Pedestrian Wind Distribution Within an Urban University City Campus using Wind Tunnel Test

YinMun H'ng, Ikegaya Naoki, Sheikh Ahmad Zaki Shaikh bin Salim, Hagishima Aya and Yusri Yusup

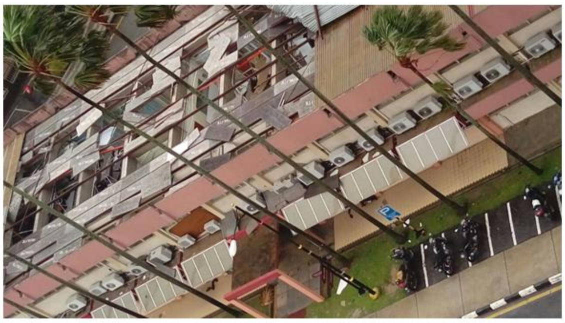
Abstract*: There is a necessity to further explore the pedestrian wind studies in Malaysia as in concerning the impact and risk of hazard wind towards community due to the occurrence of strong wind events. The gradually increase of high-rise buildings in an urban city might lead to artificial strong wind, causing wind discomfort or infrastructure damages, In this study, the research framework is demonstrated and the wind distribution within Universiti Teknologi Malaysia Kuala Lumpur (UTMKL) city campus is revealed by conducting wind tunnel test. The results showed that the high wind speeds are spotted near high buildings (MJIIT, Menara Razak, and Residensi Tower of UTMKL) where $U(z)/U(z_{ref})$ ranging from 0.60-0.90. Factors that are causing the wind amplification near tall buildings are downdraft wind at windward of building, wakes at corners, and leeward of building, as well as the venturi effect occurred between two tall buildings. The layout of the buildings also shall be one of the factors that affecting the wind distribution, as there is a case where a group of buildings served as a shelter and refrained the wind to flow through some areas. This preliminary result is also aligned with the storm event that happened. Thus, for the sake of the safety and comfort of the pedestrians, incorporating the wind tunnel data in the future master planning in this city campus should be considered to reduce the wind nuisance issues.

***Keywords* : high-rise building, pedestrian wind, wind tunnel.**

I. INTRODUCTION

The complexity layout of an urban area with densely built of tall buildings may contribute to the amplification of the wind speed at pedestrian level [1] and there were few incidents have been reported, causing death, and damages due to the locally induced strong wind [2]. Trees were uprooted and some infrastructure damaged when a storm struck Universiti Teknologi Malaysia Kuala Lumpur (UTMKL) campus on 24 Mac 2016 (see Fig. 1(a)). Thus, it is essential for us to understand the wind distribution for the pedestrians' safety purpose as well as to concern the risk in the future development master planning. During another massive storm in Klang region on 1 October 2018, buildings' roof ripped off by typhoon-like wind and debris has damaged some of the vehicles (shown in Fig. 1(b)) [3]. For some countries such as Netherlands, United Kingdom, and Japan, they had an established regulatory framework for the pre-assessment of pedestrian wind. A short review has complied the criteria for pedestrian wind assessment [4]. Netherlands Normalisation Institute (NEN) has published the Dutch code NEN8100, providing the criteria for the assessment [5]. Meanwhile, Architectural Institute Japan (AIJ) has a compilation of practical guideline which comprises of different flow field studies [6]. However, standard reference for pedestrian wind assessment has yet to develop in Malaysia due to less interest. The literature of the pedestrian wind studies in Malaysia is still lacking although a group of Malaysian researchers have conducted a pedestrian wind study in Klang Valley [7]. Thus, this paper serves as a reference of research framework, and the overview of the wind distribution within UTMKL city campus may contribute to the future planning work for the campus.

(a)



(b)

Revised Manuscript Received on October 22, 2019.

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Fig. 1(a) Some losses caused by the storm event in UTMKL campus (b) Roof being ripped off and trees were uprooted due to the impact of typhoon-like wind in Klang.

Malaysia is a tropical country that experienced two monsoon wind seasons per year (which are Southwest Monsoon and Northeast Monsoon). Although the monsoon wind is considered mild, Malaysia still expose to the tropical thunderstorms which accompanied with strong wind gust [8]. Reports show that the strong wind occurrence in Malaysia had caused losses and damages [9], [10] and it reminded us the necessity to explore the pedestrian wind studies in Malaysia. To assess the wind flow field, methods that mostly implemented are wind tunnel test, computational fluid dynamics (CFD) simulation, and on-site measurement. During the wind tunnel test, building models are placed on the test table and sensors are installed for wind flow measurement. Although it is time consuming to conduct a wind tunnel test, it is still a preferable method as it served as the validation for the latter method [11]. Meanwhile, CFD simulations are slowly emerged as the modern technique to explore and analyze the flow studies [12], [13] as well as in assessment or application [14]. However, the inappropriate of parameters control in the numerical studies may leads to high uncertainties of result [13]. In the other hand, compare to wind tunnel test, the operating cost for the full scale on-site measurement is high and the consistency of the condition during the repetition measurement is hardly control [15]. Therefore, wind tunnel test remains as an important method for wind field studies. The complex building morphology in an urban area causing the difficulty to assess the wind condition and hence the pedestrian wind has always been neglected [16]. In this study, the research framework of the wind tunnel test is presented, and the results shall reveal the wind distribution of the UTMKL city campus.

