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The effects of orientation and width of space between buildings on ventilation of high-rise areas

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Abstract:

In recent years, excessive heat in the urban texture has become the main problem in the humid and calm wind city of Babolsar with high density, especially in high-rise areas. Therefore, in order to create comfort in this region, it is necessary to establish and continue the wind circulation in space with an environmentally compatible and optimal configuration. The study applies combination of literature, field measurement, experimental validation of CFD simulation output, and comparative analysis. After field measurement and validation of FLOW-3D simulation software (V11.2.2), the relationship between these parameters (height, the width of passages, enclosure between buildings, and buildings' orientation) will be studied which affects the wind's velocity and direction. The factors of the buildings' orientation and enclosure based on the passages' width have opposite reactions in the direction of the prevailing wind especially from perpendicular side. In this study, two effective factors are on wind velocity: 1- The orientation of the buildings towards the wind flow by creating permeability 2- Reducing the enclosure by increasing the width of the passage's perpendicular to the wind flow (w '= 3w, E' = 0.33E). According to the theoretical and practical study, first, the creation of permeability in the body of the block and the separation of buildings instead of aggregation has been studied, and then reducing the confinement of streets perpendicular to the wind flow has been discussed as effective solutions to improve the wind velocity and circulation between the urban environment.

Keywords: High-rise Building; Urban Ventilation; Wind Flow; CFD; Babolsar

1. Introduction:

1.1. Background

About two-thirds of world's population will be living in cities by 2050 and this ratio is still growing [1](Cohen, 2003). The urbanization growth has led to the expansion of the city and the increase of urban density [2]. New cities are characterized by massive high-rise structures [3](Golany, 1996) so that urban space is becoming a high-density space with high construction intensity [2](Ying et al., 2020). Since the urban environment is affected by the urban form, this type of city deformation often causes dysfunction of the urban environment [2](Ying et al., 2020). Urban development as a combination of complex forms significantly affects the aerodynamics of the environment. Hence, high-density areas are environmentally unfavorable and high-rise buildings which are inseparable from a modern city, can significantly deteriorate the urban environment [4](Giyasov et al., 2018).

Meanwhile, in developing countries indoor thermal comfort has been widely studied but outdoor comfort effects on air quality, human comfort, and building energy use have been almost ignored. Urban shapes (geometry and placement) without structure and correct planning are common in the high urbanization growth areas [5](Lee et al., 2015). Regarding current world trends and aspects of the economic impacts, urbanization will become one of the fundamental aspects in the future of developing countries. Countries are currently experiencing extensive urban growth that has shown its impact on urban structures and environmental micro-climate [5](Lee et al., 2015).

Urban shape variables have a great impact on climatic factors such as temperature, humidity, wind flow, shade, and sunlight [3](Golany, 1996). Living in high-rise buildings means more daylight, cooler winds, and less humidity in the residential area. Non-compliance with planning and design standards in accordance with the mentioned climatic factors are probably the reasons for residents refusing to live in hot and humid cities. [6](Kubota et al., 2008). Therefore, urban design should create a micro-climate to reduce the temperature produced by the urban block layout. Design strategies can create or modify an environment that improves thermal conditions [7](Yang et al., 2013).

In this study, the effect of the physical characteristics of the urban block shape on climatic factors in the humid region is investigated. In humid areas, wind flow is one of the main climatic factors that have a direct effect on the optimal temperature and humidity, and changes with the geometrical ratio of building block and urban pattern [8,9](Erell et al., 2011; Shishegar, 2013). The growth of high-rise buildings and high-density urban blocks prevents the prevailing wind flow [10](Buccolieri et al., 2010). One way to neutralize or reduce outdoor ventilation problems is an optimal design into prevailing wind flow. This process removes the trapped heat air between the urban masses [5](Lee et al., 2015). A large number of studies investigated the relationship between outdoor air conditioning and urban form. Given to their findings, there are fundamental variables that guide outdoor natural ventilation. The urban form includes the physical details of the urban texture. The physical details consist of the buildings' orientation [11-13](Pancholy et al., 2016; Shi et al., 2015; Shishegar, 2013), their enclosure in space [11,14-16](Dadioti & Rees, 2016; Jędrzejewski et al., 2017; Shi et al., 2015), the type of their configuration in the texture [17,18], the buildings' height [20,21], and the streets' width between them [19,22,23] small modifications in their configuration and orientation, such as changes in the corners of buildings as well as setbacks in the building shape, can improve wind comfort in the texture. In addition to the configuration, the suitability between the building blocks' height and the streets' width between them can be an effective factor in the wind flow pattern. However, each of these two factors alone has a significant effect on wind velocity and its distribution [24,25].

Increased enclosure (H/W), in other words the ratio between building height and passage width has been reported in many studies in hot and humid regions [26,27]. Also, the direction of the wind flow is another important factor in reducing the temperature, especially in summer [28,29]. Investigation of these factors gives us a better understanding of the behavior of urban form changes in an area. Also, urban shape variables support the conditions for providing a model for improving ventilation. This article aims to investigate the changes in the building's masses and changes' effect on wind flow to improve outdoor comfort for inhabitants in their living environment.

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In recent years, two main categories of design evaluations and simulations for urban ventilation have been widely used in the urban local scale: A) observational approaches and B) simulation approaches. The observational approach is performed with real urban areas measurement techniques or small-scale physical modeling using wind tunnel testing. The simulation approach is done using computational resources. An important feature of numerical simulation, compared to observational approach, is the possibility of performing comparative analyses based on different scenarios [29,30]. In addition, numerical simulations can provide information about each variable studied in the whole computational domain, which is otherwise not possible due to limitations in actual measurements [6,31,32].

1.2. objectives of the study

In this research, the case study is a local context of northern Iran, in the city of Babolsar. Babolsar city has a temperate climate and is very humid because it is in proximity to the sea. In recent years, dense and high-rise construction has taken place due to the geographical location of the city, tourism, and economic benefits. According to the urban plan, limited and decentralized high-rise buildings have been proposed to prevent the horizontal growth of the city. Meanwhile, outdoor space, ventilation, lighting, etc. are not considered, and urban planning is strongly influenced by economic interests. The northern parts of the city and the streets leading to the beach have been surrounded by high-rise buildings. This sudden deformation in the building blocks has reduced the wind velocity between them. Reducing wind velocity and wind circulation leads to a feeling of high heat and decreasing residents and pedestrians' comfort in the space between buildings. As a result, the effective factors of urban shape on wind velocity should be evaluated and researched Based on the previous studies and the physics of building masses in the studied area, these effective factors of urban shape are building height, the width of passages and space between buildings, confinement, and orientation of buildings to the prevailing wind.

Thus, the research is framed by the following questions: 1) What are the wind velocity changes by variation of the urban block enclosure, height, width, orientation? 2) Which of these variables is the most effective factor on the wind velocity? And 3) how the combination of the effective variables improves outdoor ventilation through reforming the urban block?

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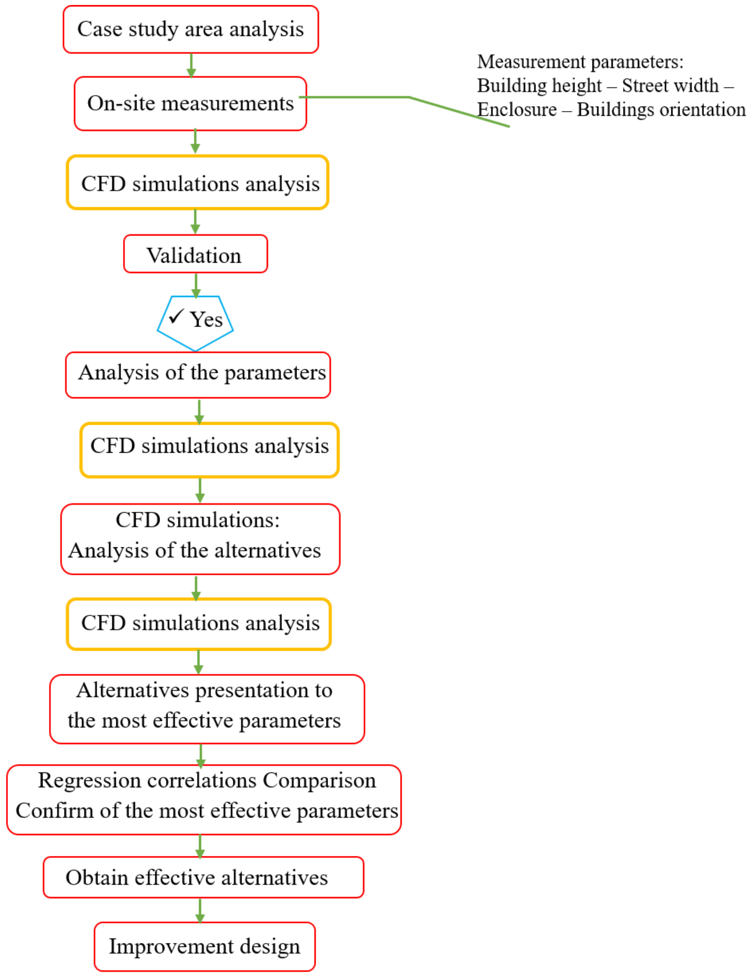

Fig. (1): Graph of improvement design procedures for natural ventilation

In Fig.1, the framework of the research process is summarized. This process begins with the introduction of the study area and its analysis. This analysis is performed with computational fluid dynamic software due to its ease of operation and accuracy. Before using the software, the validation process takes place with field measurements. In the next step, the site is analyzed using CFD simulation. According to the results of the analyzes and the relationship between them and the wind velocity, alternatives are presented. Improving alternatives lead to the improve model for better ventilation.

1.3. Limitations

The limitation of this study is the 3-day field measurement in unstable environments with moving vehicle and disrupting climatic currents in the environment, that can increase the error. Since the focus of the study was on wind flow in summer and its problems, the field measurement and software simulation have been performed. Other seasons with different climate conditions, can produce different results, different climatic factors such as sunlight, temperature, etc. can also impact the urban block climate, this research did not consider the impact of these factors at this stage.

2. Methodology

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Dependent factors of Micro-climate, such as buildings' height, streets' width, enclosure between buildings, buildings' orientation and configuration, have a significant impact on outdoor air quality. Various methods have been proposed to investigate the impact of climatic factors on outdoor comfort including field measurement and simulation. The influence of climatic factors in each geographical area is different from its own physical context, so a general conclusion cannot be made based on the data of a region. In recent years, computational tools have been used for the simulation method, which had been effective in speeding up and facilitating the study of climate issues. However, this method cannot evaluate all aspects of climatic factors simultaneously. Most of these shortcomings are due to the weakness of credible theories and high costs for measurement and computation. Therefore, an area with its own characteristics is examined to study micro-climatic factors such as wind flow [51,52].

An important advantage of the simulation method compared with the field measurement method is that many analyzes can be performed based on different alternatives. While in the field measurement method, a limited number of points can be examined in space. The micro-climatic conditions of the city can also be characterized before the modifications of design strategies. Modifying the layout of the buildings along urban blocks based on the simulated results can be much effective and convincible [53].

2.1. Case study area:

Babolsar is a city located in 36°42′09″ latitude and 52°39′27″ longitude in Mazandaran province in the northern part of Iran between the Caspian Sea and the Alborz mountains. The study area is in Amir-Mazandarani Street in the northern part of the city (Fig.3).

In recent years, waterfront area has been witnessing ongoing development where low-rise and low-density areas have become high-rise and high-density, because of visual access to seafront and proper infrastructures and facilities in coastal area.

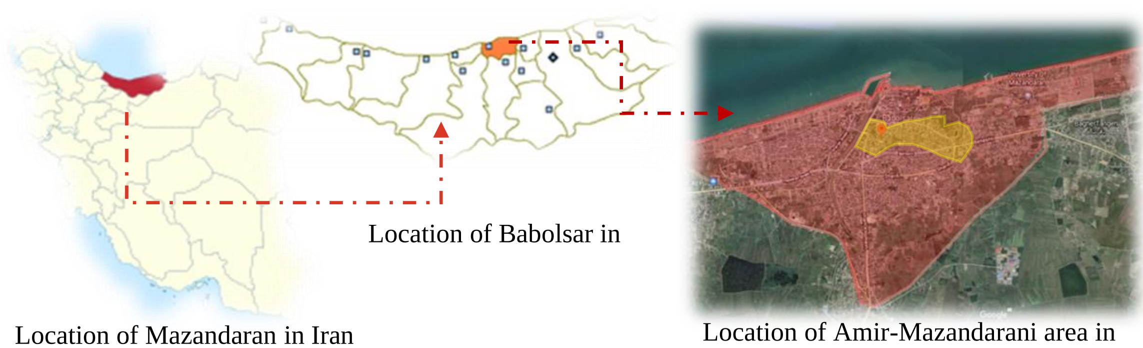

Fig. (2): Location of Babolsar city in Mazandaran Province and Amir-Mazandarani area in Babolsar city

- ***2.1.1. Location of the site for the field study:***

The study area has two urban blocks (shown as block 1 and block 2 in fig. 4) with the total area of 111315 m2. The length of the area is 466 m and the width is 258 m. Comparing Block 1 and 2 indicated that in block 1 density and setting of buildings have been adapted to the nearby fabric while block 2 has maintained its traditional physical condition. Demand for construction is going to change morphology of block 2 and transform it into high-rise buildings. Minimum height of buildings is 4 m in block 2, and the maximum height of buildings is 39 m in block 1.

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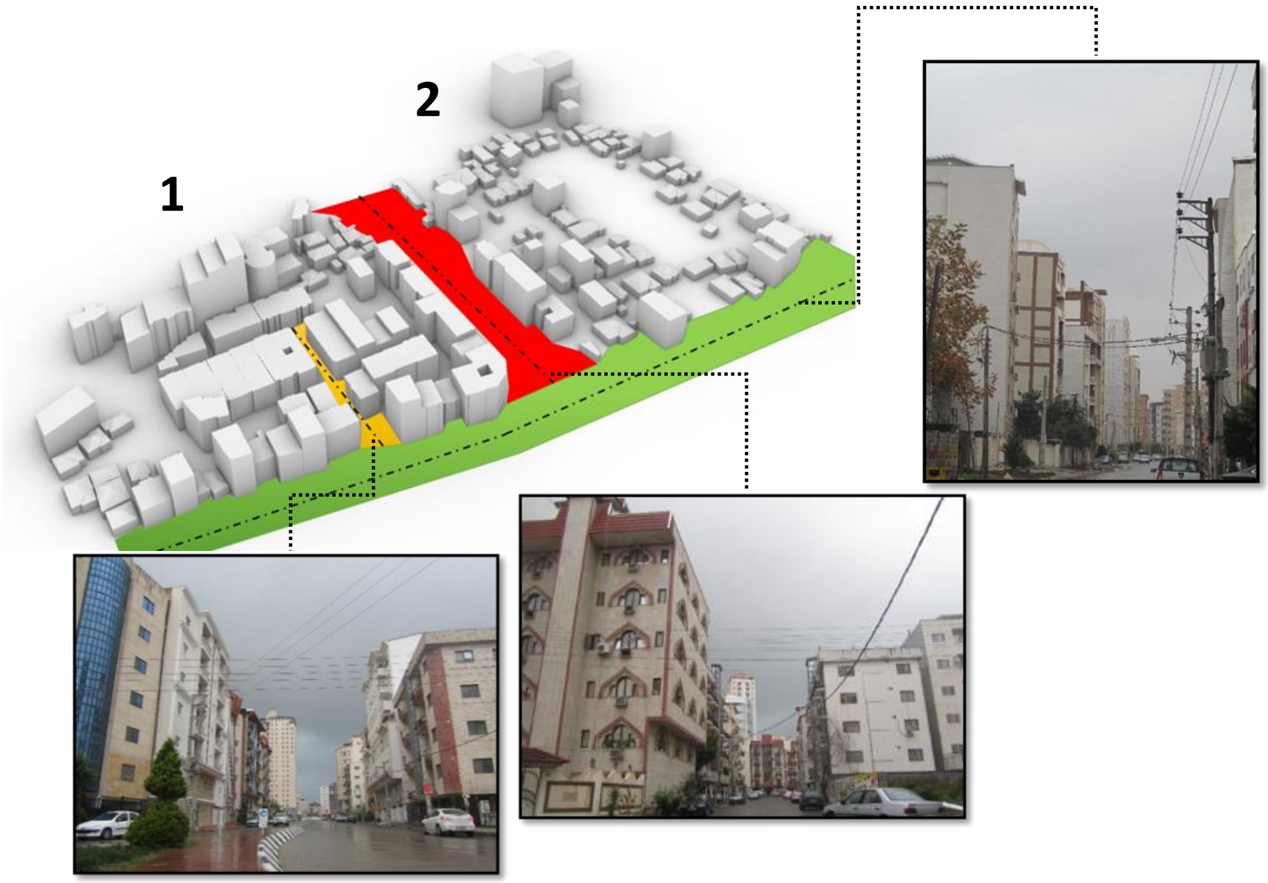

Fig (3): Model and street views of study area

- ***2.1.2. Climatic conditions:***

The temperature of the comfort zone is defined as 21 to 27 degrees and the humidity is between 20 and 70 percent [54]. According to the psychometric chart in fig.5a, the Babolsar region has a humidity between 60 and 100 percent, which in some seasons changes according to the air temperature, because as the temperature increases, the humidity decreases. The air humidity in Babolsar city is higher than other cities in Mazandaran due to its proximity to the sea and the prevailing weather conditions, in other words, it is sultry. Therefore, humidity is the major problem of the city climate. The humid air rests lower than the dry air because of its density. The enclosure of urban space prevents the wind flow and causes dissatisfaction of residents and citizens due to the high humidity of the air. This issue has become the main dilemma in this area.

Wind is the main cause of humidity movement in the area. Wind movement can reduce humidity between the masses. In climatic studies, Babolsar is a moderate and humid climatic. Its dominant wind direction during different months of the year is the west and its speed has been estimated 1.4 m/s at an annual average [55].

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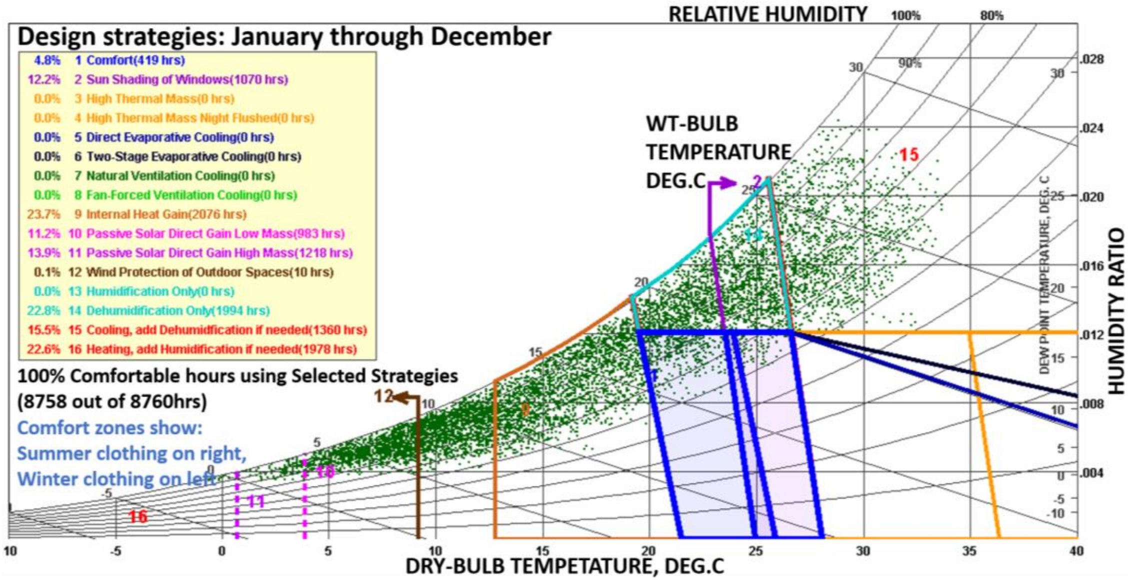
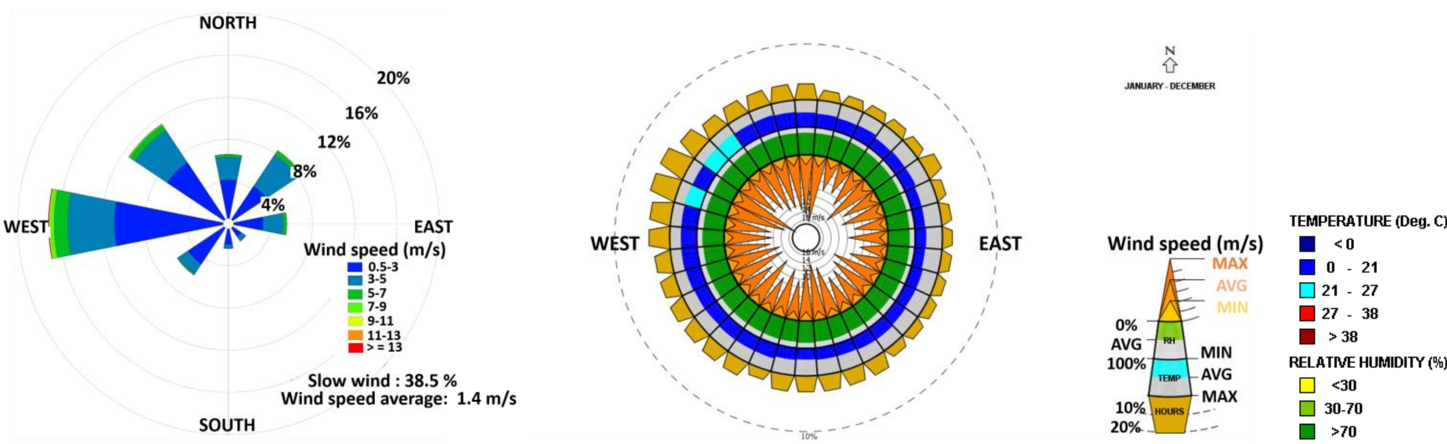


a)



b)

Fig (4): a) Psychometric chart of BABOLSAR [62], b) Wind rose graph of the direction and velocity of dominate wind of BABOLSAR [55&56]

2.2. Field measurements:

The devices were set at a height of 1.75 meters above the ground [68]. Wind data were obtained in summer, in 5 periods. The site is in Amir-Mazandarani district, northern part of Babolsar. Thirteen positions with different physical characteristics were chosen in study area and climate data is surveyed during the day separately in each of these positions on three warm summer days in 2018. In this study, field measurements of micro-climatic data and CFD simulation were carried out at 2 urban blocks of Babolsar (Fig.4). Meanwhile, mobile equipment's recorded wind velocity (WV) during the survey. The wind velocity was measured by ANEMOMETER 3880 every 5 minutes.

2.3. CFD simulations: computational model, domain, grid and solution parameters

- ***2.3.1. Computational domain size and mesh generation:***

The city's setting model and layout meshing have been created using ArchiCAD 16.0 and Flow-3D (V11.2) [57]. The computational geometry of the research area produces in the software at scale 1:1. The dimensions of the computational domain are chosen based on the practice guidelines by Refs. [25,50] (Fig. 6). The domain includes the total area of 566 m × 258 m, containing all the buildings in two blocks. The height of the domain is 78m where 39m is the maximum building height. The downwind domain size is 200m. For wind direction 270°, the domain dimensions are L x W x H = 566 x 258 x 78 m³. The mesh included 550 segments in the x direction, 300 in y direction and 50 in z direction, resulting in a grid with 11,390,184 cells in a Computational domain system. The computational grid is shown in Fig.6.

- ***2.3.2. Boundary conditions:***

The boundary condition sorts are described in Fig.6. As stated in the physical environment data, different inflow volume rates were determined in the model. The inflow status on the left side of the fluid (y-z plane) of the domain is given as follows. The wind inlet boundary conditions are in accordance with the measured profiles of mean wind velocity along the middle line upstream of the model. The inflow wind velocity is 1.4 m/s. The orientation of the city's setting has been selected according to the dominant wind direction. The aerodynamic length is assigned in accordance with the measured profiles of mean wind velocity. For the interior of the domain, the buildings are modeled clearly. It means that the model of buildings, the base plane of the simulation model, and building walls are modeled with z0 = 0m. Sidewalls were assigned to the wall boundary condition. The velocity outflow status put is placed to the right side of the fluid (y-z plate) of the domain. At the outlet of the domain, zero static module pressure is applied.

