Welsh School of Architecture
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A parametric investigation of natural ventilation retrofit strategies for the cosmopolitan heritage buildings of Alexandria.

Thesis submitted for the degree for the degree of Doctor of Philosophy

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Abstract

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The impacts of political, economic and social changes in Egypt during the second half of the twentieth century put its distinctive architectural heritage at risk. The Mediterranean city of Alexandria is a case in point, its existing heritage buildings having endured many levels of relapse in the form of neglect, misuse and demolition in favor of new-build concrete blocks, which are assumed to better meet modern standards of climatic comfort.

Heritage buildings are an important aspect of any city in their capacity to provide cultural reference points. Demonstrating capacity for better levels of energy efficiency and thermal comfort has become a critical challenge to such buildings' survival. Previous heritage retrofit research to date, has been more influenced towards cold climates in Europe and north America. However, different climatic conditions and building styles raise other issues. From an architectural perspective, the European style courtyarded buildings that established the nineteenth-century heritage fabric of Alexandria theoretically offer good potential for healthy indoor air replacement, while the Mediterranean climate of the city provides enhanced possibilities for promoting indoor thermal comfort. Yet observation of these heritage buildings demonstrates that occupants today rely heavily on energy consuming mechanical ventilation systems.

The principal aim of this thesis is to evaluate a range of potential retrofitting strategies for improving natural ventilation performance and thermal comfort of the typical nineteenth-century listed residential buildings located in the heritage district of Alexandria. This thesis aims to establish a rationale for the sustainable conservation and the potential for the passive upgrading of Alexandrian built heritage to better meet performance targets. This is achieved by applying different research methods to address the various values at stake. These methods include historical analysis, values-based theoretical positioning and practical assessment in the form of both measured field data, and scientific modelling (computational fluid dynamics).

There are four stages in this thesis: firstly, it identifies the significance and key problems facing the heritage context of Alexandria, the impact of its climate conditions and the applicability of natural ventilation strategies. From this a representative case study is selected. Secondly, a review of heritage retrofitting research projects is used to establish how and to what extent those practices can be transferred to the Alexandrian heritage context. Thirdly, the potential for natural ventilation in the case study was evaluated using computational fluid dynamics. Finally, a proposed parametrical study was formulated using the selected natural ventilation design measures based on the literature review and

considering the evaluation study results. The effectiveness in terms of enhancing natural ventilation performance was quantified using “ANSYS Fluent”.

The findings show a detailed natural ventilation deficiency performance in the case study building with an average internal airflow magnitude of 0.22 m/s as modified today. However, the study indicates potential for future improvement. The parametrical simulations indicate that the proposed measures can significantly enhance the natural ventilation performance inside the case study building. This in turn increases the potential for providing internal thermal comfort. This investigation of a typical building aims to contribute to the understanding of conservation approaches that not only preserve a building’s cultural value but also reclaim its natural ventilation performance.

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Chapter 1 Introduction

1.1 Research background

Heritage buildings are an important aspect of any city in their capacity to provide cultural reference points. The last few decades have witnessed renewed interest in heritage buildings forming the historical centres due to multiple factors, including their historical, architectural and significant environmental values as well as their importance to local economies. Today's conservation work to the built cultural heritage has to adjust as a result of new requirements to lower carbon emissions and reduce energy use. On both a national and international level, energy efficiency measures must be considered as an important consideration in most conservation work as noted in the ICOMOS guidelines or Sustainable Development Goals of UN (Hosagrahar et al., 2016). Demonstrating the capacity for better levels of energy efficiency and thermal comfort within these buildings has become a critical challenge to such buildings' survival.

The heritage building stock is a part of the built environment, the total building stock represents a large portion of the world's energy consumption and associated carbon emissions, the building sector by itself represents 40% of the energy consumption and 38% of the carbon emissions based on the studies conducted in different region (Amasyali et al., 2018). These percentages and the general aim of reducing the sector's carbon foot print has stimulated a significant amount of research to be carried out to develop and investigate different energy efficiency opportunities in order to improve energy performance of existing buildings (Ma et al., 2012).

The process of retrofitting existing buildings can offer a significant opportunity for reducing global energy consumptions and greenhouse emissions. Research has shown that energy used in existing buildings can be reduced significantly through proper retrofitting or refurbishment (Ardente et al., 2011). Ardente et al conclude that existing building energy retrofit can be considered one of the main approaches to realistically reduce energy consumption and carbon emissions.

Heritage buildings, however, differ from other segments of the existing building stock in two primary ways that can affect energy retrofit; firstly their physical characteristics, as these buildings may have complex and irregular geometry, different envelope construction, vernacular construction methods, and natural non-standardized materials; secondly with respect to conservation principles, the treatment of heritage buildings is governed by established principles and practices relating to a wider set of values.

The process of meeting these concerns requires a sensitive approach and a complex process, often described as a balancing act between applying sound conservation principles and aspiring to reduced energy consumption. The outcome requiring the protection of the building's heritage fabric and distinguished character to be merged with the technical advancements of energy retrofits used in newer modern buildings or buildings with no distinctive preservation character. The risk of alterations which may cause the loss of the collective cultural heritage or may not be compatible with the building's traditional systems is significant.

The city of Alexandria is formed of many layers of history expressed through its complex and plural culture heritage throughout its evolution. The city was founded 331 BC by Alexander the Great who conquered Egypt. He decided to build a new capital for the Egyptian kingdom, representing the Greek metropolis. The city's heritage emerged through different rulers of Egypt gaining and losing significance and importance from the Greeks, Romans, Arabs, and Turkish till the evolution of modern Egypt by Mohamed Ali in 1805.

During the period between 1805 and 1952, Mohamed Ali and his successors had a different vision of Alexandria, the city became the second important city and the principle port of Egypt. With support for great developments the city attracted foreign migrants to settle in the city, enhancing the city's diversity and sophisticated urban development comprising different communities of various nationalities (Heba, 2011). the city's development led it to become the second largest in Egypt, with a cosmopolitan population and character (Dix, 1986).

The city of Alexandria evolved into a unique architectural pattern with its built fabric influenced by foreign residents from various nationalities who were spread all over the city by the end of the nineteenth century. This has contributed to the development of the city's cosmopolitan character with diversity and a richness of architectural references becoming incorporated into Alexandria's heritage identity.

However, during the second half of the twentieth century, after the 1952 revolution and declaring Egypt as a republic abolishing the Mohamed Ali's monarchy, creating a different political, social and economic factor. The city faced a variety of levels of deterioration, neglect and misuse putting its distinctive nineteenth century architectural character at risk collectively. The problem has been amplified again during the last decade, facing its worst period of deterioration with the absence of law leading to the unchecked destruction of the city's heritage buildings. As a result, more than 40 heritage buildings have been demolished in this period, including small villas and low-rise buildings in favor of concrete expansions exceeding twelve floors. Aghion villa is an example, it was demolished in 2013 after a great debate between the owner and environmentalists and heritage specialists in order to build a course residential block for economic benefits (Kingsley, 2014).

In this instance, the sustainable retrofit process for the Alexandrian heritage is considered to be an opportunity to protect these heritage buildings which are condemned by neglect and deterioration. By suggesting that there is an option of upgrading them on the basis of their environmental performance, it also aims to explore the scope for responding to global environmental concerns.

Different global attempts in the European Union and north America have been made towards providing guidelines and decision-making processes for selecting the appropriate retrofit for heritage buildings. Many organizations such as Historic England, Historic Scotland, ASHRAE and CIBSE are starting to develop research programs for improving energy efficiency in heritage and traditionally constructed buildings. The most immediate observation is that research to this date including different guidelines, are more focused on considering cold climates, as a result of concentrated research and awareness in these regions. Different climatic conditions and building traditions in other regions would raise different issues.

In the case of this research the heritage building in question falls under a hot humid climate for the heritage buildings of Alexandria, which requires different solutions. In particular, the retrofit process needs to focus more on passive cooling techniques to achieve thermal comfort.

Alexandria demonstrates a strong potential for natural ventilation by the consistent presence of cool wind from the Mediterranean Sea. Yet observations of the buildings today demonstrate that occupants rely heavily on mechanical ventilation (air conditioning) (Gomaa, 2015). Wind driven natural ventilation in buildings is one way of reducing energy use by dependence on mechanical ventilation. Natural ventilation has served as an effective passive cooling design strategy to reduce energy used by air conditioning systems (Cuce et al., 2019). For hot humid regions, where the air temperature and relative humidity are generally high, the effectiveness of natural ventilation is always considerable.

From an architectural perspective, the European style courtyarded buildings in Alexandria can also offer good potential for healthy indoor air replacement, and the Mediterranean climate of the city provides enhanced possibilities for promoting indoor thermal comfort.

In an attempt to address these challenges as a means to preserve the built heritage, it is important to consider many aspects in Alexandria's cosmopolitan heritage buildings during the era between 1882-1930 that forms the basis of this research. The research seeks to consider the development of a principled approach for the conservation of these heritage buildings through a sustainable retrofitting method considering the potential of natural ventilation as a passive cooling method. Using a case study, it aims to explore more suitable, sustainable and effective ways to implement the natural ventilation retrofits, while understanding the importance of their significance of heritage buildings and preserving their architectural identity.

1.2 Gaps in the knowledge

According to the given differences in circumstance, energy retrofit methods used in contemporary newer buildings may not be appropriate for and may cause damage to heritage buildings, resulting in the loss of their collective cultural heritage. This impetus is forcing different organizations and researchers to produce retrofitting guidelines adapting heritage buildings to meet current needs ensuring that they will continue to be used, rather than neglected and demolished. The literature review which was undertaken at the outset of this research indicates that most of the research which has been conducted so far has focused on cold climates emphasized on the preservation of heat loss (wall insulation, windows air infiltration and double-glazing applications, airtightness and heating approaches). Different climatic conditions and building traditions in other regions would raise different issues. In general, very few guides were more concerned with warmer climates in general and the application of natural ventilation as a passive cooling heritage retrofit in specific. Previous research has indicated there is still a gap between the conservation principles and environmental applications, especially in the case of natural ventilation in hot climates. With no clear framework for application.

In addition, there is a no clear or consistent research for retrofitting heritage buildings in Alexandria. This is due to the lack of specific regulatory codes. The energy retrofit approach for this heritage context therefore emerges as an open question. To date, although a small number of studies have discussed methods for natural ventilation as a heritage building retrofit approach in various contexts, no studies were found for incorporating natural ventilation approach for retrofitting heritage buildings in the context of Alexandria.

1.3 Research aims

The aim of this research is to investigate the relevant criteria that should govern heritage building sustainable retrofit processes and the different means of integrating these criteria with the different natural ventilation strategies. Having established these criteria and set them as parameters, it is possible to produce natural ventilation retrofit framework in order to predict various outcomes. Exploring the retrofitting of existing heritage buildings in Alexandria's cosmopolitan heritage buildings built between 1882-1930, the research aims to find out how and to what extent the heritage retrofit strategies can be applicable for enhancing the use of natural ventilation as a passive cooling strategy in the Alexandrian heritage context. It seeks to provide pathways towards the most suitable, sustainable ventilation strategies and suggestions for implementation while balancing these approaches and improvements with the heritage buildings' cultural, heritage and architectural values.

The research is divided into three parts. The first investigates the heritage fabric of Alexandria, its architectural heritage character, how it evolved and understanding the problems they are facing, provided by their current listing and heritage grading, backed up by a study of the city's potential to deploy systems of natural ventilation. The second part explores the heritage retrofit strategies and balances these strategies with the applicability of natural ventilation improvement techniques. The final part discusses the current natural ventilation performance in terms of thermal comfort, and considering a case study building implementing the computational parametrical application of the different natural ventilation retrofit strategies, seeking a balanced result between the conservation principles and environmental gain.

1.4 Research questions

To address the research aim, several research key questions are posed;

- How does heritage building differ from contemporary building in this context? Is it possible to apply a complex retrofitting strategy without affecting their architectural values?
- What is the current state of Alexandria's heritage? How it is classified? What are the problems and challenges of the current heritage stock?
- What strategies can be gathered from this research to improve the natural ventilation performance within Alexandria's cosmopolitan heritage?
- What is the current natural ventilation performance of the current Alexandrian heritage buildings?
- To what extent can the natural ventilation performance can be enhanced in the cosmopolitan heritage buildings (1807-1952) of Alexandria without compromising their architectural identity?