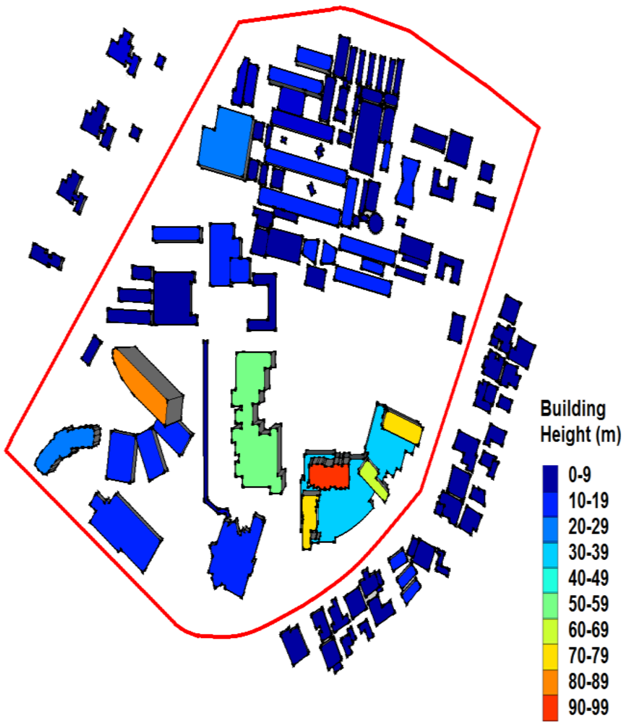
II. METHODS

UTMKL city camps is the target site of this study which located in the center of Kuala Lumpur, the capital city of Malaysia. The research framework of the wind tunnel test is demonstrated in this section. The information of the building dimension is essential for the preparation of the test models. Meanwhile, the local meteorological data is collected to provide us the information about the prevailing wind direction and the wind frequency distribution. Wind tunnel setup and the measurement methods are also presented.

A. Building Morphology and Preparation of Testing Model

The three-dimensional (3D) modelling plan layout of the UTMKL city camps and its 300 m surrounding is sketched using SketchUp Pro 2018 software and the respective building heights [17] are represented using colors as shown in Fig. 2(a). The three tallest buildings within the campus are Malaysia-Japan International Institute of Technology (MJIIT) (53 m), Menara Razak (84 m), following by Residensi Tower of UTMKL with the height of 94 m (hereafter denoted as RT). The details of the building properties are simplified, and the trees are omitted when preparing the test model [18]. The Polylactic Acid (PLA) test models are printed using 3D printer at a scale of 1750 which comply with the blockage ratio (*BR*) below 3% [19]. Fig. 2(b) illustrates the calculation of the *BR* to prevent the flow effects caused by the wind tunnel wall due to the large test model, using the equation *BR* (%) = $A_{model}/A_{windtunnel}$.

(a)



(b)

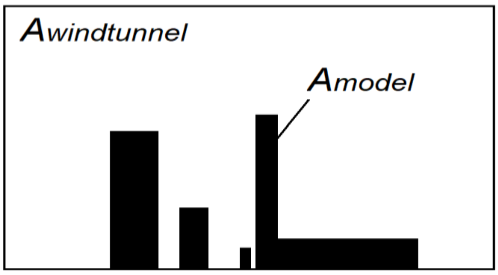
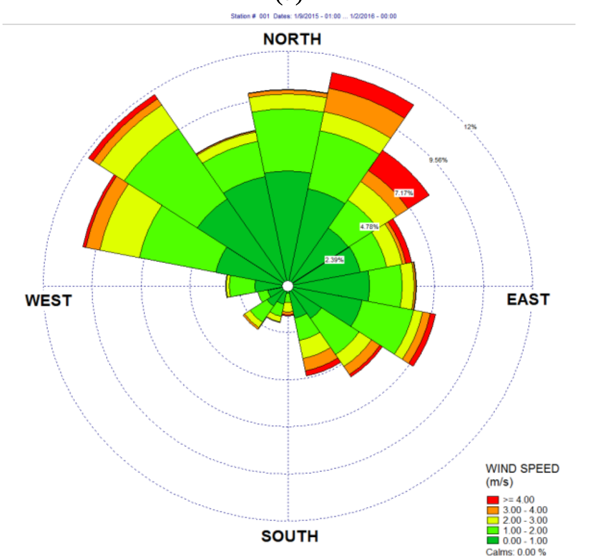


Fig. 2(a) 3D plan layout of UTMKL city campus with buildings' height: MJIIT building is colored with light green Menara Razak is colored with orange, and the mix-colored blocks represents the Residensi Tower (RT) of UTMKL (b) Diagram shows the calculation of the blockage ratio where A_{model} represents the frontal area of the test model and $A_{windtunnel}$ is the test section area of wind tunnel.