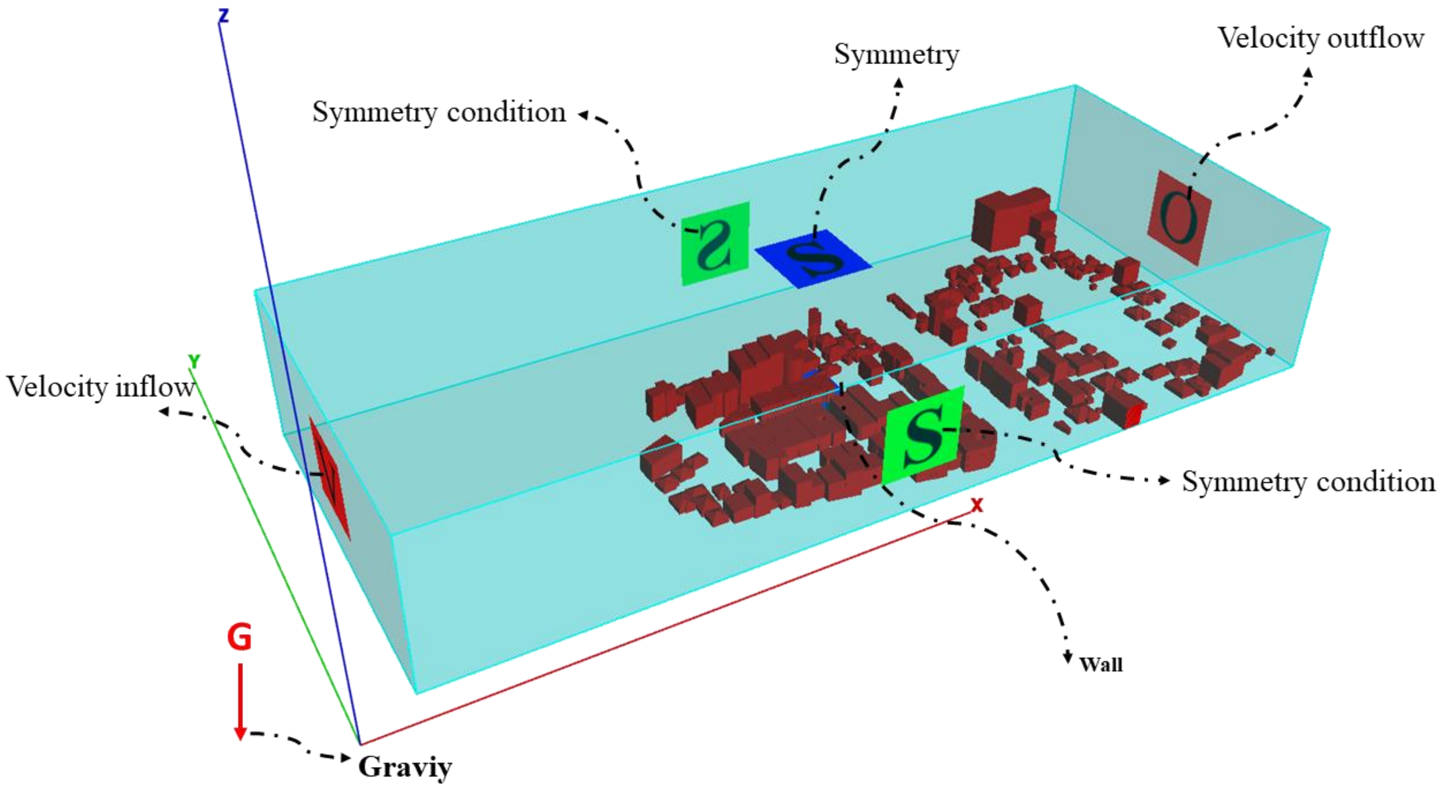


Fig. (5): 3D view of computational fluid dynamics domain with sign of main dimensions and boundary conditions

- ***2.3.3. Solver settings:***

The CFD simulations are performed using the commercial CFD code FLOW-3D (V11.2). FLOW-3D solves the flow field equations based on the finite volume method which is a highly used type of numerical solution methods [67]. There are different turbulent models which can be applied to the flow field cells, including Spalart-Allmaras, Standard K-ε, RNG K-ε, Realizable K-ε, and Reynolds Stress Model. RNG turbulent model is a reasonably accurate and robustious turbulent that applied to the model [59]. Based on literature reviews, RNG applied to the model, which is a robust, reasonably accurate, and robust turbulent model for modeling flow. The k-ε turbulence model can exactly describe the outdoor air environment. However, the outdoor wind environment is all the time changing, the steady-state model has been able to describe and solve the problem; therefore, it is used a steady-state model to calculate. K-e equations are derived from the application of a rigorous statistical technique (Renormalization Group Method) to the instantaneous Navier-Stokes equations. The solver setting equations can be written as follows: [59,60]

1) $\frac{\partial U_j}{\partial x_i}=0$

2) $U_j\frac{\partial U_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_j}\left[(v+\ v_t)\frac{\partial U_i}{\partial x_j}\right] + \frac{\partial}{\partial x_j}\left(v_t\ \frac{\partial U_j}{\partial x_i}\right)$

Where xi and yi are the component of axes x and y. Ui are the average velocity component along the axes x, y and z, respectively; κ and ε are turbulent kinetic energy and turbulent dissipation rate, respectively; P is mean pressure, ρ is air density and v is the kinematic viscosity of air.

Equations for the RNG – Model:

3) 3) $\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}(\rho k u_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + P_k - \rho\epsilon$

4) 4) $\frac{\partial}{\partial t}(\rho\epsilon) + \frac{\partial}{\partial x_i}(\rho\epsilon u_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\epsilon}\right)\frac{\partial \epsilon}{\partial x_j}\right] + C_{1\epsilon}\frac{\epsilon}{k}P_k - C^*_{2\epsilon\rho}\frac{\epsilon^2}{k}$

2.4. Validation study:

Validation by testing is a basic requirement for CFD studies in urban structure for accurate and reliable results. For real urban areas, field measurement in the study area is done directly to measure the data, but the suitable conditions for measuring the data for scientific use and especially for validation can be a limitation. Due to the inherent instability of environmental conditions, it is necessary to accurately and completely measure the parameters of the urban area, including measurement setup and measurement accuracy which will be possible with accurate and complete validation [61]. For validation purposes, on-site wind speed measurements have been performed with 3D ultrasonic anemometers. Measurements were positioned at a height of 1.75 m and in 13 different positions, on 3 warm days in summer. The measurement positions are indicated in fig.7 [62].

Fig (6): The in-field surveyed points

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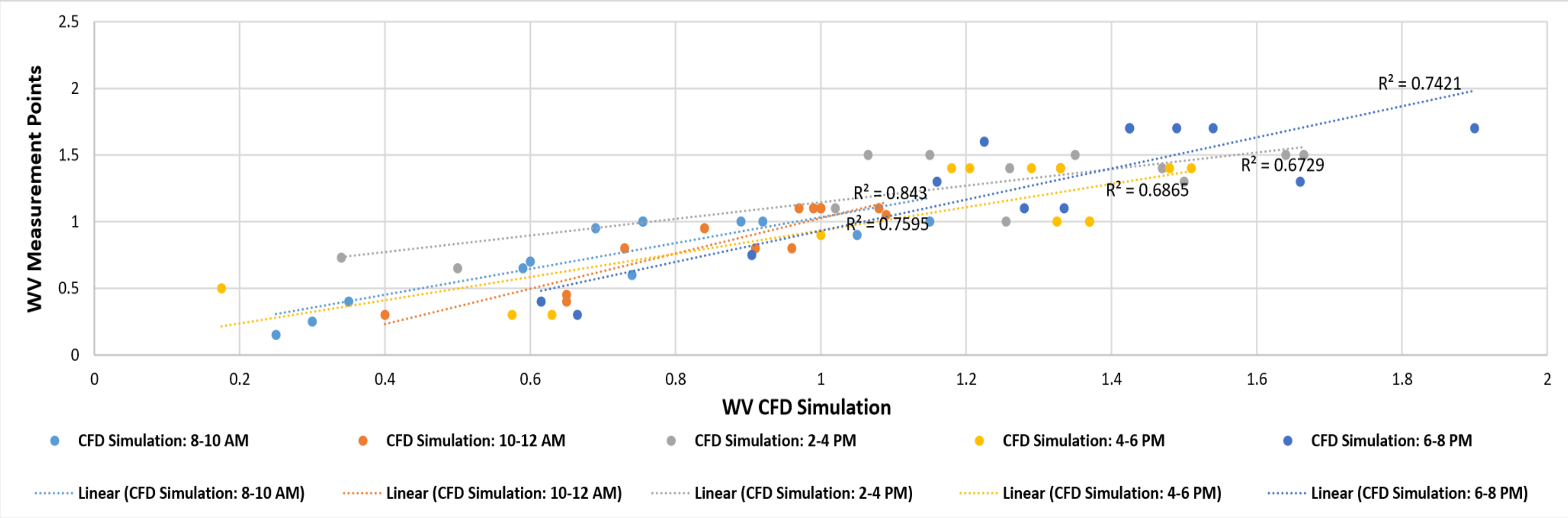
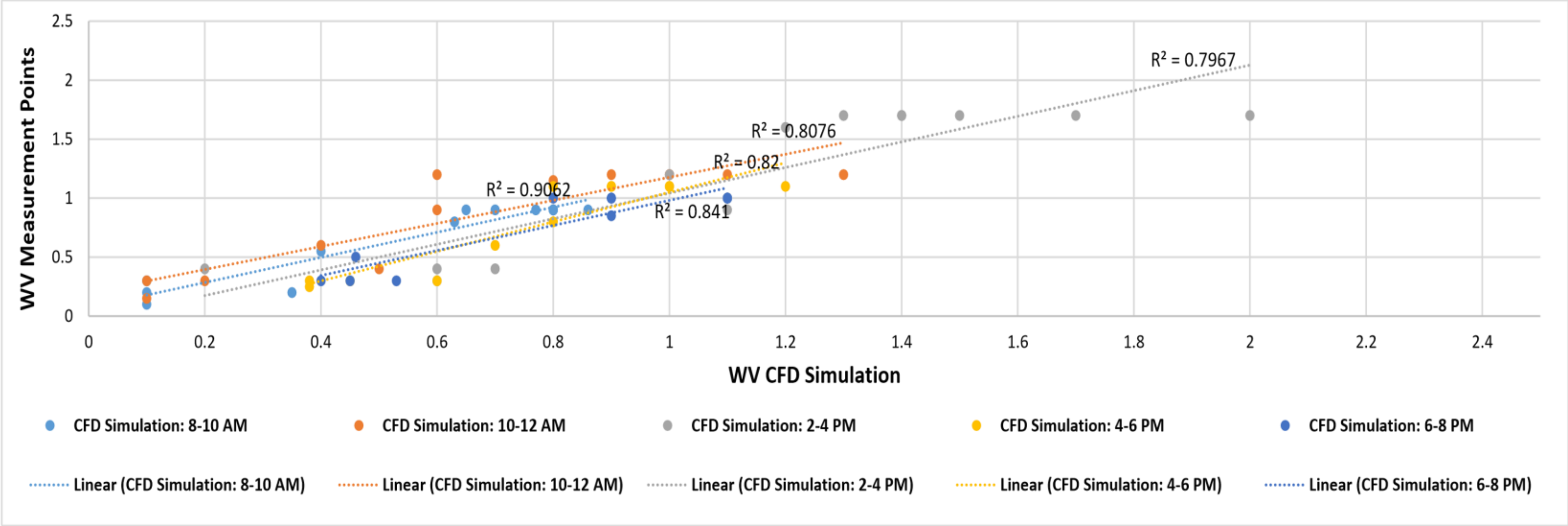
The characteristics of wind flow between buildings are revealed by field harvesting in the environment. CFD simulations with the present data can provide more and better analyses of the flow aspect, although high-precision simulation is required. The velocity factor is recorded and compared in both the measurement and simulation environments.

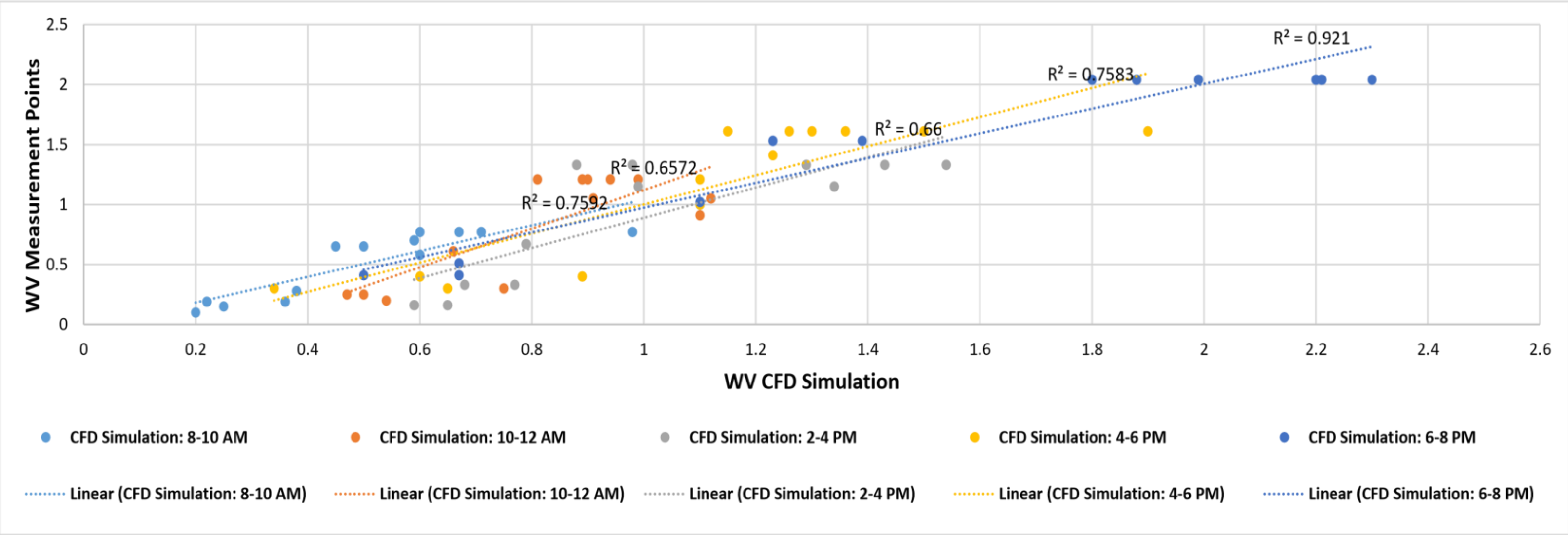
Schatzmann and Leitl have exactly explained the systematic differences between environmental data measurement, laboratory experiments, and RANS simulation. Measuring environmental data averages 10 minutes to 30 minutes, but the results of the average RANS simulation time are quite consistent with theoretical time intervals, because environmental climate conditions change in 30 minutes [63]. Also measured environmental data in constant situations and the measured wind velocity average can be used in validation data [62] To validate the CFD simulations, on-site measurements must be performed for actual configuration and then compared with CFD simulations performed with different turbulence models.
The validation results from the comparison study are shown in the charts of fig. 8:



a): Scatter-plot and linear-fit estimate of Wind Velocity (WV) CFD Simulation with Wind Velocity (WV) measurement points 97.5.16



b): Scatter-plot and linear-fit estimate of Wind Velocity (WV) CFD Simulation with Wind Velocity (WV) measurement points 97.5.17



c): Scatter-plot and linear-fit estimate of Wind Velocity (WV) CFD Simulation with Wind Velocity (WV) measurement points 97.5.18

Fig (7): Scatter-plot and linear-fit estimate of Wind Velocity (WV) in several days

Table (1): Information of scatter-plot and linear-fit estimate of wind velocity (WV)

	August 7	August 8	August 9
8-10 AM	y = 0.9683x + 0.0651 R^2 = 0.7595	y = 1.0716x - 0.0312 R^2 = 0.7592	y = 1.0716x - 0.0312 R^2 = 0.7592
10-12 AM	y = 1.323x - 0.297 R^2 = 0.843	y = 1.6088x - 0.4885 R^2 = 0.6572	y = 1.6088x - 0.4885 R^2 = 0.6572
2-4 PM	y = 0.6222x + 0.5237 R^2 = 0.6729	y = 1.0854x - 0.0427 R^2 = 0.7967	y = 1.2582x - 0.3688 R^2 = 0.66
4-6 PM	y = 0.8718x + 0.0624 R^2 = 0.6865	y = 1.2519x - 0.2025 R^2 = 0.82	y = 1.2124x - 0.2119 R^2 = 0.7583
6-8 PM	y = 1.168x - 0.236 R^2 = 0.7421	y = 1.0614x - 0.0802 R^2 = 0.841	y = 1.0318x - 0.0585 R^2 = 0.921

According to these three charts on different days (table 2), the positive relationship between the velocity of the points is measured and simulated. Linear regression between data is in most cases higher than 0.5, and in some cases R^2 = 0.843 at 10-12 AM on August 7, R^2 = 0.9062 at 8-10 AM on August 8, and R^2 = 6-8 PM on August 8, which was the longest day that has given the highest value. Weak relationship existed in some points and this error was apparently due to unpredictable environmental factors such as disturbances due to vehicle and pedestrian traffic. From the data measurement, it can be concluded that CFD simulation is valid for the study area and can be used to statistically analyze the range.

3. Theory

In humid areas with high density, attention to urban design is highly necessary. High-rise buildings prevent wind flow from circulating and make it difficult for urban ventilation. Attention to the important parameters for urban ventilation has been investigated in this section. In this study, the demand for high-rise buildings is high, so other effective factors in addition to the height factor should be evaluated. In recent years, research has been conducted on the wind flow simulation in the outdoor spaces, which can be improved by changing the urban physics. Table 2 provides an overview of studies on wind flows into buildings physics in order to increase urban ventilation performance.

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Table 2

Overview of studies on urban wind flow and ventilation conditions by CFD simulation in urban areas.

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					the factor	the factor	of WV	of WV	
Albrecht and Grunow, 1933	[33]	Street canyon	E	-		E		✓	Inc. Enclosure → Inc. WV
Li et al. 2005	[34]	Street canyon	W, H, E	WT				✓	Inc. Enclosure → Inc. WV
Ali-Toudert and Mayer, 2006	[35]	Building block	E, SO	-		E, O		✓	Inc. Enclosure + Dec. orientation →Inc. WV
Blocken et al. 2008	[36]	Street canyon	W, H	WT	E	O	✓	✓	Dec. enclosure → Inc. WV
Zhang et al. 2009	[37]	Building block	C, BO	-			✓	✓	Inc. Enclosure → Inc. WV→ into W direction Dec. enclosure → Inc. WV →perpendicular to W
Bourbia and boucheriba, 2010	[38]	Street canyon	E, S, O	FM		E, O		✓	Enclosure + orientation→ Direct effect on WV Inc. enclosure → Inc. WV
Hang & Li, 2010	[39]	Building block	W, H, SL, E	WT	H		✓		Inc. High-rise buildings → Red. WV on subsidiary street into main street → perpendicular to W
Al-Sallal and Al-Rais. 2012	[40]	City	C, E, S	-	W	E		✓	Dec. street width → Dec. WV → perpendicular to W direction In open space and wide street → Inc. WV → into W direction
Yuan and Ng, 2012	[41]	Building block	C, H, SO, P	WT		P		✓	Improve or Inc. porosity → Inc. WV
Yang et al., 2013	[7]	City	H, E, BO	-	H			✓	Eliminating or Red. high-rise blocks → Inc. WV
Hong and Lin, 2015	[42]	Building block	C, TA	FM		C, TA		✓	Building blocks configuration and plants around them → Inc. WV
Hang et al. 2015	[43]	Building block	H, W, D, O	WT		H, O	✓		Improve urban size + Inc. Building height, Improve Building Orientation → Improve or Inc. WV
Pancholy et al. 2016	[13]	Street Canyon	E, O	WT		O	✓		Building Orientation into W direction → Inc. WV Building Orientation → perpendicular to W direction → Dec. WV
Xuan et al. 2016	[20]		-	WT	W	S		✓	Red. distance between buildings → Inc. WV Inc. building shade → Inc. WV
Gan and chen. 2016	[44]		C, H, P	WT		P		✓	Inc. porosity and rugosity → Inc. WV → Inc. block ventilation
Zeyaeyan et al. 2017	[45]	City	SH, SI, C	-	C	H	✓		Relocation and removal of mid blocks → Inc. WV Tall buildings → perpendicular to W direction → Dec. WV
Wen et al. 2017	[19]	Building block	H, D	WT		H	✓		Inc. building height → Inc. WV Inc. height of the arcade→ Red. WF across opening of streets
Guo et al. 2017	[46]	City	D, E, C, H, W	FM		E, TA		✓	Improving morphology + Inc. green space system → Inc. WV → Inc. urban ventilation Strip apartments in rows + enclosed city blocks → Dec. WV → Dec. urban ventilation
Juan et al. 2017	[47]	Building block	H, W, D	FM		E		✓	Incorporating the arcade design into buildings→ Inc. WV Optimal arcade design → Improving city breathability
Du et al. 2018	[48]	Building block	H, P	WT		H		✓	Inc. building height → improve or Inc. WV for isolated building and grouped buildings Inc. porosity on the first floor → Inc. WV Larger porosity size → Inc. WV than smaller porosity size
Yang et al. 2019	[24]	City	D, H, E	FM		SO, BO, H		✓	Street Orientation + Building Height + Open spaces + Shape and Orientation of Buildings → to dominant wind direction → Inc. WV
Qin et al. 2020	[49]	Street canyon	E, D, C	WT		O		✓	streets parallel + extra-large site division strategies (S4000) → into the prevailing

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							wind direction → Inc. WV → Inc. urban ventilation
Zhang et al. 2020	[25]	Building block	SH, C, BO, E	WT	C, O	✓	Corner modifications + Buildings' Configuration + Buildings' Orientation → into prevailing wind → Inc. WV
Jiang et al. 2020	[50]	Building block	C, W, BO, H, BL	PS (FM & WT)	W, E	✓	an open space + a ventilation corridor + using narrow canyon + Corner effects + Enclosed type layout → Improving WV

Validation_ FM= Field measurement, WT= Wind tunnel, PS= Previous studies; **Focus_** E= Enclosure (passage height-to-width ratio), W= Street width, H= Buildings height, O= Street orientation, SO= Street orientation, BO= Block orientation, C= Configurations, S= Sky view factor, L= Street length, TA= Trees Arrangement, D= Density, P= Porosity, SH= Shape, SI= Size; **Effective factors_** Dec.= Decrease, Decreasing, Inc.= Increase, Increasing, Red.= Reduce, Reducing, WV= Wind Velocity, WF= Wind flow

Albrecht et al. [33] Have studied the urban airflow of air, urban geometry, and enclosure of urban masses, and have concluded that in spaces with a suitable enclosure ratio (height to width H / W), better airflow can be controlled Li et al. [34] Focused on ideal urban canyons (H/W = 0.2, 0.1, and 0.5). The enclosure of 0.3 to 0.65 leads to turbulent and intermittent airflow. They also emphasized the significant savings in computer resources and computing time by the RANS method. For the purpose of the outdoor thermal comfort study for pedestrians, Toudert and Mayer [35] examined two factors, the enclosure of urban geometry and the rotation of urban streets orientation into a wind direction perpendicular to the street axis. Their studies showed that a height-to-width ratio = 2 by N-S orientation to the prevailing wind provides the best thermal comfort. Blocken et al. [36] have studied the environmental conditions of the wind around tall buildings. In this study, the parameters of width street, building height, and wind velocity have been studied and the results show that the factors that strengthen wind velocity in divergent streets are usually larger than convergent streets. It has also been shown that the maximum wind speed increases uniformly as the width of the passages decreases. Zhang et al. [37] investigated the different configurations and urban block orientations by using three-dimensional simulations of ideal blocks to examine. In their study, the group highlighted the importance of paying attention to these factors to improve the built environment in this way. Al-Sallal and Al-Rais [40] have simulated winds around the building and the pedestrian area based on the adaptive ASHRAE model, and have concluded that the funnel-shaped wind flow moves hardly between the urban blocks. wind velocity is increased in this kind of street and sometimes improves wind rotation in some areas. In urban environments, the wind velocity is less than in open space because of masses configuration. Wind velocity is also reduced by hitting building masses and wider by a height-to-width rate = 1.75. Yuan and Ng [41] conducted a study on compact building blocks in hot and humid areas. In this area, stagnant air is created between building blocks, which lowers the urban thermal comfort in the open air. In this computational parameter study, wind velocity classification has been performed to evaluate the wind velocity effect on outdoor thermal comfort. The present study concluded that the building porosity was effective in improving better urban ventilation at the pedestrian level, without losing the effectiveness of land use. Yang et al. [7] have examined the relationship between the building geometric structure and wind behavior in the Taiwanese Dan region to analyze wind behavior and the natural ventilation rate in the city area. In this study, the ventilation conditions improvement in urban areas has been achieved by removing high-rise blocks. Hong and Lin [42] have examined the effect of changing the pattern of buildings next to each other (location) and how trees are arranged around them on the climatic comfort of pedestrians. In this study, the proper arrangement of building blocks and plants around the building leads to increased natural ventilation and thermal comfort Pancholy et al. [13] Conducted a fundamental study using the steady Reynolds-Averaged Navier-Stokes (RANS) of computational dynamic simulation (CFD) to investigate the effect of different angles of attack (AOA) on the wind flow pattern at a pedestrian level within a similar street. In this study, the width-to-height is considered to be (S / H) = 2 because the long distance between buildings is dangerous for pedestrian comfort. This study shows that at a certain distance of buildings in the street for pedestrian comfort is higher when flow approaches angles of 0◦, 15◦, 60◦, and 75◦ compared to other AOA. It also shows that the wind flow structure within a street at a specific dimension rate differs from a building case. Xuan et al. [20] have explored outdoor comfort for various urban forms under the summer conditions of Sendai, Japan, and Guangzhou, China. their research shows that as the distance between the buildings decreased, the wind velocity distribution around the buildings became polarized and the wind velocity ratio increased slightly. This condition mainly caused poor ventilation and thermal discomfort. Safe outdoor thermal conditions can be achieved to some extent by reducing the building distance. Zeyaeyan et al. [45] have simulated about 80 towers in parts of the Chitgarh district of Tehran, and the impact of tall buildings on wind flow has been investigated. By studying this research, they have concluded that wind flow is affected by the texture, shape, and structure of pedestrians in urban areas. The tall buildings in the wind flow direction have prevented it and cause weak wind flow, and the building height has doubled its effect. Therefore, by removing some building blocks in the wind flow direction, it is possible to significantly improve the air conditioning around the current and future towers. In a report on the city of Dalian, Guo et al. [46] pointed to urban expansion using the high-density morphological pattern in the city center, which causes wind velocity to decline in the year. The results show that urban buildings such as enclosed urban blocks, row and continuous apartments, high-rise buildings are undesirable for natural ventilation, and solutions by using ventilation ducts and increase the building height into wind direction while reducing their land cover can be improved urban ventilation performance. By focusing on the arcade design, Juan et al. [47] evaluated the ventilation performance in high-rise urban environments and related natural ventilation capabilities. Field measurements have been made on the site to validate the computational model. Due to concerns about urban respiration, the arcade buildings arrangement with the favorable height and width in the street is used to enhance the effect of natural ventilation to increase the city's breathing. The windy environment at the pedestrian level is affected by stagnant airflow in dense cities, so Du et al. [48] discuss the true effects of building height and the size of the porosity on wind comfort at the pedestrian level. They concluded that an increased building height could improve wind comfort inside the site boundary for both the isolated building and group of buildings. The wind comfort benefits increased when porosity is on the first floor compared to when it is on the second floor. The larger porosity size generally results in better wind comfort than the smaller porosity size.