1.5 Research objectives

In order to meet the research aims and to answer each of the research questions, the objectives to be achieved are classified as follows:

1.5.1 Main objective

The main objective of this research is to investigate the potential for developing a Sustainable retrofitting framework for upgrading Alexandria's heritage buildings energy performance, through applying a compatible passive cooling system (Natural ventilation). By using a parametrical investigation, a means of balancing judgements is developed between maintaining their architectural identity and physical form and evaluating various means to improve their current energy usage efficiency as a means to preserve the built heritage identity into the future.

1.5.2 Secondary objectives

The secondary objectives of this thesis are;

- To study the heritage significance of the downtown Alexandria cosmopolitan heritage; its historic evolution, urban formation, architectural character and current state, and justify the importance of their preservation.

- To set a retrofit methodology for improving natural ventilation performance as a passive cooling technique balanced with different heritage building's levels of classification.
- To study the natural ventilation performance of the cosmopolitan heritage of Alexandria
- to identify the most effective, sustainable, preserving parametrical approach for improving the current natural ventilation performance in the target case study heritage building

1.5.3 Indirect objectives

The following are considered indirect objectives of this thesis;

- The setting of an internal space categorization method focusing on internal airflow patterns and magnitude, according to the internal spaces according to their location, use and relation with the external environment.
- The assessment of the effectiveness of modelling internal airflow using a coupled model combining the internal and external urban environment in computational fluid dynamics (CFD) software by comparing the results with those of field measurement data
- The methodology of how to set up the input information and parameters for the 3D models in order to achieve a reliable CFD simulation results to assist further studies which are in the same field

1.6 Research scope and focus

The research focused on the natural ventilation retrofitting of heritage buildings and develop a sustainable framework. The research is concerned with the heritage fabric of Alexandria from the turn of the last century that predominate in the city's centre. The research is not dealing with high profile outstanding universal value heritage value as identified in the world heritage convention (World Heritage Committee, 1998). This research is more concerned with the local inherited heritage and culture.

The main research object is a typical residential listed heritage building representing the cosmopolitan heritage of Alexandria built between (1882-1930). Most of them face deterioration and neglect and poor natural ventilation performance. The research examines the different heritage retrofit approaches and different ventilation strategies relating to conservation, technologies, and best practices. Aiming to present an assessment procedure and a parametrical approach for improving the wind driven natural ventilation performance for the existing heritage fabric in Alexandria.

1.7 Methodology

In order to achieve the objectives proposed, this research uses different methods of investigations which involved different types of analysis, including historical research, theoretical research, case study application, practical assessment, field measurement data, and scientific computational modelling (computational fluid dynamics CFD). This leads to a mixed methods approach in the thesis, where qualitative and quantitative techniques are both required to answer the research question posed, results are compared, integrated, and interpreted.

literature review and scientific background

- Data collection; Literature review sustainable heritage building retrofitting techniques, backed up by different institutions guidance and successful practices. A review of different guidelines for heritage buildings sustainable development performed by different organizations (English heritage, U.S. Secretary of interior, etc...), and analyzing successful sustainable conservation practices similar to the case study building type. This phase is expected to conclude different means of retrofitting strategies and determine different collaboration techniques with historic preservation and the applicability to retrofit heritage buildings
- Literature review; the natural ventilation and airflow science and methods of application, the interlink with thermal comfort in terms of impacts and limitation. In addition, the related physics of natural ventilation, the strategic and technical levels of application, design measures and their parameters.

Case study evaluation

- Data collection, archival research, and site survey; These were undertaken in order to understand the current morphology and the problems facing the architectural heritage of Alexandria. Evaluation and recording to take place reviewing Heritage buildings in Downtown Alexandria (built between 1882-1930) architectural style, urban character, structure system, building materials (external facades, windows, and insulation), floor height, wall thickness, external openings ratio and construction techniques (inferencing and actual survey would be done as case study heritage buildings archives are not available).
- Scientific computer simulations and on-site field measurements; assessing the airflow patterns and magnitude, for the selected case study building. Comparing these measurements to comfort scales benchmarks
- Historic reconstruction; using scientific computer simulation, reconstructing the heritage building the way it was built. Gaining critical understanding for natural ventilation performance with correspondence to its original layout.

Enhancing natural ventilation performance in case study heritage buildings

- Parametrical study application; a series of amendment proposals scenarios applied to the case study according to the scope of the research. The amendment proposals selection criteria were based on the collaborative synthesis between the conservation principles and natural ventilation environmental practices.
- computer simulations and comparative analysis; a series of computer simulations is performed comprises the effect of the different scenarios. Followed by a comparative analysis of the different results obtained between the different scenarios and the current building's performance, in terms of natural ventilation airflow patterns and magnitude. verify the effects of suggested amendments to case study

1.8 Thesis structure

This thesis has five parts, and its subdivided into nine chapters

- Part 1: introduction to the research

This first part consists of one chapter. In chapter 1 the background information will be discussed, including the research aim, gaps in the subject, questions, objectives, and scope.

- Part 2: Research context

This part presents the research context and background of the study through a literature review structured in three chapters which relate to three distinct but relevant disciplinary fields, relating to historical significance, professional practice and building physics. Chapter 2 "The heritage context of Alexandria" describes the heritage context of Alexandria, featuring its historical evolution, architectural style, and problems facing the heritage context, combined with the climate conditions and applicability of natural ventilation; chapter 3 "heritage building sustainable retrofit" discusses the heritage retrofit criteria and guidelines and the application of natural ventilation as a retrofit strategies are presented in chapter 4 " natural ventilation strategic science and methods of application", addressing theory and physics of airflow, applications for improving internal environment, and methods for modelling and simulation of the airflow.

- Part 3: case study evaluation

The case study evaluation will be covered in two chapters which again address the subject from two perspectives, firstly through valorisation in context to establish its relevance and significance as a case study and secondly an environmental study of its performance based on monitored and measured data as well as CFD modelling: chapter 5 "case study analysis" describing the case study building architectural background including heritage value backed up by field architectural survey, including an analysis of architectural style, the structural system and current condition survey. In addition to analysing the building structure according to the natural ventilation parameters, and introducing the internal space categorization for future analysis of the internal spaces; chapter 6 “Assessment of natural ventilation inside the case study” presents the current natural ventilation performance of the building, using computational fluid dynamics simulation backed up by field monitoring.

- Part 4: natural ventilation retrofit in the case study building

Chapter 7 “Parametrical approach to enhance natural ventilation in the case study” details of the method for the parametrical approach used in the research for the modelling the potential improvement of the internal environment through natural ventilation. Drawing on the application of natural ventilation approaches that emerged from the review in chapter 3 and selecting the appropriate measures according to the emerging retrofitting plan. The CFD simulation is then used to consider the implementation of a range of different actions.

- Part 5: Results, analysis and conclusion

Chapter 8 analyses the results of the simulations with an overall comparison between the retrofitting measures against the original base case. Using the ventilation assessment of the different actions and demonstrating its potential effect on heritage value of the building in order that these options may be compared. Finally, chapter 9 presents the final conclusions, it also contains a reflection on the limitations of the study, a summary of its implications and contribution to knowledge, together with recommendations for further research.

1.9 Conclusion

This chapter introduced the basic information of this research including the research background, gaps in the area, research aims, questions, objectives, scope and focus. It then presented the methodology adopted, and finally outlined the thesis structure. Every chapter will contain its own introduction and conclusion to clarify what is being discussed.

Chapter 2 The Cosmopolitan built heritage fabric of Alexandria

2.1 Introduction

Alexandria has a unique architectural pattern influenced by foreign residents from various nationalities who were spread all over the city by the end of the nineteenth century. That gave Alexandria a unique architectural heritage that imbedded several European architectural patterns, as a result, the city adapted its cosmopolitan character with diversity and richness.

The city has been altered during the second half of the twentieth century politically, economically and socially, this conversion has arguably led to having destructive impacts on this distinctive architectural heritage. The city faced different levels of deterioration against the existing heritage, including neglect, misuse and the increased spread of new concrete buildings.

This chapter will highlight the city's architectural patterns and its evolution against different external influences, especially the European architecture within the city of the late nineteenth and early twentieth century that form the cosmopolitan heritage of the city, reviewing; architectural style, current listing and its deterioration. Finally, the chapter will demonstrate the heritage fabric's compatibility with natural ventilation and introduce with justification of the selected case study building. The chapter is a part of the data collection, archival research and site survey for the heritage context of Alexandria.

2.2 The historic evolution of the city

The review of the historical and urban evolution of Alexandria provides useful insight into the complex and plural culture of the city. Alexandria, second city and principal port of Egypt, was founded in 331 BC by Alexander the Great who conquered Egypt. He instigated the building of a new capital for the Egyptian kingdom, representing the Greek metropolis. (Dix, 1986). Dinocratis, Alexander's architect, laid out the city into a grid pattern with seven avenues parallel to the sea and eleven running perpendicular to them. This layout appeared to be the most suitable due to the topography of the city, where the two main streets were both colonnaded avenues with more than 30 meters wide and used for martial expeditions. The first street was known as Canopic street, connecting the East gate to the West gate. The second main street perpendicular to Canopic was called Soma. The two streets intersected at a large open space called the Mesonpedion, a major commercial focus (Khirfan, 2010; Salam, 1995),Figure 2-1.

During the reign of Ptolemy II (285-246 BC), the city original state was an island lying off Egypt. Dinocrates built a break water called the Heptastadium, linking the island where the lighthouse stood, which was identified as one of the seven wonders of the ancient world with the mainland (Clayton et al., 2013), forming the basis of the present eastern and western harbours. The Heptastadium was a huge stone pier, more than 1250 meters long and 30 meters wide, dividing the harbour into two eastern and western harbours. The original urban planning of the city was based on a grid plan with two principal streets that are still existing till today. (Dix, 1986), Figure 2-2.

The city was divided into five districts named after the first five letters of the Greek alphabet (Alpha, Beta, Delta and Epsilon), where each district was for a social group. The Royalty lived in the Beta district near the East-Port and the Delta quarter was allotted by Ptolemy I (Soter) to the Jewish immigrants whom he had encouraged to settle in Alexandria. Rhakotis remained the native Egyptian sector in the southern part of the city (Reid, 2003; Salam, 1995).

Alexandria was captured by the Romans in 30 BC, Octavious Augustus founded a new town to the east of the city called Nicopolis 'city of victory'. The city was admired amongst other cities of the world, commerce was developed in the city under the Roman rule, it had became second only in importance to Rome by the 4th century AD. A Roman citadel and administrative buildings replaced the royal quarter and a new wall was built by Caracalla (Forster, 1961; Lebon, 1970; Marlowe et al., 1971), Figure 2-3.

The Arabs captured Alexandria in the 7th century with 4000 palaces, 4000 baths, 400 theatres and 12000 greengrocers (Dix, 1986). After the Islamic conquest of Egypt in 642 A.D. Alexandria began to lose its significance and focus as the Rosetta was the new capital, causing the city to face its first phase of decline and neglect. The city was walled by the end of the 9th century. The urban character of the streets were still influenced by the grid organisation; however, it was not densley built up. Throughout the next successive thousand years, urban growth progress was limited, the preeminent position of Alexandria among the Mediterranean cities was lost. The Canopic mouth of the Nile silted up and lake Maryut no longer fed the Nile and so ceased to be a navigational and transport asset (Forster, 1961).

Ottoman rule followed the Arabs, however, the importance of the city continued to decline for more than a thousand years under the Turkish rule, caused by epidemics, water shortages, and the weakness of provincial administration. The narrow enclosure of the Arab walls became too restrictive. New settlements began upon the neck of the land which was between the two harbours, formed strips of houses intermixed with small mosques forming the Turkish district (Forster, 1961; Reimer, 1993; Salam, 1995), Figure 2-4.