B. Local Meteorology

The five months weather data (1 September 2015 to 31 January 2016) is collected from the weather station that mounted on the rooftop of the Malaysia-Japan International Institute of Technology (MJIIT) at the height of 68 m, using 3D sonic anemometer (CSAT3B, Campbell Scientific) with interval of 10 min averaging time. Fig. 3(a) and (b) depicted the wind speed information at respective wind directions and the frequency distribution of the wind speed.

(a)



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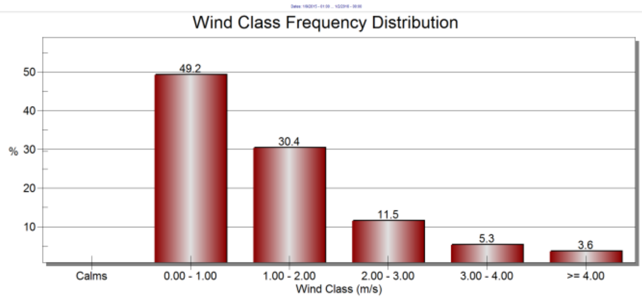
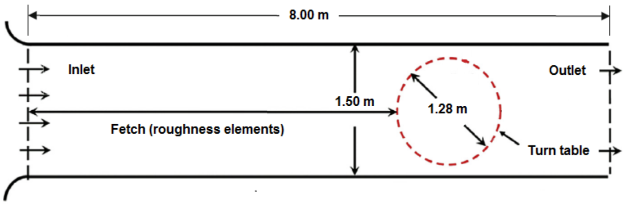


Fig. 3(a) Wind rose plot reveals the prevailing wind direction and (b) the wind speed frequency distribution.

C. Wind Tunnel Setup

The wind tunnel test is conducted at the laboratory of the Interdisciplinary Graduate School of Engineering Sciences, Kyushu University, Japan. Fig. 4 shows the plan view of the closed-circuit wind tunnel with dimension of 8.0 m x 1.5 m x 1.0 m (length x width x height). The red dotted circle represents the turn table (diameter of 1.28 m), where the test models are placed, and measurement took place. It is crucial to simulate the incoming flow with the aids of some roughness elements before the experiment is conducted.

(a)



(b)

Fig. 4(a) Schematic plan view of the wind tunnel (b) Front view of the castellated block that placed at the inlet before the roughness elements.

D. Roughness Configuration for Simulation of Incoming Flow

The configuration of the roughness elements placed before the test section is important to reproduce the appropriate atmospheric boundary layer. It is to ensure the incoming flow is approximate to the approaching wind from suburban or urban terrain before hitting the building test models at the targeted area. Vortex generators such as barriers, roughness elements or spires are mostly implemented in wind tunnel test to simulate the turbulent and reproduce the atmospheric boundary layer [15], [20]. In this study, the installation of the surface roughness elements comprised of both 17% packing density of 25 mm cubic wooden blocks that arranged in a staggered form and a castellated block (see Fig. 4(b)). The incoming flow velocity profile is measured at the upstream center of the turn table and the wind profile is shown in Fig. 5. The vertical velocity wind profile is presented using power law model that commonly used to show the variation of the wind at different height. Besides that, turbulence intensity also can be calculated. The formula for both power law and turbulence intensity are shown (refer to (1) and (2)).

$$\frac{\bar{U}(z)}{\bar{U}(z_{ref})} = \left(\frac{z}{z_{ref}}\right)^{\alpha} \tag{1}$$

$$I_u = \frac{\sigma_u(z)}{\bar{U}(z)} \tag{2}$$

Where,

$\bar{U}(z)$: mean wind velocity at height z

$\bar{U}(z_{ref})$: mean wind

velocity at reference height

α : power exponent index

z : height above the ground surface

z_{ref} : reference height

I_u : turbulence intensity

σ_u : standard deviation of velocity fluctuation component in horizontal stream-wise

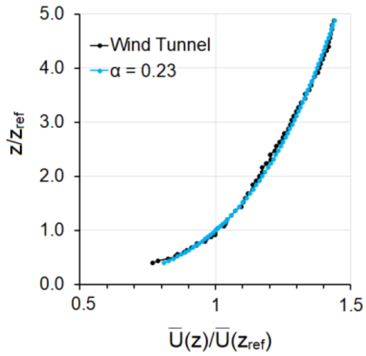


Fig. 5. Vertical profile of incoming flow velocity.

The power exponent index, α, represents a certain terrain roughness conditions, are listed in Table- I. Assuming the surroundings of UTMKL city campus are under suburban category, the simulated incoming flow vertical profile has a power index of 0.23 which falls within the range.