The following observations can be made:

- CFD simulations are used to pursue such studies. This method is one of the most common methods for airflow simulation studies.
- The urban ventilation study takes place according to the masses'-built layout, and most of these layout properties have focused on the physical structure of the blocks and their configuration type.
- Finally, there is a significant effect of these characteristics (enclosure, street width, buildings height, buildings and streets orientation, configurations, density. etc.) on wind velocity in different conditions. The wind treatment is altered in the block by changing each of these characteristics.

In this study, the effective physical factors on wind velocity that have been introduced in previous studies, are investigated in the study area. By recognizing the effective factors on wind velocity and improving the built environment, it can help urban breathing and provide better environmental comfort for the future.

4. Result

- **3.1. Analysis of masses' physical characteristics:**

After validating CFD simulation, 45 points were selected due to their different physical condition in the simulated environment (fig.9). Parameters of wind velocity, mass orientation to the wind, average height of buildings and width of space between masses were surveyed at the 45 points on the two urban blocks. Wind velocity is dependent to the orientation, enclosure, height of masses, and width between them.

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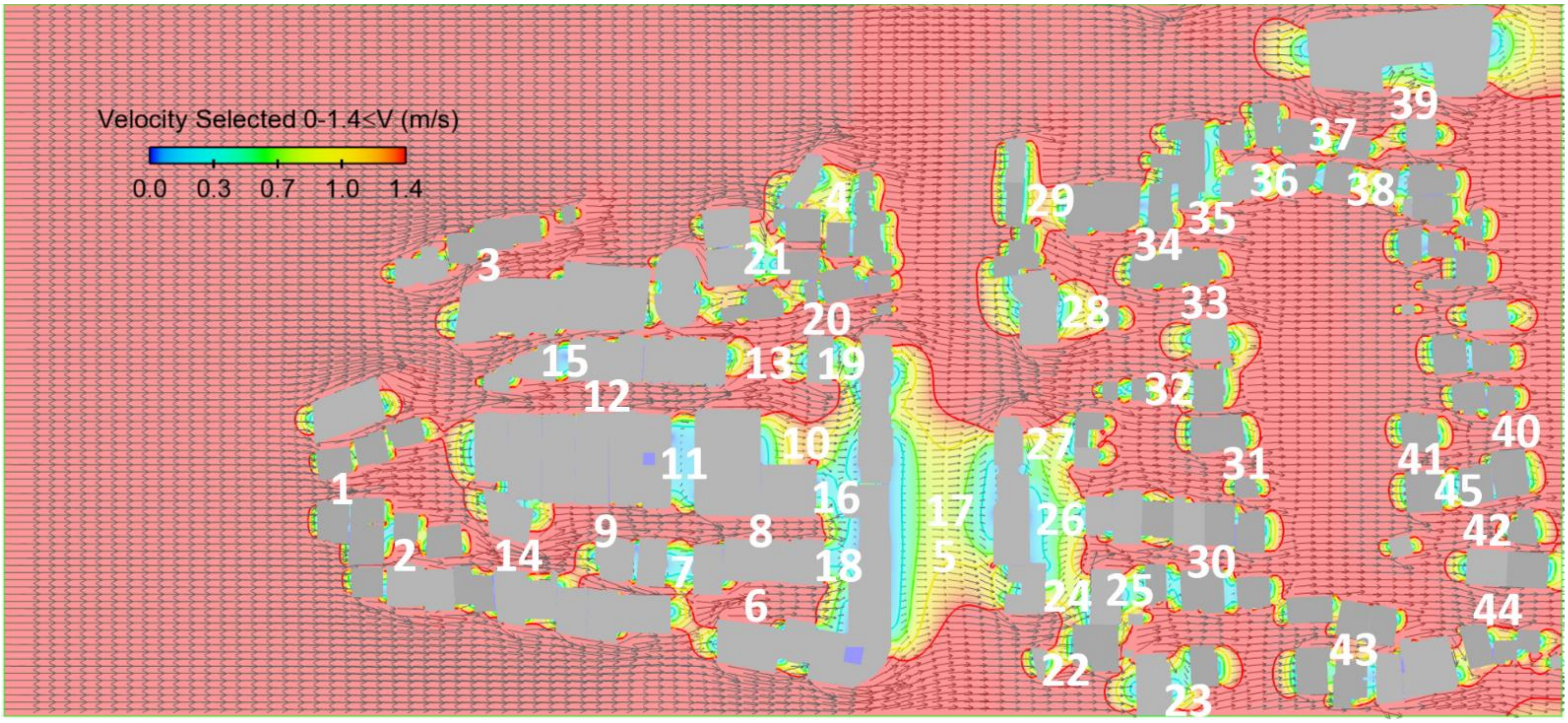

Fig. (8): 45 points simulation area

Wind velocity variations have been measured and all the factors influencing the flow pattern and wind velocity have been investigated. In table 3, the correlations between the velocity and four variables are shown in the domain of the model. The linear regression analysis of variable factors and wind velocity has been presented in fig.10.

Table (3): Correlations between variable factors and velocity

Index1	**Index2**	**R^2**
Velocity	Orientation	**0.504**
Velocity	Enclosure	**0.2226**
Velocity	Height	**0.0321**
Velocity	Width	**0.0305**

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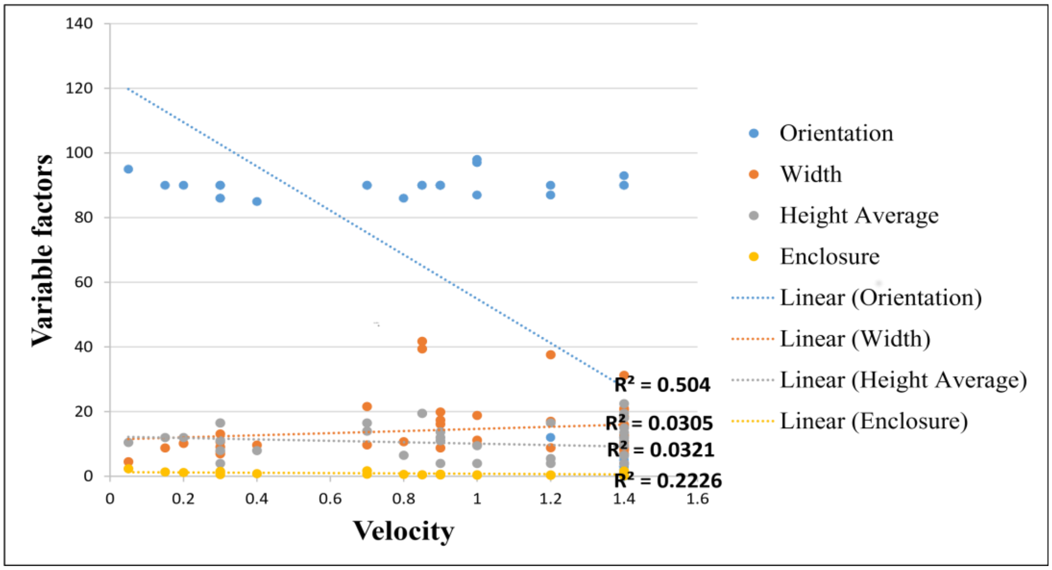

Fig. (9): Linear regression analysis of variable factors and wind velocity

According to table 3, the correlation of masses orientation to the wind is different from other factors. Its correlation coefficient is 0.504 and it has significant positive correlation. When the masses orientation reaches zero-degree, subsequently wind velocity increases, and vice versa.

Correlation is significant between two variables of enclosure and wind velocity. Its correlation coefficient is 0.2226 and it has a positive correlation. It means that when enclosure increases, the wind velocity increases too. Unlike this result, in some points, despite the high degree of enclosure, the wind flow rate is low, which may be due to changes in other variables.

The correlation between average building height and wind speed is 0.0321 and there is 0.0305 correlation between width between building masses and wind velocity. The slope of linear regression between variables is very weak and it shows that their effect on wind velocity in a pedestrian level is not significant.

3.1.1. Points with different behavior

In table 4, in the points where the behavior is different from the results, the correlation test between 4 variables and velocity is repeated. It is observed in fig.11 that the correlation of the mass's orientation, enclosure, height, and width are 0.0106, 0.5376, 0.0854 and 0.0034 respectively. There is the least correlation between the velocity and masses orientation. The correlation between the velocity and the width between masses is also low, it can be concluded that a weak correlation between width between masses and velocity leads to a very weak correlation between the mass's orientation and the velocity.

Table (4): Excluding 15 data measurements

Enclosure	height Average	width	orientation	velocity	place name
0.466730493	19.5	41.78	90	0.85	**17**
0.494923858	19.5	39.4	90	0.85	**5**
0.438596491	16.5	37.62	90	1.2	**10**
0.432276657	13.5	31.23	93	1.4	**13**
0.690261044	13.75	19.92	90	0.9	**27**
0.504782147	9.5	18.82	87	1	**28**
0.215517241	4	18.56	90	1.4	**32**

0.689655172	12	17.4	90	0.9	**24**
0.323149236	5.5	17.02	87	1.2	**29**
0.680693069	11	16.16	90	0.9	**4**
0.252844501	4	15.82	90	1.4	**35**
0.356824264	4	11.21	98	1	**38**
0.60690943	6.5	10.71	86	0.8	**36**
0.407747197	4	9.81	97	1	**22**
0.455580866	4	8.78	90	0.9	**37**

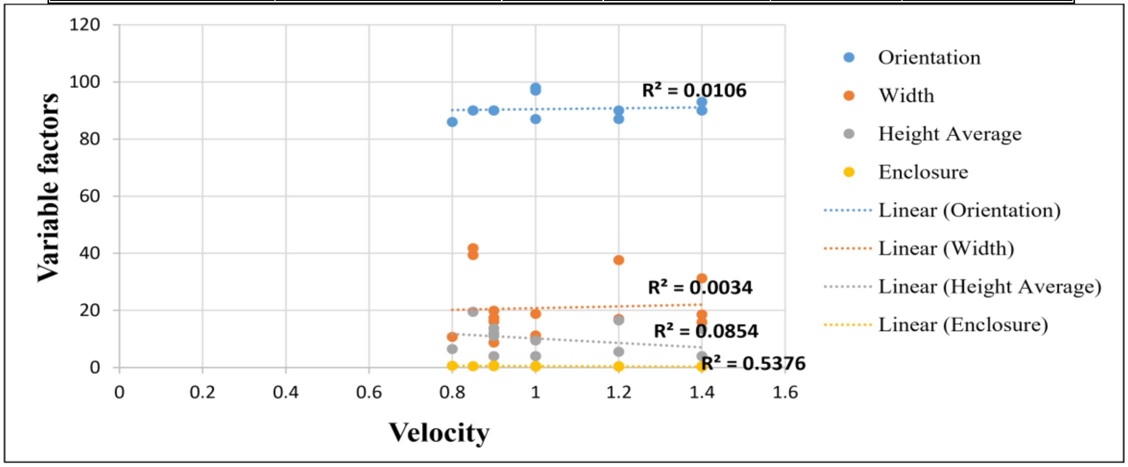

Fig. (10): Linear regression analysis of variable factors and wind velocity at 15 points

3.1.2. TOPSIS statistical test

The proximity correlation coefficient of the four variables (orientation, enclosure, average height, and width between masses) and the wind velocity are calculated with the TOPSIS statistical test. The theoretical foundations of this technique are based on this relationship, which at first has been calculating the positive ideals (the most efficient mode) and the negative ideals (the least inefficient mode) for each of the variables; Then, the distance has been calculated for each Variable from positive ideals and negative ideals. The selected Variable has the least distance from the negative and the most distance from the positive ideal. According to this test, the proximity correlation coefficient of four variables is shown in fig.12 and they have a positive correlation with the velocity. The variables of orientation and enclosure have a high correlation. The masses orientation reaches to zero-degree; subsequently, the wind velocity increases and if the enclosure increases, the wind velocity will increase too. This correlation shows that the meaningful relationship is between the two variables (orientation, enclosure) and wind velocity, so these parameters must be considered carefully in the design and development process of urban spaces.

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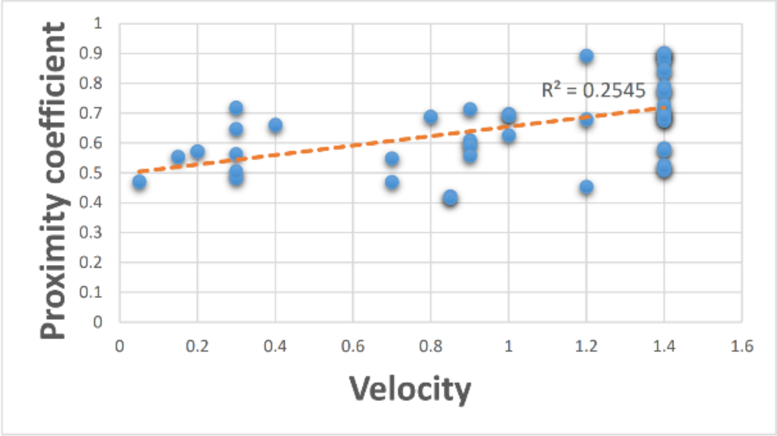

Fig (12): Linear regression analysis coefficient of proximity of 4 variables dependent and function variable (Velocity)

The changing cities due to the consecutive rise of multi-story buildings in the urban environment necessitates a detailed computational and physical modelling to optimize the design of new buildings and control the exposure of the residents to humid air. In this study, the urban block development effects on wind flows in an urban environment were evaluated. In the first step, 3D steady-state RANS simulations were performed on northern urban blocks of Babolsar. The following observations can be made:

- The results clearly show that the orientation of buildings mass reaching zero-degree can have positive effects in increasing of wind velocity on-site, and the wind velocity increases along mass. Thus, the buildings mass orientation must be in the same direction as the wind flow.
- The enclosure has a significant impact on the wind velocity. The height and width between masses have a little effect on the wind velocity and direction alone. But the enclosure with an appropriate and balanced height and width can create suitable condition for wind flow.

- **3.2. Suggested alternatives for two main effective factors in this area:**

Suggestions have been made to modify areas incompatible to the environmental comfort conditions them according to the results of the current situation simulation in fig.13.

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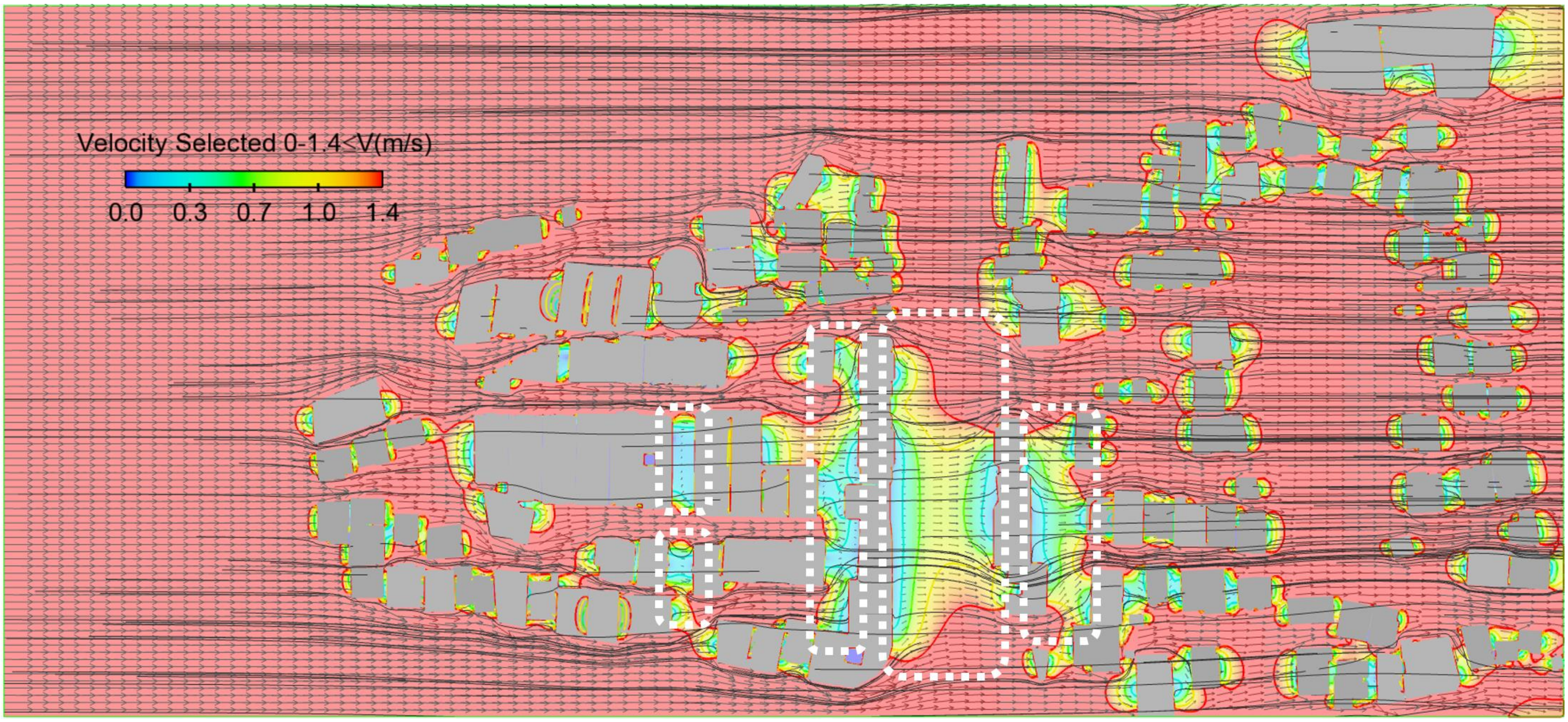

Fig. (13): Incompatible areas to environmental comfort conditions

To this purpose, the variables of masses orientation to dominant wind and enclosure have been examined in the form of distinct proposed options for solving the problem:

- **3.2.1. Create an opening to change the wind direction into the masses:**

❖ ***3.2.1.1. Strategy No. 1: Creating permeability by opening along passage in the prevailing wind direction***

The line graphs show the numeral of wind velocity before and after the physical modification at the pedestrian level of 0-1.75 m and above 1.75 in the distance between 0-50 m in fig.14. Before and after the modification, the velocity graphs show different reactions. There is a gradual decrease in the velocity profile before modification followed by a rise after a constant value of 0 where the construction was built but after the modification, there is a soft increase in velocity, followed by a rise, and then a drop. As can be seen, the velocity profile shows a big rise in velocity after modification due to the eliminating of the part of the building mass obstructing the prevailing wind direction.

A)

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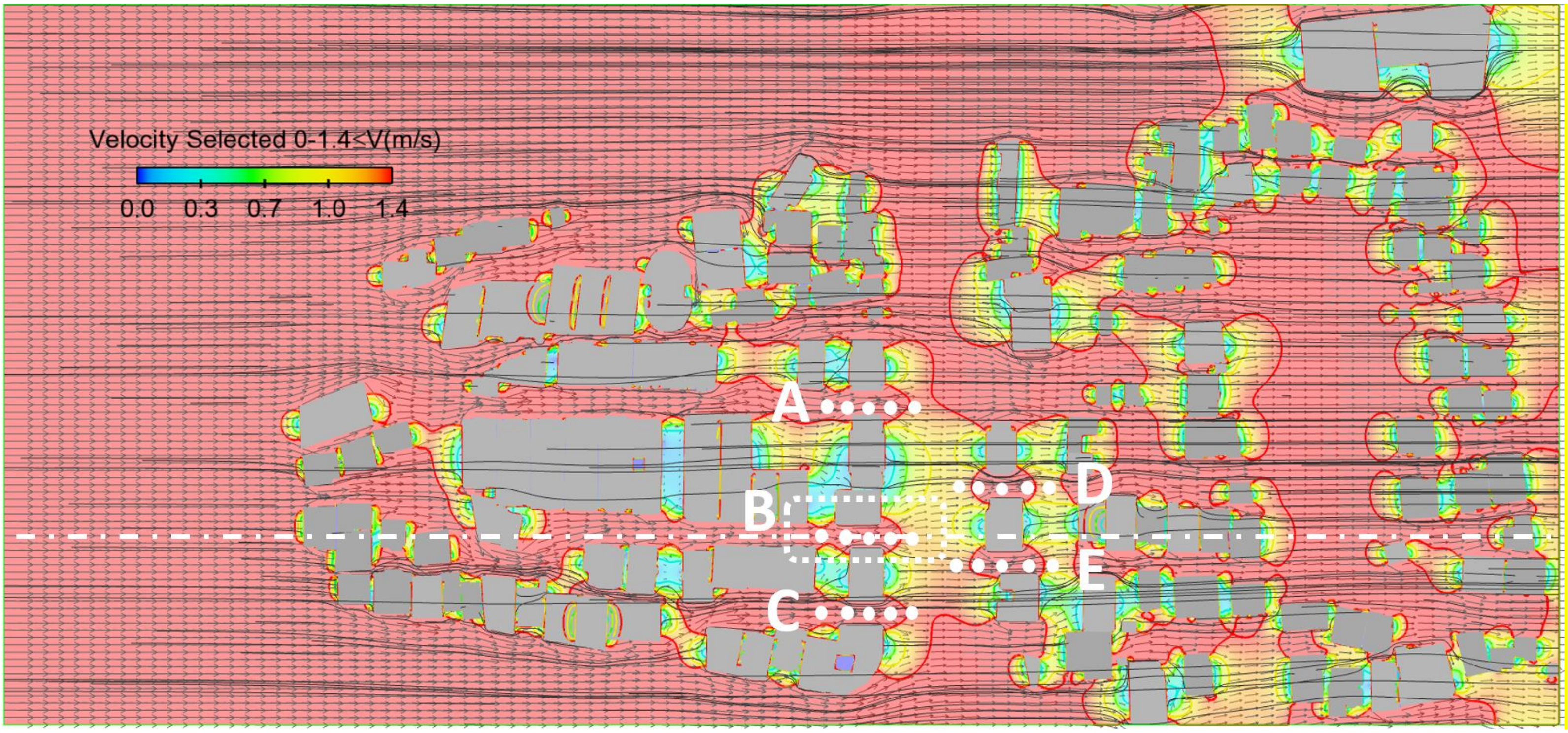

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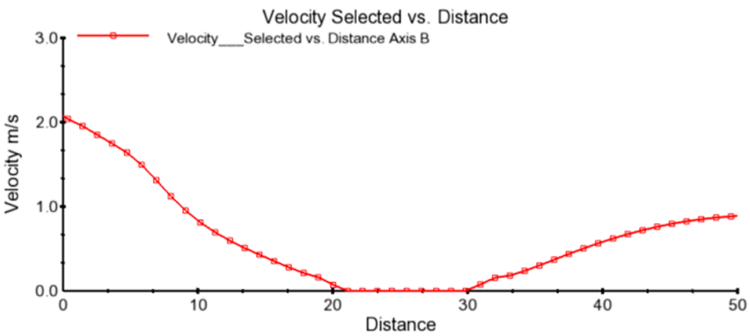
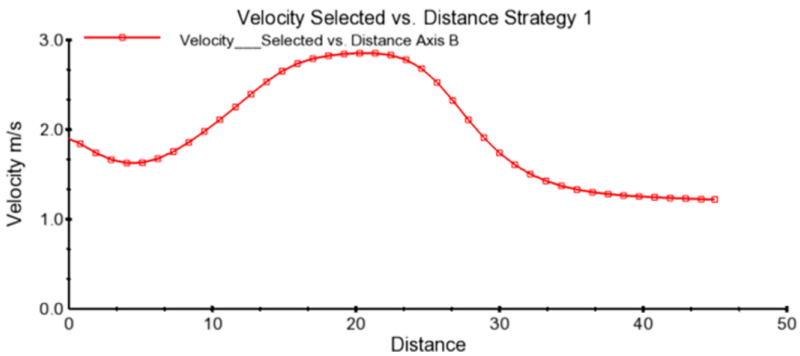
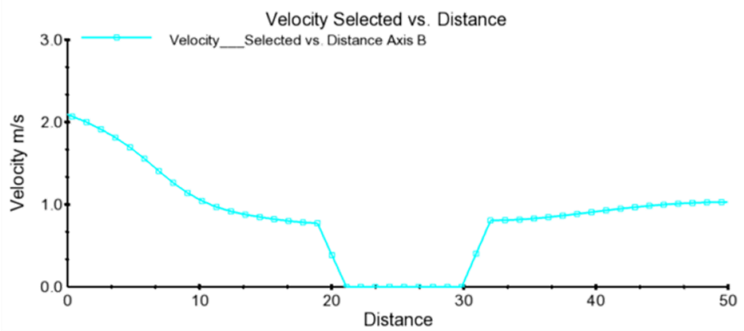


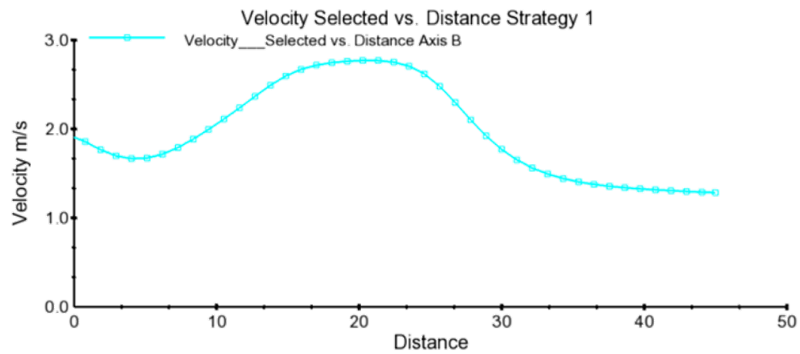
d) Before modification at height 1.75m



e) After modification at height 1.75m



f) Before modification at height 10m



g) After modification at height 10m

Fig. (14): A) Modification plan and simulation of creating an opening along passage in the prevailing wind direction B) Elaborate comparison between wind flow profiles of before and after modification of creating an opening in axis B section

3.2.1.2. Strategy No. 2: Creating permeability by opening along passage on ground floor in the prevailing wind direction

As in strategy of opening along passage in the prevailing wind direction (strategy No.1), the modifications were done at two levels in the distance between 0-50m. At pedestrian level, the before and after modifications are the same as in strategy No.1. However, above pedestrian level at height 10m, there is a sharp decrease in velocity profile of after modification, followed by a rise after a constant value of 0 where the construction was built. As can be seen in fig.15, the velocity profile shows a clear fall in velocity after modification at height 10m due to the eliminating of the part of the building mass on the ground floor obstructing the prevailing wind direction.

