UNIVERSITI PUTRA MALAYSIA

PEDESTRIAN LEVEL WIND ENVIRONMENT INVESTIGATIONS IN RESIDENTIAL COMPLEXES IN IRAQ

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

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DEDICATION

This thesis is dedicated to Almighty Allah, He who taught Man by the pen and taught him that which he knew not.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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April 2021

Chairman : Siti Sarah binti Herman, PhD
Faculty : Design and Architecture

In urban areas, outdoor thermal comfort influences the performance of people and their work. Wind flow is affected by several parameters, such as the arrangement of buildings and the architecture of buildings with regard to shapes, height of buildings, and aspect ratio of street-canyon width. Modern design techniques will lead to the enhancement of many architectural buildings' thermal performance which may have an impact on Iraq Government’s criteria. While policies and design standards deal with key planning and there are no obvious guidelines in designing buildings that have effective energy performance. Moreover, the contemporary urban design pays no attention to the environmental solution in residential buildings which will lead to the production of a rather large calm zone of wind speed and the potential to increase the risk of pollutant exposure in many areas of outdoor places. Hence, the study aimed to determine the extent of the impacts of wind flow around the outdoor residential buildings at the pedestrian-level wind (PLW) in Iraq and to what extent can they be invested in finding healthy and comfortable living conditions , as well as, focusing to uncover the current practices in outdoor conditions for existing residential buildings in terms of (arrangement, shape, height of the building, and street -canyon width) as well as, the patterns of wind flow behavior among occupants of different models. Consequently, a quantitative field study was conducted to evaluate the wind effects on outdoor spaces in Iraq residential buildings in a hot-dry climate to achieve a comfortable pedestrian thermal level. The field measurement had measured seven points using Digital Anemometer in Al-Salam residential building as a case study in Najaf city in summer (July). Computer simulation (Autodesk CFD) was used to simulate the existing complex building modeling with three wind velocities (1.2, 2.1, and 3.2 m/s) in the winter and summer conditions respectively, based on the meteorological data of Najaf to compare with the simulation results during the summer season obtained from the field measurements under similar conditions and same measured points so that the accuracy of the results could be acquired. In addition, the study investigated the possibility of wind flow on 28 simulation models in Iraq residential buildings based on different parameters such the buildings' arrangement, shape, height, and aspect ratio of street canyon by using Autodesk CFD simulation with high accuracy mesh and κ-ε turbulence model. The results of Autodesk CFD simulation and field measurements of the existing complex building of Al Salam Residential Complex showed approximately similar data and slight differences in the accurate value with the error percentage of 4.942 %. The modified models with plants are also capable of improving wind flow in Iraq residential buildings through the use of trees with L-shaped arrangement and of different heights. Furthermore, it was observed from the simulation results of the 6 simulation models that the average wind speed in the staggered arrangement at 45° rotation angle is the best distribution which provides the most appropriate average wind speed. Meanwhile, L-shaped buildings with 45° rotation angle is the optimal shape that provides the most appropriate average speed and creates the best outdoor wind environment and the smallest calm zone. In respect of building height, the results confirmed the use of some solutions to make the gradient of the buildings' height that allows the shortest one to be exposed to the wind first, while the highest to be the last being exposed to the wind, in order to avoid wall impact blockage. With regard to street-canyon width, wind velocity observed in Model 1 and Model 2 for (12 simulations) had accelerated with increasing street width and resulted in high velocity in some areas. The wind flow characteristics have been influenced by the approaching width of the street canyon and the height of building inside the street canyon. The study was also suggested to increase the inter-distance between the blocks or to reduce the height of the blocks so that the aspect ratio (H/W) is 0.5 between the buildings. The results of this study can be used in future design, concerning outdoor voids to provide comfortable thermal in outdoor spaces. In conclusion, the findings of this study contribute towards improving the designing process.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PENYELIDIKAN TAHAP ANGIN PERSEKITARAN PEJALAN KAKI DI KOMPLEKS KEDIAMAN DI IRAQ