Table- I: Estimated power index according to terrain roughness (ASCE 7-16) [15]

Terrain Categories	α
Open sea	0.12
Mud flats, no obstacles	0.16
Parklands, bushes, numerous obstacles	0.22
Regular large obstacle coverage	0.33

E. Data Collection

The wind tunnel test was conducted at a free stream of approximately 6.40 m/s. All printed building test models are placed on the turn table. By rotating the turn table at an interval of 22.5°, the wind velocity is measured at 16 wind directions with total of 214 points are selected for the measurement. The selection of measurement points is decided by concerning the urban effects where high wind speed might be experienced, such as: (1) downdraft wind (2) wake of buildings (3) corners of the buildings (4) venturi effect, and (5) the affected region during storm occurred. The measurement is conducted at a duration of 30 seconds at each measuring point.

The calibration of the thermistors is carried out with the pitot static tube in the wind tunnel. Twelve I-shaped thermistors (KANOMAX: Model 0965-03) and multichannel (KANOMAX: Model 1560) with 4 channels air velocity module (Model 1504) are connected to the PC for data acquisition via RS-232C cable. The installation of KANOMAX data processing software enable us to view the data recording (see Fig. 6). The wind tunnel test layout is shown in Fig. 7.

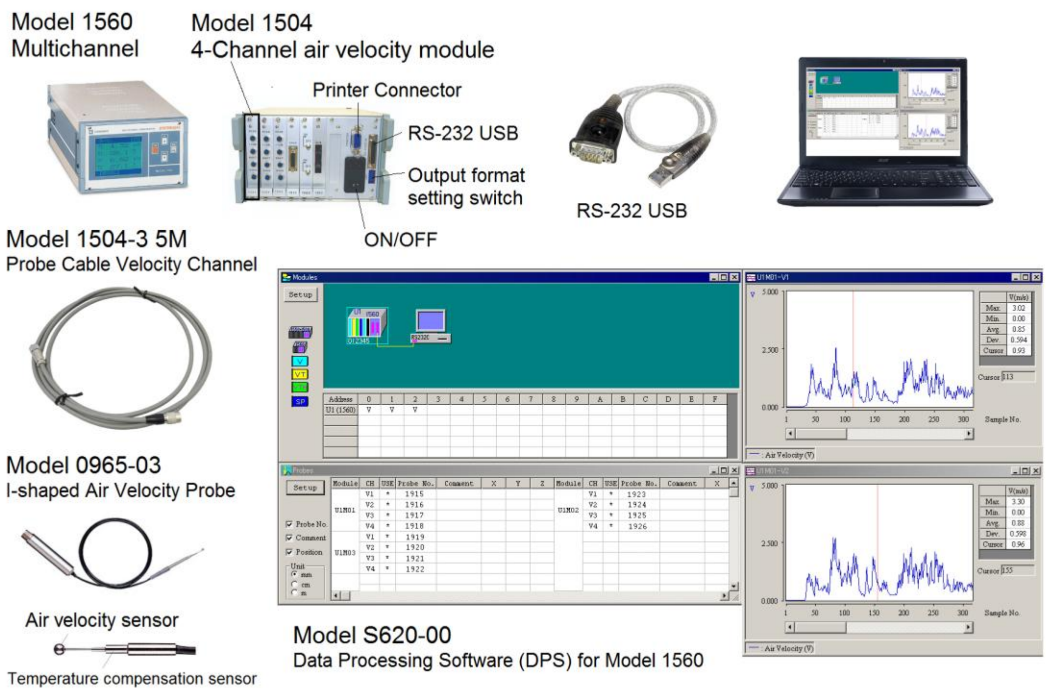


Fig. 6. Data measuring system: The multichannel consists of 4 channels air velocity modules is used to connect the I-shaped air velocity sensor (thermistors) using the probe cable. To view and save the data, RS-232C cable is connected to the PC that installed with the KANOMAX data processing software.