The beginning of the 19^{th} century represents a turning point in the city's history, with a noticeable exposure to western influences related to Egyptian independence from Ottoman rule. Egypt was then ruled my Mohamed Ali, an Albanian general, he transformed Alexandria into Egypt's main Mediterranean port and naval arsenal. During his rule he was encouraging the Europeans to move into Alexandria, offering incentives such as tax exemptions and land ownership. This process transformed Alexandria into a cosmopolitan hub, with the arrival and settlement of European immigrants (Awad, 1996; Reimer, 1993; Salam, 1995)

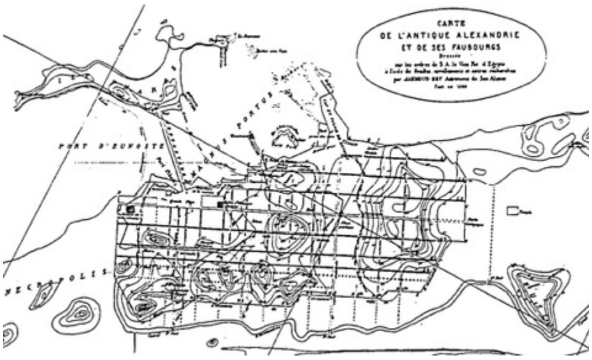

Figure 2-1 Dinocratis plan for Alexandria by Mahmoud Bey in 1856 (Awad et al., 1987)

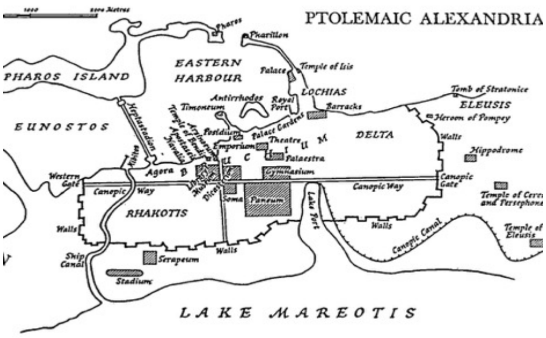

Figure 2-2 Ptolemaic Alexandria (Marlowe et al., 1971)

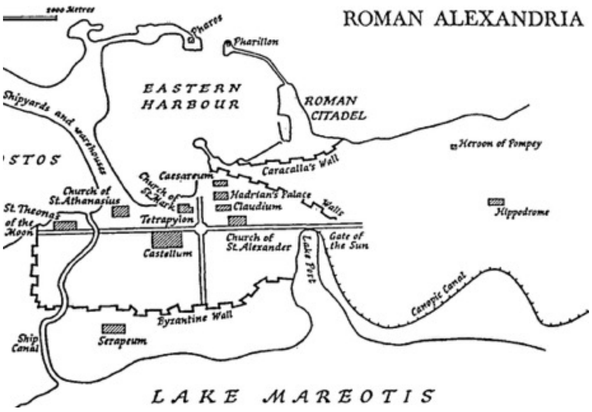

Figure 2-3 Roman Alexandria (Marlowe et al., 1971)

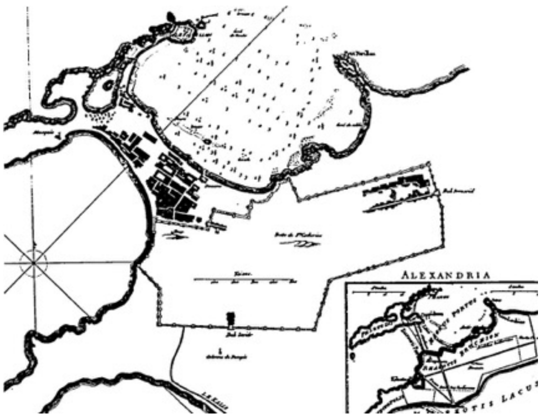

Figure 2-4 The Turkish town outside the Arab walls in 1766 (Jondet, 1921)

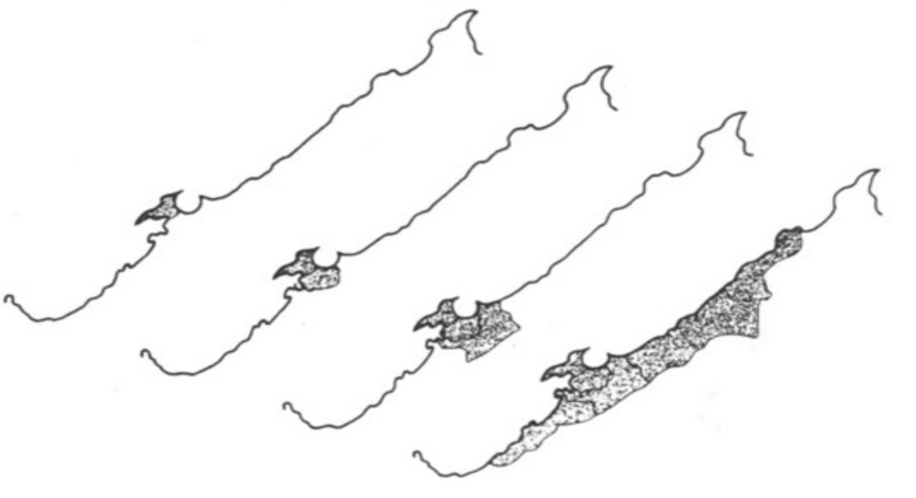

Figure 2-5 Alexandria expansion during the last 150 years (Dix, 1986)

2.3 The evolution of modern Alexandria and the built environment

The development of modern Alexandria up to the present day could be traced through four successive periods. Each period contributed to the current built environment and the character formation of the contemporary built form, through diverse economic and political circumstances. This part aims to identify the morphological components of the existing city of Alexandria's urban fabric and the existing architectural heritage.

During these developments there were phases of crucial demand that professionals had to respond to by interpreting the circumstantial and prevailing conditions such as demonstrating the power of the ruling class, projecting new lifestyles serving the needs of several ethnic composition of the cosmopolitan society

2.3.1 Old districts: The first half of the nineteenth century (1805-1854)

Modern architectural history of Egypt started during the era of Mohamed Ali. Since then, it has been a turning point in the history of Egypt and the city's revival and was considered the first phase of the modern city's development. From that moment, Egypt was exposed to the west and to European norms of cultural, social and political life. The architectural history of Egypt was shaped by this era till the 1952 revolution.

During the period of modern Egypt, which started when Mohamed Ali took over the throne in 1805, he started his development project for Egypt by establishing the modern state. He had a different vision for Alexandria. As a result, a great development of the city was marked, which attracted foreign migration to settle in the city to form the city's diversity and urban development forming different communities of various nationalities (Heba, 2011). Part of the city began to develop outwards the old Turkish town behind the Arab walls. This is the oldest part of the existing urban tissue of Alexandria within EL Gomrok district. It is characterized by its small-scale streets and buildings, Figure 2-6.

During Mohamed Ali's reign, Egypt witnessed a gradual decline of traditional architecture as he imported the Turkish architecture to Egypt. Turkish architecture by then had been already influenced by Europe. The traditional private house before 1800 was made of bricks and stones, either plastered or left bare, the roof left flat covered with a coat of plaster, while windows where made of *mashrabiya* style windows (Sakr, 1992). However, the architectural style evolved from the 1820's until Ismail's reign.

The nineteenth century witnessed the creation of the new European center. El-Manshiya square, bordering this area, was introduced at this stage as the 'Place Des Consuls'. Foreign communities such as the British, French and Greek were granted land around it. There was no attempt to co-ordinate the various enterprises or to utilize the existing features of the site such as the sea or the lake. A new strip of buildings and two streets were developed parallel to the Eastern Harbour on reclaimed land resulting from the retreat of the sea. In this strip, the buildings are higher than the three-storey average in the old built fabric and their styles were influenced by the European eclecticism which prevailed at the turn of the nineteenth century.

The European quarter had expanded during Mohamed Ali's reign and the beginning of modern Egypt. He built Ras El Tin palace and the Mahmudia canal had been degraded linking the Nile with the western harbor (Haag, 2004a). The industrial revolution began with the construction of early factories in the city, the building of Egypt's first railway with the consolidation of the western harbor and the naval base, the city developed rapidly (Salam, 1995). As the city started to develop a Municipal council was established in1834 which became the nucleus of the city and the first of its kind in Egypt, the main concern of this council was to improve the city’s image and its urban planning, ensuring a role for the cosmopolitan community in the management and the future of the city (Alleaume et al., 2001; Shalaby, 1988) Figure 2-7.

The physical form of the urban fabric was characterized by its narrow streets creating an irregular parcel of land, which were developed as residential, small mosques and shops. The blocks are developed right up to property edges and have minimal inner voids and alleyways -see Figure 2-8.The building heights are often low with an average of two to three storeys.

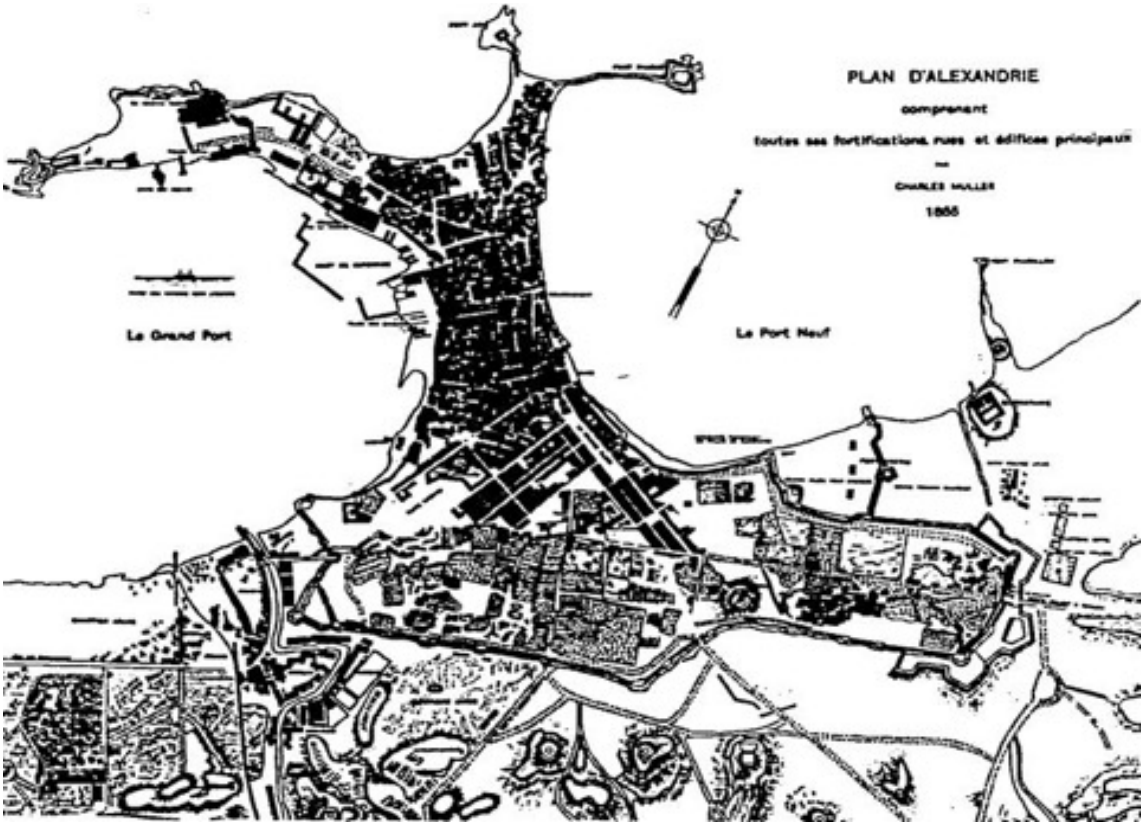

Figure 2-6 plan of old Alexandria 1855 (Awad et al., 1987)

Figure 2-7 Plan of Alexandria showing the Place Des Consuls inserted adjacent to the old Turkish town (Jondet, 1921)

Figure 2-8 The irregular street pattern and land subdivision of the inner area of the old quarter, separated from the Eastern Harbor by twentieth century European-influenced developments (Salam, 1995)

2.3.2 Early expansion: The second half of the nineteenth century (1854-1890)

The utmost connection with the west was built during Khedive Ismail's period, amongst his concerns was an aim to turn Egyptian cities to resemble European cities. Moreover, he appointed De Curel del Rosso as his assistant, after that not only building contractors were imported from Europe but also European architects were trusted with the field of architectural design in Egyptian cities during the 19th and the early 20th century (Abu-Lughod, 1971). Under Ismail pasha rule, Alexandria’s urban structure was improved. New roads were planned and new districts were established including Al-ramleh station.

Mohamed Ali’s successors established the first railway line between Alexandria and Cairo (1851-1856) and together with its tramways, these contributed to the growing status of the city, stimulating suburban growth, principally eastwards (Heba, 2011). Many of these buildings were villas used only in the summer by affluent Cairenes. There are now more than one and a half million visitors each summer, not by any means are these all very wealthy, but they all contribute to the city's commercial life and so play a part in creating important planning problems. Despite these impacts however, throughout history, the prosperity of Alexandria has been primarily related to its port. It is the port and its dependent activities and industries that the city still largely depends on for its affluence and its influence.