Oleh

KHAN ALI HUSSEIN ABDULMUTTALEB

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Di kawasan bandar, keselesaan terma luaran mempengaruhi proses kerja seseorang dan prestasi pekerjaan mereka. Aliran angin dipengaruhi oleh beberapa parameter, seperti susunan bangunan dan seni bina bangunan dengan memperhatikan bentuk, ketinggian bangunan, dan nisbah aspek lebar jalan-ngarai. Teknik reka bentuk moden akan membawa kepada peningkatan prestasi termal bangunan seni bina yang mungkin impak pada kriteria Kerajaan Iraq. Walaupun dasar dan standard reka bentuk menangani perancangan utama tidak ada garis panduan yang jelas dalam merancang bangunan yang mempunyai prestasi tenaga yang berkesan. Lebih-lebih lagi, reka bentuk bandar kontemporari tidak memperhatikan penyelesaian persekitaran di bangunan kediaman yang akan menyebabkan pengeluaran zon tenang yang cukup besar dengan kelajuan angin dan berpotensi meningkatkan risiko pendedahan pencemaran di banyak kawasan di luar. Oleh itu, kajian ini bertujuan untuk menentukan sejauh mana kesan aliran angin di sekitar bangunan kediaman luar di tingkat pejalan kaki di Iraq dan sejauh mana mereka dapat dilaburkan untuk mencari keadaan hidup yang sihat dan selesa, serta, fokus untuk menerokai amalan semasa dalam keadaan luaran untuk bangunan kediaman yang ada dari segi (susunan, bentuk, ketinggian bangunan, dan lebar jalan-ngarai) serta, pola tingkah laku aliran angin di kalangan penghuni model yang berbeza. Oleh itu, kajian kuantitatif dilakukan untuk menilai kesan angin pada ruang luar di bangunan kediaman Iraq dalam iklim kering-panas untuk mencapai tahap termal pejalan kaki yang selesa. Pengukuran lapangan telah mengukur tujuh titik menggunakan Digital Anemometer di bangunan kediaman Al-Salam sebagai kajian kes di kota Najaf pada musim panas (Julai). Simulasi komputer (Autodesk CFD) digunakan untuk mensimulasikan pemodelan bangunan kompleks yang ada dengan tiga halaju angin (1.2, 2.1, dan 3.2 m / s) masing-masing dalam keadaan musim sejuk dan musim panas, berdasarkan data meteorologi Najaf untuk dibandingkan dengan simulasi hasil semasa musim panas diperoleh dari pengukuran di lapangan dalam keadaan yang serupa dan titik pengukuran yang

sama sehingga ketepatan hasilnya dapat diperoleh. Di samping itu, kajian menyelidiki kemungkinan aliran angin pada 28 model simulasi di bangunan kediaman Iraq berdasarkan parameter yang berbeza seperti susunan bangunan, bentuk, ketinggian, dan nisbah aspek ngarai jalan dengan menggunakan simulasi Autodesk CFD dengan mesh ketepatan tinggi dan κ -ε model pergolakan. Hasil simulasi Autodesk CFD dan pengukuran lapangan dari bangunan kompleks Kompleks Kediaman Al Salam yang ada menunjukkan kira-kira data yang serupa dan sedikit perbezaan dalam nilai tepat dengan peratusan ralat 4.942%. Model yang diubah suai dengan tanaman juga mampu meningkatkan aliran angin di bangunan kediaman Iraq melalui penggunaan pohon dengan susunan berbentuk L dan ketinggian yang berbeza. Selanjutnya, ia diperhatikan dari hasil simulasi dari 6 model simulasi bahawa kelajuan angin rata-rata dalam susunan berperingkat pada sudut putaran 45° adalah taburan terbaik yang memberikan kelajuan angin purata yang paling tepat. Sementara itu, bangunan berbentuk L dengan sudut putaran 45° adalah bentuk optimum yang memberikan kelajuan rata-rata yang paling sesuai dan mewujudkan persekitaran angin luar terbaik dan zon tenang terkecil. Mengenai ketinggian bangunan, hasilnya mengesahkan penggunaan beberapa penyelesaian untuk membuat kecerunan ketinggian bangunan yang memungkinkan yang terpendek terdedah kepada angin terlebih dahulu, sementara yang tertinggi menjadi yang terakhir terkena angin, di untuk mengelakkan penyumbatan hentaman dinding. Berkenaan dengan lebar jalan-ngarai, kecepatan angin yang diperhatikan pada Model 1 dan Model 2 untuk (12 simulasi) telah dipercepat dengan peningkatan lebar jalan dan menghasilkan halaju tinggi di beberapa daerah. Ciri-ciri aliran angin telah dipengaruhi oleh lebar canyon jalan dan ketinggian bangunan di dalam canyon jalan. Kajian ini juga disarankan untuk meningkatkan jarak antara blok atau mengurangkan ketinggian blok sehingga nisbah aspek (H / W) adalah 0.5 antara bangunan. Hasil kajian ini dapat digunakan dalam rancangan masa depan, mengenai lompang luar untuk memberikan haba yang selesa di ruang luar. Kesimpulannya, penemuan kajian ini menyumbang ke arah peningkatan proses reka bentuk.

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This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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2D	Two Dimensional
3D	Three Dimensional
AC	Accuracy
ASHRAE	American Society of Heating, Refrigerating and Air conditioning Engineers
AutoCAD	Computer Aided Design
BM	Benchmarking
CFD	Computational Fluid Dynamics
Co2	Carbon dioxide
DNS	Direct Numerical Simulation
DO	documentation (manuals, help, etc.)
E	East
EU	ease of use (problem set-up, user interface, etc.)
EX	expandability to new areas/problems
GF	geometric flexibility
H	Height of building
H/W	Height of building to the street width
H_{max}	The highest building in modeling
H_{ref}	Reference height (height of the modeled boundary layer)
HVAC	Air Conditioning Ventilation, and Heating system
INHP	Iraq National Housing Policy
K	Peak factor
K-ϵ	Turbulence kinetic energy