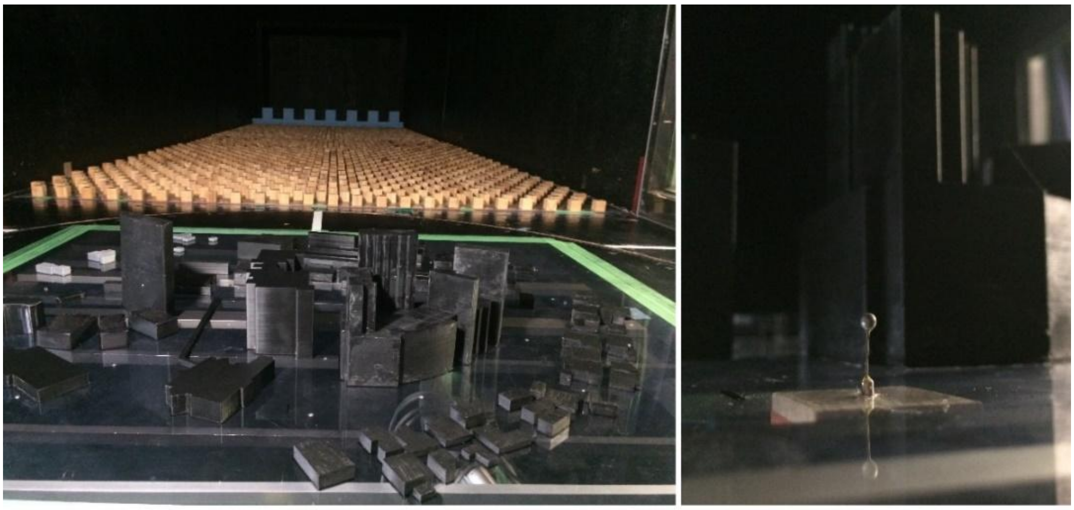
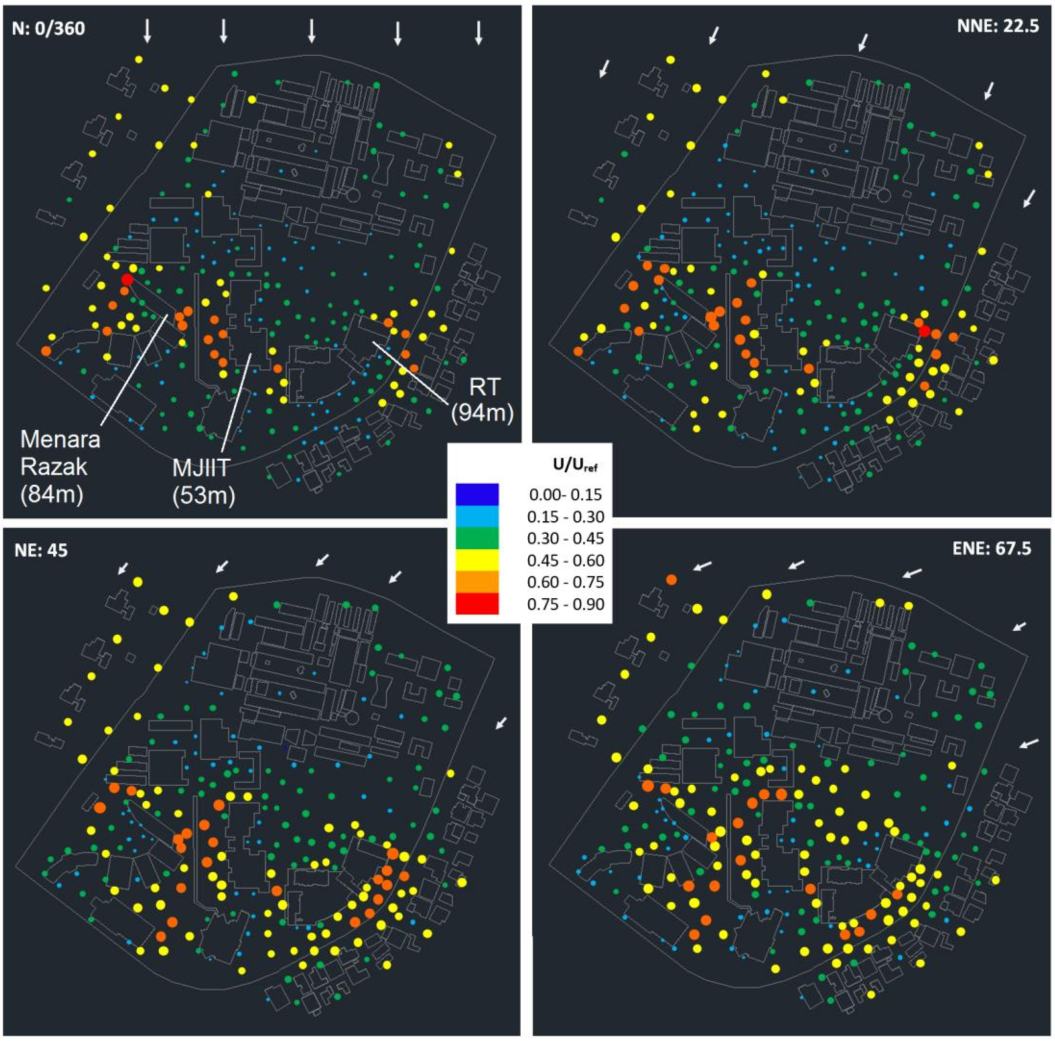