A)

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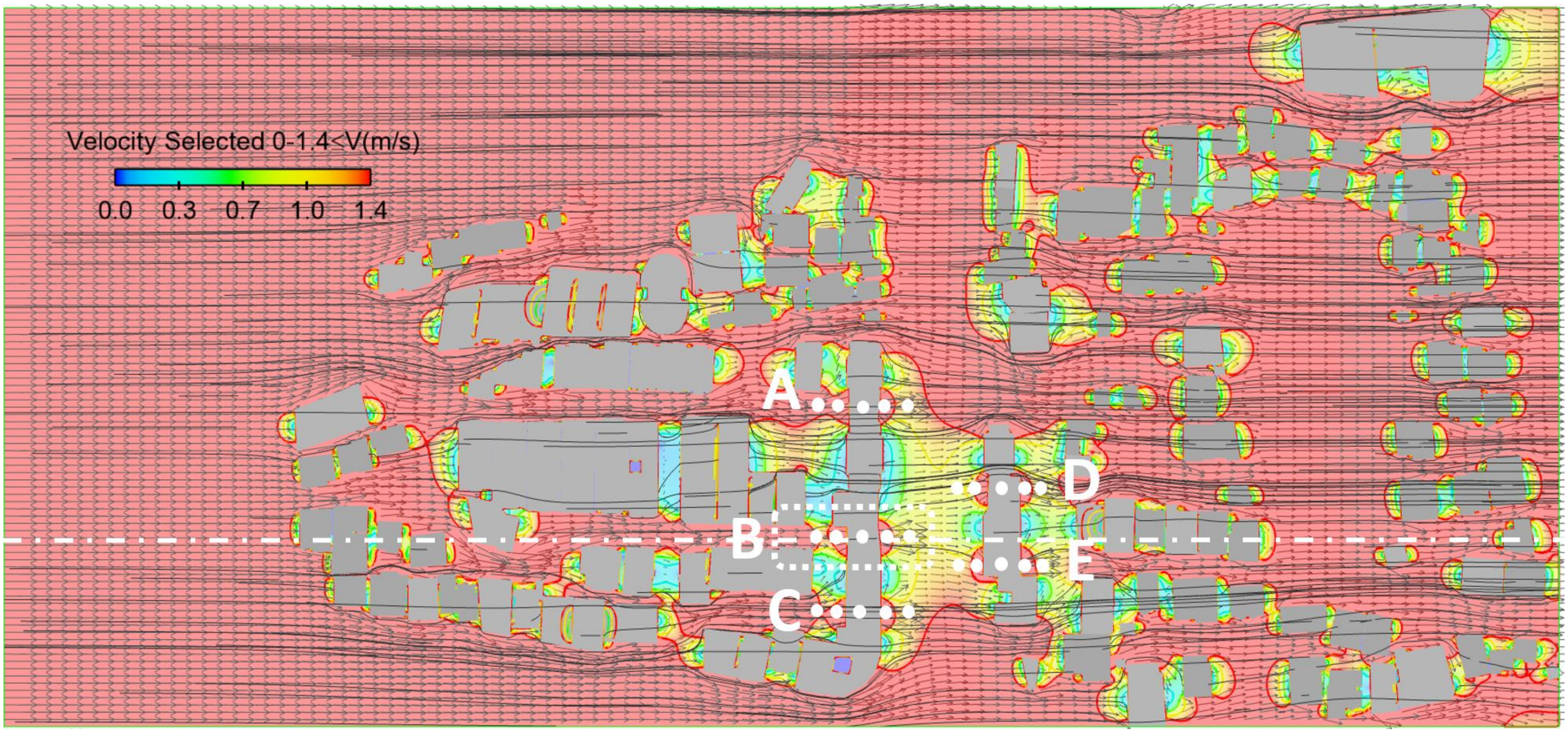

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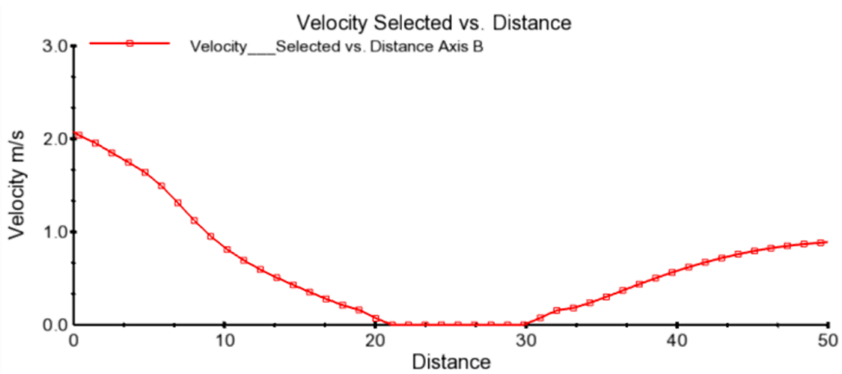
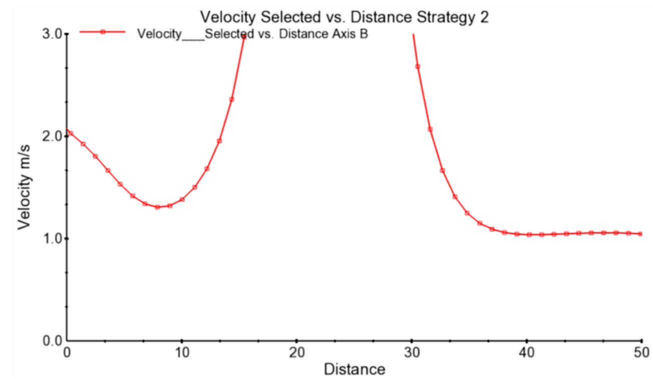
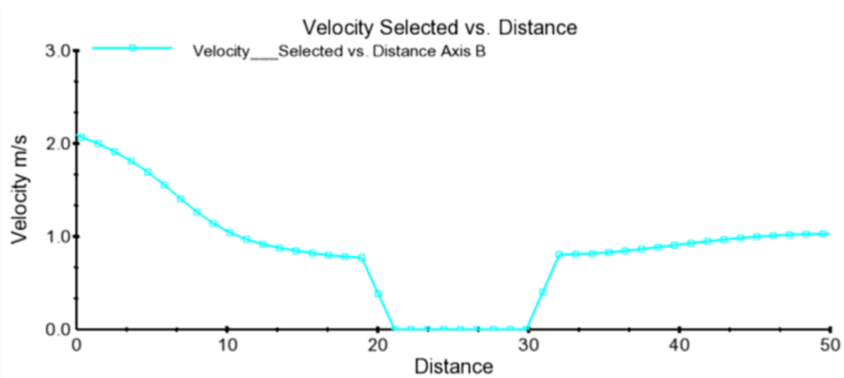


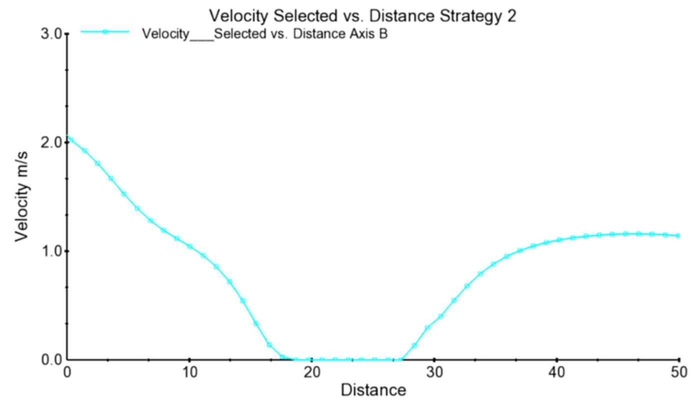
d) Before modification at height 1.75m 6



e) After modification at height 1.75m



f) Before modification at height 10m



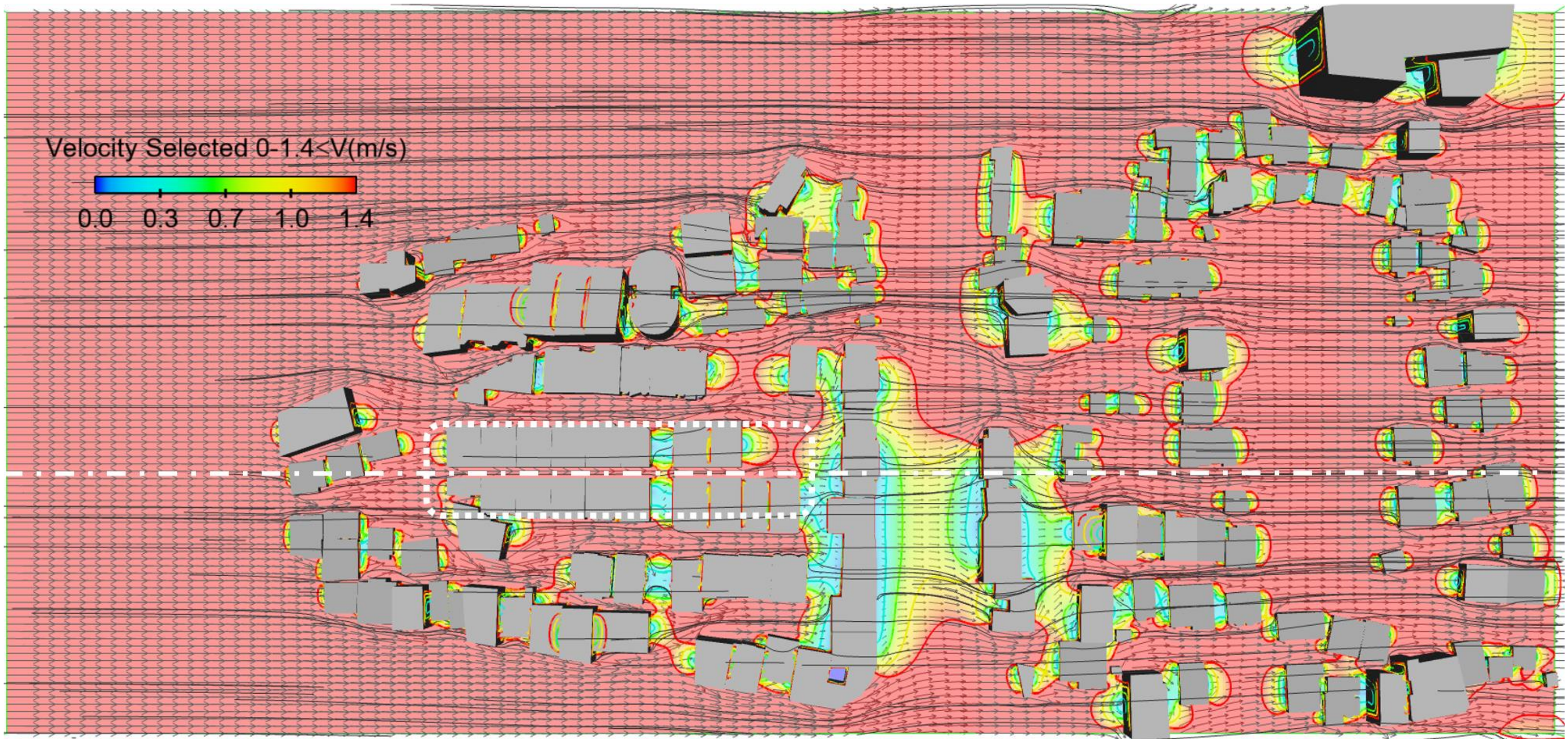
g) After modification at height 10m

Fig. (15): A) Modification plan and simulation of creating an opening along passage on ground floor
B) Elaborate comparison between wind flow profiles of before and after modification of creating an opening along passage on ground floor in axis B section

❖ ***3.2.1.3. Strategy No. 3: Creating open space between building masses by separating buildings in the wind direction***

In fig.16, the strategy of creating open space between building masses by separating buildings in the wind direction is presented. the line graphs show wind velocity of the physical modifications at 1.75m and 10m in the distance between 0-150 m. The velocity graphs show different reactions before and after the modification at both levels (at 1.75m and 10m) like to the strategy of creating permeability by opening along passage (strategy No.1). There is a sharp decrease in velocity profiles before the modifications, followed by a sharp rise after a constant value of 0 where the constructions were built, but there is sharp increase in velocity followed by a fall and then a rise in velocity profiles after modification. As can be seen, the velocity profiles show a large-rise in velocity after modification due to Creating open space between building masses in masses separation in the wind direction.

A)



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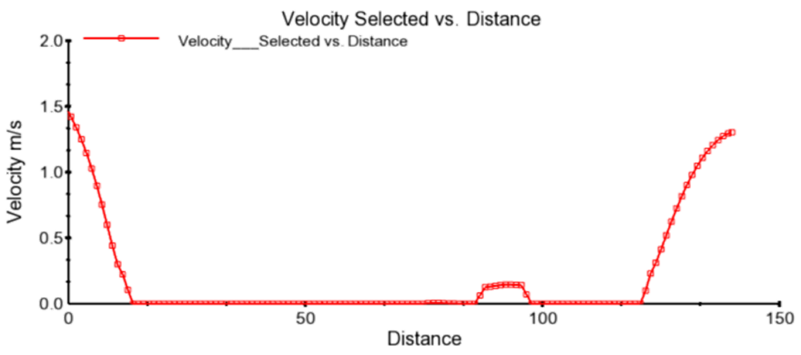
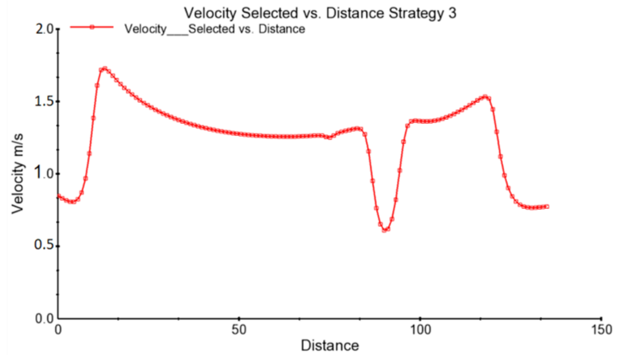
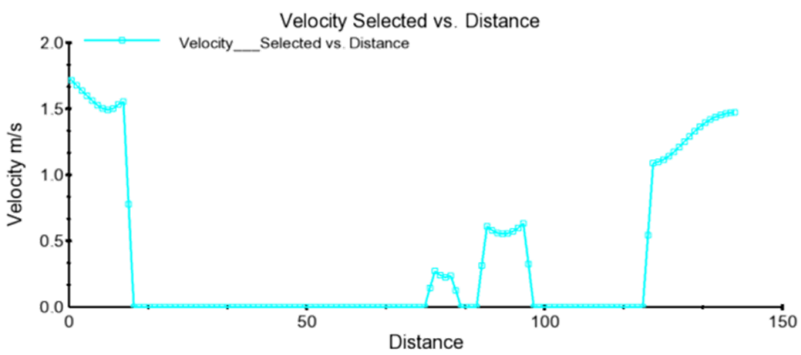


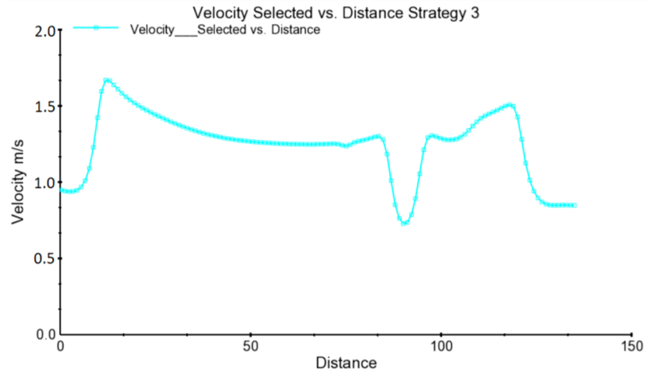
d) Before modification at height 1.75m



e) After modification at height 1.75m



f) Before modification at height 10m



g) After modification at 10m

Fig. (16): A) Modification plan and simulation of creating open space between building masses by separating buildings
B) Elaborate comparison between wind flow profiles of before and after modification of creating open space between building masses by separating buildings in axis B section

❖ ***3.2.1.4. Strategy No. 4: Creating open space between building masses on the ground floor of masses aggregation in the wind direction***

As in the strategy of creating open space between building masses by separating buildings in the wind direction (strategy No.3), the modifications are done at a distance of 0-150 meters in fig.17. At the pedestrian level, before and after are like in strategy No.3. However, above the pedestrian level, there is a sharp decrease in the velocity profiles before and after modifications, followed by a sharp rise after a long constant value of 0 where the constructions were built. As can be seen, the velocity profile shows a clear drop in velocity after the modification at10m due to the eliminating of the open space between the building mass on the ground floor obstructing the prevailing wind direction.

A)

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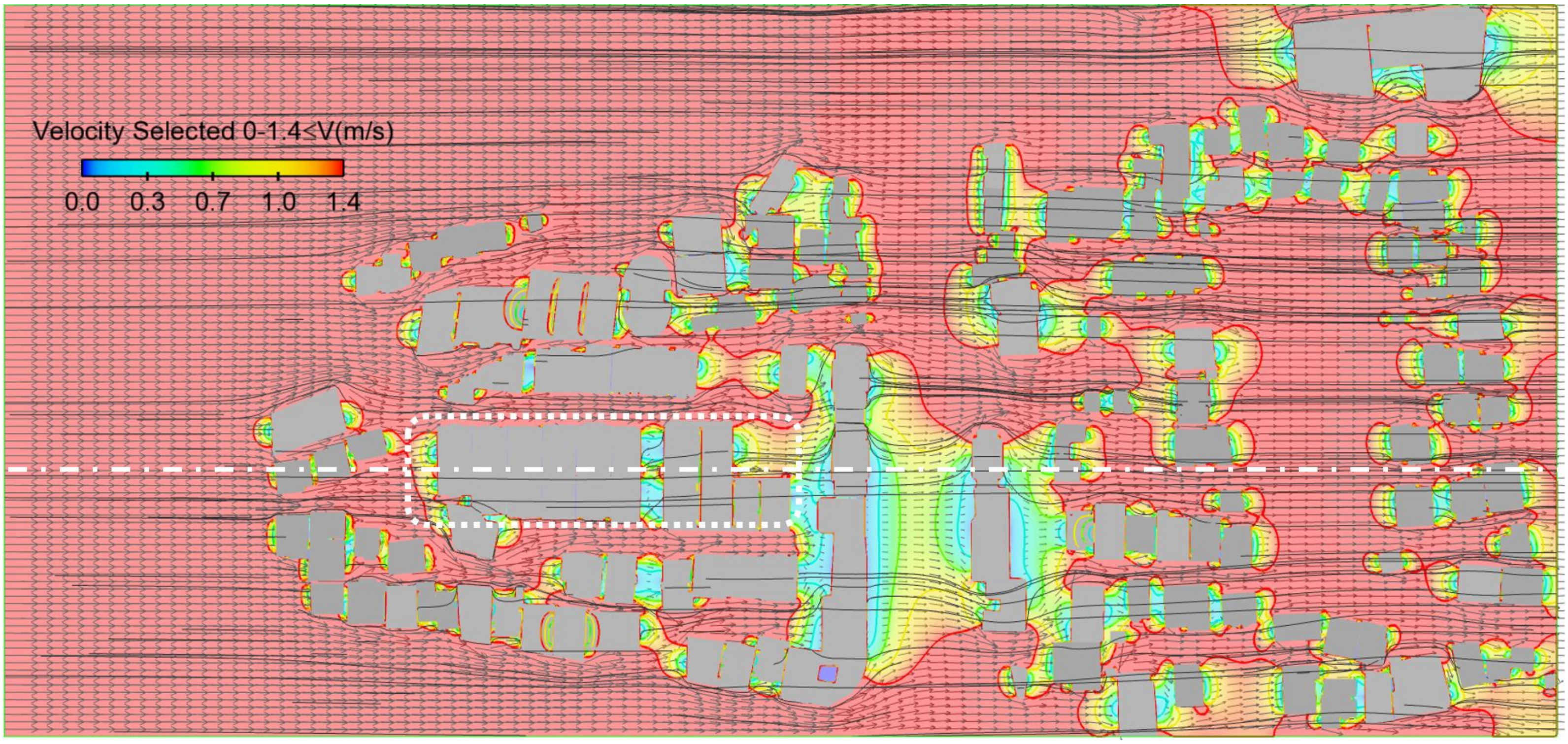

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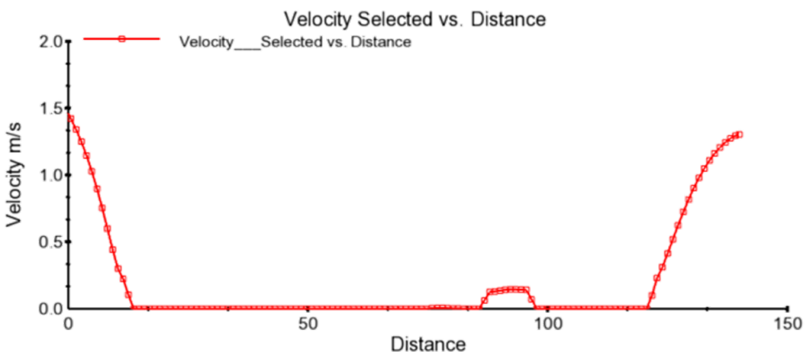
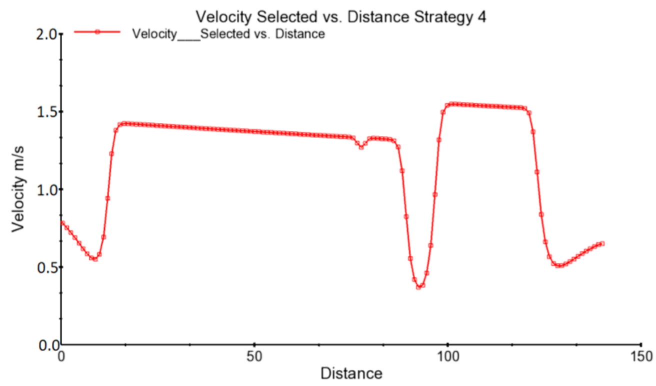
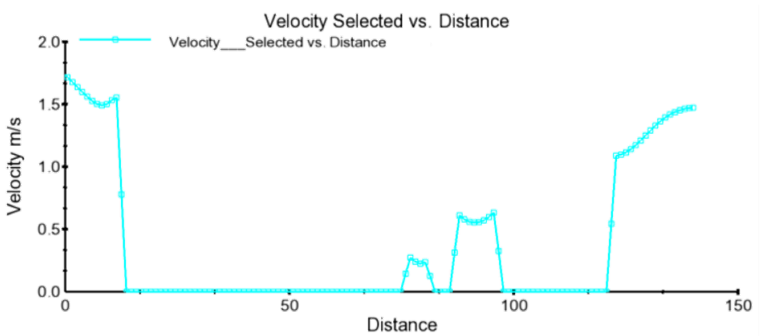


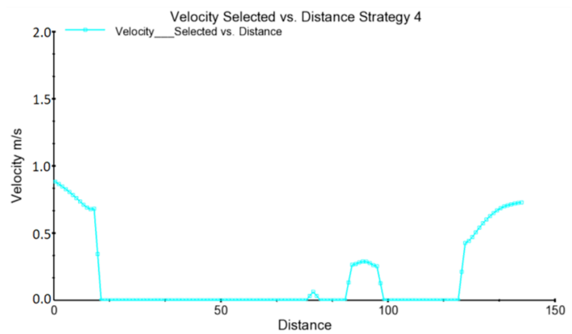
d) Before modification at height 1.75m



e) After modification above height 1.75m



f) Before modification at height 10m



g) After modification above 1.75m

Fig. (17): A) Modification plan and simulation of Creating open space between building masses on the ground floor of masses aggregation
B) Elaborate comparison between wind flow profiles of before and after modification of Creating open space between building masses on the ground floor of masses aggregation in axis B section

- ***3.2.2. Enclosure between the masses:***

❖ ***3.2.2.1. Strategy No. 5: Changing passage width A and B to 1/5A and 1/5B – changing enclosure E and E' to 0.66E and 0.66E' between masses***

In the second part of the alternative suggestion, three alternatives of enclosure modifications are suggested in fig.18-20. The line graphs show the wind velocity by changing passage width A and B to 1/5A and 1/5B, as a result changing enclosure E and E' to 0.66E and 0.66E' between masses. The modifications are displayed at 2 levels based on the previous ones (at height 1.75m & 10m) in the distance between 0 - 150m in fig.18 for two axes (A&B). If you pay attention to before and after the modifications, it can be seen that there is no noticeable change in the velocity profiles. This means that increasing the proposed width is not enough to change the wind velocity conditions.

