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OPTIMUM WINDBREAKER TO REDUCE WIND TUNNEL EFFECT ON OCCUPANT COMFORT AT PEDESTRIAN LEVEL (A CASE STUDY OF BAU BUILDING IN TRIPOLI)

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OPTIMUM WINDBREAKER TO REDUCE WIND TUNNEL EFFECT ON OCCUPANT COMFORT AT PEDESTRIAN LEVEL (A CASE STUDY OF BAU BUILDING IN TRIPOLI)

Abstract

Shape, size, building orientation and its interaction with the surrounding buildings can cause wind tunnel that affect the pedestrian comfort. This paper aims to select the optimum windbreaker height and thickness for reducing the effect of wind tunnels on pedestrian comfort, by selecting the building of Beirut Arab University (BAU)-Tripoli campus as a case study. Different alternative designs have been simulated and compared with the comfort criteria of pedestrians to conclude the optimum solution that can be adapted on the selected building and on any other cases that have similar characteristics.

Keywords

Wind tunnel, wind simulations, pedestrian comfort, windbreaker

1. INTRODUCTION

Interaction between wind and buildings plays an important role in dealing with outdoor human comfort in an urban climate. Buildings can create large air currents and wind flow with high speed and low pressure, due to its location, orientation, shape and height and its interaction with the surrounding. Yet the distances between the building's blocks and the impact of these distances on the movement and the pressure of wind, causes wind tunnels that leads to uncomfortable and dangerous conditions for pedestrians. This paper discusses the effect of wind tunnels produced by the building form on pedestrians, and aims to develop a methodology to optimize windbreaker configurations to reduce the effect of wind tunnels on pedestrian comfort. This paper neglects materials, orientation, void volume fraction of windbreaker, and its distance from area to be protected, and only focuses on height and thickness.

1.1. Research Methodology

This paper is divided into four sections: part one is literature review about similar studies, part two discusses the selection of the case study, part three studies the assessment of pedestrian wind comfort, part four is simulations of different windbreaker configurations models using Autodesk Flow Design software, and analytical study of results, part five is the conclusion of the study

1.2. Literature Review

The literature review in this paper discusses the dangerous effects of wind tunnel on pedestrian, and states the use of trees as windbreaker; also it illustrates the different windbreaker parameters. Then it outlines three studies: the first is by Revenkar that discusses the optimum windbreaker configurations, the second is by Celine Biggore that discusses the optimum wind assessment software, and the last discusses the different criteria of wind comfort. Researchers have investigated many studies of wind effect on pedestrian comfort. Penwarden proposed that pedestrian discomfort starts when the wind speed is higher than 5m/s (A.D.Penwarden, 1973). Also Penwarden and Lawson reported the death of two elderly women after they fell in response to the forces of high-speed winds at the base of a building (Lawson, T. V., & Penwarden, A. D, 1975). A wind tunnel study was carried out to examine the effects of various tree configurations on wind-induced air infiltration and structural loading of low-rise buildings. The results showed that a single row, high density windbreak reduced air infiltration by about 60% when planted approximately four tree heights away from the building (Theodore Stathopoulos, 2003). A windbreaker efficiency is evaluated based on its height, its length, the wind incidence and its porosity (Bigorre, 2015). A study by Revankar, has investigated the optimum configuration of windbreaker to reduce sustained wind speed of 44.7 m/s on a modular data center, by using different parameters of windbreakers such as height, length, distance from area to be protected, orientation, and void volume fraction, at a distance of 0.3m from the wall of the data center. Using FloTHERM 10.1 to model the windbreaker, two windbreakers are used as a split wall, one on the ground and other on the roof of the modular data center. The optimum height of windbreakers is equal to the height of the data center; however, the length of a windbreak should exceed the height by 1/10 for maximum efficiency. The optimum distance should be very close to the protected area, and the most effective orientation for a windbreaker is to have it perpendicular to the prevailing winds. In addition, the optimum density to provide the greatest downwind area of protection is between 40 and 60 percent, which is 30% void volume fraction (Revankar, 2015). A study by Celine Biggore, focuses on the wind flows impact in urban context on the outdoor and pedestrian comfort. The assessment of the impact of buildings on one another, has been simulated by using Autodesk Flow Design, after proposing eight different softwares: Vasari, N3S, CitySim, Archiwizard, Solene, Envi-met, Urba-wind, and Autodesk Flow Design. Each software has been rated one out of five according to: license cost, quantity of data needed, use of UP activity models, time to run the simulation, study area size, accuracy, take topology into account, and visual features. The results give the Autodesk

