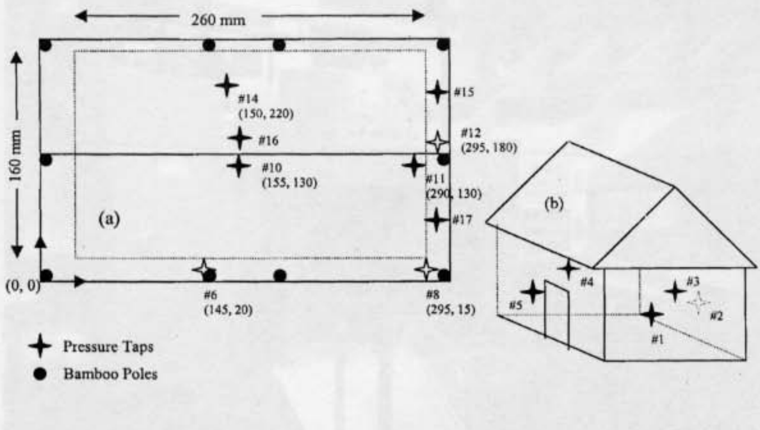

Figure 6 : Dimensions shown are for 1/20th scale with flexible base model (a) top view and (b) side view of model hut showing location and numbering of pressure taps (Hollow taps are placed inside the roof and wall)

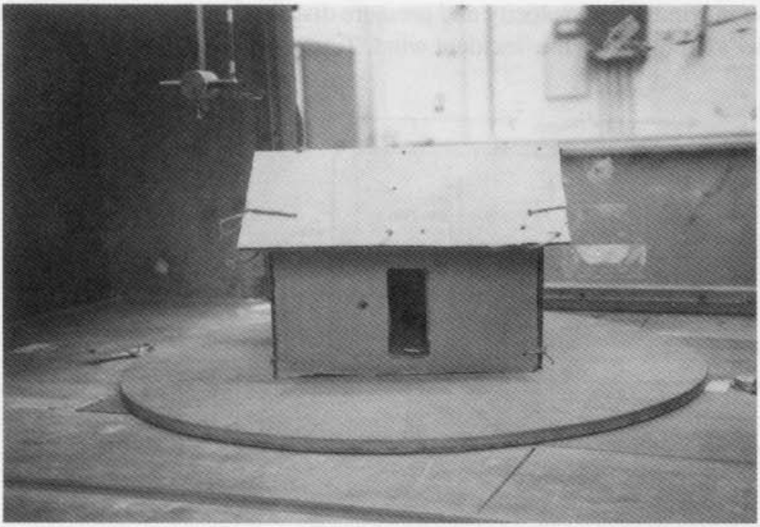

Figure 7 : Model rural hut with rotating base

Figure 8 : Pressure bank, velocity control and measurement system of the wind tunnel

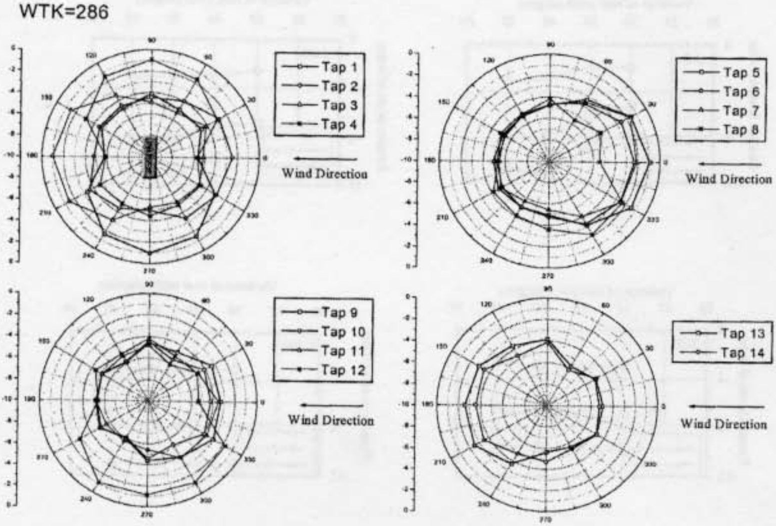

Figure 9 : Pressure distribution for various angle of model's front from the incident wind and for wind-tunnel velocity of 20 m/s (rigid base, pitch=45^{0})