The expansion of the city took place in three directions: south, east and west. The south is the earliest development. The expansion to the west was the least important in terms of density and quality. The expansion to the east where a new residential quarter was slowly but steadily growing for the city’s elitist and foreign residents, Figure 2-9.

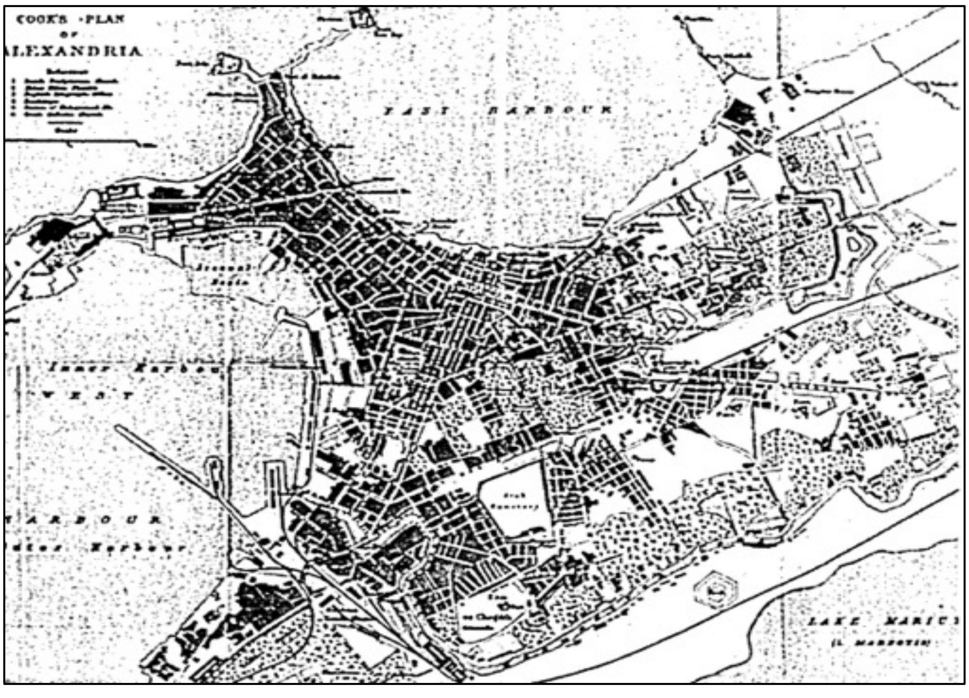

Figure 2-9 Early expansion of the city of Alexandria as shown in Cook's plan in 1895 (Awad et al., 1987)

The improvements promoted the commercial growth and construction of the city. Migration towards Alexandria from outlying regions increased, and with it new settlements arose. In 1860, a second railway was added to link the new suburb district of El-Ramleh with the city. It caused rapid expansion of the new prestige suburb further east, and was transformed into an electric street-car line in 1904. In 1876, a new railway station for passengers was built south of the eastern harbour and the old one was reserved for freight traffic (Salam, 1995).

During this period, post 1882, the second phase of the city's development rose and this continued up to world war 1. The tragic events of the British bombardment of the city in 1882 and the devastating destruction of the city was followed by a rebuilding boom. The rebuilding process was marked by the institutionalization of public function in the heart of the European square, now identified as place Mohamed Ali and its surrounding areas, with such constructions as the bourse, the mixed courts, banks and service institutions. The urban square also included the commercial presence noticed in the Primi building, the Galleria Monferrato and the Galleria Menasce commercial blocks (Alleaume et al., 2001).

The urban center's improvement was demonstrated by the spread of elite residence along Moharem Bey and in suburban Ramleh. Areas in these districts which are adjacent to the city center in the north part of the city were connected to the center. Generally, the area is over-crowded with a high concentration of residential use. Commercial activities located on ground floors are complementary to the center's functions. The number of European nationals migrating to Alexandria was increasing, promoted and encouraged by rulers seeking modernization and economic reforms in the country. This process of European penetration was further accelerated by Egypt's reintegration into the world economic system as a major cotton exporter. The most important phenomena related to this period was the intense building related to a specific community or ethnic activities. The Italian and the Greek community and other groups, were actively involved responding to their population growing needs of their community, which included building their own schools, hospitals, and social foundations (Alleaume et al., 2001)

The process of borrowing western styles of urban form manifested itself in the adoption of mostly eclectic revival styles such as Neo-Renaissance, Neo-Gothic, Neo-Classic and later Art Deco. The tendency to imitate European styles, and change the open space structure and typology, also reflects the government's concern for boosting the property market for the new pluralistic society. It is also at this stage that Alexandria first set up an electricity and gas company (1869), a sewerage network (1878) and water company (1879) (Awad, 2008).

The physical form of the urban fabric was characterized by its basic grid fabric, with low building heights. The buildings occupy all of the blocks and are of an almost uniform typology, predominantly apartment blocks built on small subdivisions of land. Building heights vary between two and three storeys. Except for the streets and a few squares. Little open space is available for public use, Figure 2-10.

Figure 2-10 the typology of open space and landform division in the southern districts joining the existing city center (Salam, 1995)

2.3.3 Late expansion: The first half of the twentieth century (1890-1951)

In the early 20th century, despite the British occupation, urban improvements continued in Alexandria and the number of foreigners increased as a result of its trading connections. The city developed a unique cosmopolitan society seeking to epitomize the best of Middle Eastern and European civilization. From being international, in some aspects even an seen as an un-Egyptian community, Alexandria was to become the second manufacturing center of Egypt (Heba, 2011).

The urban and constructional activities increased, making Alexandria a model European city, except for the older west districts, which retained the Islamic architectural fabric. This period encountered progressive interaction between the eastern and western cultures, especially with southern Europe. Alexandria had witnessed a unique wave of construction, possessing the characteristics of Neo-classical eclectic European architectural styles. Alexandria has gained several recognised masterpieces of architecture from this era, created by foreign architects such as the famous French architect August Pirier, the Italian Mario Rossi and many others Figure 2-11 (Shalaby, 1988).

The growth of the city continued in the three directions south, west and east respectively. The southerly extension attracted large number of settlers forming a popular low-class district. A less dense area was added to the west according to its near position to the port, the western extension was associated with the working class and living conditions were modest. Furthermore, efforts to develop the western coast were gaining momentum. New settlements were emerging as summer resorts. This trend has persisted up to the present day and the number of tourist villages and small towns has greatly increased (figure 12).

There were efforts to develop an eastern extension forming new districts across the coast connecting the old suburban areas. This extension was a futuristic approach from foreign planners targeted towards high class residents creating low density residential areas with villas. They developed most of the places which still today bear their names; *Zizinia, Bulkely, Ginaclis, Fleming* and *Stanley* Figure 2-12.

During this period, the third phase of the city's demands are identified with the inter-war period (1918-1939) which occurred during the booming economic conditions in the Egyptian environment. The political climate was in favour with the Egyptian royalty. The Italian contribution remained significant during an intense period of building activity, however, they were no longer monopolistic. The period was identified by the intense collectivity in community projects, a diversity of clients, a strong Egyptian involvement, while having to cater for the aspirations of a new rising professional and technocrat bourgeoisie, who favoured modern international styles (Alleaume et al., 2001).

As a result of the increased awareness of the importance of planning regarding the city's growth, the municipality commissioned an extensive planning study. The study resulted in the introduction of many new public spaces to the city's fabric including the Saad Zaghloul and El Goumhouria squares. It also suggested a new costal road El-cournish wa built along the eastern coastline. Residential buildings and fine beaches expanded along it (Salam, 1995). This part of Alexandria accommodates a high concentration of other uses such as educational and recreational ones. Recently, new commercial centres with a rich variety of retail, business and entertainment activities were also developed. Alexandria University and many of the city's distinguished educational institutions are located there.

The physical form of the urban fabric was characterized by the form of regular streets and squares. Main streets ran parallel to coast, while secondary streets perpendicularly intersect with them. Those parts adjacent to the city centre have a walk-up type of a shopping street consisting of apartment blocks with shops on their ground floor. However, the expansion to the east of the city is where the new building typology was formed of a single-family house. These are currently being replaced by high rise buildings.

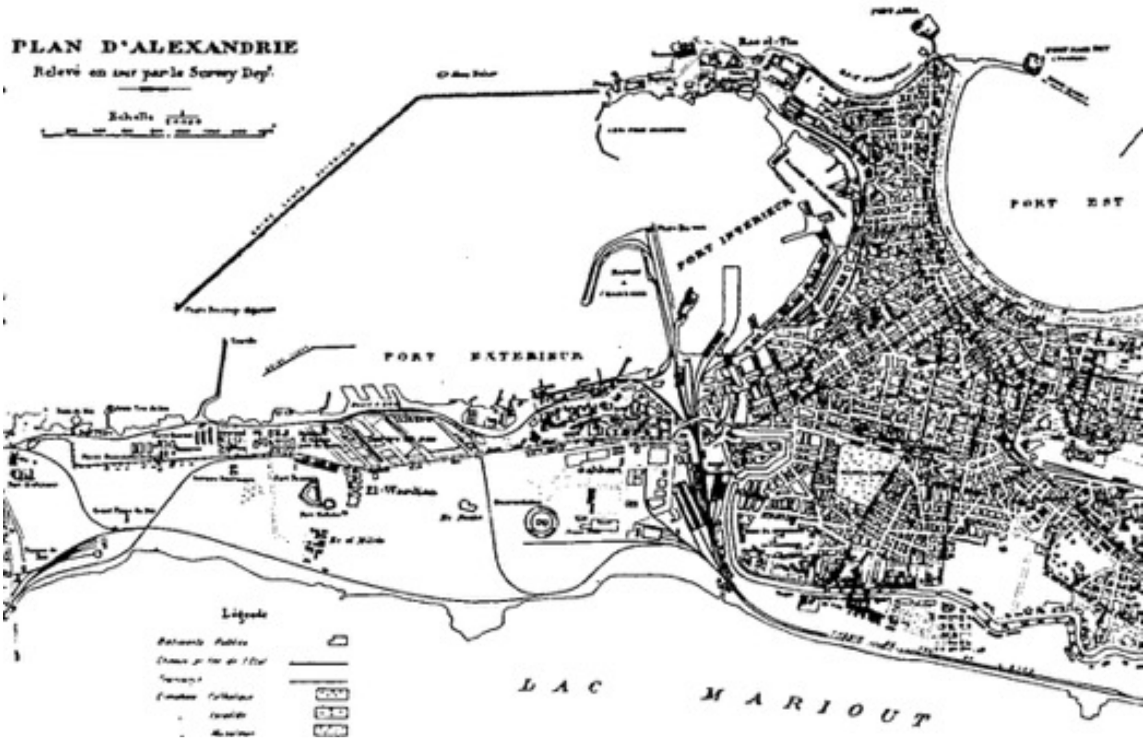

Figure 2-11 Plan of central and western Alexandria in 1917 (Awad et al., 1987)

Figure 2-12 Plan of the residential expansion of Alexandria towards the east in 1917 (Awad et al., 1987)

2.3.4 Recent Transformation: (1952-present day)

During the second half of the 20th century, the character of the city has been influenced by the political, economic and social changes due to the migration of the foreign nationals from the city, while rural migration toward the city has increased with a high-density growing population. During these changes the city has witnessed a process of deterioration in its architectural heritage and the spread of concrete buildings that lack the same aesthetic values.

The 1952 revolution persuaded a large number of foreigners to leave Egypt and to return to their home countries. On the other hand, Alexandria witnessed a large unplanned rural migration looking for opportunity in the city. This migration flow to Alexandria caused a change in the population characteristics of the city. Large numbers of completely different populations have occupied the city. The city became burdened with a new rural population that was unfamiliar with the habits that framed the city's previous identity. As a result of the population change in Alexandria, the urban character of the city changed significantly (Hamza, 1989; Heba, 2011).

The political, economic and social changes, the decolonization measures of the 1950s and 1960s and the nationalization of European properties, led to a mass exodus of Europeans from Egypt. As a result, the city's urban and architectural character as designed has been felt to be left to suffer. The departure of the foreign community caused many areas to be left for speculative development. The existing buildings within the city were often transformed into government and public offices. This period was identified by widespread transformation of the urban fabric due to rapid demolition of older buildings and their substitution with new high-rise ones. New extensions to both east and west, further residential areas have been added and summer resorts have been transformed into permanent residential quarters (Awad, 2008; Hamza, 1989).