Flow Design a 3.35 as the best choice, UrbaWind a 3.2 as second choice, and Solene a 3.15 as last choice (Bigorre, 2015). Several criteria have been developed in the wind engineering community for evaluating only the wind-induced mechanical forces on the human body and the resulting pedestrian comfort and safety (Stathopoulos, 2009). Stathopoulos displays In European & African Conferences on Wind Engineering (EACWE) 5th. 2009, the different wind criteria. Beaufort criteria is used in ship navigation, Pendwarden and Wise criteria consider the acceptable wind conditions is when the wind speed is less than 5m/s. The Melbourne criteria depends on mean and gust speeds, only for daylight hours and on the assumption that the max 2-sec gust speed will be roughly twice as large as the mean speed, for cities with harsh winter conditions (Stathopoulos, 2009). Isyumov and Davenport criteria specify frequencies of occurrence instead of specifying wind speed. Lawson criteria takes into account human activities in terms of wind speeds assessed at 1.5m above ground level. NEN 8100 criteria (Netherlands Standards) in not a legal building requirement, but a helping hand to include wind comfort in a building programme that defines five grades of wind comfort A-E. The corresponding P-ranges are in agreement with the attainable overall accuracy in wind tunnel simulations. The maximum shift in comfort grade due to possible errors is one grade (Eddy Willemsen; Jacob A. Wisse, 2007). Bottema has proposed a method for optimizing wind discomfort criteria, after comparing different criteria. Revankar has studied the height, length, distance from area to be protected, orientation, and void volume fraction of the windbreaker (Revankar, 2015). However, this study only focuses on the optimum windbreaker height and length to reduce the mean velocity of air downstream of the windbreaker, thereby reducing the wind loading on pedestrian behind the barrier. The wind assessment in this paper is done by using the Autodesk Flow Design software, which was used by Celine Biggore study after proposing eight different softwares (Bigorre, 2015). The comfort criteria of Bottema (Bottema, 2000) will be used in this study.

1.3. Case Study

The building of Beirut Arab University (BAU) of Tripoli has been selected as a case study, since students suffer from a serious wind tunnel effect problem that causes discomfort and dangers at times. The BAU building which faces the sea front, consists of five blocks separated by a distance of 12 m each, leading to the formation of strong wind tunnels that affect pedestrian comfort when the wind is in high speed, especially in winter conditions, Where wind tunnel effect can be felt flowing between building's blocks, which form a rectangle with narrow passageways with 53m long and 12m width. Therefore, the air pressure drops, causing the wind to move faster and circle between the two buildings. This spot is notorious among students because of the whipping winds that hit them. Many students find themselves leaning forward in order to make their way up the passageway. Thus, a number of tests and building simulations have been conducted to describe these wind tunnel effects using Autodesk Flow Design software as a simulation tool, taking into account Bottema criteria of pedestrian comfort code, as shown in table 1.

Table 1: Observed wind effects on people – Source: (Bottema, 2000)

Wind Speed (m/s)	Wind Effect
4.0	Clothing flaps
5.0-6.0	Hair is disturbed/ Hair disarranged
10.0	Irregular footsteps, walking difficult to control
11	Difficult to hold umbrella (wind tunnel)
12	Violent flapping of clothes
13-14	Appreciably slowed into the wind
15	Walking difficult; dangerous for elderly person Impossible to hold umbrella (wind tunnel)
16	Blown sideways
17	Appreciably slowed into the wind
18	Almost halted in the wind
19	Uncontrolled tottering walking downwind
20	Great difficulty with balance in gusts
23	People blown over by gusts
24	Unbalanced, grabbing at supports

2. PEDESTRIAN WIND COMFORT ASSESSMENT

Consequently, to assess the wind comfort, a weather data of the “wind rose” that presents wind speed and direction for the BAU location have been obtained to predict wind behavior, vortex, and wind tunnel of the building in its location (figure1). The results obtained will be used to assess the pedestrian comfort around the building, showing the severity of the wind tunnel and how much it affects the pedestrian comfort. Overall, Tripoli averages wind speeds of 4.5m/s (figure 2). Contributing to the city’s wind speed is the jet stream that hits Tripoli from west throughout the year (figure 3). Another factor is the cooler air over the sea being pushed toward land. This “sea breeze” is more common in El Mina - Tripoli than it is in other places because wider bodies of water surround El Mina.