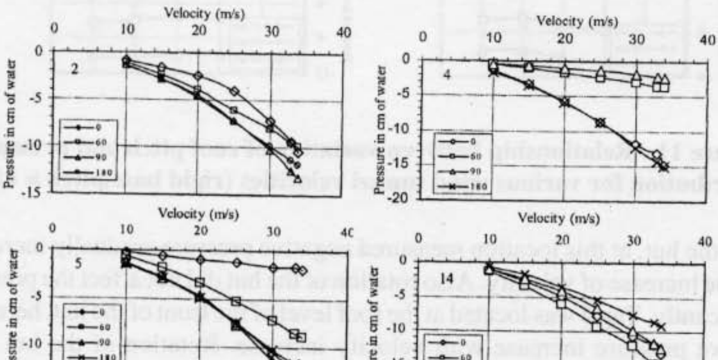

Figure 10 : Relationship between wind tunnel velocity and pressure distribution for various angle of model's front from the incident wind (rigid base, pitch=45^{0})

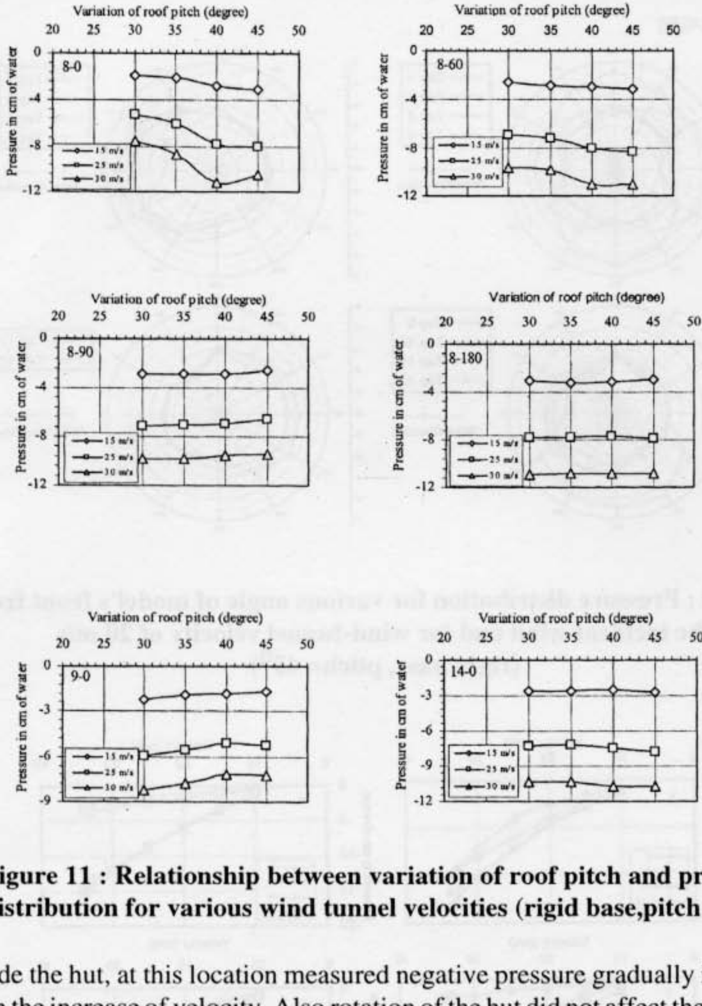

Figure 11 : Relationship between variation of roof pitch and pressure distribution for various wind tunnel velocities (rigid base,pitch = 45^{0})

inside the hut, at this location measured negative pressure gradually increases with the increase of velocity. Also rotation of the hut did not affect the pressure significantly. Tap 4 was located at the roof level of the front of the hut, here also negative pressure increase with velocity increase. Rotation of the hut with respect to the wind direction had significant effect on the measured negative pressure. It was high for 0^{0} and 180^{0} whereas very low for 60^{0} to 90^{0}. For tap 5, hut rotation had significant effect on the measured pressure but for tap 14, the effect was small. Figure 11 shows the relationship between variation of roof pitch and pressure distribution for various wind tunnel velocities. Variation of roof pitch was low for taps 9 and 14, whereas significant effect was observed for tap 8. Higher wind tunnel velocity had higher effect on the measured pressure.