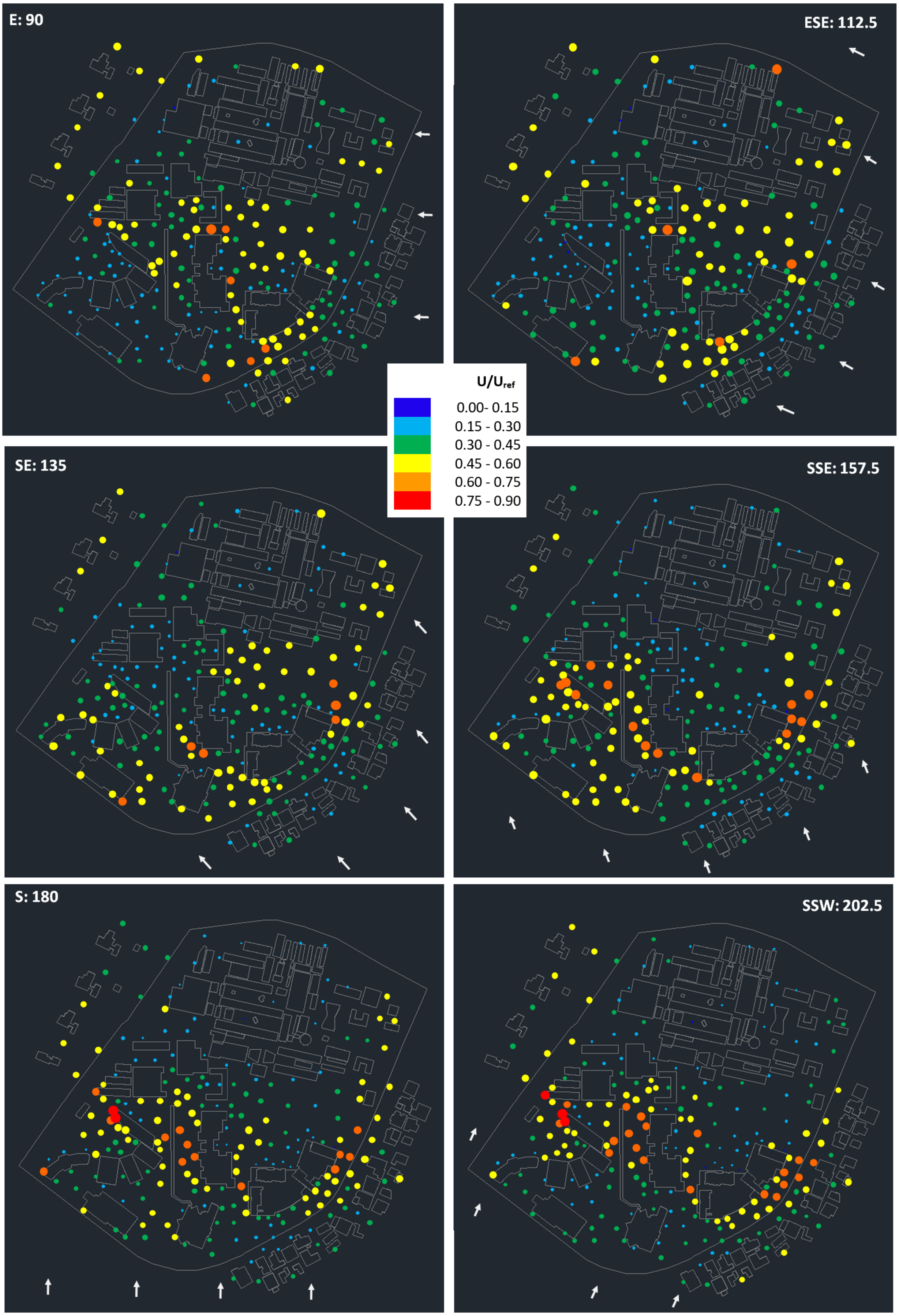
Fig. 7. The view of the experiment layout in the wind tunnel. I-shaped sensors (right figure) are installed at 8 mm height from the ground surface.

III. RESULTS AND DISCUSSION

The wind distribution map of UTMKL city campus with total of 214 measurement points at 16 wind directions are presented in Fig. 8 respectively, where U denoted as velocity measured by thermistor, and U_{ref} is the velocity at height of 500 mm.