Further deterioration of the built heritage increased vigorously by the beginning of the 21st century, consequent to the change in population for achieving more benefits with no consideration of the potential loss of cultural and aesthetic values. Disregarding the future economic values of this architectural built heritage, the importance of their preservation for the future generations was ignored. These attempts were not met by any kind of resistance (Heba, 2011).

The typology of the spaces within the city center is regular, formed by the meeting of two grids. One follows the orientation of the older nineteenth century development, while the second meets at an angle of 45^{o} and projects into the whole eastern expansion. The streets within the center have a linear enclosure and an almost uninterrupted skyline on both sides formed by the buildings of equivalent heights (20-25 m) (Salam, 1995).

The city's current expansion divided the city into seven districts: The old districts are composed of central; Al Gomrok, and the Eastern which was during the early and late expansion. However, the other four districts; Al Montazah, Western, Al Amreya and Borg AL Arab where a result to the recent transformation of the city Figure 2-13.

The city is experiencing several conflicts due to the inability of its existing urban tissue to meet the requirements of fast urbanization and population growth. Besides its continuous expansion, the built environment of the city continues to change its character making it risk losing its urban character.

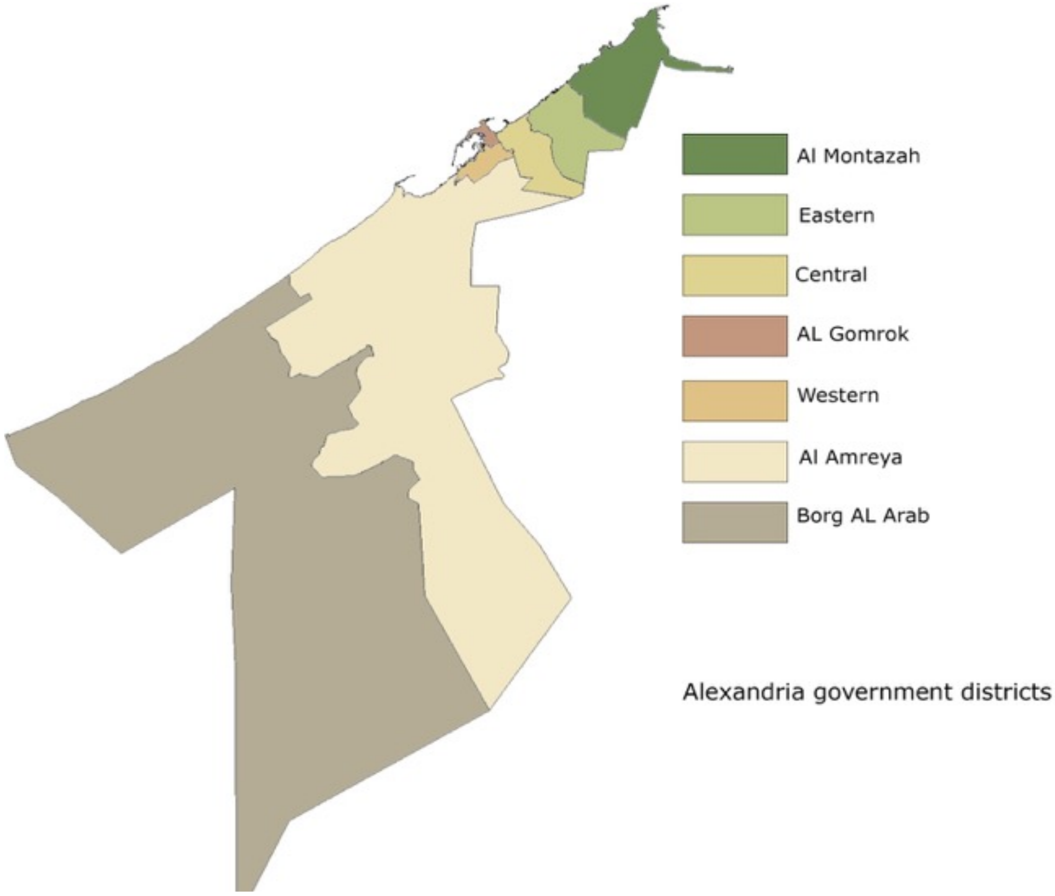

Figure 2-13 current distribution of Alexandria's districts.

2.4 Current heritage building listing in Alexandria

As a result of the city's long history, Alexandria incorporates many historic buildings of different architectural styles. The existing city structure is not reflecting the city throughout its history. From the Greco-Roman city, the only reflection exists in a few archeological sites. The existing street layout refers partially to the old plan of Alexandria. The existing El-Horreya avenue responds to the Greek canopic street and El-Nabi Daniel street to the Greek soma street. The east and west harbors are still dominant elements of the urban form (Elsorady, 2011).

The Greco-Roman and Islamic historic sites and monuments were listed in 1951 by the department of antiques (the Egyptian department responsible for monument conservation at that time) by the late king Farouk (Elsorady, 2011). The implementation was limited to insuring that major ancient sites were restored to promote international tourism. The application was limited as it didn't address properly the cultural heritage of the later periods. The cosmopolitan Alexandria conservation and listing trend was suggested in the comprehensive plan of Alexandria 2005 by the government in 1982 and underwent a local review of the city's heritage as a part of the planning policy main policies (Alexandria-Government, 1982; Dix, 1986).

The 1982 survey of heritage buildings, included buildings od distinct architectural styles revealed the registration and listing a huge number of buildings, as well as entire streets and neighborhoods. The planning established an influential historical continuity between the contemporary center and the city's historical background. The city historical center included in the 1982 comprehensive plan as a reflection to the most recent transformation is demarcated, surrounded by the Cornish road to the north, Safia Zaghloul street to the east, Masjid el Attarin to the south and Ahmed Oraby square to the west (Alexandria-Government, 1982) ,Figure 2-14.

Alexandria Preservation Trust, a private non-governmental organization updated the 1980's survey and added a number of distinctive styles in the list in 1999 (Trust, 1999). The survey was employed as a result to the number of demolished buildings. The owner's private owners of the heritage buildings won a filled demolishing lawsuit in the supreme court and won, some of them bypassed the law at that time and demolished buildings without acquiring any legal permission (Elsorady, 2011).

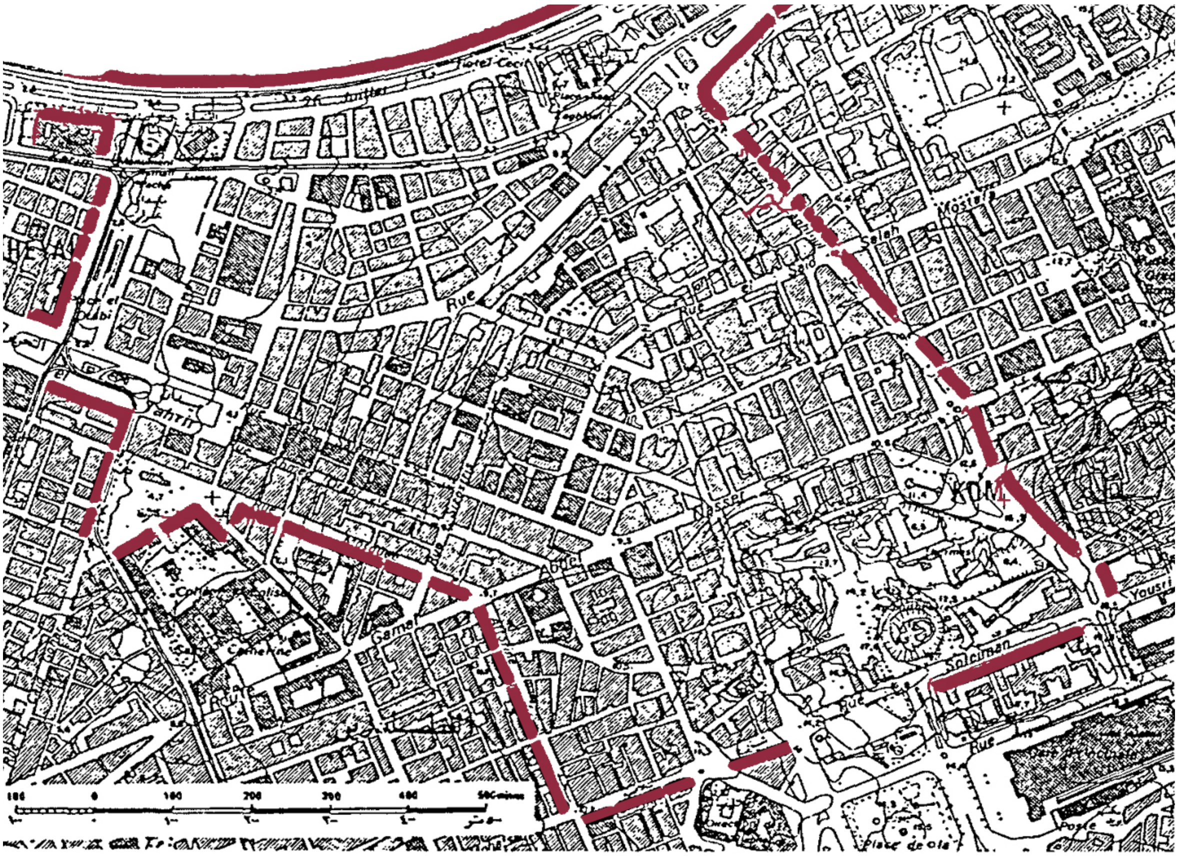

Figure 2-14 map of the historical city center recent transformation demarcation, (Salam, 1995)

The UNESCO plan for the Egyptian heritage conservation indicated the need to create an Egyptian organization, different from the supreme council of antiques, to deal with cultural conservation, the national organization for urban harmony was established in 2001 as a result “NOUH”. The organization was authorized to make all required decisions and recommendations in accordance to the current heritage legislations (D. Elsorady, 2014). The statue 144 paragraph no.83 states that during the issuing of the license of demolition, renovation, or internal changes in heritage buildings, the façade and the architectural features should be preserved even with partial or total demolition of the building to conserve the architectural style of the area (NOUH, 2010). The organization mainly focused its criteria on the architectural integrity and building form, failing to address other indicators in the regulations such as; public perception, building function and sustainable adaptation.

The buildings heritage list was upgraded for the third time as a result for the new legislation resulted in the issuing of law 144 in 2006, regarding the demolishing of heritage building in 2007. The Alexandrian and Mediterranean Research Centre at Bibliotheca Alexandrina (referred to here as “ALEX-MED”) is responsible for identifying, documenting and researching the tangible and intangible heritage of Alexandria as a part of the Mediterranean region. The resulting Alexandria Heritage Catalogue was approved according to Declaration 278 in 2008 by the by the Egyptian prime minister and was issued in 2008 (Alex-Med, 2008). The Catalogue listed 1135 conservation buildings that were divided across Alexandria's districts. The new listing catalogue was formulated according to the five criteria to include a heritage building; the position of a unique architectural style, relationship with national history or a historic figure, representing a historic period, value as a touristic attraction imposed by National Organization of Urban Harmony, Table 2-1 (NOUH, 2010).

Table 2-1 Heritage values and basic standards that distinguish heritage buildings (NOUH, 2010).

Heritage value	Main criteria
Historical value	• A building with a connection to national historical aspects • Occupied by a significant international or local figure • Related to important influencing national events • Have a symbolic value • Building's age
Architectural value	• Unique architectural style • Distinctive architectural design and unique artistic creativity • representing an important era in the history of art and architecture • Product of a prominent local or international architect • Represents a structural or technical value
Urban value	• The building is a part of a distinct integrated heritage architectural group • The building has a heritage garden of historical importance • landscaping that shows a stage or era in the history of society • Heritage buildings that complement each other in form and style of construction
Social and sentimental value	• The association with important social functions in the region • The building reflects social thought, creed or traditions in general
Local traditional value	• The building is part of an urban, rural or desert architecture of an integrated nature • The building is part of an architectural group that uses distinctive building materials that express nature characterized by its history and homogeneous architecture • Traditional building expressing experiences accumulated across generations of design, construction and traditional crafts.

The listing categorized the heritage listings into three levels, regarding their significance, considering the national, city or local classification, Table 2-2. The variation results of the number of listed buildings in the different districts provides significance to the concentration of heritage buildings in Eastern, Central, and Gomrok diistrics. These are the main districts that encompass the cosmopolitan fabric of the city center of Alexandria, Table 2-3.