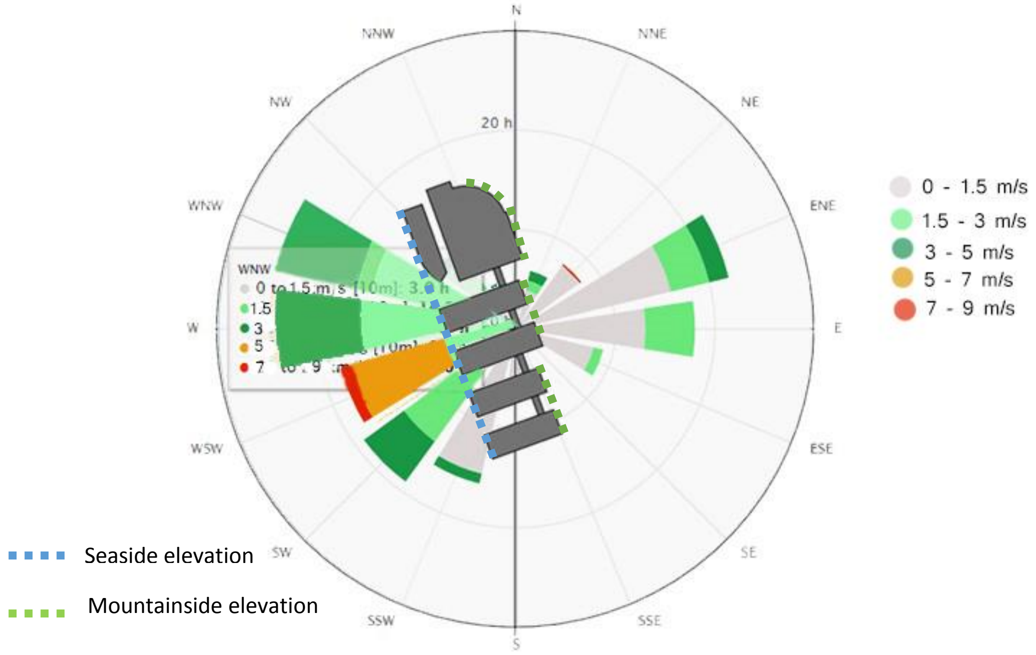

Fig. 2: The Wind Rose of Tripoli
Source: (Climate (modelled) Tripoli, 2019), while the illustration is done by Authors

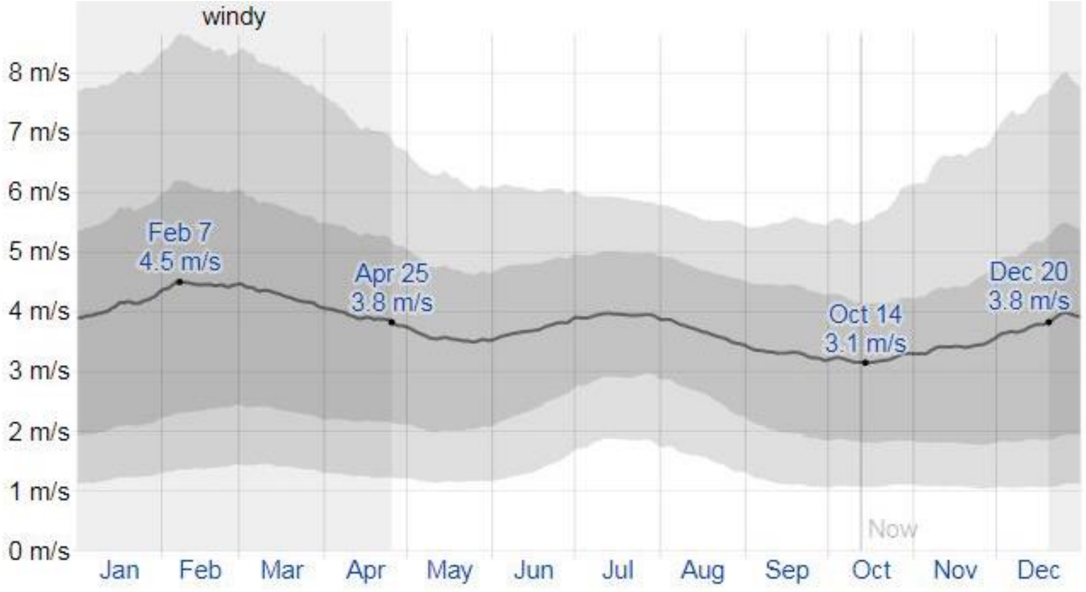

Fig. 2: Average wind speed for Tripoli
Source: (Average Weather in Tripoli Lebanon, 2017)