LES	Large Eddy Simulation
LES	Large Eddy Simulation
LMA	Local mean age
LTU	Lawrence Technological University
N	North
NE	North- East
NSE	Navier-Stokes equations
NSE	Navier-Stokes equations
NW	North- West
P	Point
PLW	Pedestrian-level wind
R^2	Coefficient of multiple determination
RANS	Reynolds-averaged Navier-Stokes
RH	Relative humidity
S	South
SE	South- East
SP	Speed
SW	South- West
TT	turnaround time (set-up to end result)
U	Wind speed
U_{cfd}	Mean wind velocity of CFD simulation
Ue	The equivalent wind speed
U_{exp}	Mean wind velocity of field measurements
UN	United Nations

U_{ref}	Reference wind speed
UTHR	Threshold value (all at pedestrian height)
W	West
Z	Height level from the ground surface
σu	Standard deviation of wind speed (turbulence)

CHAPTER 1

INTRODUCTION

1.1 Research background

It has been shown that rapid population development and fixed accessible land resources contribute towards urbanization, especially in modern cities, while designing intensive urban regions for the pedestrian comfort and natural ventilation is a substantial factor. In general, the shapes of building consist of three types, namely the high-rise, medium-rise, and low-rise buildings with complex forms. Hence, it is substantial to realize the pedestrian level wind (PLW) environment around these buildings' shapes (Mittal et al., 2017). Various studies that result in the development of diverse designs, assisted to counter the impacts of climate component and supply the greatest potential.

In urban areas, wind flow pattern is highly impactful upon the comfort level of pedestrians and natural ventilation. There are several parameters that affect the wind flow patterns like the arrangement of neighbouring buildings, the architecture of the buildings, terrain conditions of building's location, and also wind direction (Mittal et al., 2017). Wind flow may be greatly affected due to location of the building which is in the urban cities, for instance, buildings can be used to induce wind movement in it, relying on the prevailing winds for the cities, or protect the site from undesired wind currents. Wind pressure is the major ventilation driving force in the case of hot climates and will cause the airflow to penetrate the buildings across their facades because of the pressure difference (Asfour, 2010).

The arrangement of building has been presumed to be the major counter-measure to enhance the outdoor conditions and wind flow by changing the building's layout (building arrangement, height, and shape). Several studies had been performed to look for some solutions for particular or regular cases, such as simulating several wind flow effects which could happen near the buildings based on wind tunnel tests (Hong & Lin, 2018), examining the relationship between building's density of actual residential buildings and the average wind velocities at pedestrian-level (Kubota et al., 2008); architectural design is also accepted as an influential way of easing thermal comfort, which provides a better outdoor environment(Ng et al., 2012).

In terms of high buildings and street canyons, there is a big influence on the ground-level wind flow and air pollution within the urban fabric; nevertheless, wind flow interaction is frequently not taken into consideration when it comes to urban planning and urban development decisions (Abd Razak et al., 2013).

Consequently, increased air pollutants influence general health issues and raise the spread level of communicable diseases (Gao et al., 2009); air ventilation is a valuable process in urban pollutant drainage of residential buildings to acquire clean air. Particularly, outdoor air quality could be enhanced by the airflow as wind removes pollutants. Wind flow is highly related to the building's morphology and the mutual arrangement of buildings (Yu et al., 2017).

In a study by (Kubota et al., 2008), there is a strong relationship between pedestrian-level wind environment and different building height found in residential areas. Ikegaya et al (2017) investigated the impact of different building height on wind velocity and revealed that the height difference of building blocks will improve the wind flow path at pedestrian level (Ikegaya et al., 2017). High-rise buildings indicate the architectural building height ranging from 35 to 100 meters based on (Emporis Standards, 2015a). In general, a high-rise building refers to a structure with 7- storeys or more (Beadle, 2001). The four categories of high-rise buildings, as prescribed by the national fire incident databases, are 7–12 storeys, 13–24 storeys, 25–49 storeys, and 50 storeys or more. While, the low-rise buildings indicate the architectural building of height below 35 meters and divided at systematic intervals into livable floors (Emporis Standards, 2015b; Gabbar, 2018) . Furthermore, there are two building patterns which are the multi-family housing and single-family housing in the housing manual of Iraq. Multi-family housing consists of high-rise buildings, mid-rise buildings, and low-rise buildings. According to internationally-applied rating, low-rise buildings are determined to be of 3–4 storeys, mid-rise buildings to of 4–8 storeys and high-rise buildings to be up to eight storeys (Goody et al., 2010; Keim, 2007) because they are not shown by the Iraq manual regarding their height limits (State Commission, 2010).