A)

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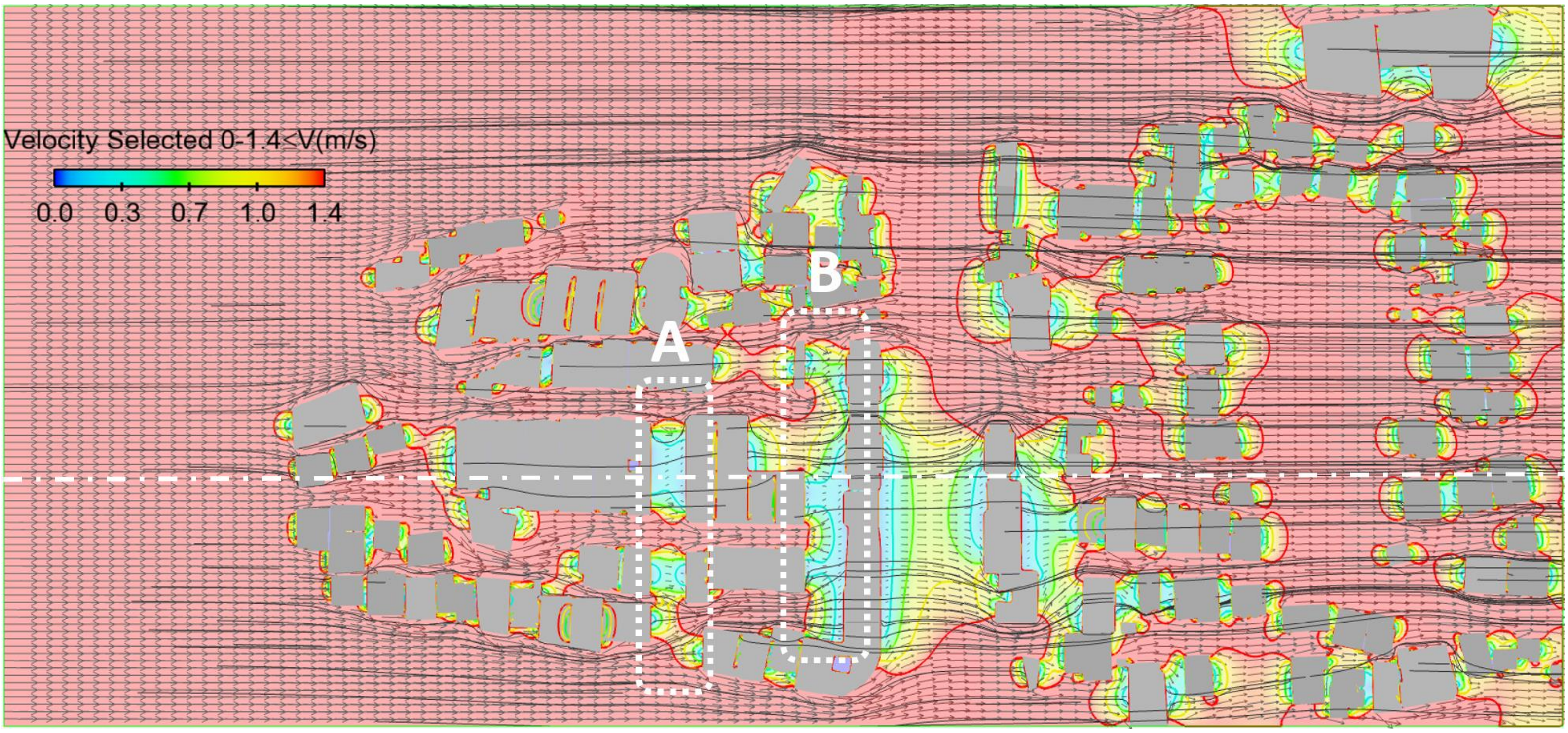

B)

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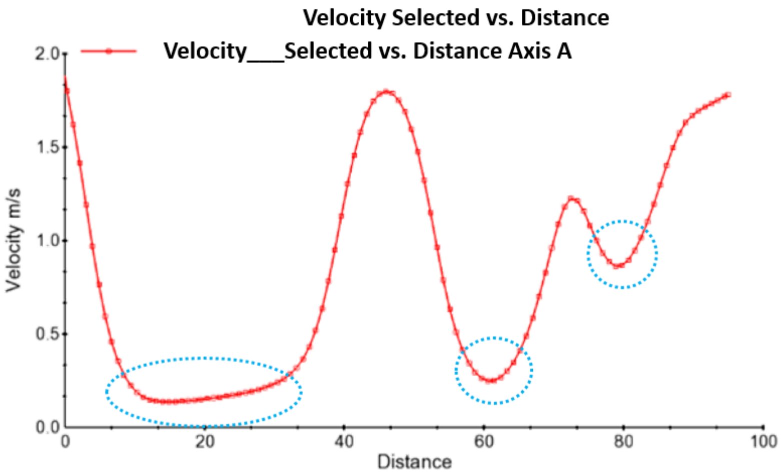
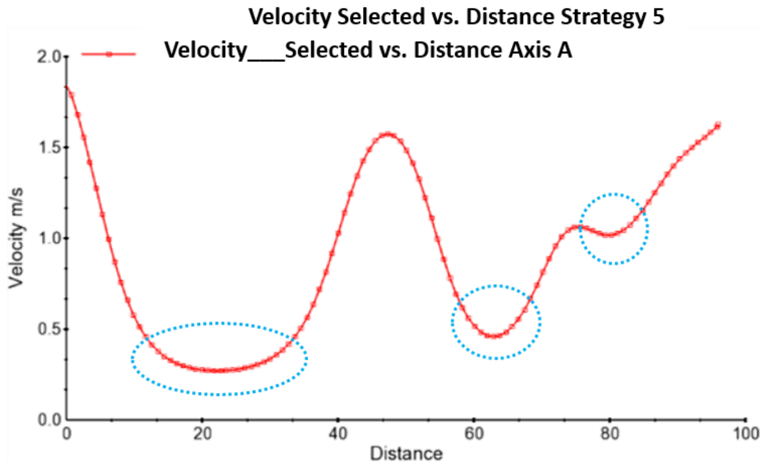
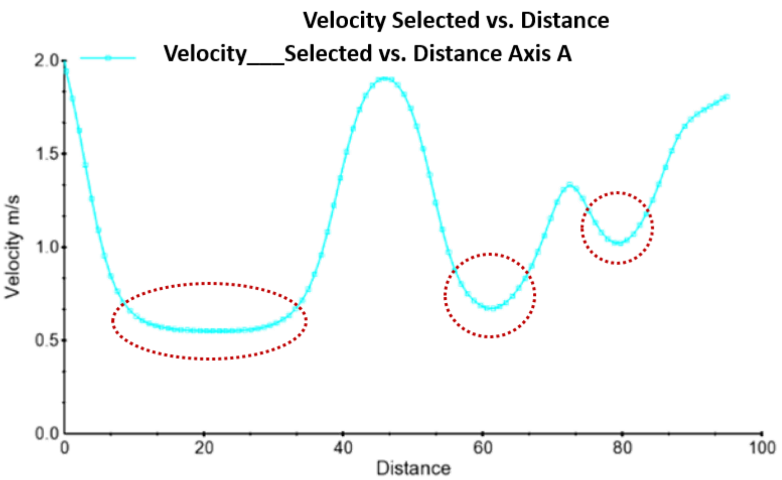


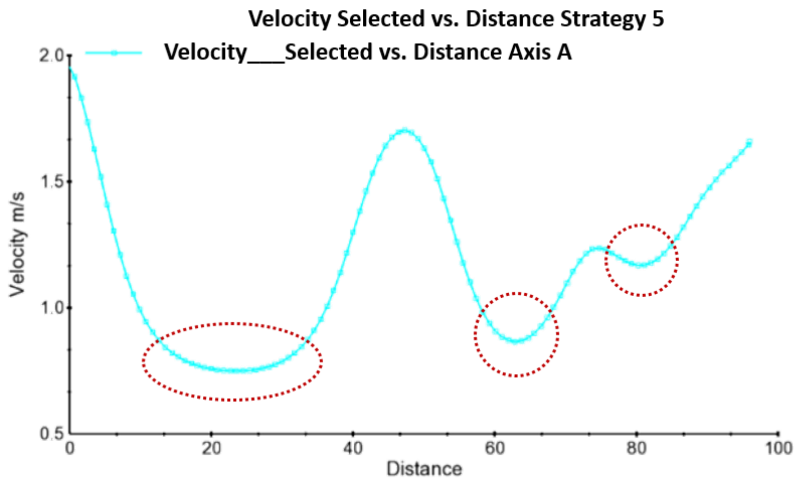
d) Before modification at height 1.75m in section A



e) After modification at height 1.75m in section A



h) Before modification at height 10m in section A



i) After modification at height 10m in section A

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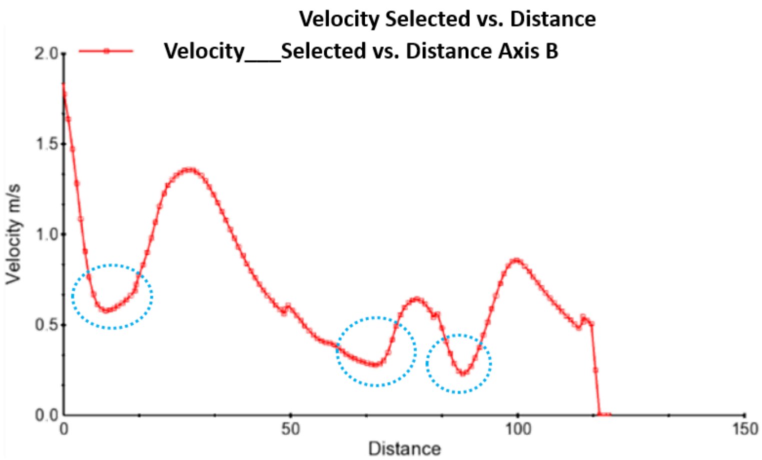
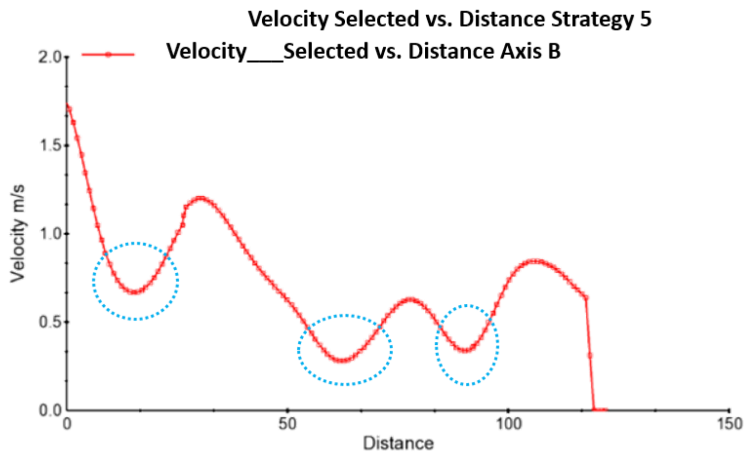
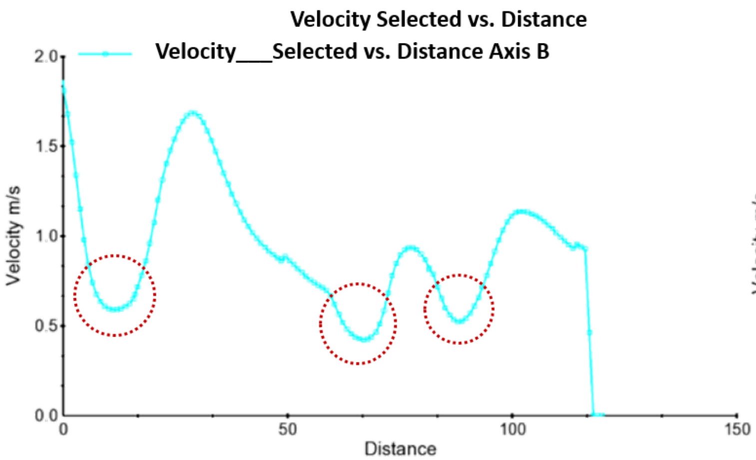


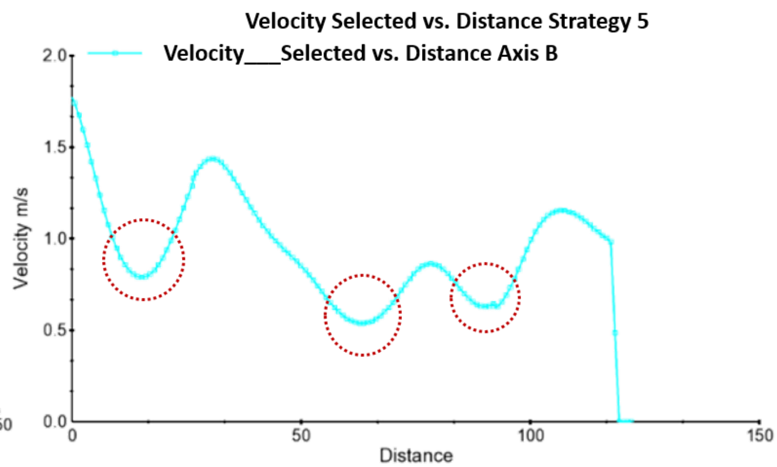
f) Before modification at height 1.75m in section B



g) After modification at height 1.75m in section B



j) Before modification at height 10m in section B



k) After modification at height 10m in section B

Fig. (18): A) Modification plan and simulation of strategy No.5
B) Elaborate comparison between wind flow profiles of before and after modification of sections A & B

- ***3.2.2.2. Strategy No. 6: Changing passage width A and B to 2A and 2B – changing enclosure E and E' to 0.5E and 0.5E' between masses***

In fig.19, The line graphs show the wind velocity by changing passage width A and B to 2A and 2B, as a result changing enclosure E and E' to 0.5E and 0.5E' between masses. The modifications are represented at 2 levels (at height 1.75m & 10m). The line graphs of wind velocity have occurred in a distance between 0-150m for two axes (A&B). If you look at before and after the corrections (marked on the diagrams), you can see that there is some change in the velocity profile, but in general, the wind flow velocity has not improved. This means that increasing the proposed width is necessary but not sufficient to change wind conditions.

A)

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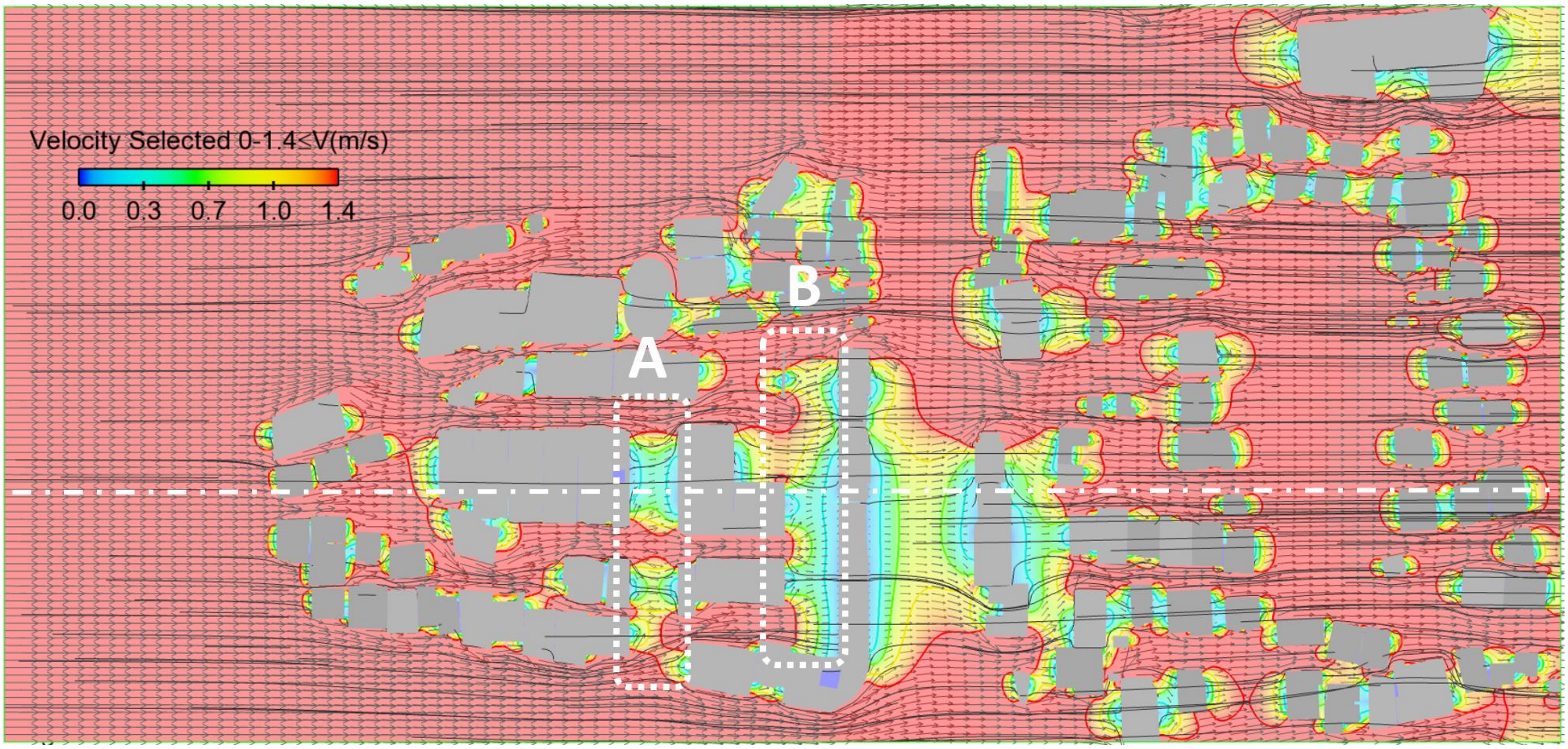

B)

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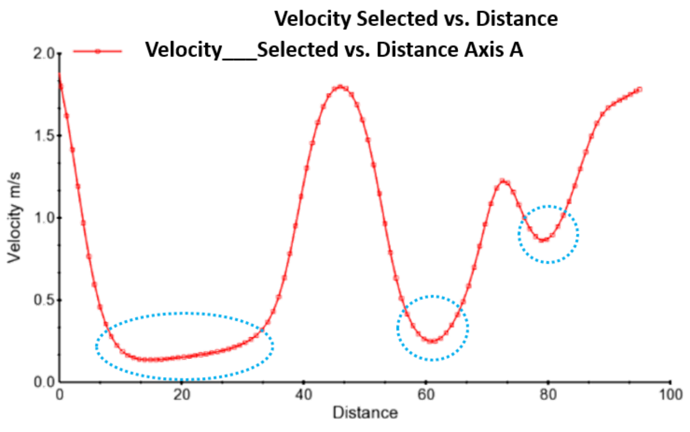
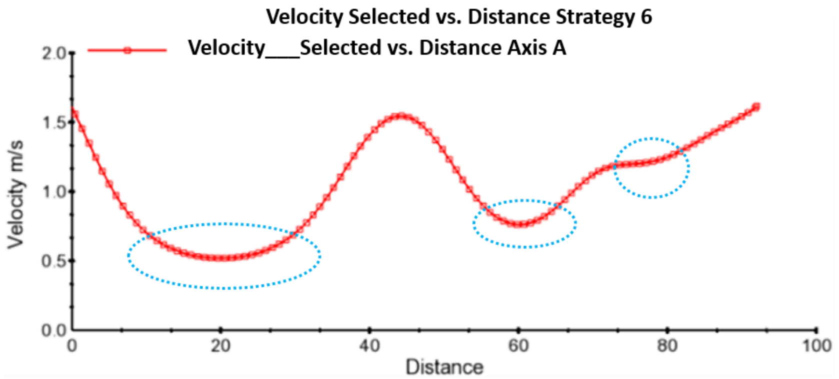
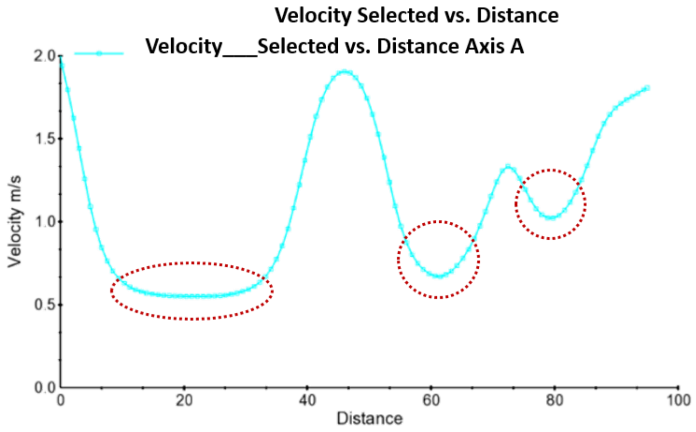


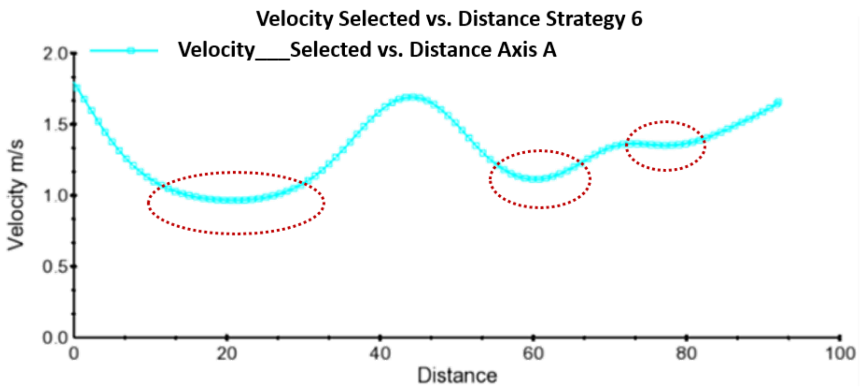
d) Before modification at height 1.75m in section A



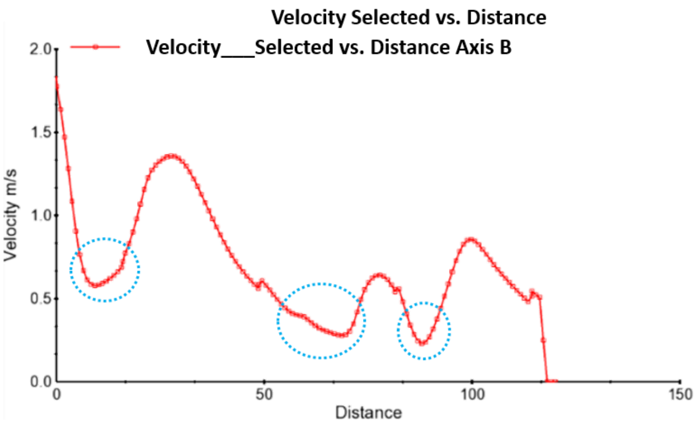
e) After modification at height 1.75m in section A



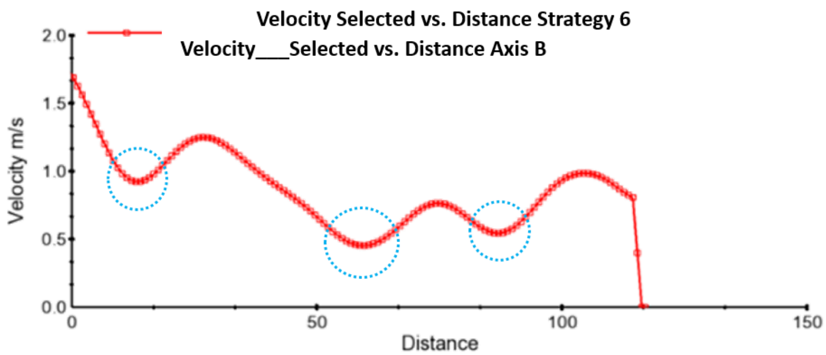
h) Before modification at height 10m in section A



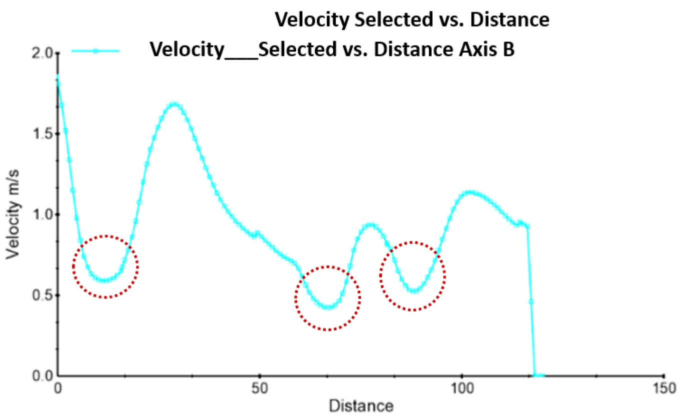
i) After modification at height 10m in section A



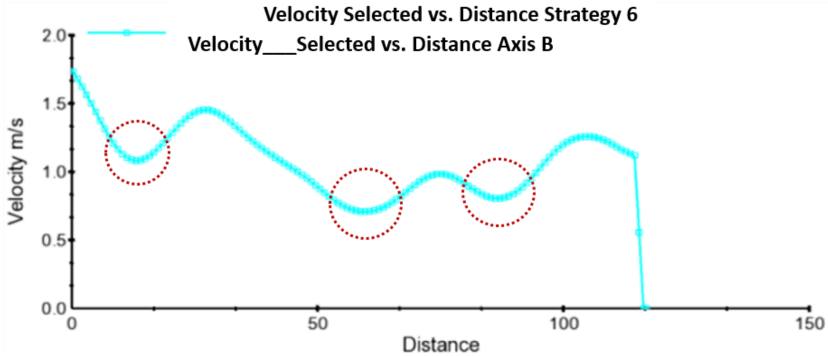
f) Before modification at height 1.75m in section B



g) After modification at height 1.75m in section B



j) Before modification at height 10m in section B



k) After modification at height 10m in section B

Fig. (19): A) Modification plan and simulation of strategy No.6
B) Elaborate comparison between wind flow profiles of before and after modification of sections A & B

❖ ***3.2.2.3. Strategy No. 7: Changing passage width A and B to 3A and 3B – changing enclosure E and E’ to 0.33E and 0.33E’ between masses***

The line graphs show the wind velocity of the physical modifications at the level of 1.75m and 10m same as the previous two strategies in the distance between 0-150 m for two axes (A&B). Strategy of changing passage width A and B to 3A and 3B – changing enclosure E and E’ to 0.33E and 0.33E’ between masses (strategy No.7), unlike the previous two strategies, the wind velocity increase after modifications by a large difference compared to before modification in fig.20. Exactly the points indicated on diagrams. These modifications show that the change in width between the buildings has made the freedom flow and wind circulation. So, these changes in width between the buildings was appropriate and created a wind flow.