Within the particular typology of buildings defining the above open spaces, an average of 80% are historic with valuable architectural styles and richly detailed facades. They bear a European cosmopolitan influence and eclecticism is evident in the different styles such as Neo-Baroque, Italian Neo-Gothic, Neo-Classical and Neo-Islamic. Modern styles are also present such as the Early Modern, Grand Style and even the International glass-box architecture. Buildings are generally in medium to excellent conditions, yet their finishing materials are increasingly deteriorating and require regular intervention from the current Alexandrian heritage listing was a logical reflection of the city's urban and architectural development throughout the last 150 years. The catalogue

Table 2-2 Alexandria heritage classification

Alexandria heritage building classification	
National level classification	12
City level classification	256
Local level classification	836
City edge classification	31
Total	1135

Table 2-3 the distribution of heritage buildings across city's districts

Total number of heritage buildings in Alexandria's District	
Al Montazah District	31
Eastern District	463
Central District	435
Al Gomrok District	163
Western District	20
Borg Al Arab District	5
Al Amreya District	18
Total	1135

The list classified heritage buildings into four levels: National level, City level, Local level and City edge level, the distribution across the different districts are shown in Table 2-4, Figure 2-15. According to that classification 1135 building, across the different districts' conservation buildings were concentrated in Downtown Alexandria around the eastern harbor, represented in the Eastern and Central districts, which is a true reflection of the city's historic and urban fabric evolution. The downtown Alexandria acts as the Heritage node of the city emphasizing its urban significance.

Table 2-4 the distribution of the different heritage listing classification across the districts

Total number of heritage buildings in Alexandria's District according to classification level					
District / Classification	National level	City level	Local level	City edge	Total
Al Montazah District	1	9	18	3	31
Eastern District	3	86	373	1	463
Central District	5	130	300	-	435
Al Gomrok District	3	25	135	-	163
Western District	-	6	10	4	20
Borg Al Arab District	-	-	-	5	5
Al Amreya District	-	-	-	18	18
Total	12	256	863	31	1135

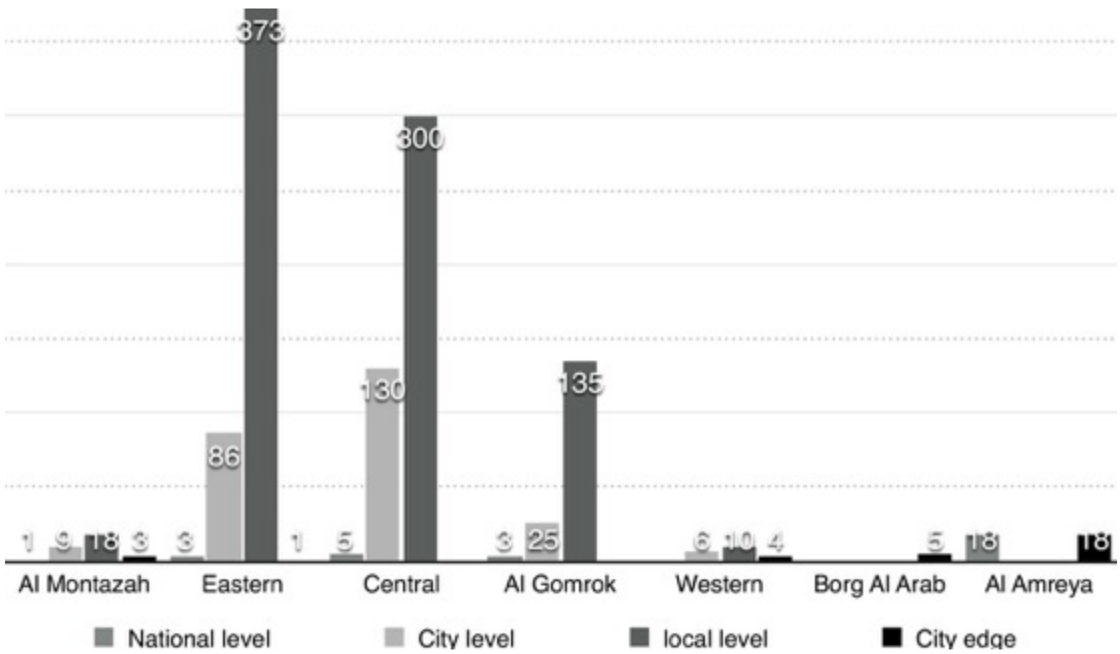

Figure 2-15 shart showing the distribution of the different heritage listing classification across the districts

The Downtown area represents around 80 percent of conservation buildings within the city as shown in the heritage building's map. The conservation buildings within this area represent the early and late expansion period influenced by the European community through the Central and Eastern districts, while the Al Gomrok district represents the Turkish style conservation building within the city Figure 2-16.

Within the Conservation Districts of Alexandria representing the true cosmopolitan identity the city once represented, the fabric was divided accordingly into different Conservation city parts as shown Downtown Alexandria conservation areas map. The European city represent the major part of the Alexandria conservation areas. The conservation catalogue listed 38 conservation streets, where 36 of them were listed within the downtown Alexandria emphasizing the heritage value of this part of the city Figure 2-18.

The national organization of urban harmony furtherly classifies the listed built heritage into three mains categorize (A), (B), and (C) according to the heritage value the building is related to. In addition, the categorization of the heritage building's according to their conditions; good, partially deteriorated, and completely deteriorated. The aim of this classification is to set dealing priorities with the heritage buildings according to their level. High value heritage buildings are set as a priority, and the level of intervention according to the listing level is determined relatively, Table 2-5 (NOUH, 2010)

Table 2-5 level of intervention according to the heritage level grading

Heritage listing grade	Level of intervention
Grade (A)	Restoration without any modifications externally or internally, in exception within the narrowest limits
Grade (B)	allowing a degree of flexibility in making some internal adjustments
Grade (C)	Maximum flexibility is allowed, the building can be destroyed and rebuilt, but the external elevation must be preserved

Figure 2-16 Heritage building's map edited by researcher (Alex-Med, 2008)

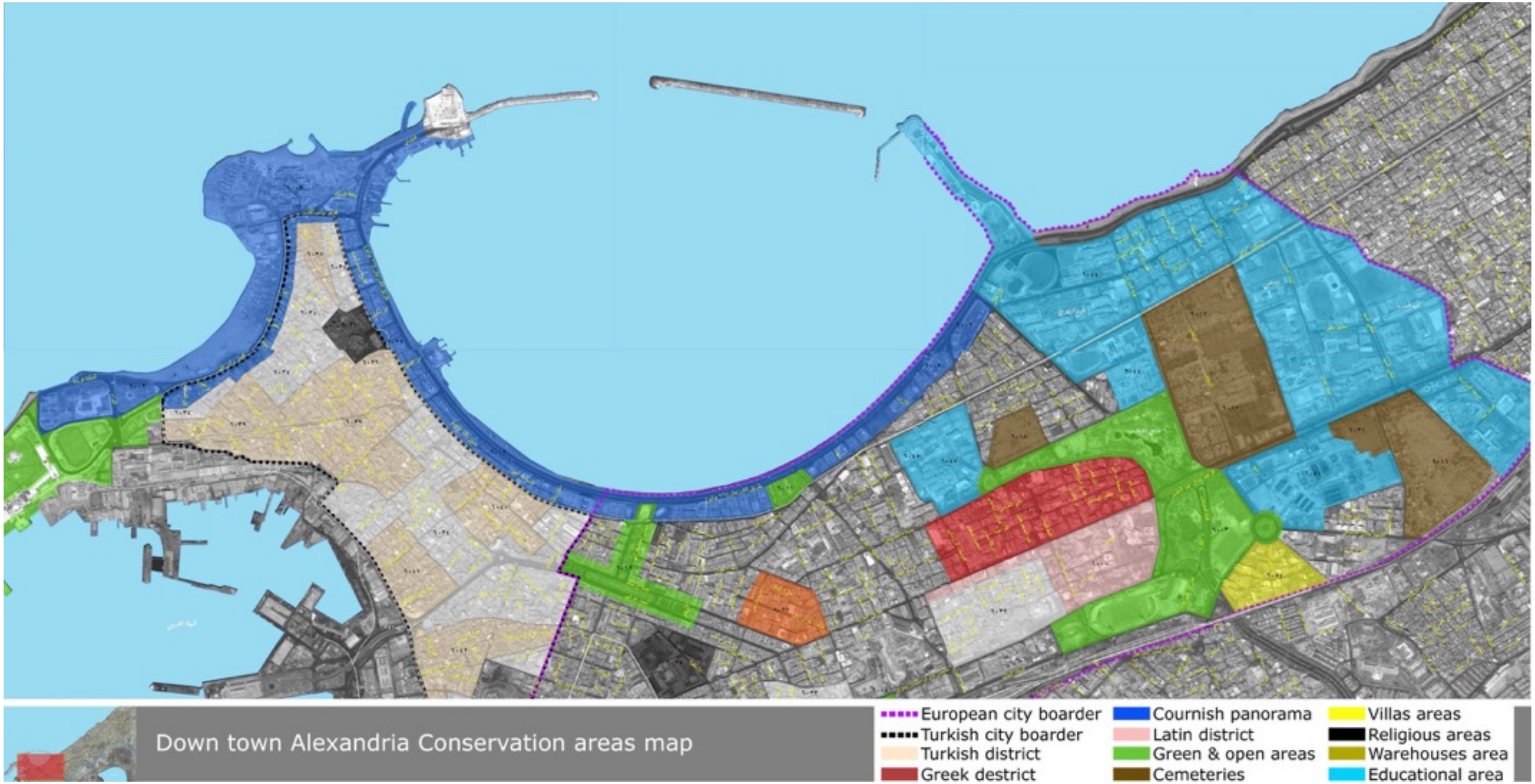

Figure 2-17 Conservation area map edited by researcher (Alex-Med, 2008)

Figure 2-18 Downtown Alexandria conservation streets map edited by researcher (Alex-Med, 2008)

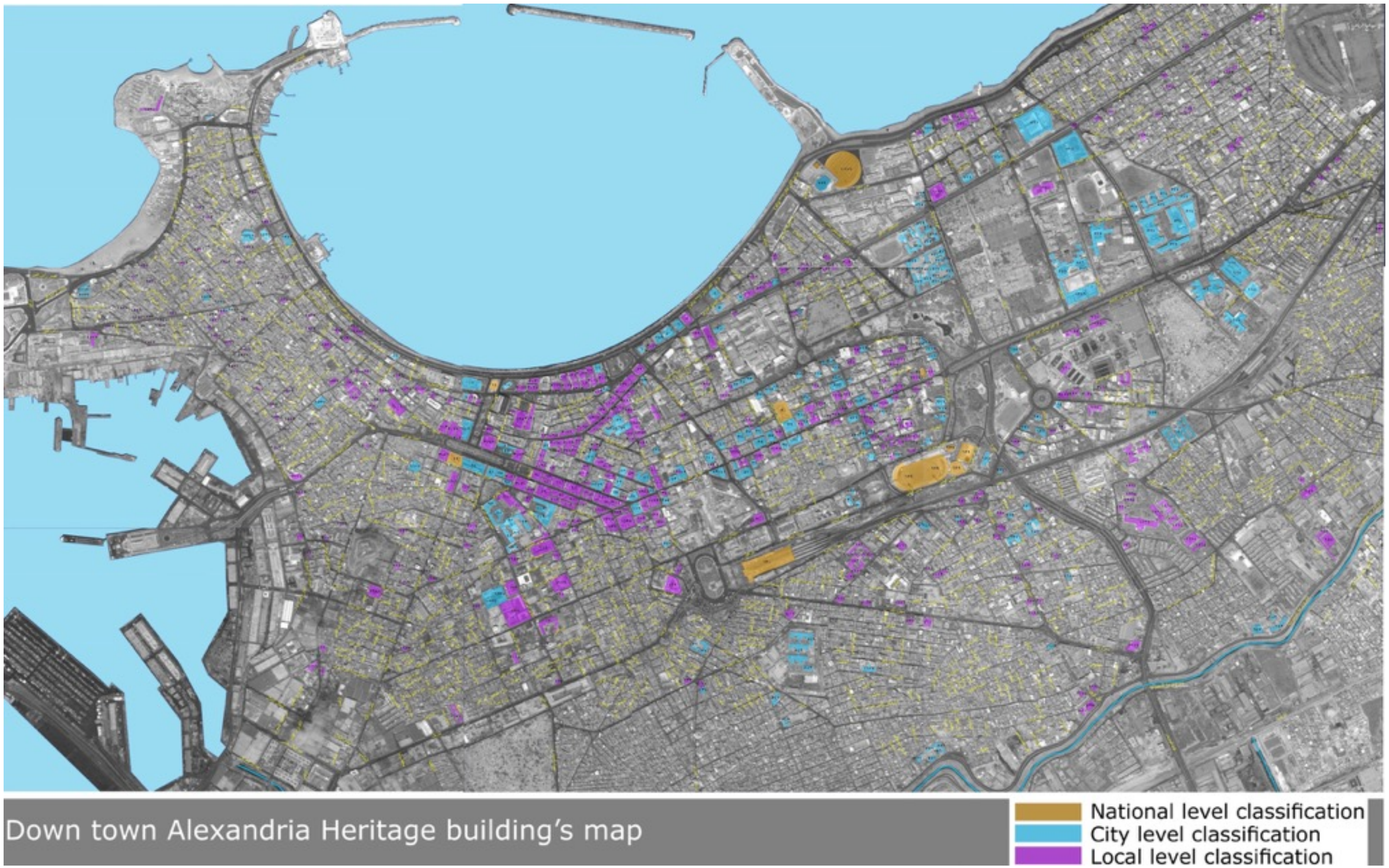

Figure 2-19 Downtown Alexandria heritage building's map edited by researcher (Alex-Med, 2008)