Finally, Iraq cities are testifying a big expansion as a result of the increasing number of residents and the enhancement of economic circumstance. This expansion has resulted in domination of modern lands and alteration of their features, which participate in the aggravation of pollution crisis as streets prevail and buildings are at the expense of farming land. However, the issue is not only about land expansion; in fact, the issues that should be taken into consideration when building houses is taking the local environment data to decrease urban air pollution. During summer in Iraq, the average temperature (April to September) ranges between 40° C to beyond 50° C. The high-temperature domain through summer time is more energy-consuming (Waheb & Yaseen, 2018). Several researchers had proposed effective ways to improve thermal comfort depending on the landscape environment and building layout (Alchapar & Correa, 2016; Barakat et al., 2017). The impact of trees in thermal comfort is considered as more effective because it supplies more shades in which the amount of tree planting is appropriate to improve outdoor thermal comfort and decrease radiant temperature. Vegetation can clearly reduce the wind speed. In addition, it plays a good role upon strong winds during the winter and establishes a convenient wind environment at pedestrian level (Zhang et al., 2018).

1.2 Problems statement

In urban area, a residential region is considered as one of the most essential living spaces and the wind environment of residential regions has a major importance in environmental urban areas and the construction of green lands. The existence of high-buildings near low-rise ones could change the wind environment and lead to uncomfortable wind conditions around high buildings (Ahuja et al., 2006). The air quality in street canyons at the pedestrian-level for low-level buildings and other high-rise buildings may be influenced by various factors, such as the wind speed, wind direction, street width, as well as the shape and height of the buildings. Nevertheless, there is still a research gap in studying the impact of residential building configurations on the outdoor thermal comfort in a hot arid climate within Iraq cites. Yet, the effect in grouping patterns, building geometries, height variation in low-rise, mid-rise buildings, and high-rise housing on outdoor thermal comfort is still not addressed in a statistical way in most of the Iraq cities (Hassan et al., 2019).

There are several assessment researches that worked with high accuracy to define the acceptability of diverse residential projects to meet special housing requirements in Iraq (Table1). Studying these researches presents that they have reached several of the possible alternatives as stated by (Al-Hafith et al., 2018)' study. Despite that, no studies have yet to focus on evaluating the possible architectural methods, and all the studies did not fulfill the housing requirements in Iraq.

Table 1 : Evaluation criteria and housing pattern requirements in Iraq

Evaluation criteria			Building patterns in Iraq		
The requirements fields		The required features	Low-rise	Mid-rise	High-rise
Iraqis' preferences	Technical requirements	Being safe structure	—	—	—
		Providing efficient services	—	—	—
		Providing sufficient rooms	—	—	—
	Internal layout requirements	Providing sufficient total area	—	—	—
		Providing the ability for modification	—	—	—
	Indoor environment requirements	Providing suitable indoor environment	—	—	—
	Psychological requirements	Having Beautiful outside form	—	—	—
		Providing Privacy	—	—	—
	Economic requirements	Reducing the initial costs	○	○	○
		Reducing the running costs	—	—	—
Current housing problems' requirements	Housing production efficiency	Having efficient housing production	○	○	○
	Land use efficiency	Increasing land use efficiency	○	○	○
		Reducing the effort to provide the infrastructure services	○	○	○
	Infrastructure use efficiency	Having efficient energy consumption	—	—	—
		Having efficient water consumption	—	—	—
	construction materials use efficiency	Increasing construction material use efficiency	—	—	—
	Housing affordability	Reducing the initial costs	○	○	○
		Reducing the running costs	—	—	—

(Al-Hafith et al., 2018)

The symbols in the Table refer to the determined impact (◯) : A housing pattern that is positively affecting satisfies a housing requirement; Undetermined impact (─): The impact of housing pattern satisfying requirements had not been investigated by the study.

In Iraq, there is an urgent need for sustainable environment, where Iraq residential buildings are required to be promoted towards having the wind effects in order to be capable of providing a good wind comfort in urban spaces. In the 20th century, a lot of parks, squares and gardens in Iraq have been constructed. Baghdad and many other cities in Iraq are among the locations with many parks built for the purpose of social integration to improve the thermal comfort at PLW and so that people can have more relaxing places. However, the currently existing parks do not play their role well in Iraq. This is reflected in user's interaction and limited to indoor spaces only. In addition, the responsible authorities do not make constructions and administrations, parks' maintenance, and enough efforts for open spaces (Rikabi & Ali, 2013). The present parks have insufficient space and number, and the facilities are not effective especially the children's facilities within the parks (not protected). Such thing will be reflected on community interaction (Rikabi & Ali, 2013). (Salih et al., 2018)' study elaborated that there was a lack of open spaces resulting in lack of social interaction based on assessment study that supplying important information of outdoor spaces contributes to active social interaction and outdoor recreation in Baghdad- Iraq. Thus, the results proved that achieving green open space is fundamental to improve the aspects of wind comfort environment besides health in terms of mental, social and physical for residential area and the residents. This could be achieved by implementing appropriate criteria in that space which encourage social interactions between the citizens in the city.