A)

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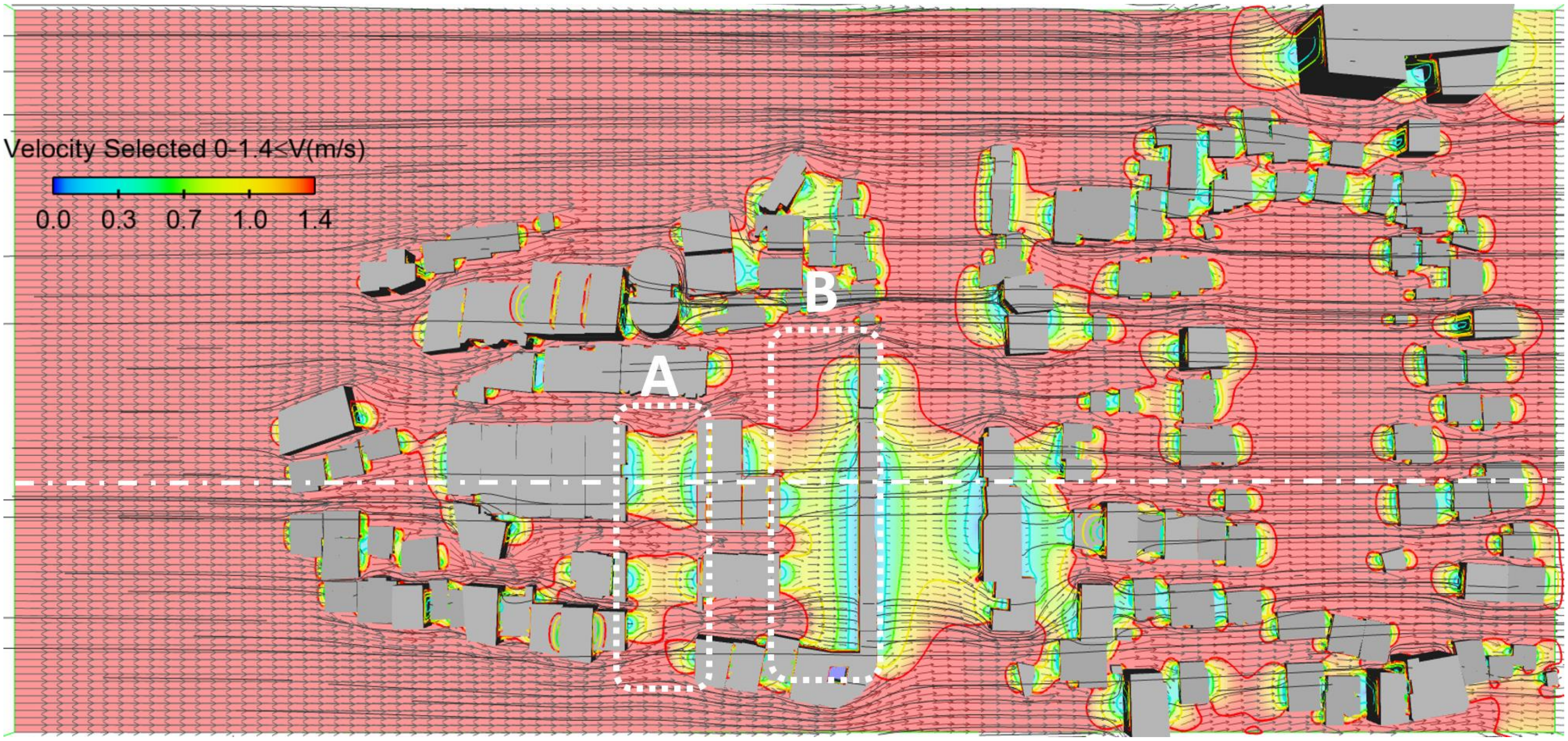

B)

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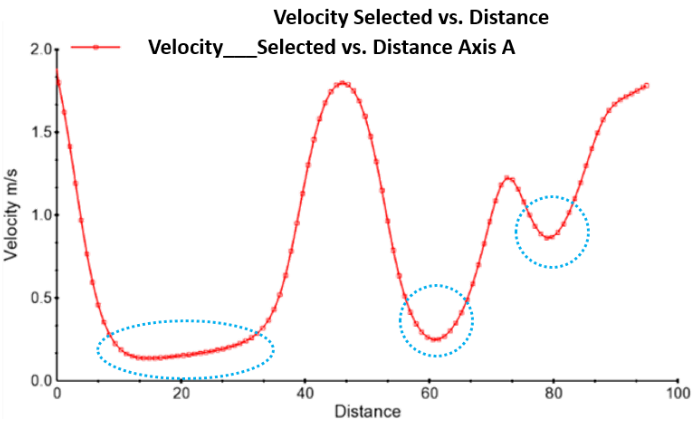
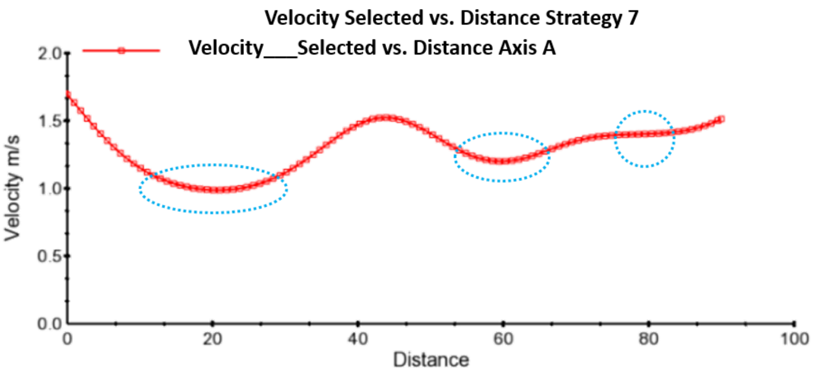
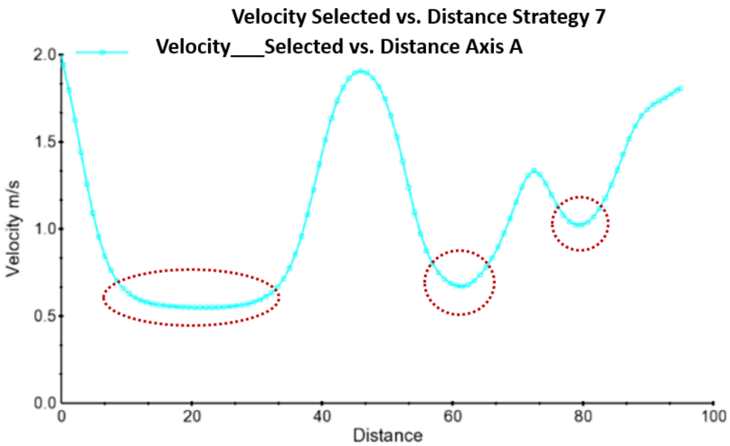


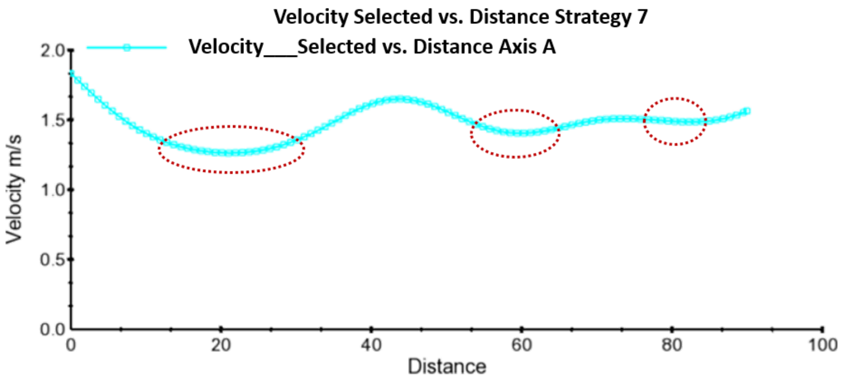
d) Before modification at height 1.75m in section A



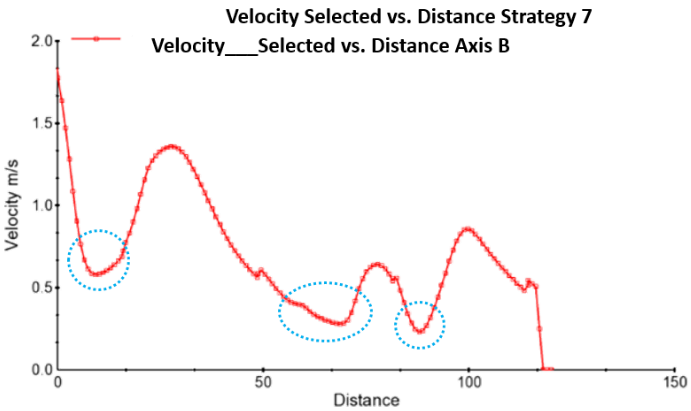
e) After modification at height 1.75m in section A



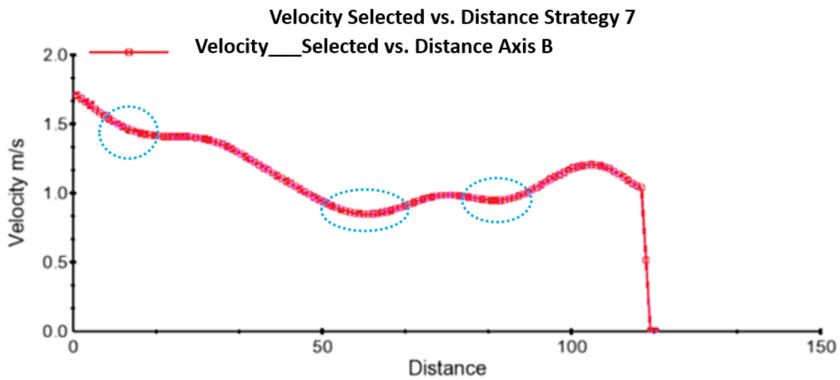
h) Before modification at height 10m in section A



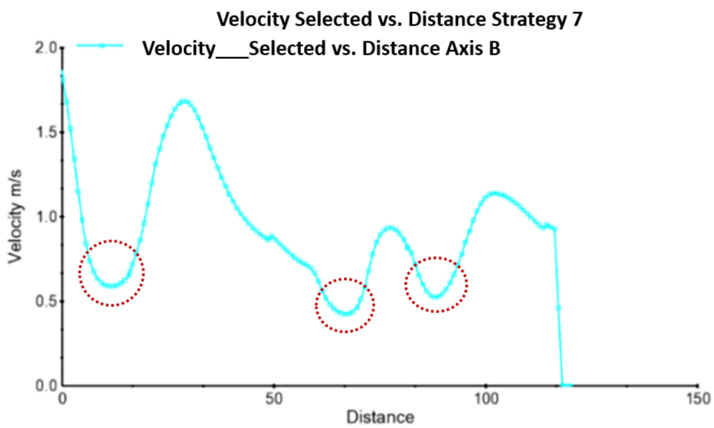
i) After modification at height 10m in section A



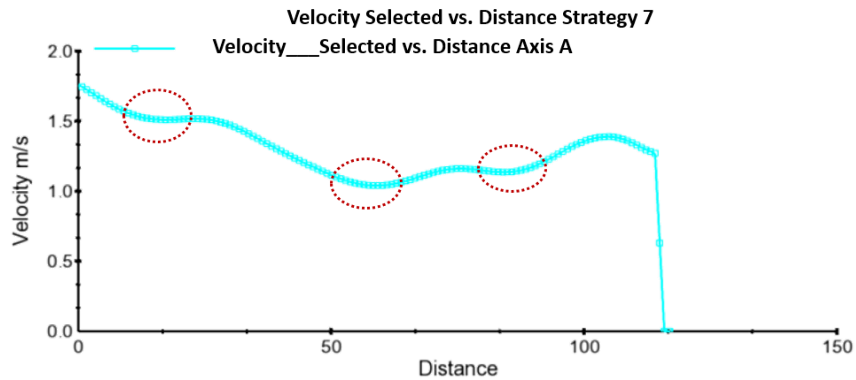
f) Before modification at height 1.75m in section B



g) After modification at height 1.75m in section B



j) Before modification at height 10m in section B



k) After modification at height 10m in section B

Fig. (20): A) Modification plan and simulation of strategy No.7
B) Elaborate comparison between wind flow profiles of before and after modification of sections A & B

According to creating permeability by opening along passage (Strategy No.1) and also creating the opening just on the ground floor in the prevailing wind direction (strategy No.2the strategy No.1 is preferable to the strategy No.2 because the wind movement occurs better without prevention and has a significant effect. Meanwhile, creating an opening only in the ground floor prevents the wind movement in the upper levels, and the problem of the wind not moving in the higher part is not completely solved.

The strategies of creating open space between building masses by separating buildings (strategy No.3) and also creating it just on the ground floor (strategy No.4) were compared. it should be said that the strategy No.3 is recommended because it is necessary to create an open space between buildings and pass the wind flow through all parts of the mass, and creating it on the ground floor will reduce the problem in the upper floors but will not solve it.

Regarding the enclosure between the masses by changing the width of the passage between the buildings, the passage width 1/5A,1/5B and 2A, 2B with the enclosure 0.66E, 0.66E’ and 0.5E, 0.5E’ (strategies No.5 and 6) were not responsive compared to the passage width 3A, 3B with the enclosure 0.33E, 0.33E’ (strategy No.7) and have low efficiency. But in strategy No.7 in order to improve wind-flow, the north-south passages width have been changed from A (A = 9M) to 3A and performs better than the previous two strategies for the prevailing urban wind flow, finally the velocity increases logically with this type of enclosure. Overall, in order to create a suitable enclosure for urban ventilation and wind movement, changes have been made in the passages width and the space between the masses.

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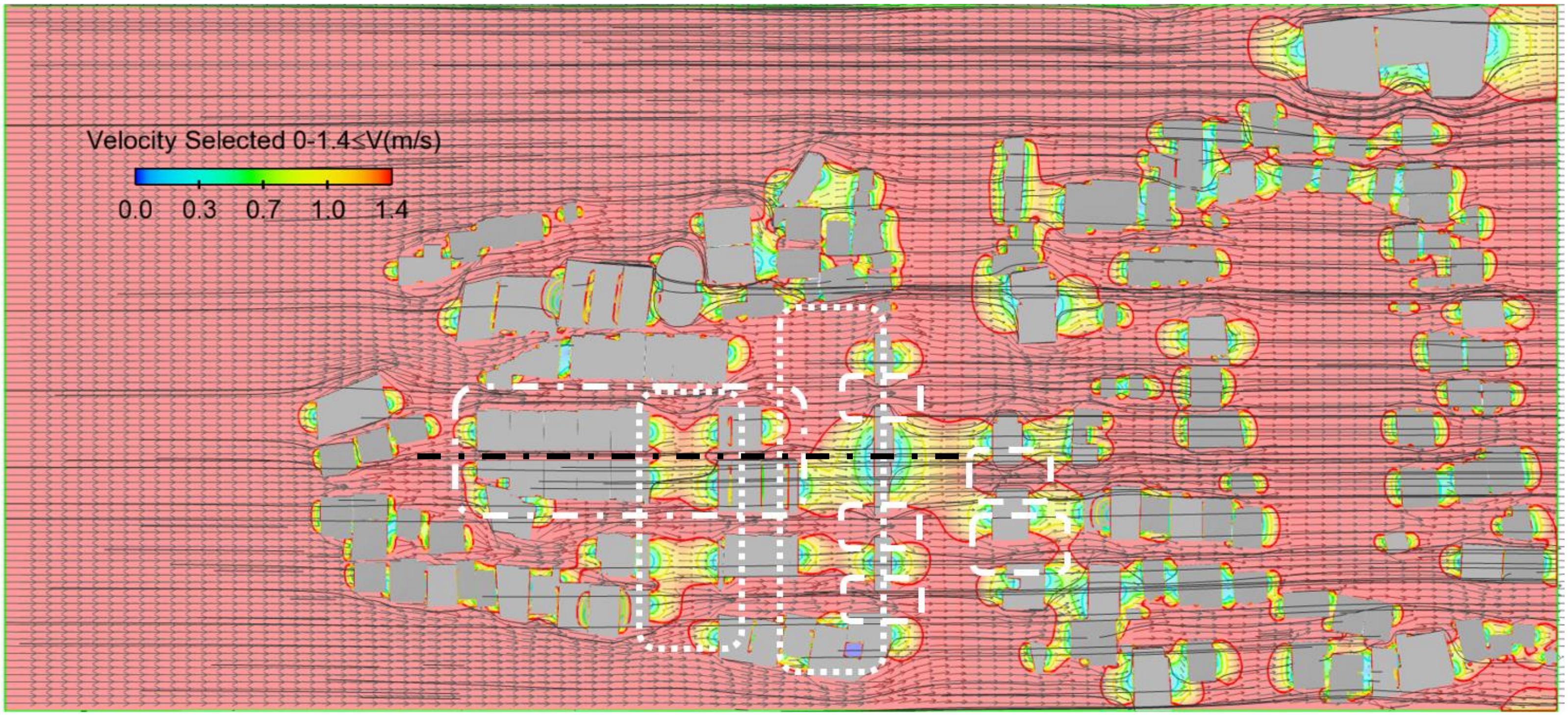
- **3.3. A combination of the best previous strategies as improving the wind environmental condition**

Observing the principles of shape and volume in the texture in fig.21, an option will be selected and presented as the improvement design option. In this option, in addition to the least amount of the wind intensity reduction in the space between the masses, we see a common configuration in the design that will increase the efficiency of changes in texture.

A)



B)

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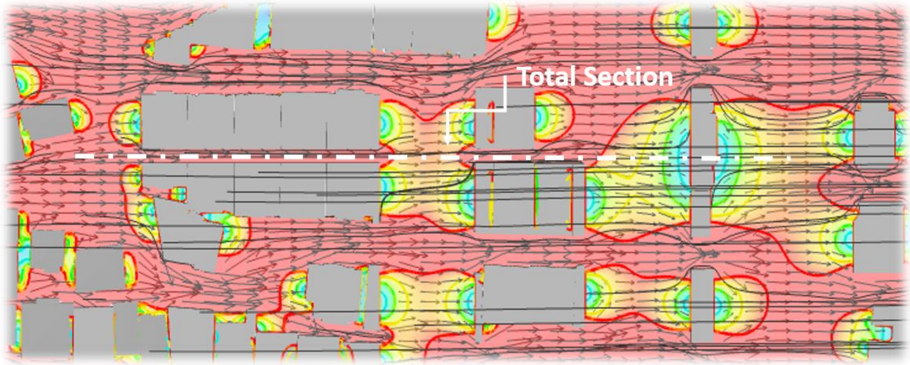
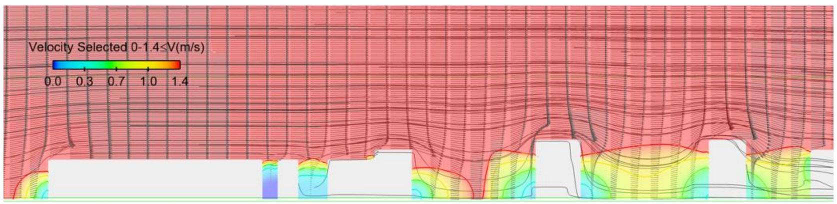
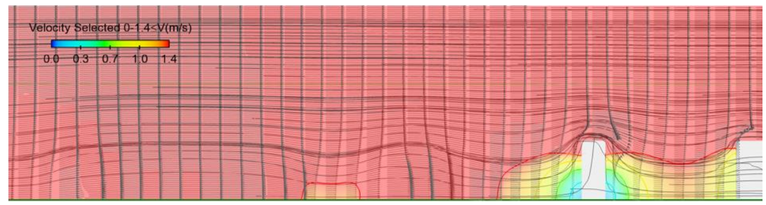


a) Improvement design simulation (section)



b) Before modification



c) After modification

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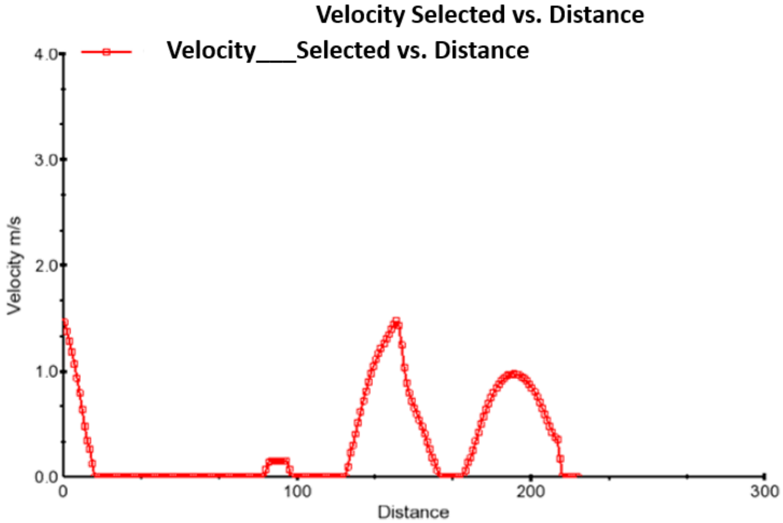
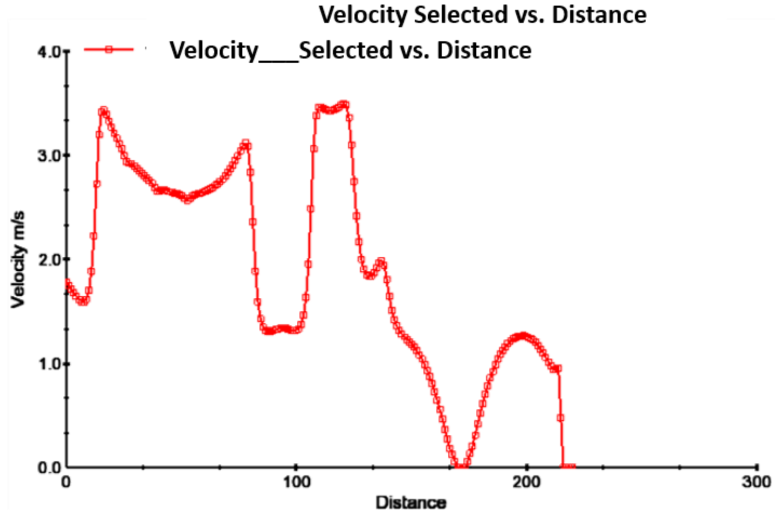
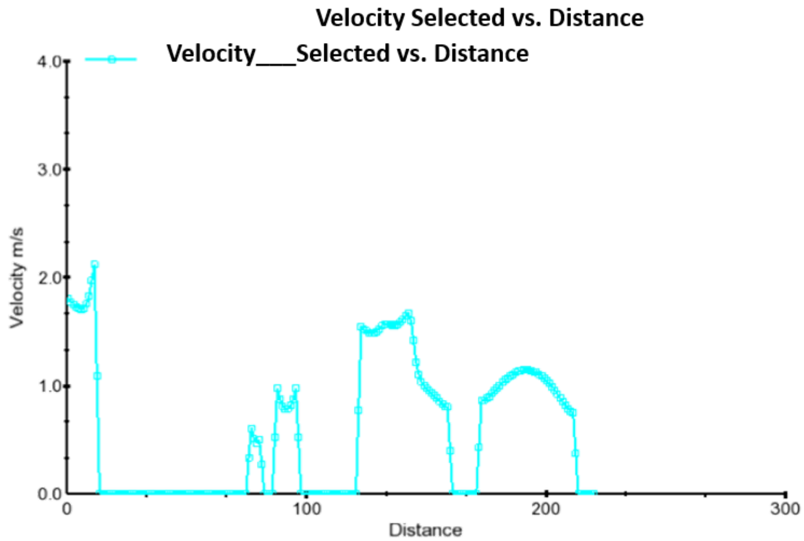