2.5 Alexandria's architectural character and the European influence

The character of downtown Alexandria, despite its present condition, represents the high style architecture of the city described as the city's "Belle Époque". The area used to be occupied by the city's elitist residence (Empereur, 2002). The city during the end of the 19th century was very vital and witnessing the rapid expansion of the economy. The urban landscape was focused in the city center that was named the European city building; department stores, theatres, coffee shops, consulates and hotels to follow the European life style. Expressing the cosmopolitan and pluralism dominating the city center (Awad, 2008).

The street character is an expansion of the cosmopolitan city during the second half of the nineteenth century. The expansion came as a natural continuity of the growth of the European quarter (Awad, 2008). The growth towards this area around the eastern harbor was resulted in the creation of promenade Abbas II. Later, it was called promenade queen Nazli and the eastern harbor was dominated by Italianized style (Giacomelli et al., 2008).

The appeal to Mohamed Ali and his successors was to assign the different urban projects and construction to foreign professionals. The contribution in the urban development in the first place where Europeans especially Italians. The Italian professional involvement increased in the open and pluralist society of cosmopolitan Alexandria. The Italian contribution was not exclusively involved in their own community developments, but extended their activities to build for other communities such as the Egyptian, Greek, Syrian-Lebanese and the Jewish, especially the elite (Godoli et al., 2007). The Italians built most of the city's prominent buildings during the reconstruction of the city followed by the British bombardment in 1882.

As the city of Alexandria grew to become Egypt's hub of cosmopolitanism and an economic capital, the Italian community, the second largest after the Greeks, constituted in around 30 percent of the European population around 1897 (Awad, 1990; Reid, 2003). Among the different occupation the Italian, they were reputed as professional builders and craftsmen (Haag, 2008). Insofar as Alexandria is concerned, the community had a major role in the establishment of the Commissione d'Ornato (Alexandria's first planning commission established as early as 1834) and followed by the creation of its Municipality in 1890, the Italian community gained a sort of monopoly in developing the city's architecture and directing its urban development. The foreign Italian architects had a major influence in the city's urban development and image, they were responsible for the designs reflecting the growing power, wealth and influence of the city. Francesco Mancini was assigned for the redesign the "Place d'Armes" that was renamed "Place de Consuls". Peitro Avoscani designed the new sea front corniche of the city (AbdelNaby, 2018; Pallini, 2006). Their involvement extended to the public buildings like the royal palaces, the stoch exchange, Boursa of Mina El Basal, Ramley rail way station, and police headquarters. Some Italian architects focused on residential architecture, building many houses in the Latin quarter, Ramleh and Attarin district and the Major streets within the city center (AbdelNaby, 2018; Awad, 2008), Figure 2-20, Figure 2-21, Figure 2-22, and Figure 2-23.

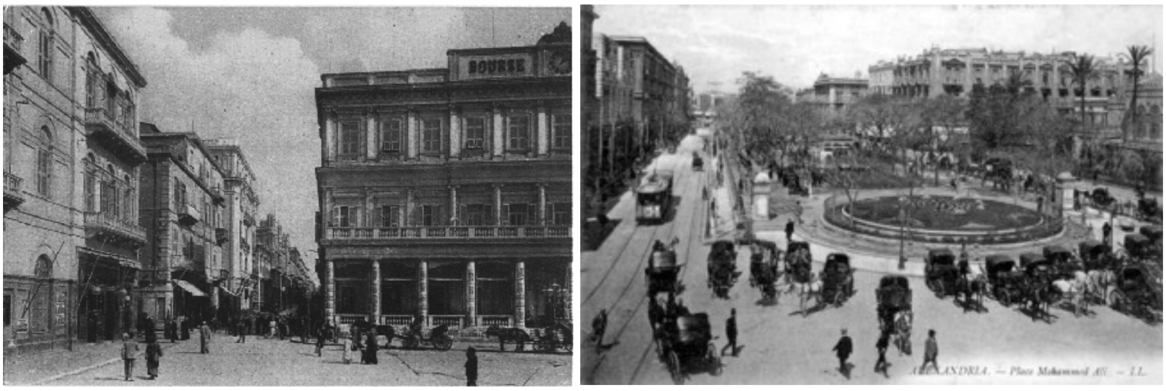

Figure 2-20 Place de Consuls by Francesco Mancini (Haag, 2008)

Figure 2-21 corniche design by Avoscani (Haag, 2004)

Figure 2-22 Ras El Tin Palace by Romero (AbdelNaby, 2018)

Figure 2-23 Boursa of Minet el Basal By Avoscani (Haag, 2008)

2.5.1 Architectural style

The city's identity is more recognizable through the architectural facades, rather than their typology. The design choice, styles and the architectural language used was certainly affected by the customers viewpoints. However, the design mainly was affected by two prevailing approaches to the projects; the first was to import from the motherland, the architectural style and type in residential buildings, the second employed in Egyptian type buildings demonstrated in the effort to take the characters of the architecture traditions, like a mosques (Turchiarulo, 2009). The extensively adopted Neo-Classic style in contrast with the Turkish town with other styles introduced, may also have been considered a classical revival attempting to link the new city's image and stage with its Hellenistic origins, or the means to establish the European image to the new Alexandria (Pallini, 2006).

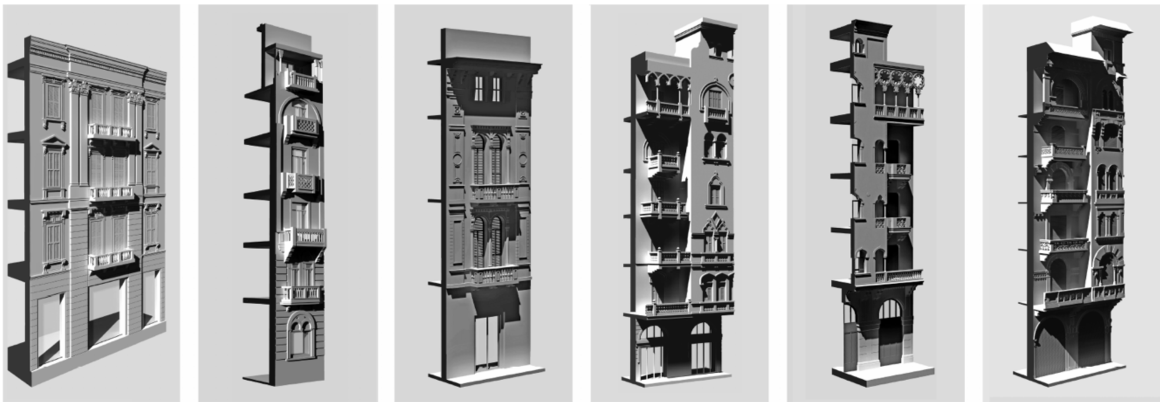

Figure 2-24 the eclectic revivalist style examples introduced by Italian architects: Okèlle Menasce by Lasciac, Cecil Hotel by Loira, Okèlle Monferrato by Piattoli, Mourice apartment (Turchiarulo, 2009). building and Betesh apartments buildings by Loira, Gorpha el togrya apartment building by Riccardo (from left to right)

The responsive building styles following the 1882 British bombardment of the city and the rebuilding boom that followed, architects introduced a sort of adaptive eclecticism experienced in the city's architecture. The eclectic and historic revivals styles such as neo-renaissance and neo-classic styles were introduced presented in many prestigious buildings that remain to the present day such as the Egyptian National bank 'Banco di Roma', Figure 2-25 . The eclecticism was perceived as the city's intentions to adopt rules and forms coming from different places (Bertocchini, 2005; Giacomelli et al., 2008).

Early eclecticism, pre-first world war, can be identified as being less articulate in form than in the inter war period. Two good examples displaying these characteristics are the ensemble of the society of Egyptian builders by Antoine Lasciac in 1885 Figure 2-26, and the Cordahi complex on Gamal Abdel Nasser avenue Figure 2-27, designed by G.Parcq in the 1920s (Awad, 2010).

The eclectic revivalist styles of the city during the late 19th and the early 20th century evolved in the context of eclectic historicism. Revivalist styles dominated the architectural language and expressed an architectural pluralism and the pro-European cosmopolitan society that prevailed the city. The period between the two world wars and in the immediate post-second war period, the most favored architectural expression became the decorative style and the early modern international style. The most popular eclectic style was the neo-renaissance, there are also, some examples of eclectic neo-classic trends, the water company building and an apartment building designed by N. Paraskevas Figure 2-28 and Figure 2-29, and even of neo-Romanesque styles such as the Adriana Pinto apartment block by G.Loria Figure 2-30Figure 2-29 (Awad, 2010; Yehia, 2006).

Local revivalist styles are mostly present in the form of exoticism, seen in the Moorish architecture of the Tawa apartment block on Salah salem street and Cicel hotel by Loira Figure 2-31. Revivalist Neo-Islamic trends were allowed by the ministry of Waqf (endowment) to develop new language for some of the city's iconic monuments demonstrated in mosque designs seen in Attarin mosque and the Morsi Abo el Abbas mosque, Figure 2-32 and Figure 2-33 (Awad, 2010; Yehia, 2006).

The post-first world war period showed the favor of the decorative styles in the form of Art Nouveau movement which widely spread in Europe and north America. Foreign architects in Egypt argued to be free from the main stream eclecticism aligned their architectural vocabulary with their country of origin new tendency which they were never disconnected (Yehia, 2006). Italians like Sinigallia inserted Art Nouveau details in the façades of some few fine residential buildings of Alexandria demonstrated in the Luzzatto apartment building in 1914 Figure 2-34, and the Sayed Darwish theater (originally the Mohamed Ali theater) in 1921 by G. Parcq, Figure 2-35 (Awad, 2010; Yehia, 2006).

During the 1930s up to the 1950s, Art Deco was more fully developed represented a flourishing and economical state, this trend was popular in bourgeois and elitist apartment blocks. The style was also demonstrated in leisure ,commercial and industrial buildings in the city's center such as department stores Cicurel and salon vert designed by Carmona and Lessous respectively, cinemas such as Amir and Metro, and some pastry shops such as Pastroudis, in such buildings as the Menasce apartment block designed by G. Aghion, and the Fiat orient car manufacturer by Mario Avena, Figure 2-36, Figure 2-37, Figure 2-38, and Figure 2-39 (Giacomelli et al., 2008; Yehia, 2006).

Figure 2-25 Egyptian National bank

Figure 2-26 the society of Egyptian builders   Figure 2-27 Cordahi complex

Figure 2-28 the water company

Figure 2-29 Paraskevas apartment block

Figure 2-30 Adriana Pinto apartment block

Figure 2-31 Cicel hotel

Figure 2-32 El Attarin mosque

Figure 2-33 El Morsi Abo el Abbas mosque

Figure 2-34 Luzzatto apartment building

Figure 2-35 Sayed Darwish theater

Figure 2-36 Salon Vert apartment store

Figure 2-37 Cinema Amir

Figure 2-38 Cinema Metro

Figure 2-39 Fiat car manufacturer

2.5.2 Heritage context morphology

Later to the city's bombardment in July 1882 and the occupation of the country, compensations were paid by the government to foreigners and Egyptians for the loss of their properties to rebuild the city. As a result, a building and construction boom, in order to put these construction projects under control, the city Municipality was founded in 1980 (Moore, 2012).