On the other hand, the outdoor climate will be altered by the building construction. Wind velocity, wind direction, daylight, air pollution, and radiation are all samples of physical appearances that specify the wind comfort and that are altered by the existing buildings (Blocken & Carmeliet, 2004). The change of these quantities depends on the size, shape, and orientation of the building and the building interaction with the encirclement buildings. Unsuitable outdoor thermal comfort may result in several problems regarding the well-being and health of humans as well as negatively affects commercial and social outdoor activities as a result of low wind speeds and high temperatures (Johansson & Emmanuel, 2006). The reduction of vegetation areas and the increasing number of buildings in a city will influence wind comfort in urban spaces which could affect the usage of outdoor space. People's expectations are different when staying outdoor instead of indoor, which means they anticipate variability in outdoor conditions, such as the modifications in wind direction and speed (Givoni et al., 2003). Pedestrian satisfaction level with wind comfort environment is one of the indications of the essential issue which sets the number of hours to spend into outdoor public areas. Nevertheless, it is hard to determine peoples' satisfaction level with outdoor thermal comfort, as it may differ from one person to another which will result in changing satisfaction and perception of occupants at PLW, particularly in hot dry climates. These indicators pose challenges to urban space designers and many researchers in finding the suitable ways to improve outdoor thermal comfort at pedestrian areas (Setaih et al., 2013).

The significance of safe and comfortable wind conditions in the surroundings of buildings has been confirmed by many authors. Inconvenient wind environments have been assumed to be detrimental to the success of new constructions (Durgin & Chock, 1982). (Wise, 1970) reported regarding shops that are left without monitoring due to the stormy environment that frustrated the shoppers. In 1972, after being blown over by abrupt wind storms near a high-rise building. (Lawson & AD, 1977) declared a significant risk of wind conditions to be responsible for killing two old ladies. Iraq is considered one of the most influenced countries in the Middle East concerning the occurrences of strong dust as a result of climatic changes within the region which leaves a major impact on human health and more economic losses (Sissakian et al., 2013). Figure1 presents the relation between the average monthly wind speed (m / s) and the frequency of dust storms (day) in Iraq during 1982-2011 (Salam Aljubouri, 2019). While, the predicted value of annual dust storms in 2013 was assessed to be 300 days (UOF, 2006). According to the studies by (Bottema, 1993; Murakami et al., 1980), an unexpected increase in wind velocity could be enough to bring people out of balance and is considered quite dangerous for the infirm and the elderly at pedestrian level. (Ridha et al., 2018)' study was focused on potential mitigation methods to improve the thermal comfort for urban area at PLW. The outdoor thermal comfort is affected especially in hot and arid climates by the satisfaction of the pedestrians in Iraq.

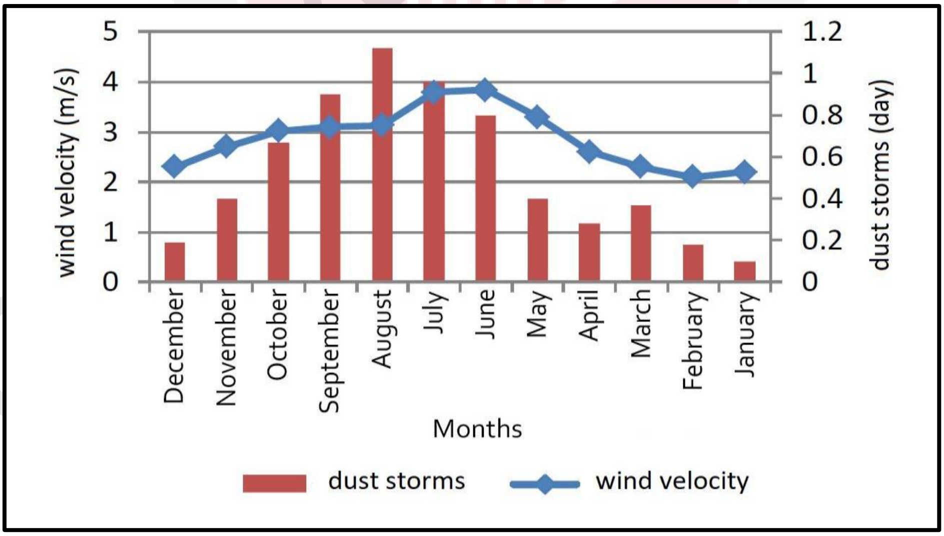

Figure 1 : Presents the relation between the average monthly wind speed (m / s) and the frequency of dust storms (day) in Iraq during 1982-2011 (Salam Aljubouri, 2019)

In arid climate, human thermal comfort has confronted with difficulties in urban areas without taking the pedestrians into consideration particularly in a hot season of summer. As asymmetrical canyons, high-rise buildings, the loss of shading feature, lack of vegetation, and the big spacing between buildings play an important part and this will lead to undesirable thermal comfort. Furthermore, there is a lack of classification and summary of the characteristics of residential areas in hot regions, and studies concerning the comparison of wind conditions between various layouts of residential regions are also limited in Iraq. Therefore, in current residential area planning, planners can carefully observe the time of construction to enhance wind environment in outdoor space. It is considered as one of the most important reasons that should be assessed for pedestrian wind conditions of residential areas in severe hot regions in Iraq.

This research investigated the potentiality to enhance the wind flow in outdoor spaces in Iraq residential buildings. To investigate this potentiality, the research questions addressed in this study are as follows:

Main research question:

How to apply pedestrian level wind (PLW) to improve outdoor thermal conditions of residential buildings in the hot-dry climate of Iraq?