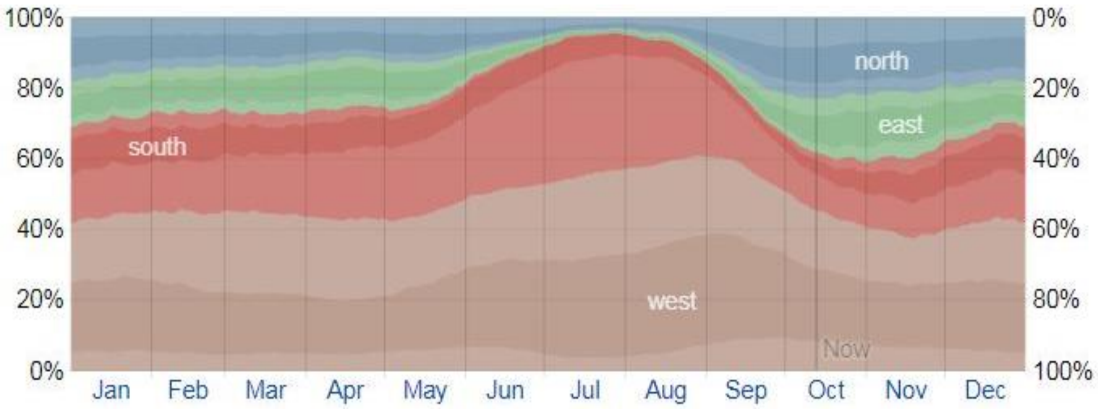

Fig. 3: Tripoli wind directions throughout the year
Source: (Average Weather in Tripoli Lebanon, 2017)

According to previous charts, The BAU building in its location shows a serious wind velocity that can create wind tunnel between the building's blocks, which can affect the pedestrian comfort, especially because the predominant average hourly wind direction in Tripoli is from the west throughout the year. A wind flow simulation study on the existing building has been generated by using Autodesk Flow Design (figures 4 and 5).

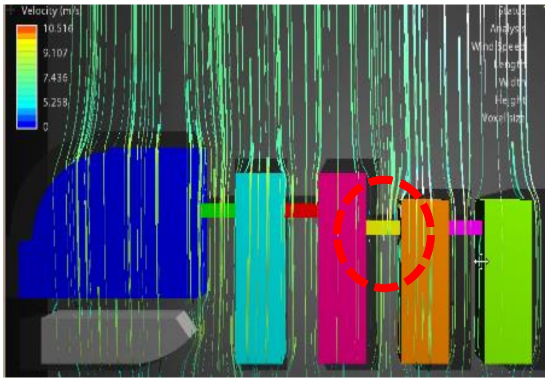

Fig. 4: Wind tunnel simulation between BAU building's blocks (wind speed 5m/s)
Source: Authors

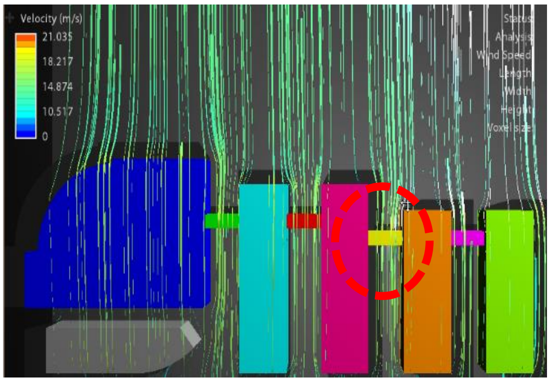

Fig. 5: Wind tunnel simulation between BAU building's blocks (wind speed 10m/s)
Source: Authors

Pedestrian of BAU building can perceive the motions of the building, which is not designed carefully to reduce wind acceleration, and not followed any structural design wind standards such as Australian/New Zealand Standard 1170.2:2011, American Standard ASCE 7-02, National Building Code of Canada, and the Eurocode that provide a detailed instruction on assessing along-wind and cross-wind accelerations. However, some design modification can be applied on the existing building to reduce the wind tunnel effect on pedestrian, by taking into consideration, the existing building case where limited modifications are allowed. The area of study will be between the two blocks as shown in figure 4 and figure 5, which can be applied on all areas between the other blocks.

3. WINDBREAKER DESIGN CONFIGURATION

There are many types of windbreaks, including natural trees and artificial fences used for reducing wind speed and improving pedestrian comfort. The main parameters that define the amount of wind speed reduction are height, width and void volume fraction of windbreaker. Many researchers have carried out studies of sheltering effects of windbreaks. Heisler and Dewalle have studied the effects of windbreak structure on wind flow, in which the effects of a windbreak on air movement are examined in details (Gordon M.Heisler; David R.Dewalle, 1988). Wang and Tackle conducted a series of numerical studies about the wind flow pattern around windbreaks (Hao Wang; Eugene S. Takle, 1996).