The peak pressures are plotted as a function of wind direction in Fig 12. This is only for a velocity of 20 m/s and for a flexible base model. The maximum value is for tap 16 when wind is coming at 210 angle.

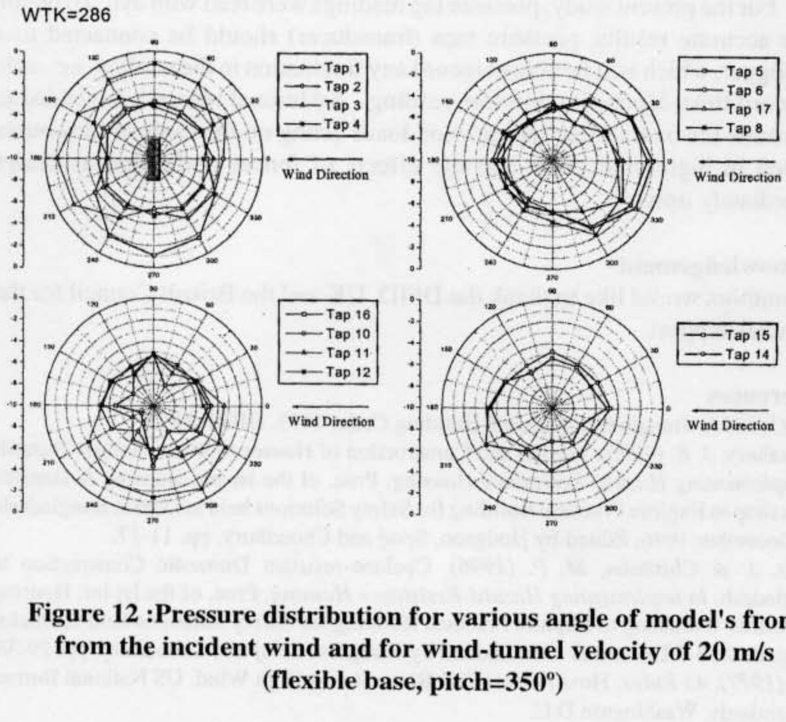

Figure 12 :Pressure distribution for various angle of model's front from the incident wind and for wind-tunnel velocity of 20 m/s (flexible base, pitch=350°)

Concluding remarks

A detailed wind tunnel experiment on a typical Bangladeshi rural hut was carried out. In the experiment, a 1:20 scale model of a typical Bangladeshi rural hut was made. The external peak pressure was measured at different locations which was considered to be significant on the model for different wind speeds in smooth flow condition. The external pressure over both the windward and leeward roof was found to be negative i.e. suction. This low pressure was created by the tunnel fan located at the downstream of the model as the fan creates a low-pressure region on its upstream and high-pressure region in the downstream. Measurements of pressure were also made at different roof pitch angles and significant effect of roof pitch was observed on the pressure at overhang compared with other locations on the model. With the increase of wind velocity in the tunnel, negative pressure at different locations increases. Direction of wind has significant effect on the external pressure distribution on the model and the effect is maximum for the wind normal to the breadth of the model.

For the present study, pressure tap readings were read with eye. To obtain more accurate results, pressure taps (transducer) should be connected to a datalogger, which will be able to record any fluctuation in the reading, i.e., able to record time-dependent pressure reading. Additional research is needed to determine the overall fluctuating wind loads acting on the roofs of the houses located in high-wind areas and the effects of fences and other structures immediately upwind.

Acknowledgement

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