Sub-research questions:

a. How to apply optimal conditions in PLW by using CFD simulation to describe the wind flow around the existing residential buildings?

b. What is the current Iraq practices of outdoor conditions in residential buildings (building's arrangement, shape, height, and street-canyon width) and the relationship between building's design and wind flow at PLW?

1.3 Significance of study

This study aimed to uncover the current practices of outdoor conditions in Iraq residential buildings (building's arrangement, shape, height, and street-canyon width) and the patterns of wind flow behavior among occupants of different models. Consequently, the study tended to reveal the suitable wind comfort as shown in (Table 3) with pedestrian level which gives the required favorable conditions. Furthermore, the study looked into the ability of CFD simulation by studying the airflow behaviors in each design category. The findings of this study will also inform designers on the importance of the research recommendations in Iraq residential buildings to reach the optimal outdoor thermal comfort.

1.4 Aim of study

The study aimed to determine the extent of the impacts of wind flow around the outdoor buildings and to what extent can they be invested in finding healthy and comfortable living conditions.

1.5 Research objectives

1- To evaluate the current wind flow for 7 points around an existing residential building in Iraq (Al-Salam residential building) by using field measurement and Autodesk CFD simulations and propose the recommendations to achieve suitable conditions in PLW as shown in Figure 2.

2- To evaluate various practices that are commonly applied for residential buildings (building's arrangement, shape, height, and street-canyon width) and their respective weaknesses and strengths.

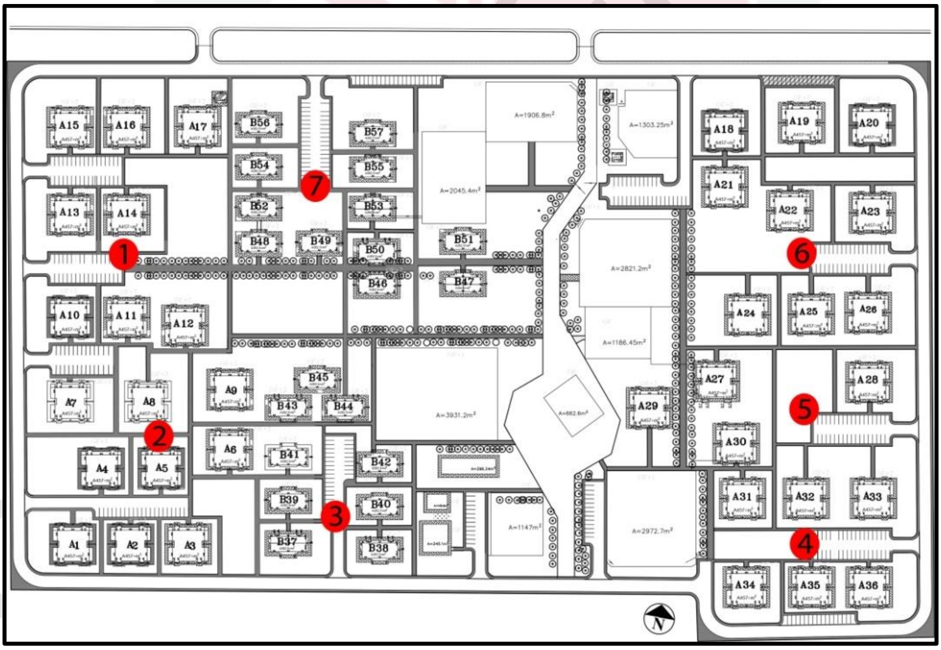

Figure 2 : Presents the locations of studied 7 points in Al Salam Residential building
(Najaf urban Planning, 2019)

1.6 Scope and Limitations

This research focused on the wind comfort in a hot-dry climate to achieve a comfortable pedestrian thermal level. The wind velocity was measured in 7 points in Al-Salam residential building as a case study in Najaf- Iraq in summer (July) which represents the typical wind speed day according to Najaf meteorological data using a Digital Anemometer. The range of wind velocity measurements for meter per second is 0.40-30.00 m/s, Resolution 0.0, and the accuracy is ± (2.0%+0.5m/s). The wind velocity was also measured at 7 points by using Autodesk CFD simulation of three simulations cases in the existing complex building modeling via three wind velocities (1.2, 2.1, and 3.2) m/s in winter and summer conditions respectively. The κ-ε turbulence model was only used in simulating the wind flow around residential buildings. The Autodesk CFD simulation was performed on a high-resolution grid which can be useful for a more accurate analysis of outdoor wind at pedestrian level. Furthermore, the study investigated the possibility of wind flow in Iraq existing residential buildings based on different design parameters modeling of 28 simulation cases (building's arrangement, shape, height, and street-canyon width). Finally, the thermal comfort performance was assessed depending on the wind velocity and restricted to the outdoor spaces at pedestrian level only.