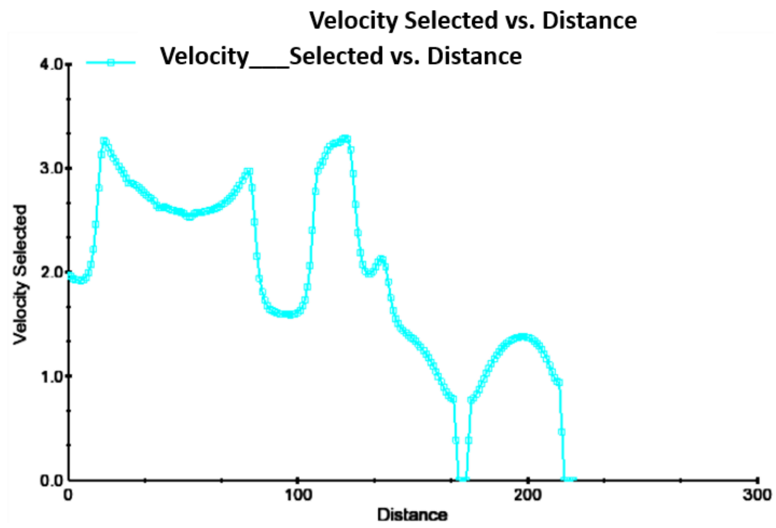
d) Before modification at height 1.75m



e) After modification at height 1.75m



f) Before modification at height 10m



g) After modification at height 10m

Fig. (21): A) Improvement plan and simulation
B) Simulation of wind current situation and the improvement design above height 1.75

5. Discussion

In the past, wind disturbance was insignificant in the urban context. Because the tissue is scattered and less disruptive to wind flow. Today, the dense texture with large and high structures generated a great impact on micro-climate, especially on wind. In Babolsar, the humidity is high and the air in the city is sultry; by enhancing air flow, micro-climate conditions can improve. High-rise construction will increase according to the master plan, but investors are ignoring its rules. This study keeps the height parameter constant to provide alternatives and focus on other variables. The physical structure of building masses are parameters that can be examined in the urban tissue and can be monitored and controlled [64]. These influential parameters are the height of the buildings, the width of the passages and the space between the buildings, the confinement (ratio of height to width) and the orientation of the building masses in regard to the wind flow. Examining the range using CFD simulation and previous studies [7,13,39,20,33-50], the study concludes that the orientation (masses and passages) to the wind, as well as the confinement between the building masses, have a significant effect on wind speed.

7 strategies have been presented to achieve a design appropriate to enhance the wind flow in urban blocks. Finally, a software-based analysis has increased the accuracy of this analysis. Based on the tested strategies, it can be seen that the strategies of creating permeability by opening along passage (Strategy No.1), creating open space between building masses by separating buildings (strategy No.3) and changing passage width A and B to 3A and 3B – changing enclosure E and E' to 0.33E and 0.33E' between masses (strategy No.7) establish the best velocity flow in the urban fabric and therefore will have the least velocity reduction in urban blocks.

4.1. The research findings are:

- Recent studies have investigated the potential of the opening between building masses and the masses orientation to the prevailing wind to control wind velocity. They have concluded that the prevailing wind flow, when parallel to the openings and the space between the buildings, increases the wind velocity and creates windy conditions for areas with high average velocity [37,13]. Also, increasing wind velocity between building blocks and streets parallel to the prevailing wind flow can cause stagnant wind movement and ventilation [49]. Therefore, strategies No.1 and 2, which are about creating an opening to the prevailing wind flow along the passages, are solutions for better ventilation in a sultry environment as they increase air quality. Creating permeability by opening along passage (Strategy No.1) is preferable to creating it just on the ground floor (Strategy No.2), because the wind-flow distribution occurs without obstruction and causes a significant increase in wind velocity. In addition, creating an opening only on the ground floor obstructs the wind flow in the higher parts and the problem of lacking wind flow is not completely solved there [48].
- Strategies No. 3 and 4 are about creating an open space for aggregated masses. It is necessary to create an open space or permeability of wind flow in all parts of the building masses creating infiltration on the ground floor will reduce the problem on the upper floors but will not solve it. According to studies by Du et al. 2018 [48] on the effect of porosity on wind comfort around a detached building and a group of buildings, it was decided to place the porosity on the first floor, which is closer to the pedestrian surface, (better than the second floor) is. Besides, wind comfort improves with increasing porosity. For the group of buildings, in the present study wind comfort is improved in the upstream areas by increasing porosity of the building, while other areas are not sensitive to changes in the size of the porosity. Therefore, strategy No.3 works better for the upper levels.
- To create enclosure in urban blocks, changes have been proposed in the buildings' passages. Enclosure is derived from the ratio of height to width in the environment. In the Babolsar master plan, height density has been proposed in an appropriate manner for protection of agricultural lands and useful application of buildable and residential lands. Therefore, in order to create a suitable enclosure for urban ventilation, changes have been proposed in the passages' width and the space between the masses. Research on passages between urban masses and their effect on wind flow shows that increasing the passages enclosure parallel to the prevailing wind flow increases wind velocity [65]. Moreover, reducing the enclosure of wind-blocking passages (90-degree angle to wind) increases the wind velocity [66]. As a result, according to studies, the passage width 3A, 3B with the enclosure 0.33E, 0.33E' (strategy No.7) performs better for the prevailing urban wind flow than the passage width 1/5 and 2 times of existent width (strategies No.5 and 6), and the wind velocity is increased reasonably.

6. Conclusion

This study aims to evaluate the effect of tall buildings on wind distribution and intensity in humid and dense areas. The first phase was to provide increase velocity solutions for dehumidification and decentralization. Then improving the structure of building masses and airflow leads to ameliorate the quality of urban spaces in high-rise urban blocks. Finally, it resulted in an urban space that is compatible with the climate and the comfort needs of residents.

As the theoretical implication, the wind is one of the influential climatic phenomena in humid areas, especially along the where coast the demand for high-rise buildings is high. Therefore, in the spatial-physical design of the city, the wind has a very important role in improving the urban environment quality and provides environmental comfort for residents. Design principles that are compatible with climate, can play an effective role in improving environmental comfort in typical urban construction. The physical structure of building blocks has a significant effect to absorb and facilitate the circulation of desirable wind for dehumidification. The high wind velocity, in the range to create these conditions, has caused an inverse relationship with the amount of moisture trapped between the masses and the most optimal occurrence in this range, due to climatic conditions and high relative humidity.

As the practical implication, in answer to the first question of the research, it should be said that the interaction of buildings' layout and wind flow has been investigated by field measurement and CFD simulation using FLOW-3D (V11.2) software. on the analysis of the physics of buildings in terms of configuration and type of forms, it can be seen that wind flow changes and increases and decreases, and as a result, this is a sign of the direct impact of city physics on wind flow.

In answer to the second question of the research, that after validation of FLOW-3D simulation software, the relationship between these parameters (height, the width of passages, enclosure between buildings, and buildings' orientation) studied which affects the wind's velocity and direction. It can be said environmental comfort depends on two important factors in areas near the sea with high humidity and high demand for high-rise construction: the orientation of the building masses and the confinement to the prevailing wind. The important actions to increase the velocity by orienting the buildings in the direction of the prevailing wind are the alignment of the wind flow with the passages, the narrow width of the passages, its canalization, and the removal of obstruction blocks.

The advantage of increasing and decreasing enclosure can also be expressed as follows:

- Increasing the enclosure increases the wind velocity in narrow passages, parallel to the prevailing wind flow and wind channeling in them.
- Reducing the enclosure increases the wind velocity with wide passages and perpendicular to the prevailing wind flow (creating an interconnected wall and preventing the wind flow passage).

Finally, the answer to the third question can be stated as follows condition-improving factors have different results in two cases. These two modes depend on the direction of wind flow, which means that in the direction of wind flow, the wind flow increases with the increasing enclosure by reducing the width of passages between tall buildings. The same result with the direction of flow perpendicular to the building masses by reducing the enclosure can increase the wind velocity relatively or create a way for the permeability of wind flow. In fact, applying each of these factors alone grants a small change in the wind flow increase, which is not enough to improve the environmental conditions. Improving the structure of the urban block by applying the best alternatives of important factors simultaneously has improved the wind flow conditions.

Future study: The results were obtained based on existent conditions; The aim was to improve the existing conditions in the urban context. As a rule, not all influential physical factors such as the vegetations, layout of masses' geometry (U-shaped, L-shaped, parallel, etc.) have been considered on wind flow simulation. Further works will be conducted to suggest design alternatives based on the buildings' the layout of masses' geometry in a residential land with the same boundary conditions of wind environment.

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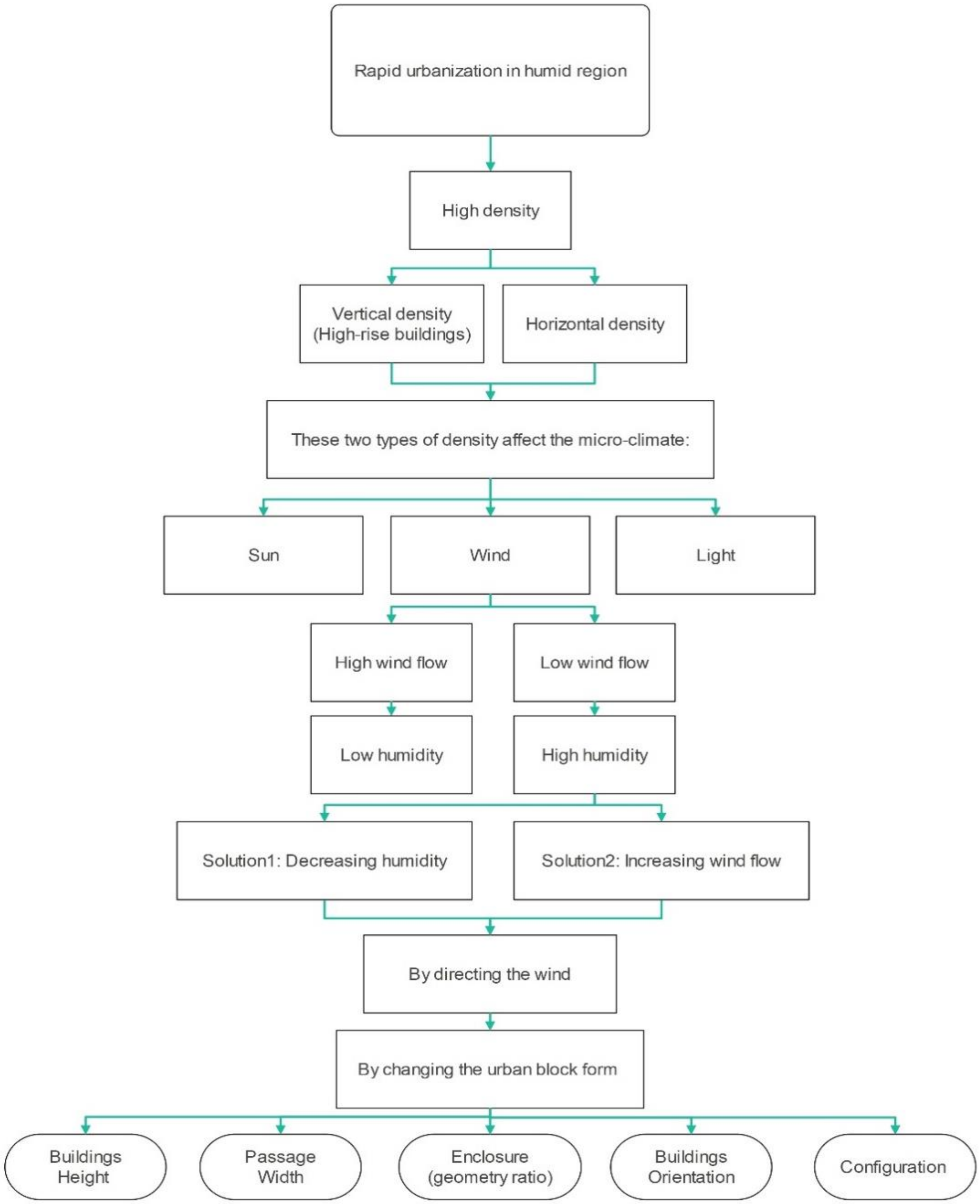
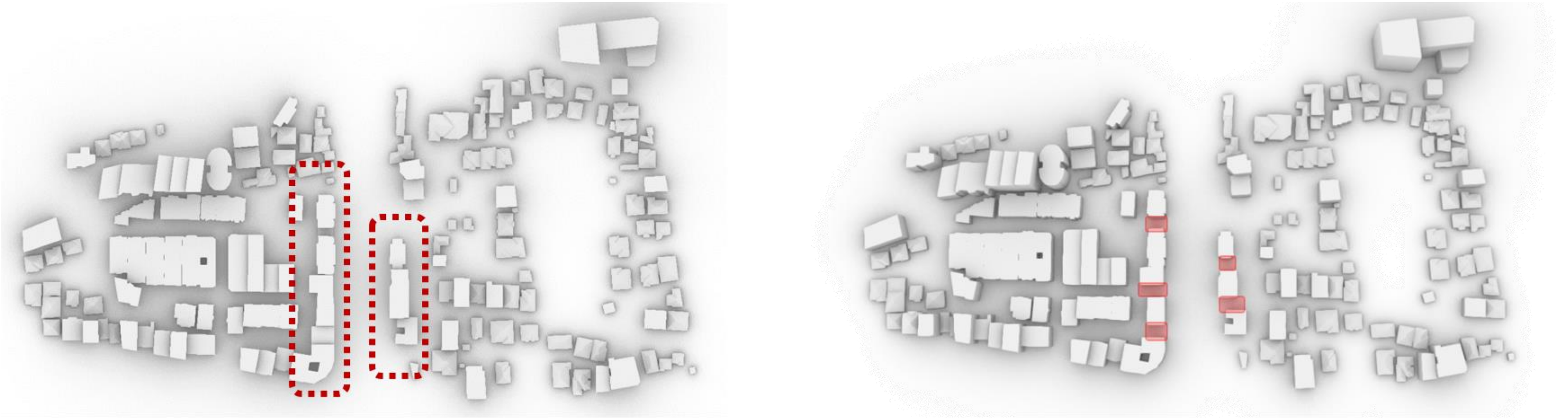
Appendix A:

Fig. A. Investigating the effect of 2 blocks physical factors on wind flow pattern



Appendix B:

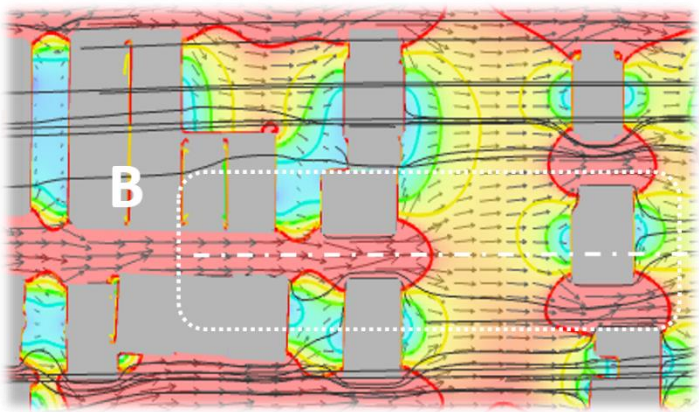
Fig.B.1.



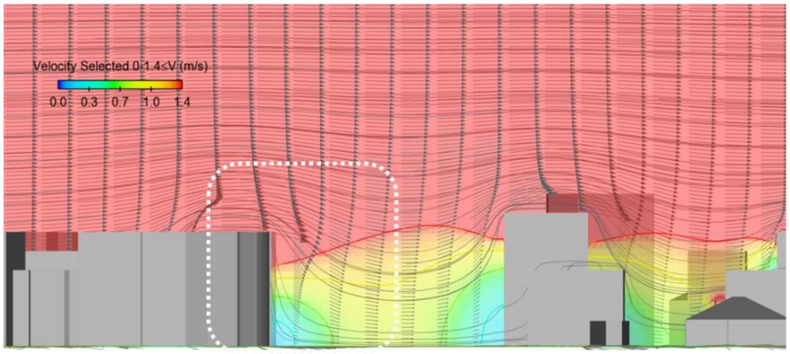
Before modification After modification

3D Plan Strategy No.1

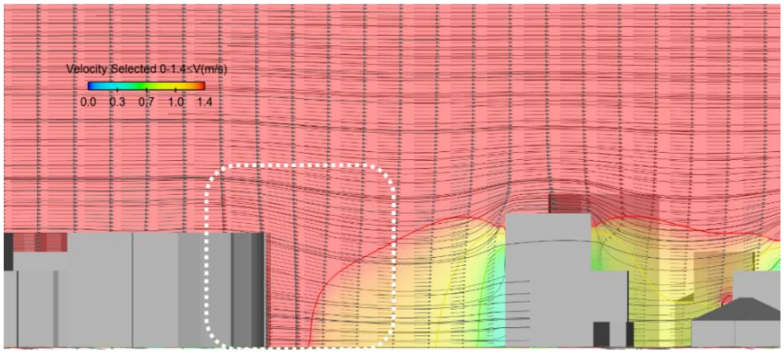
Fig.B.2.



a) Simulation No. 1 (section of axis B)



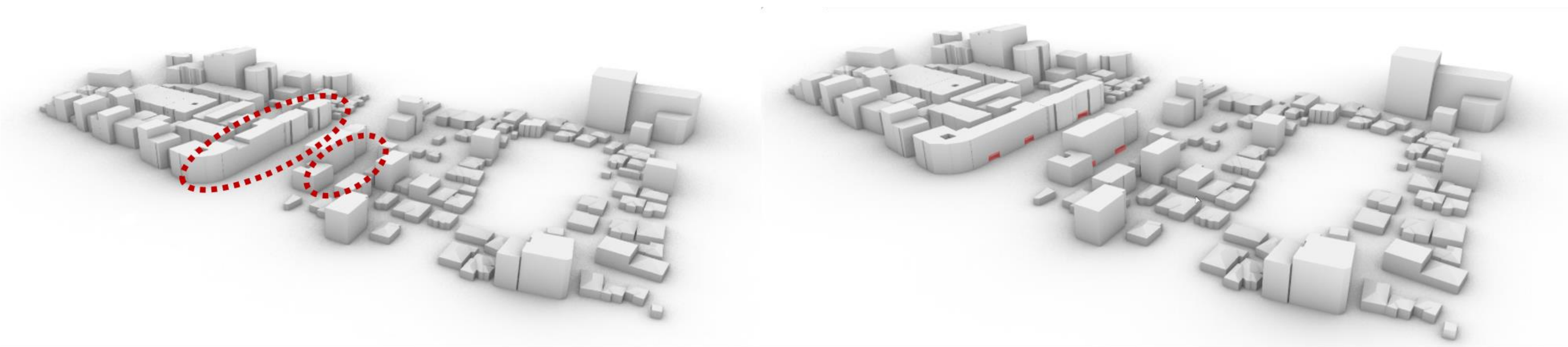
b) Before modification



c) After modification

Appendix C:

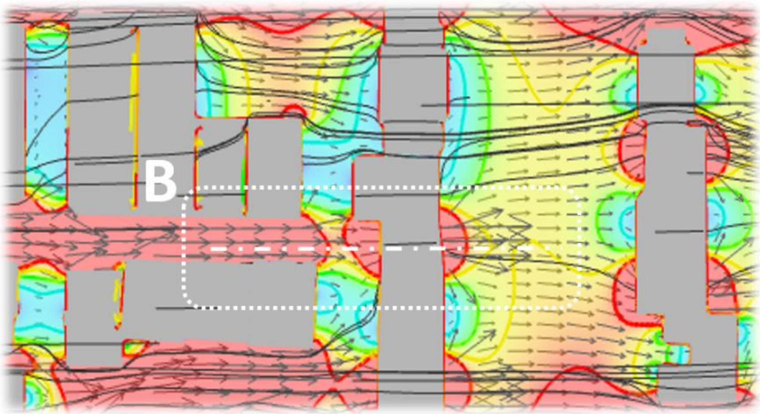
Fig.C.1.



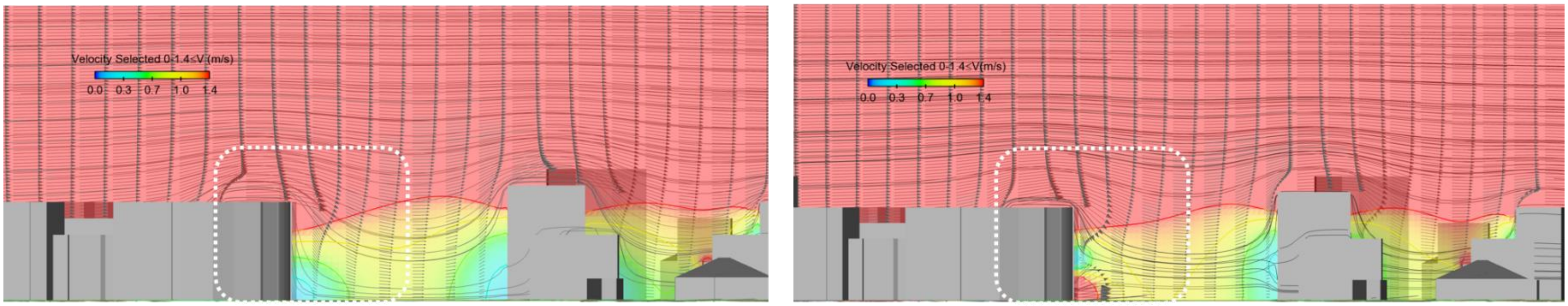
Before modification **After modification**

3D Plan Strategy No.2

Fig.C.2.



a) Simulation No. 2 (section of axis B)



b) Before modification **c) After modification**

Appendix D:

Fig.D.1.