This paper neglects the materials, porosity, and distance of windbreaker from the air flow, and studies the optimum height and thickness of windbreaker, by suggesting five different windbreaker's height, and studies the effects of wind tunnel on the pedestrian comfort in each case at 3m height in the selected areas between the building's blocks. The optimum height of windbreaker will be tested depending on three different thicknesses: 10, 30, and 60 cm. Simulation of each windbreaker's height is used to occur fast iterations with low detail levels, and these inform the design process. Then, detail design is being supported by simulation. In the aim of assessing the optimum pedestrian comfort design against wind tunnel effect, the wind behavior is analyzed. In the first scenario, the 1m windbreaker's height wall has been simulated. The focus will be on wind velocity at 3 m height value in the selected areas between the building's blocks (Figure 6).

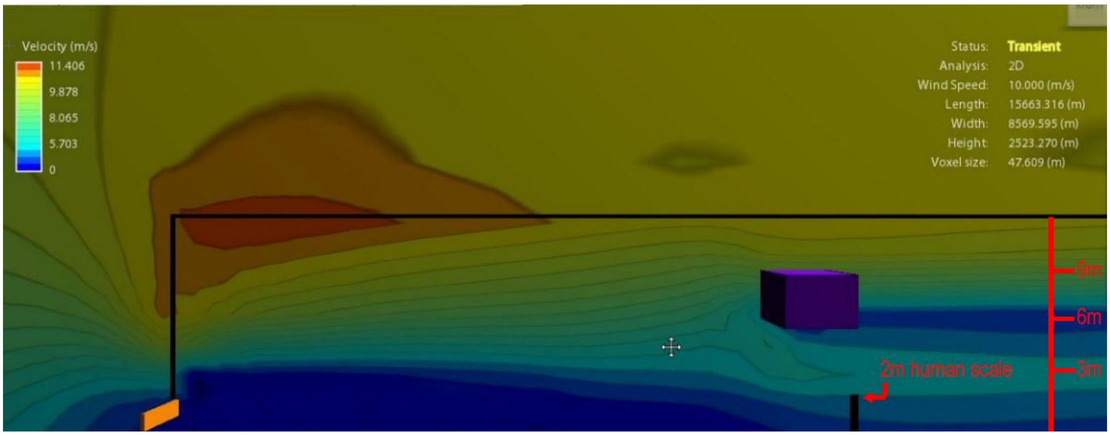

Fig. 6: Wind tunnel simulation between BAU building's blocks after using 1m windbreaker (wind speed 10m/s) - Source: Authors

The result shows high wind velocity on pedestrian level, wind accelerations are still on the interest regions between five and seven m/s, which constitute an uncomfortable condition for pedestrians according to Bottema investigation (table 1) when the wind speed attend 10 m/s causing irregular footsteps, and difficult to control walking. A second scenario has been proposed by using 1.5m windbreaker. The proposed design is simulated (figure 7) and the results don't show any reduction of wind flow than the previous proposal. In the third scenario, a 2m windbreaker is simulated (figure 8). The result shows a low reduction of wind velocity at pedestrian level, wind speed in the interest regions is between four and six m/s.

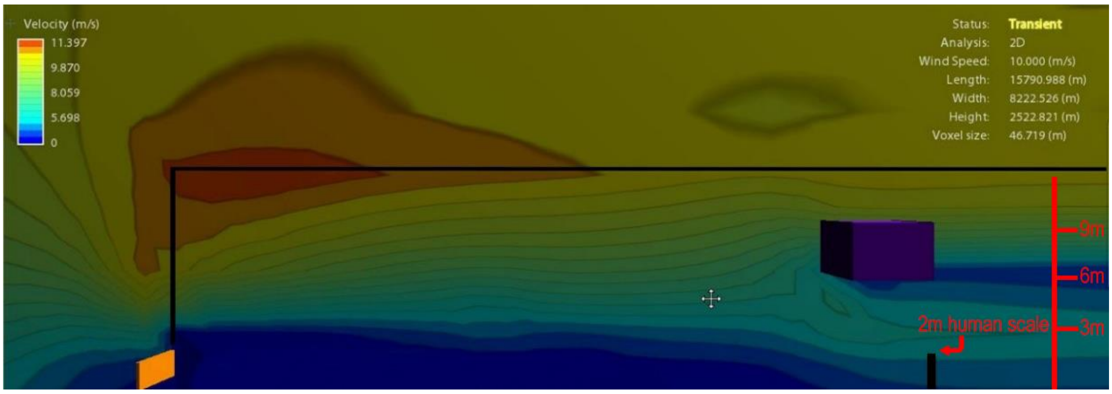

Fig. 7: Wind tunnel simulation between BAU building's blocks after using 1.5m windbreaker (wind speed 10m/s) – Source: Authors