1.7 Research methodology

The research used a quantitative research methodology by using the Field measurement (Digital Anemometer) and Computer simulation (Autodesk CFD simulation) to measure 7 points of Al-Salam residential building in a case study in Najaf- Iraq. The study methodology was then divided into three matters to answer the research questions as follows: 1- Field measurement in an existing complex building in summer (July), these results will provide the wind velocity data from the case study to evaluate the current outdoor thermal condition and compare it to CFD program results. 2- Computer simulation (CFD) will be used to simulate the existing complex building modeling with three wind velocities (1.2, 2.1, and 3.2 m/s) in winter and summer conditions respectively. In addition, the meteorological data of Najaf will be used for modeling preparation in CFD simulation program, to compared with the simulation results of that during summer as obtained from the field measurements under similar conditions and the same measured points to get more accurate results. 3- Simulation procedure: all simulation processes will be defined to investigate the possibility of wind flow in Iraq existing residential buildings based on different design parameter modeling of 28 simulation cases (building arrangement, shape, height, and street-canyon width) so as to obtain the experimental results of this study. The objectives will be achieved through CFD simulations, which respectively refer to the suitable conditions and influencing factors on sustainable building design such as wind velocity, wind direction, and aspect ratio; and also, CFD simulations which are considered as the main supporting method to achieve these objectives in this study.

1.8 Thesis structure

This thesis comprises five chapters which are as follows: Chapter 1 is an introduction to the study and includes a background of wind flow, the research objectives, problem statement, and research methodology. Chapter 2 provides a critical analysis of relevant literature regarding wind flow effects on Iraq urbanization. This chapter discusses the wind flow, pedestrian-level wind, wind comfort criterion, wind forces, building arrangement, building shape, building height, and street-canyon width with density buildings, as well as the wind analysis methods, CFD software selection, and Flow Design software. Chapter 3 characterizes the methodologies of field measurement and computer simulation CFD utilized in this research. Data analysis procedures, results, and discussion of the results are stated in chapter 4. Moreover, the results of simulations are discussed in a form of visual data such as figures, tables, and charts. Finally, Chapter 5 summarizes the whole thesis which includes its results and discussion of the conclusions based on the achieved results. The steps of the research framework are presented in Figure 3.

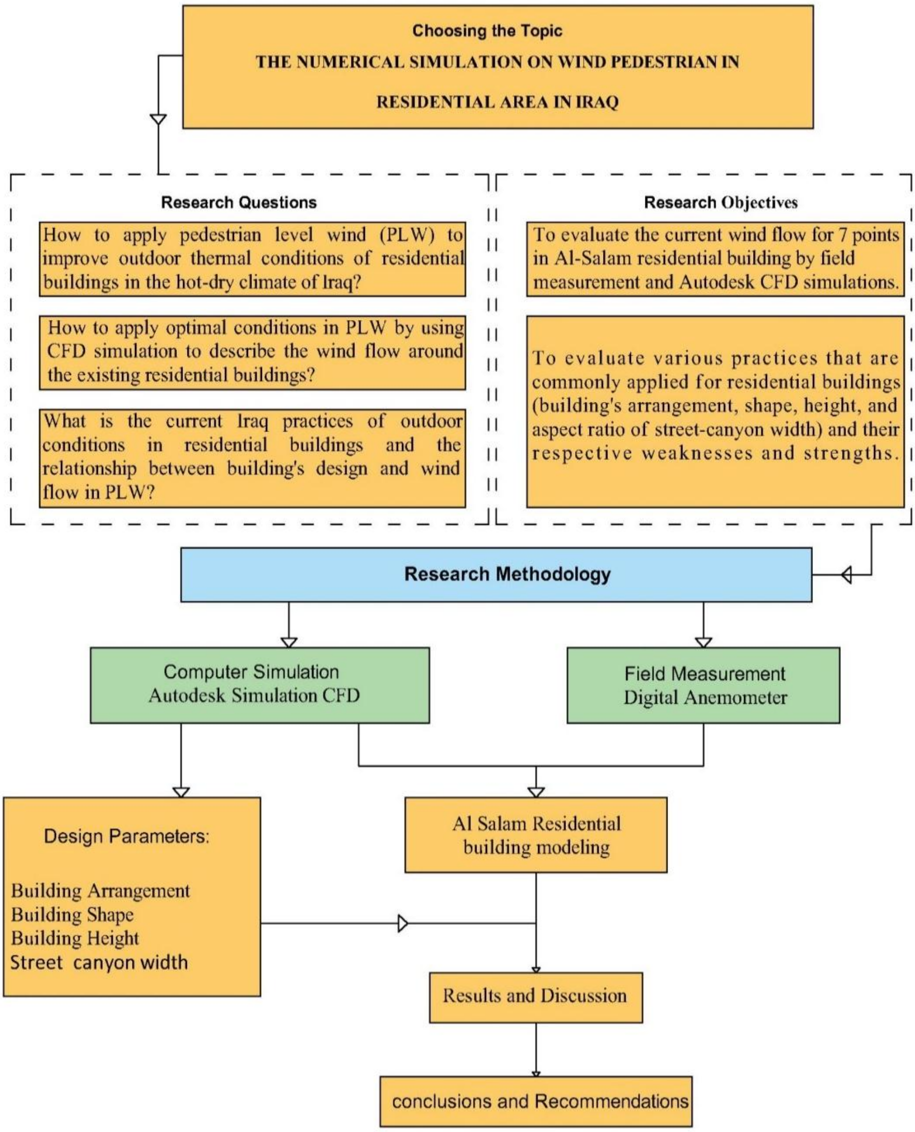

Figure 3 : Presenting the research framework

1.9 Summary

This chapter discusses relevant problems and issues with regard to the research questions, aims, objectives, the research methodology, and framework. Also, the thesis structure is shown in supplying a summarized description of the research procedures that were carried out. The next chapter will present a review of the wind flow theoretical background.