A. Data Visualization





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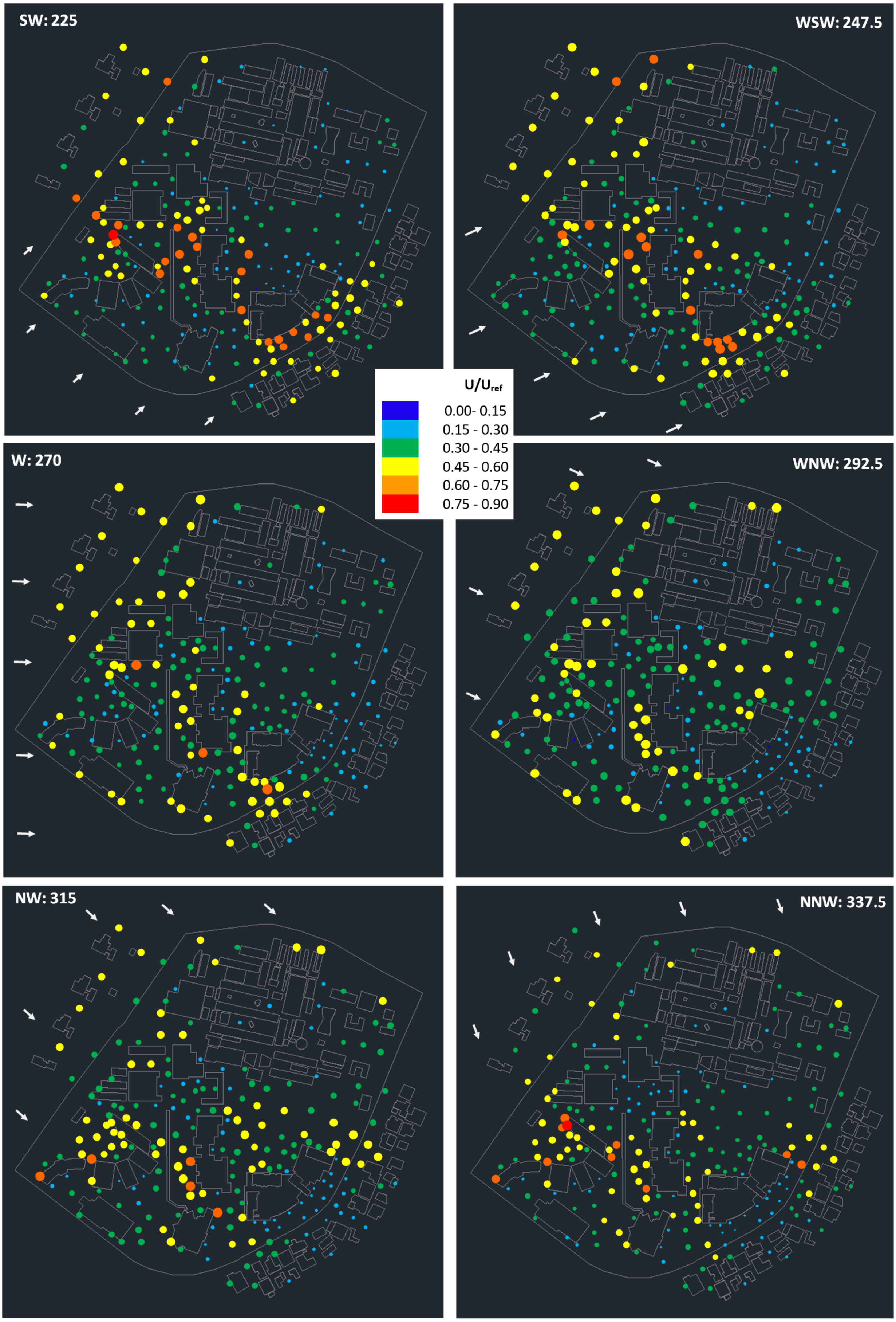

Fig. 8. Distribution of wind velocities within UTMKL city campus for 16 wind directions, measured at 214 points.

B. Wind Distribution Near Target Building: Menara Razak

The result shows that high wind speed phenomenon is mostly occurred near the high-rise buildings (Menara Razak and RT). The downdraft wind that reflected towards the pedestrian level has causes high wind speed at the windward of these high buildings. Meanwhile, at the blowing wind directions of 0°, 180°, 202.5°, 225°, and 337.5°, red dots are mostly scattered near the corner of Menara Razak (second highest building), where it received a high impact of wind. The red dots spotted at wind direction of 202.5° is the destructive region during the storm attack that destroyed some of the buildings' structure (see Fig. 1(a)). The occurrence of high wind speeds near the wake behind of the Menara Razak building's corner shall not be neglected.

However, Menara Razak receives the minimum wind impact at wind direction of 112.5°, as a group of three buildings at the windward has blocked and diverged the wind flow. The buildings group with height of more than 10 m formed a triangle-shaped layout, that would refrain the wind from going through the gaps that channel towards Menara Razak.

C. Wind Distribution Near Target Building: Residensi Tower (RT)

RT is the highest building within UTMKL city campus, that consists of four different heights of blocks. High wind speeds occurred near the surroundings of the RT at all wind directions except for 292.5°, where RT has sheltered by MJIIT building. Results also show that the medium-high wind speeds are densely scattering near the corners and the curve edges of the building. Those locations experienced high wind speed especially when wind blows parallelly (wind directions of 22.5°, 45°, 67.5°, 202.5°, 225°, and 247.5°) towards the curve edge of the building. The occurrence of high wind speed might be due to the cursive design layout of this building structure.

D. Wind Distribution Near Target Building: MJIIT

The regions between the Menara Razak and MJJIT buildings are found to experience high wind speed at most of the wind directions, except for 90° and 112.5°. The arrangement of two high buildings has formed a channel which contributed to the amplification of wind when it flows through the gaps causing the venturi effect.

IV. CONCLUSION

The overview of this wind tunnel test research framework is demonstrated and the wind distribution map within the UTMKL city camps is presented. The locations that experienced high wind speed are also identified. Generally, the factors that affect the wind flow are the building dimension, layout arrangement and the design shape of the building structure. Thus, it is essential to conduct pre-assessment of pedestrian wind studies before construction of high-rise building as to reduce the risk of wind nuisance.

The results showed are aligned with the real situation occurred during the storm attack. This result has provided some information that may help to identify the locations that might having risk of damage when storm strike, High wind speed regions are mostly occurred near tall buildings (MJIIT, Menara Razak, and RT) at the windward, leeward, and corners of the building. Wind passes through between two buildings causes the Venturi effect and thus amplify the wind speed. This preliminary study could be served as a reference for future master planning work as well as providing an experiment framework for wind tunnel test start-up procedure. More insight of research such as the wind effects caused by the building morphology can be conducted for the future work.