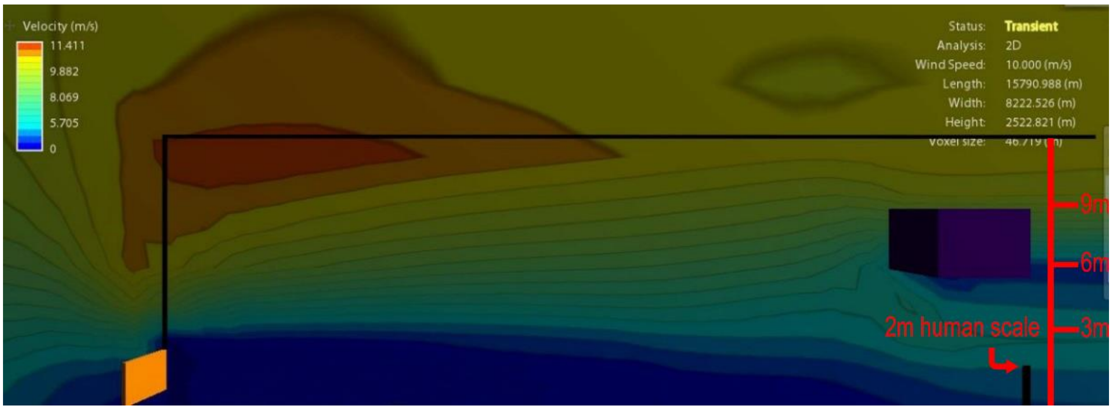

Fig. 8: Wind tunnel simulation between BAU building's blocks after using 2m windbreaker (wind speed 10m/s) – Source: Authors

In the fourth scenario, a 2.5m windbreaker is simulated (figure 9). The result shows a significant reduction of wind flow than the previous scenarios, wind accelerations in the interest regions are between zero and three m/s, which constitute a comfortable condition for pedestrians according to Bottema investigation (table 1) when the wind speed is under 4m/s. A windbreaker of 3m height is simulated as a last proposal (figure 10). The result are similar to the 2.5m windbreaker at pedestrian level, wind speed in the interest regions is still between zero and three m/s, however the comfort level is wider than the 2.5 windbreaker which is out of the interest region (study range).

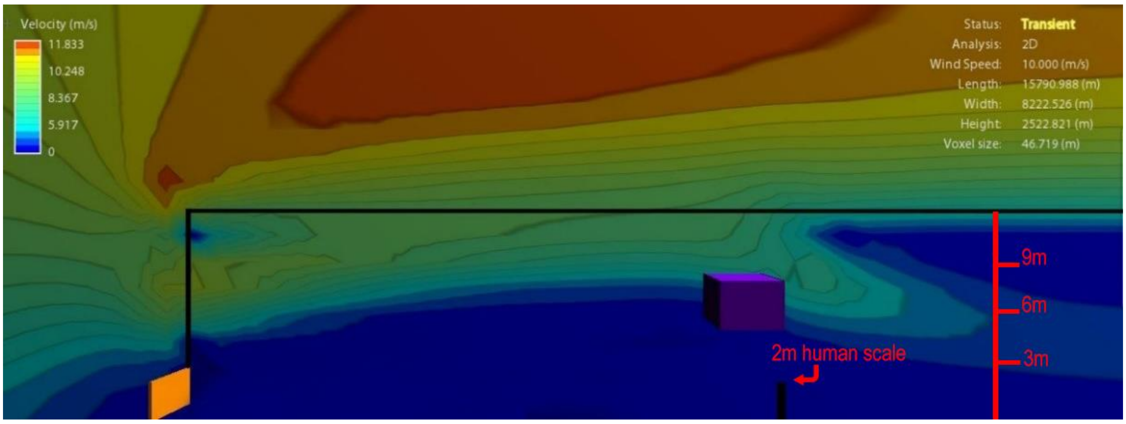

Fig. 9: Wind tunnel simulation between BAU building's blocks after using 2.5m windbreaker (wind speed 10m/s) – Source: Authors