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APPENDICES

Appendix A

Reynolds Number definition

The definition of the Reynolds number is given by the following well-known formula:

$$\mathrm{Re}_L = \frac{\mathrm{UL}}{\nu}$$

U holds for a typical velocity, L is a typical length and ν is kinematic viscosity. Its general form could be derived with help of dimensional analysis of the flow dynamics. For the case of viscose incompressible fluid-flow without presence of other volume forces the Reynolds number is the only relevant parameter defining quality of the flow under given boundary conditions. It determines presence of coherent structures in the flow and their behavior. And of course also the type of the flow: laminar or turbulent.

Source: Uruba, V. (2018, August). On Reynolds number physical interpretation. In *AIP Conference Proceedings* (Vol. 2000, No. 1, p. 020019). AIP Publishing LLC.

Appendix B

Coefficient of Determination (R^2)

The coefficient of determination (R^2) summarizes the explanatory power of the regression model and is computed from the sums-of-squares terms.

$$Coefficient\ of\ Determination \rightarrow \quad R^2 = \frac{SSR}{SST} = 1 - \frac{SSE}{SST}$$

$$Sum\ of\ Squares\ Total \rightarrow \quad SST = \sum (y - \bar{y})^2$$

$$Sum\ of\ Squares\ Regression \rightarrow \quad SSR = \sum (y' - \overline{y'})^2$$

$$Sum\ of\ Squares\ Error \rightarrow \quad SSE = \sum (y - y')^2$$

R^2 describes the proportion of variance of the dependent variable explained by the regression model. If the regression model is "perfect", SSE is zero, and R^2 is 1. If the regression model is a total failure, SSE is equal to SST, no variance is explained by regression, and R^2 is zero.

Sources:

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Appendix C

Percent Error Equation

Percent error or percentage error expresses as a percentage the difference between an approximate or measured value and an exact or known value. It is used in science to report the difference between a measured or experimental value and a true or exact value. Here is how to calculate percent error, with an example calculation.

Percent Error Formula

Percent error is the difference between a the experimental or measured value minus the known or theoretical value, divided by the theoretical value and multiplied by 100%.

percent error = [experimental value - theoretical value] / theoretical value * 100%

Percent Error Calculation Steps

1. Subtract one value from another. The order does not matter if you are dropping the sign (taking the absolute value. Subtract the theoretical value from the experimental value if you are keeping negative signs. This value is your "error."

2. Divide the error by the exact or ideal value (not your experimental or measured value). This will yield a decimal number.

3. Convert the decimal number into a percentage by multiplying it by 100.

4. Add a percent or % symbol to report your percent error value.

Source: Bennett, Jeffrey; Briggs, William (2005), *Using and Understanding Mathematics: A Quantitative Reasoning Approach* (3rd ed.), Boston: Pearson.

Table: presents the percent error calculation steps of Al Salam Residential Complex building.

Points	Field Measurement (F) m/s	Simulation model (S) m/s	F-S	Absolut value	Abs./ S	Multiplying value by 100
P1	0.445	0.5	-0.055	0.055	0.11	11
P2	0.49	0.5	-0.01	0.01	0.02	2
P3	0.85	0.9	-0.05	0.05	0.055556	5.555556
P4	0.77	0.8	-0.03	0.03	0.0375	3.75
P5	1.18	1.2	-0.02	0.02	0.016667	1.666667
P6	0.45	0.5	-0.05	0.05	0.1	10
P7	4.77	4.8	-0.03	0.03	0.00625	0.625
						Percent error = 4.94246

BIODATA OF STUDENT

The student was born on 24 August 1992 in Najaf, Iraq. He received his BSc. Degree in Architecture in 2015 from Babylon University, Iraq. He has established an architecture office in Najaf, Iraq from 2016 to 2018, at the same time worked in the building construction field and designed several architecture buildings in Iraq. In respect of academic activities. The author has an educational background in the architecture and environment field. Finally, he is currently doing a master's study in environmental design of buildings by using computational fluid dynamics (CFD) at Universiti Putra Malaysia.

LIST OF PUBLICATIONS

Khan, A.H., Herman, S.S. and Jaafar, M.F.Z. (2020), The influence of wind effects on architectural buildings heights in Iraqi residential buildings based on CFD simulations, Journal of Construction in Developing Countries, 2016. (accepted for publication).

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