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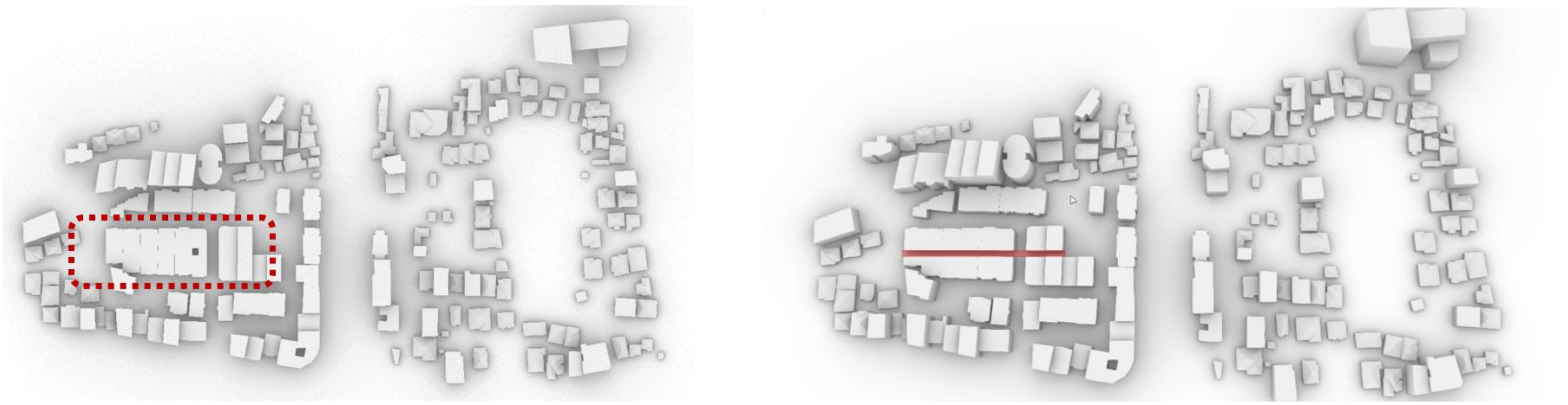
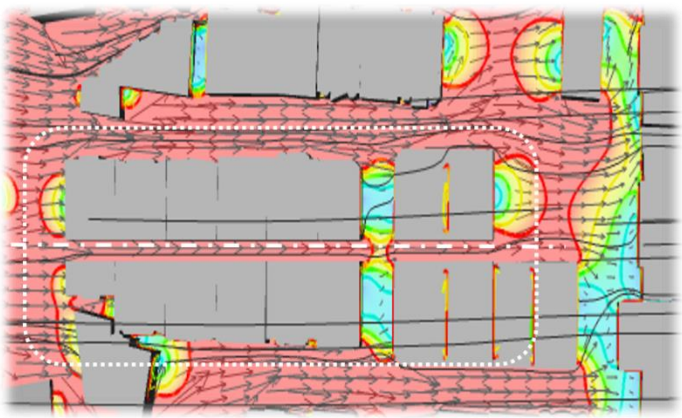


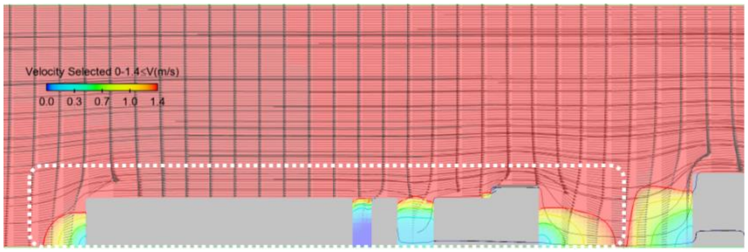
Before modification **After modification**

3D Plan Strategy No.3

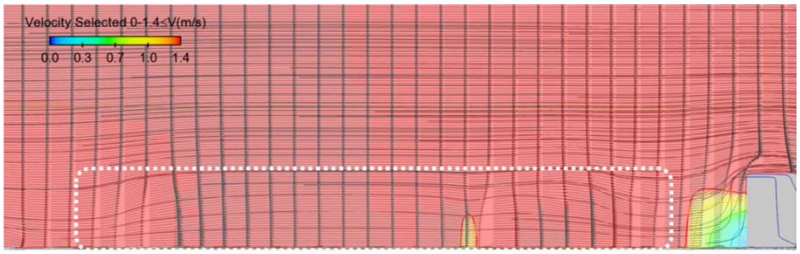
Fig.D.2.



a) Simulation No. 3 (section of axis B)



b) Before modification



c) After modification

Appendix E:

Fig.E.1.

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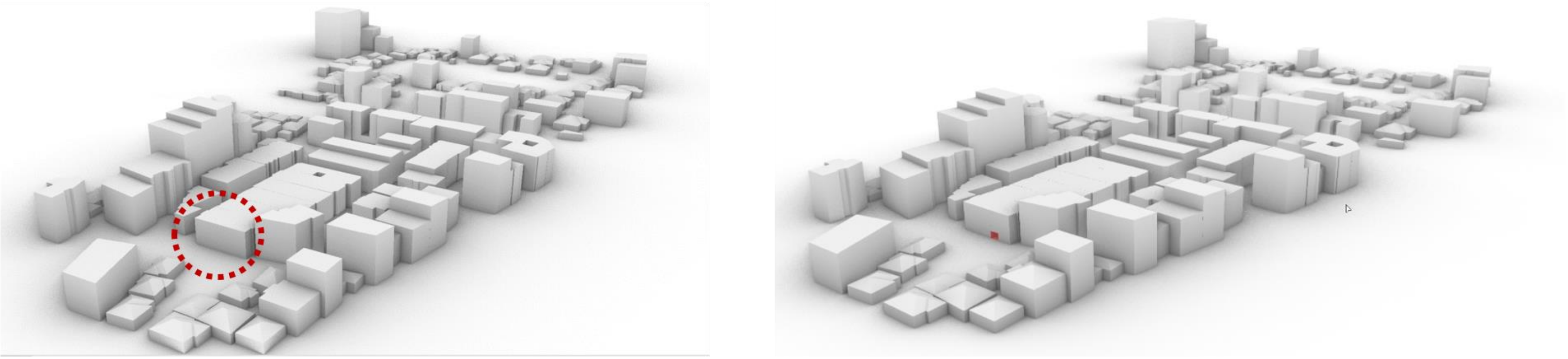
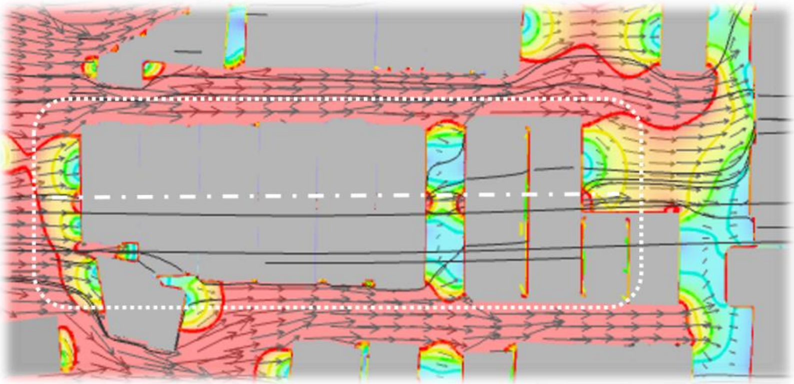


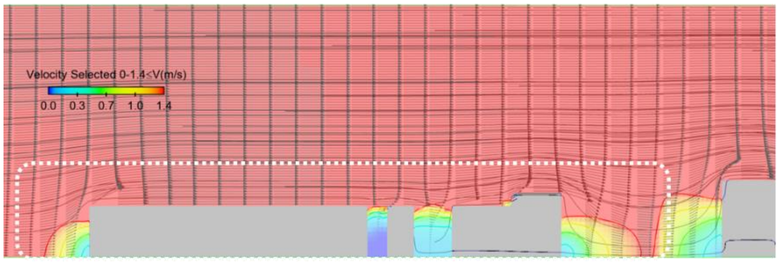
Before modification **After modification**

3D Plan Strategy No.4

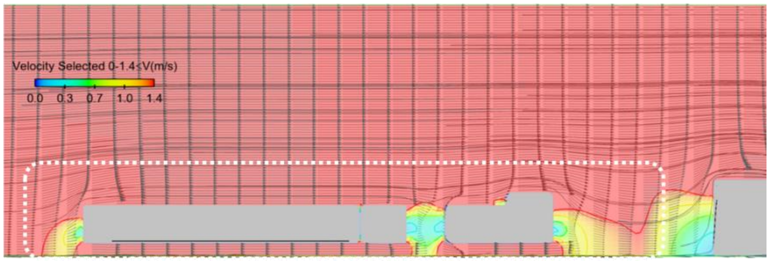
Fig.E.2



a) Simulation No. 4 (section of axis B)



b) Before modification



c) After modification

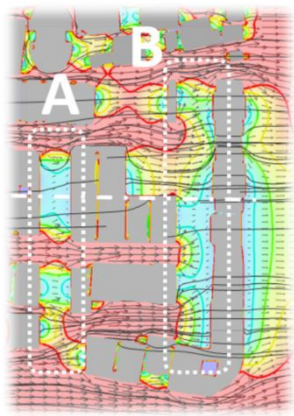
Appendix F:

Fig.F.1.

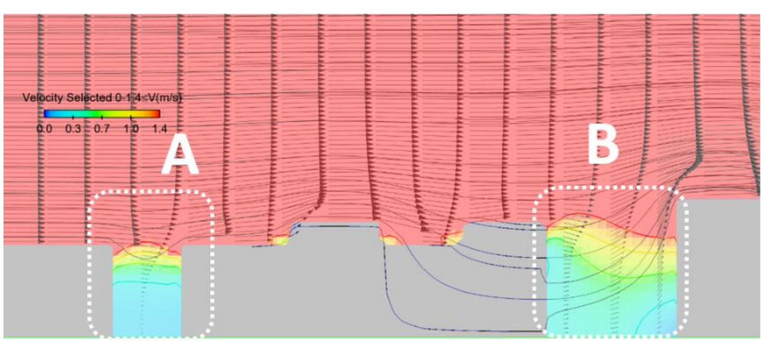
Before modification **After modification**

3D Plan Strategy No.5

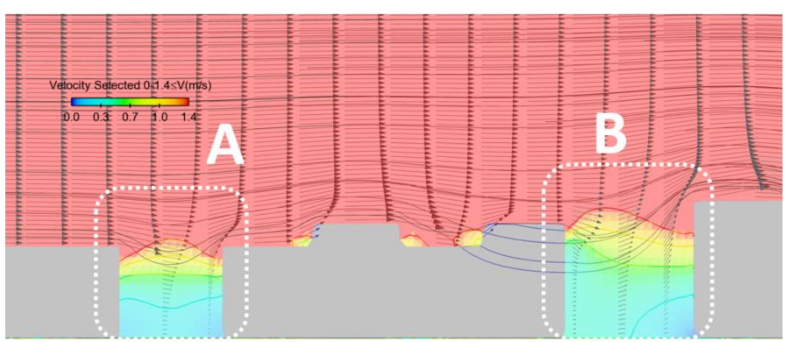
Fig.F.2.



a) Simulation No. 5
(sections of axes A &B)



b) Before modification



c) After modification

Appendix G:

Fig.G.1.

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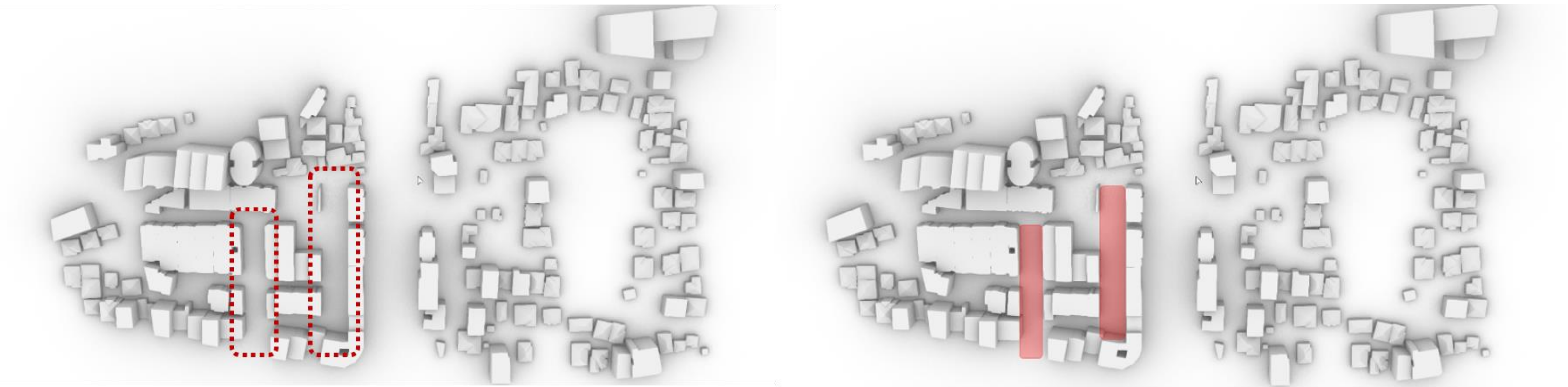
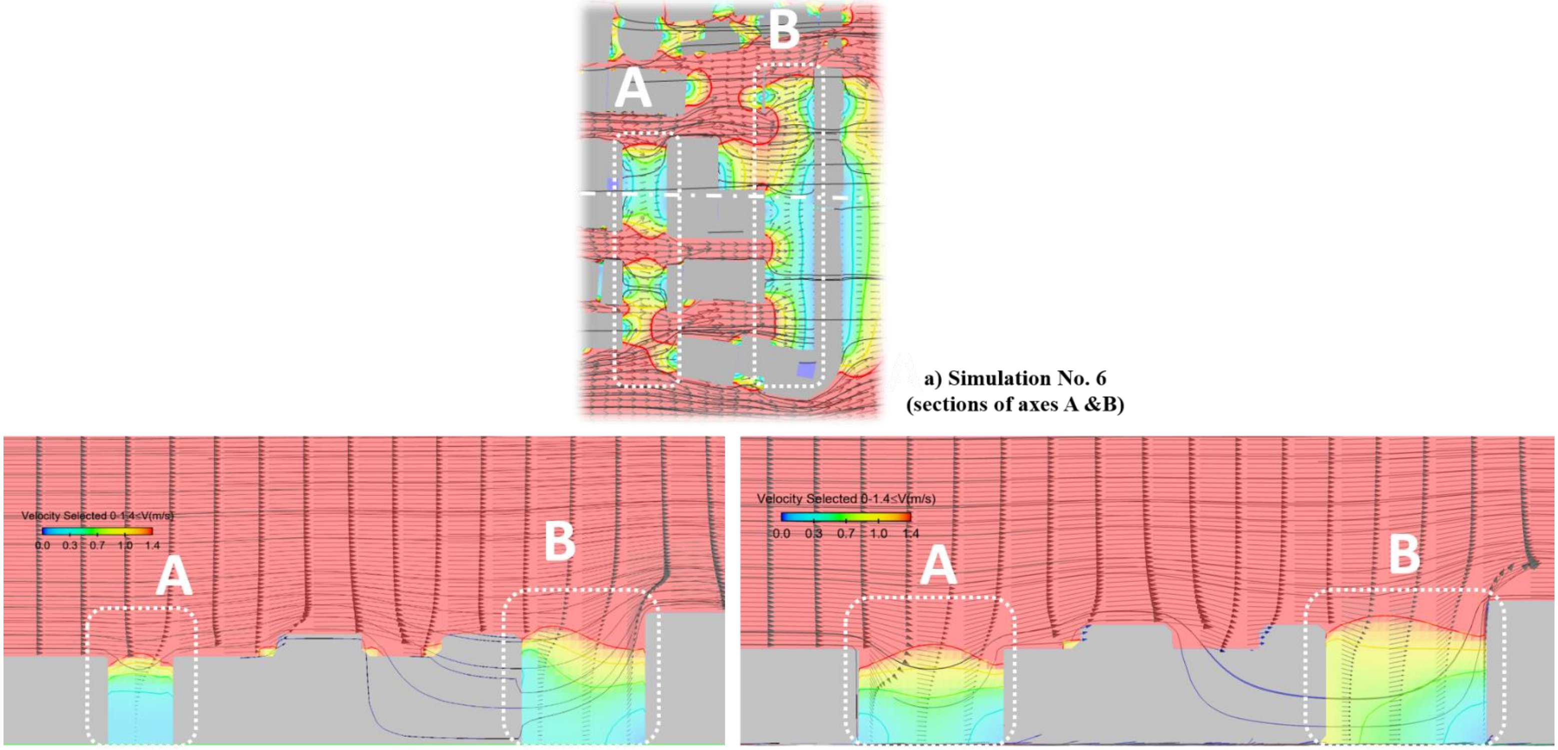


3D Plan Strategy No.6

Fig.G.2.



a) Simulation No. 6
(sections of axes A &B)

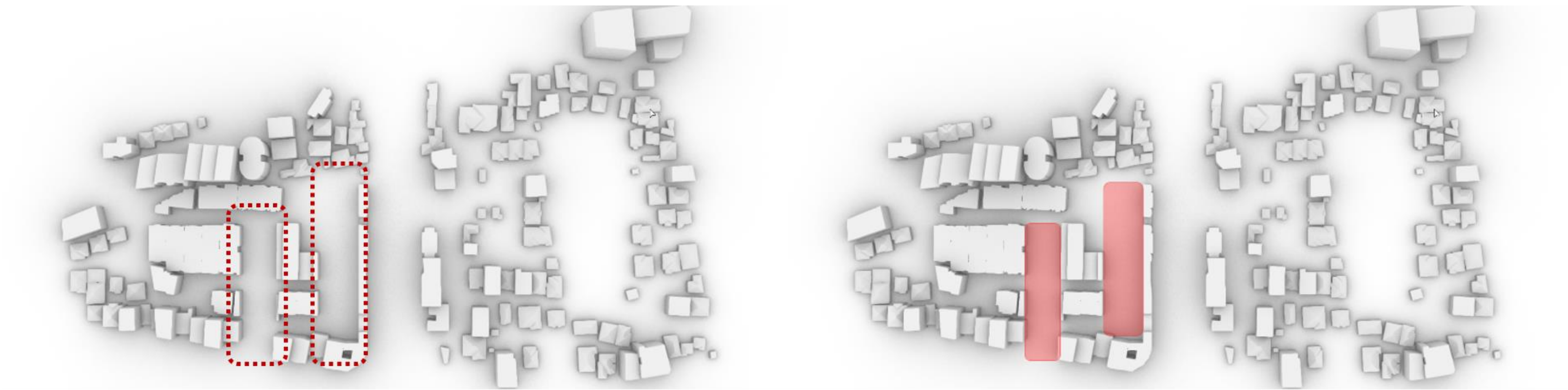
b) Before modification

c) After modification

Appendix H:

Fig.H.1.

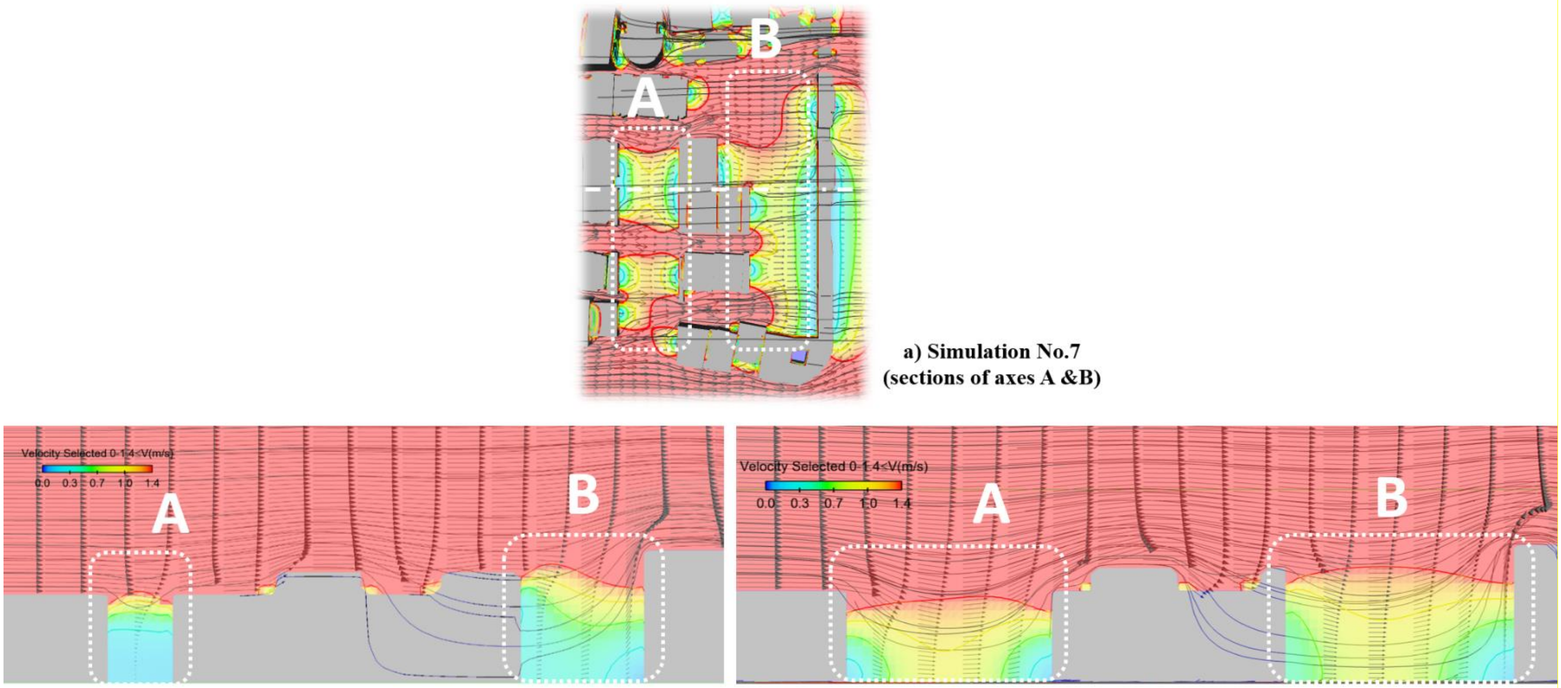
 doi:10.20944/preprints202201.0377.v1



Before modification **After modification**

3D Plan Strategy No.7

Fig.H.2.



a) Simulation No.7 (sections of axes A &B)

b) Before modification **c) After modification**

Appendix I:

Fig.I.1.

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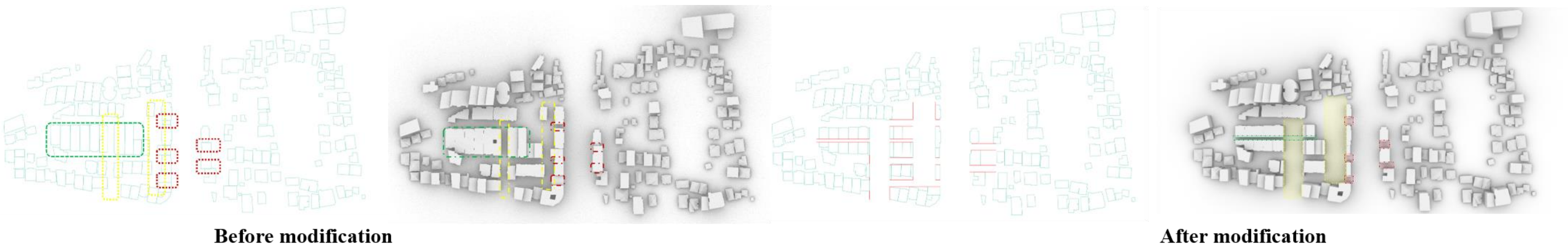
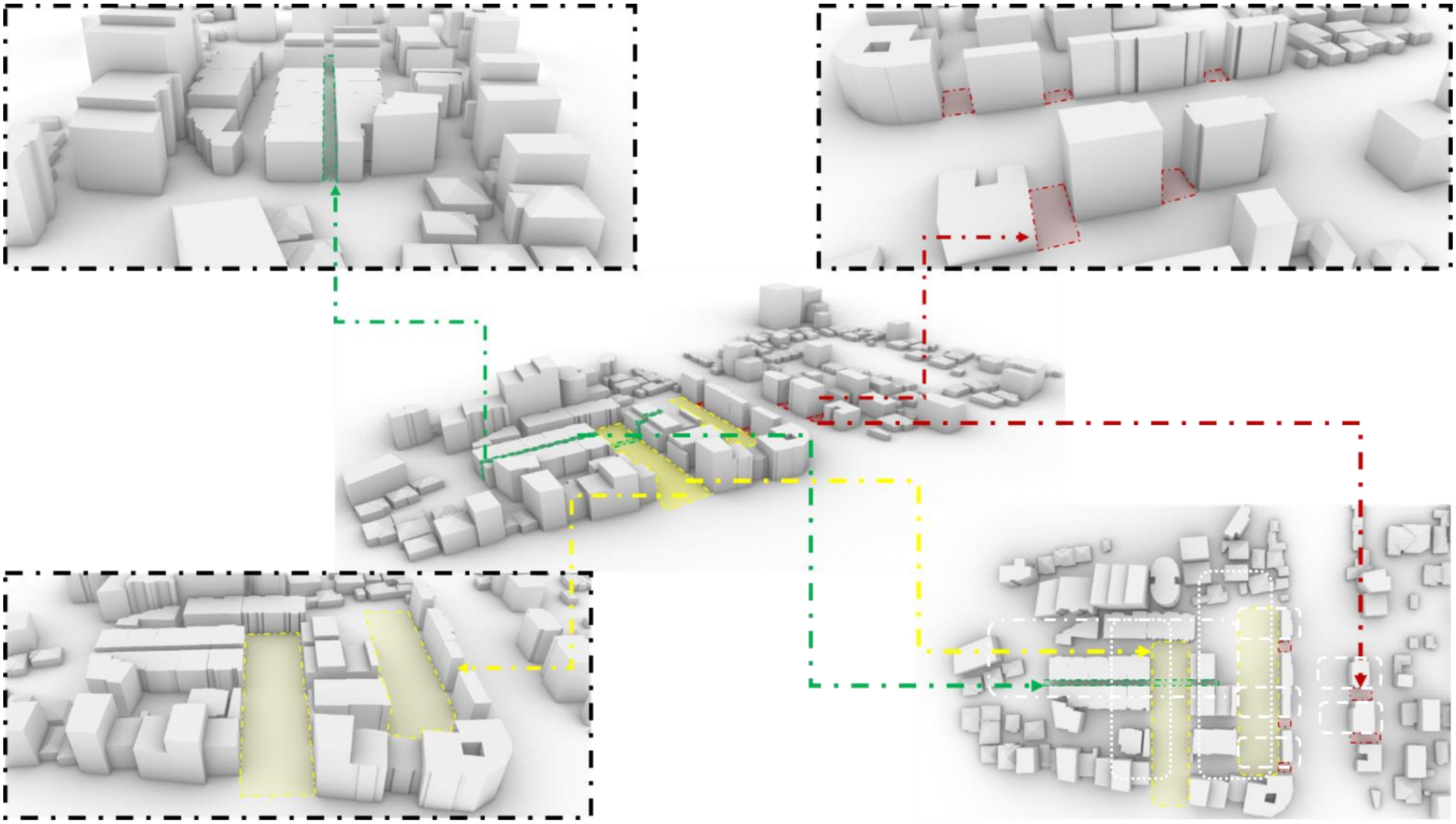


3D Improvement plan for the current situation

Fig.I.2.



b) 3D improvement design for the current situation