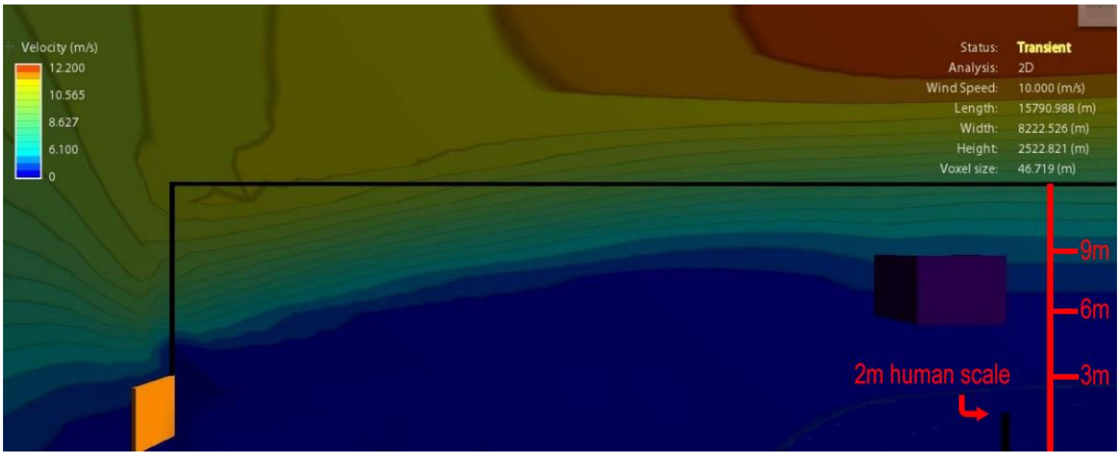

Fig. 10: Wind tunnel simulation between BAU building's blocks after using 3m windbreaker (wind speed 10m/s) – Source: Authors

Thus, the 2.5m is the optimum solution to achieve pedestrian comfort between the BAU building's blocks. The 2.5m windbreaker will be tested depending on four different thicknesses: 20, 40, 60 and 100 cm. The 20cm windbreaker's thickness wall has been simulated (figure 9). The result shows a significant reduction of wind flow than the previous scenarios, wind accelerations in the interest regions are between zero and three m/s, which constitute a comfortable condition for pedestrians according to Bottema investigation (table 1) when the wind speed is under 4m/s. However the 40cm windbreaker's thickness wall (figure 11), shows a significant acceleration of wind flow at pedestrian level, between four and five m/s. The 60cm windbreaker's thickness wall (figure 12), also shows an acceleration of wind flow at pedestrian level, between four and six m/s. The 100 cm windbreaker's thickness wall (figure 13), also shows a significant acceleration of wind flow at pedestrian level, than the previous thicknesses. Wind accelerations are between five and seven m/s.

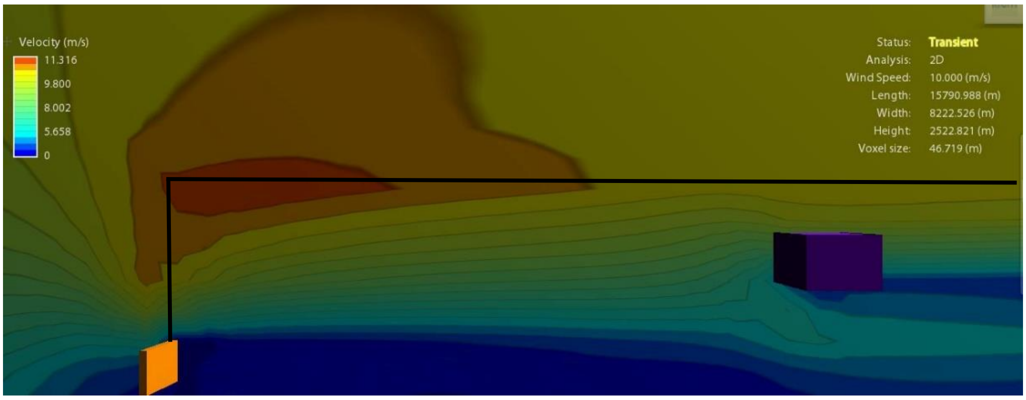

Fig. 11: Wind tunnel simulation between BAU building's blocks after using 40cm windbreaker (wind speed 10m/s) – Source: Authors

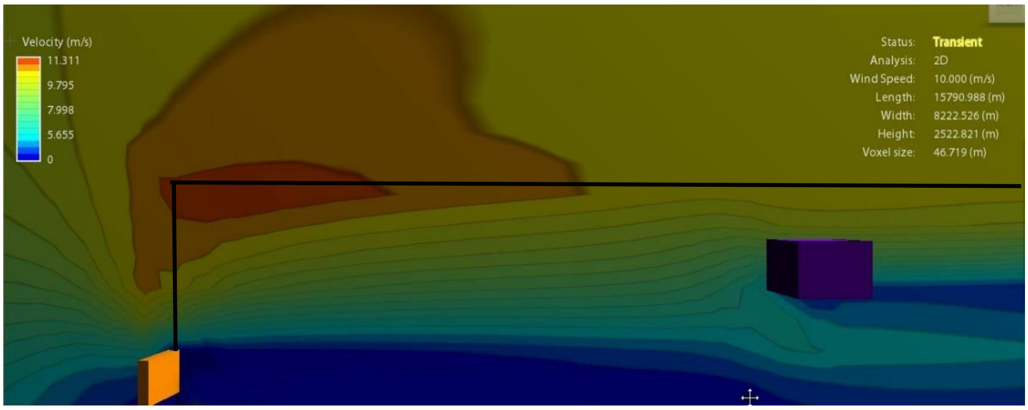

Fig. 12: Wind tunnel simulation between BAU building's blocks after using 60cm windbreaker (wind speed 10m/s) – Source: Authors