ACKNOWLEDGMENT

This research was financially supported by Ainuddin Wahid scholarship provided by Universiti Teknologi Malaysia. The authors would like to express their appreciation to the members of laboratory of the Interdisciplinary Graduate School of Engineering Sciences, Kyushu University, Japan, by providing the technical support throughout the wind tunnel measurements.

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Retrieval Number: C10091183S319/2019©BEIESP
DOI:10.35940/ijrte.C1009.1183S319

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Keyword: Occupants behavior, building energy simulation, thermal comfort, wind tunnel experiment, Particle Image Velocimetry, Laser Doppler velocimetry, CFD, LES, RANS, demands forecast, energy saving, drag coefficient, roughness length, transfer coefficient, urban boundary later, simulation, thermal load, behavior schedule, roadside tress, cool spot, thermal mitigation, outdoor field experiment, urban street canyon. Urban heat island, urban canopy model, anthropogenic heat of urban area, radiation process within urban canopy, conjoint analysis, questionnaire survey.

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Awards: 2003 Encouragement Prize of Architectural Institute of Japan (AIJ), AIJ Prize 2015 "A series of studies on the effects of urban vegetation and buildings on urban climate", The Architectural Institute of Japan (AIJ).

Yusri Yusup Assoc. Prof in the Environmental Technology Program, School of Industrial Technology, Universiti Sains Malaysia. Besides academic teaching since 2005, he conducts research on water-atmosphere (over a coastal tropical ocean) and land-atmosphere (over an oil palm plantation) interactions using the eddy covariance (EC) method, emission inventory development, and understanding how ground-level ozone change with atmospheric temperature. He also experienced in outdoor air pollution (and air quality) sampling and chemical characterization.

He has an EC tower to measure moisture and carbon dioxide fluxes and other meteorological parameters at the Centre for Marine and Coastal Studies (CEMASCS, USM) to study the carbon and water cycles of a tropical coastal ecosystem. Also, in a joint research project with Malaysian Palm Oil Board (MPOB), I work on examining the net ecosystem exchange of carbon dioxide over an oil palm plantation in Malaysia.

He is an avid user of R (statistical software), Matlab, C++ and Python (high -level programming language) in his research work. He also proficient in using air pollution dispersion models such as AERMOD View and CALPUFF.

Academic Degree: 2008, Ph.D. (Chemical Engineering and Process), University Kebangsaan Malaysia. 2003, M. of Science (Chemical Processes), Universiti Sains Malaysia. 2001, B. of Engineering (Chemical Engineering) Universiti Sains Malaysia.

Field of Specialization: Research in boundary layer meteorology and the relation to air pollution and wind resources. Mainly teach chemical engineering subjects.

Research Interest: Atmospheric modelling, air quality modeling, boundary layer meteorology, data analysis (using R), eddy covariance, micrometeorology.

Refereed International Journal Publication on Atmospheric Physics and Air Quality: Atmospheric Research, Chemistry and Ecology, Meteorological Applications, Journal of Wind Engineering &Industrial Aerodynamics, Atmospheric Pollution Research, Environmental Forensics, International Journal of Agronomy and Agricultural Research, Journal of Hydrometeorology, Chemical Engineering Transactions, Journal of Oil Palm Research, MethodsX, Data in Brief, Dynamics of Atmospheres and Oceans, Sustainable Cities and Society, Science of the Total Environment, Regional Studies in Marine Science, Environmental Science and Pollution Research.

Conference Proceedings/Presentations on Atmospheric Physics and Air Quality: Regional Conference on Ecological Modeling (ECOMOD) 2004, The 10th Asian Pacific Confederation of Chemical Engineering (APCChE) 2004, Prosiding Pelajar Siswazah Fakulti Kejuruteraan – UKM 2004, Proceedings International Conference on Environmental Research and Technology 2012, AGU Fall Meeting 2014, 32nd Conference on Agricultural and Forest Meteorology 2016, 4th USM – UL (Universiti de Lorraine) Colloquium 2017, European Geophysical Union (EGU) 2017, The 2017 Therapy &Technique, International Aerosol Conference (2017 T&T IAC), 3rd International Forum on Sustainable Future in Asia 2018, International Conference on Atmospheric Composition and Climate Change in Asia, ICACCCA 2018.

Membership in Academic Society: (1) Trainee technical assessor, 2013, Standards Malaysia (SAMM) (2) Graduate engineer, 2013, Board of Engineers Malaysia (3) Member, 2014, American Geophysical Union (4) Subject consultant, 2014, Malaysian Department of Environment, Environmental Impact Assessment (EIA).

Awards: (1) Hadiah Sanjungan Kategori Penerbitan Jurnal, National, Universiti Sains Malaysia (2008 & 2011) (2) Most Active User for the Hybrid Cluster, National, Centre for Development of Academic Excellence, Universiti Sains Malaysia (2012, 2013 & 2014).

Retrieval Number: C10091183S319/2019©BEIESP
DOI:10.35940/ijrte.C1009.1183S319

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Blue Eyes Intelligence Engineering
& Sciences Publication