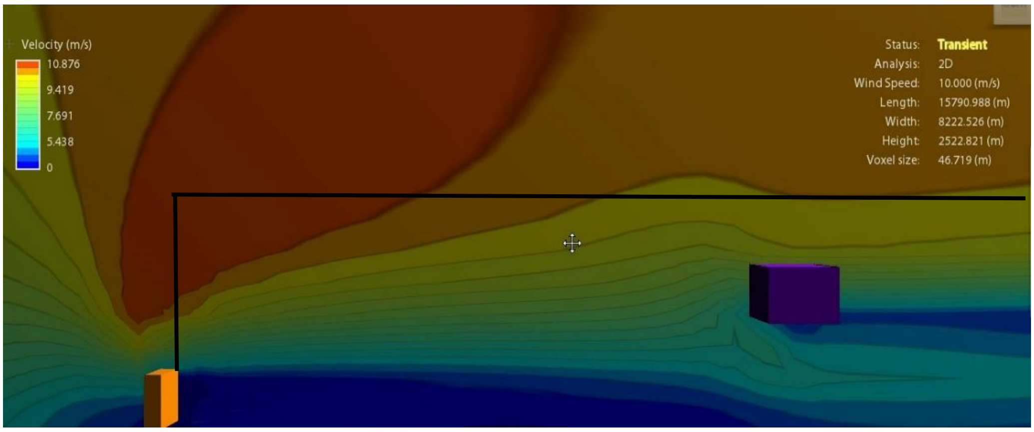

Fig. 13: Wind tunnel simulation between BAU building's blocks after using 100cm windbreaker (wind speed 10m/s) – Source: Authors

As conclusion, the results of different windbreaker heights are displayed in table 2 and show that 2.5 m windbreaker's height is the optimum. However the use of 20 cm windbreaker's width is the optimum, as shown in table 3.

Table 2: Windbreaker efficiency according to its height – Source: Authors

Wind breaker's height (m)	**Protected area's height (m)**	**Wind speed (m/s)**
1	0.3	5-7
1.5	0.5	5-7
2	1	4-6
2.5	**3**	**0-3**
3	9	0-3

Table 3: Windbreaker efficiency according to its height – Source: Authors

Wind breaker's height (m)	**Protected area's height (m)**	**Wind speed (m/s)**
20	**3**	**0-3**
40	1.5	4-5
60	1	4-6
100	0.5	5-7
20	3	0-3

4. CONCLUSION AND DISCUSSION

This study showed that the use of 2.5m height and 0.2m width of windbreaker is the optimum solution to reduce wind tunnel effect on occupant comfort at pedestrian level between the BAU building's blocks, after proposing different models of the windbreakers in front of wind flow between two buildings blocks based on a simulation approach using the Autodesk Flow Design to predict and asses wind accelerations on pedestrian level. This approach has advantages of studying wind behavior when using windbreaker at different height and thicknesses to choose the optimum. The main contributions of this paper are summarized as follows:

The variability of find flow in the response of windbreaker height are interesting, the higher the windbreaker the lower the wind tunnel effect. However, at pedestrian level, the 2.5m windbreaker is the optimum.

Although, wind tunnel effect on pedestrian level is more dangerous with the augmentation of windbreaker's thickness. Thus, the minimum windbreaker's thickness the maximum of pedestrian comfort.

It remains to conclude that the degree of agreement between this paper and Revenkar study is quite remarkable for an experiment which relies almost completely on software assessment.

This paper can deal with Revenkar findings, that states the width of a windbreak should exceed the height by 1/10 for maximum efficiency. His study takes a higher wind flow speed (44m/s) into account, however this paper take a 10m/s as a wind speed. The height of windbreaker in Revenkar study, should be equal to the height of the area to be protected. contrariwise, this paper find that the 2.5m is optimum height, by using Autodesk flow design, which is mean a 0.5 m more than the protected area. a more accurancy of finding can be obtained by using a more specific software, so the finding in this paper can match completely Revemkar's finding, who used the FloTHERM 10.1 software to model windbreakers.

Finally, this paper is a pilot study that might develop in the future by including more variables, such as materials, orientation, void volume fraction of windbreaker, and its distance from area to be protected.

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