The urban development of the city was greatly influenced by the establishment of the Municipality of Alexandria as the first council of its kind in Egypt, the influence was towards the European trends in city planning. The Municipality differentiated quarters within the city according to the communities living within the cosmopolitan city, as an example the 'Greek' quarter towards the Rosette square (Foad street) and the 'Italian' quarter towards Attarin. The major developments that literally changed the city's image were the reconstruction of Mohamed Ali square, the project of the Abbas II's promenade (the cournish) in 1904, and the French gardens linking Mohamed Ali square to the Cornish (Yehia, 2006).

The Municipality was responsible for the imposition of building regulations, which in return had a major impact on the city's image and urban morphology. Before the foundation of the Municipality, the building codes of Alexandria were mainly concerned with street alignment. New issued decrees controlling; facades, materials, building heights as complete construction plans and drawings had to be submitted for approval, extending the scope of activities and to exercise a coordinated control over the global development of the city (Reimer, 1993).

The image of the city's heritage center became a reflection of these criteria's resulting in homogeneous character within the built environment within this period. The heritage-built environment regardless their different eclectic adopted styles as discussed in the previous section, are still having a common character within the different façade treatment.

(Lynch, 1984), (Spreiregen, 1965) and (Bacon, 1974) categorizing the physical configuration of a context according to three categories; The first type is buildings masses wish discusses the massing relationship of the buildings together according to height, size and scale; secondly is building surfaces this type contains the elevations and appearances of the buildings together within the context materials, colors, openings, ornaments and articulations; The last physical consideration is the ordering principles wish discusses the order and the arrangement of the building's relation to each other within the rhythm and datum.

Accordingly, the heritage context of Alexandria will be analyzed, showing the coherence of the built fabric, demonstrating the modular relationships used for creating those typical eclectic style buildings within an intact heritage context regardless their differentiated approach;

2.5.2.1 Heritage context building masses

Building's size and spatial organization expressed within the European city context can be identified with its regular geometrical, composed mainly with residential blocks with quadrangular ratio. The blocks are mainly deep central compact masses homogenously aligned together. Within the street all the roof shapes are regular and straight in form, harmonizing the masses together, (Reimer, 1993; Salam, 1995).

The Municipality The city's planning commission, was concerned with the public health motivating the regularizing and improvements of buildings. Imposing regulations for building construction approved documents, emphasizing on both ventilation and lighting. Inner courts were obligatory within the process of the construction acceptance and commissioned as a part of the building regulations (Reimer, 1993).

The typical block within the city's heritage context are mainly deep central compact masses, requiring an inner court regarding the proportion of building, demonstrates the heritage fabric of the city and the presence of inner courts as imposed for ventilation and lighting purposes Figure 2-41.

As a result of the deep masses combined with the inner court, the internal spatial organization of the internal spaces within the heritage buildings were considered a typical layout within this period. Composed of external spaces (which were ventilated and lighted from the external street), internal spaces (lighting and ventilation is dependent on the external spaces and the inner court), and the inner court.

Building's scale and proportions the sense of scale as a result of the classic proportions of the eclectic revival trend adopted in the context are homogeneous together. In the form of the building's composition, the massing proportions, openings sizes and the articulation. The architecture of the facade, the modular composition of the urban scenes, the elevations on the street, was considered in those years, a crucial design theme for the construction of the modern city. In the early nineteenth century in Italy there was a debate about the role of the "decoration", Figure 2-42.

Building's height according to the codes of practice enforced in the 19th and the early 20th century heights didn't exceed 4 stories (3.5 m - 4 m for stories) within the whole context. However, the commercial ground floor had a generous height (5.5 – 6 m). the heights within the heritage context were considered homogeneous together with heights between 18.2 m to 22 m. These heights were imposed by the Municipality according to the width of the streets (Reimer, 1993) , Figure 2-43.

2.5.2.2 Heritage context building surfaces

Materials and colors within the heritage context all external finishing is paint with some addition of red bricks depending on the style, wooden windows frame and shutters and steel or masonry balcony handrail depending in the style. The use of decorative textured moulds. The wall bearing system is the main for practice, with the introduction of steel roofing during 1930s permitting larger spans.

The color scheme within the heritage context between whites and its incarnations, shades of beige and light brown for paint, green, blue or brown for shutters and doors were used, thus the urban façade is balanced and homogenous, Figure 2-44.

Openings size of openings is standardized and stems directly from the occidental model of the eclectic revivalist style. Windows and doorways of the heritage context share similar characters and have relatively equivalent linear proportions within the context sharing the same wooden window frames and balconies character, Figure 2-45.

Ornaments featured in the use of horizontal molded cornices, balusters and consoles that support friezes with classical motifs. Triangle pediments and ornate frames of openings are derived from the eclectic architecture of the city center. The door entrances of buildings are flanked with integrated plasters and ornate lintels. Within the heritage context Decorative elements and cornices have the same proportion and materials, Figure 2-46.

Articulations The sense of depth and solidity of the buildings is created by the cantilevered parts of the balconies and the curved bay window have uniform proportions and repetition within the context, extending from the building masses by 1.5 m. The upper storey corbels, the projection gives the existing buildings a sense of unity in the projection, Figure 2-47.

2.5.2.3 Heritage context ordering principles

Rhythm The rhythms between buildings are seen through the repetition of the vertical projected window's bays. This rhythm is continued through the original buildings in the context and a part of the new additions to it, creating a partial rhythm in the whole context, Figure 2-48.

Datum the ordered composition of the façade suggests a homogeneous continuity as a result to the prevailing eclectic trend. The datum with the context is seen in the used materials, colours, ornaments, articulations and openings. In addition, the stories heights form a line together within the heritage context. The continuous generous height commercial ground floor within the context, while the height in the rest of the stories continuous together.

The modular relationships used are those typical of neo-Renaissance Italian buildings. In the horizontal stratification of the buildings still visible, in fact, the succession base elevation crowning is often clearly legible. The design of the facade becomes, again, a unifying motif with architectural elements that recur in multiple combinations: the projecting and soaring towers, placed in the corners to frame the façade, or in the center line in axis with the entrance; the corniche ornaments on the top floor that crown the building and connect the vertical tripartition imposed by the towers; the balconies that jutting out the windows. The layering of the materials and the surface treatment also gives a sense of unity, Figure 2-49.

Figure 2-40 deep central compact masses within the heritage context (Haag, 2004b)

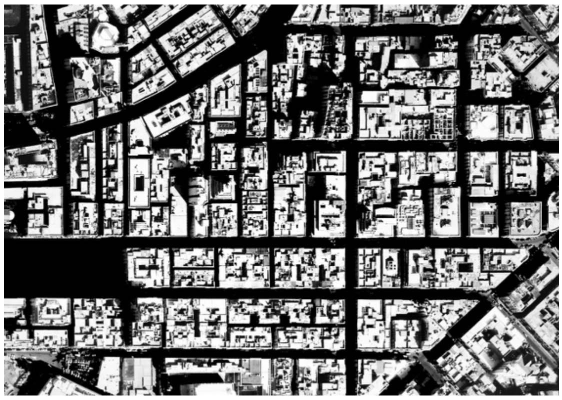

Figure 2-41 imbedded inner court within the heritage context

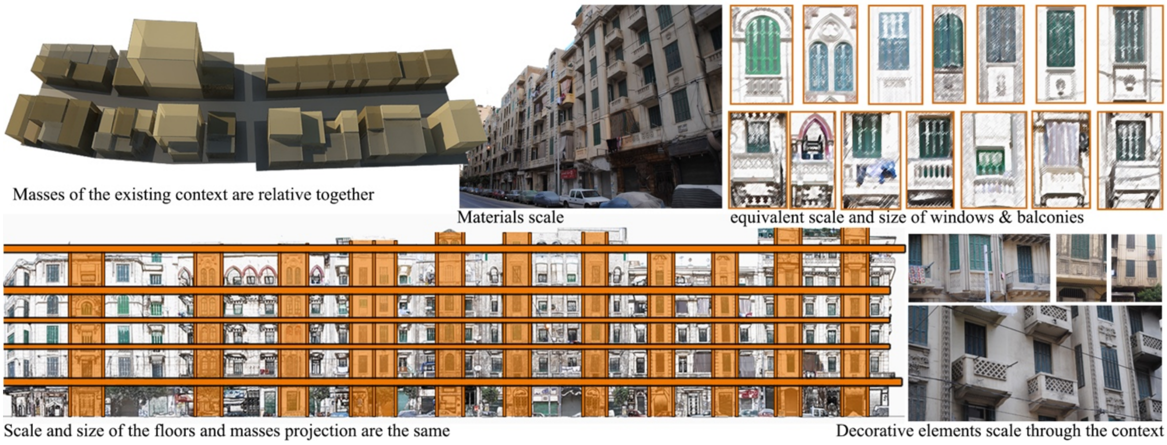

Figure 2-42 El Sayed Mohamed Koriem conservation street scale and proportions

Figure 2-43 The homogeneous heights within the heritage contex, Elasyed Mohamed Koriem, Saad Zaghloul square and El Manshia square Facades from top

Figure 2-44 Alexandria's heritage context materials and colours

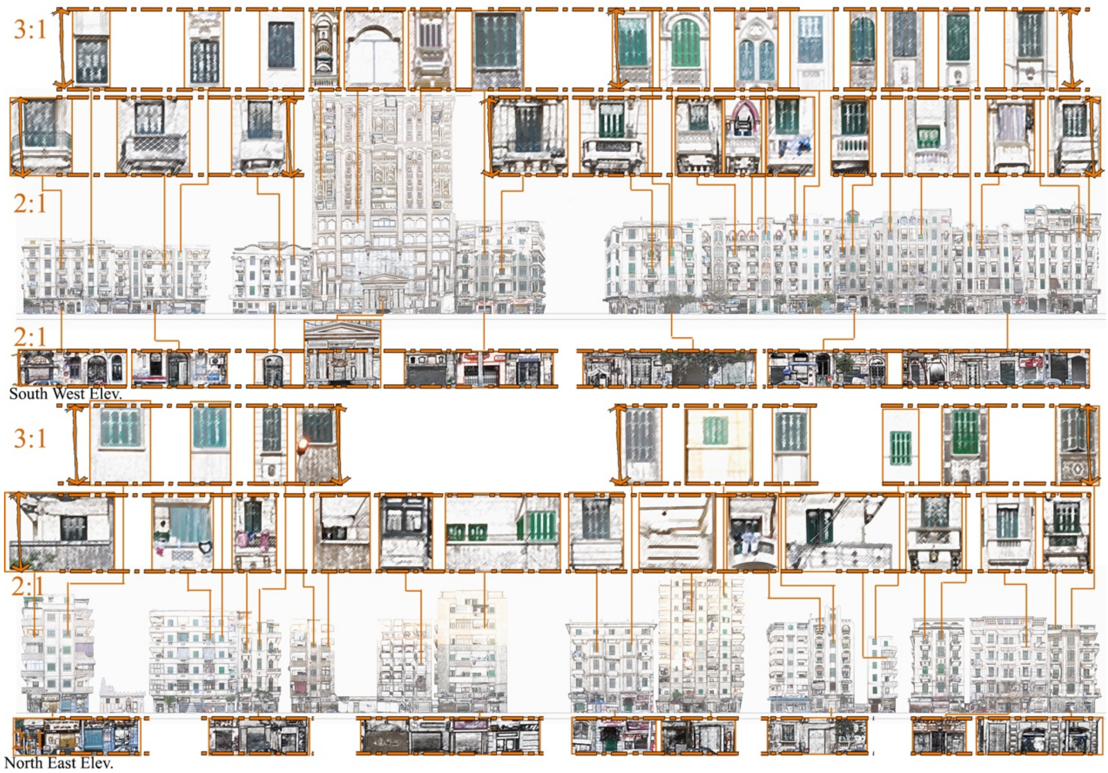

Figure 2-45 facade openings features

Figure 2-46 ornaments details with Alexandria heritage context

Figure 2-47 articulation within the heritage context in the for of balconies and window bays

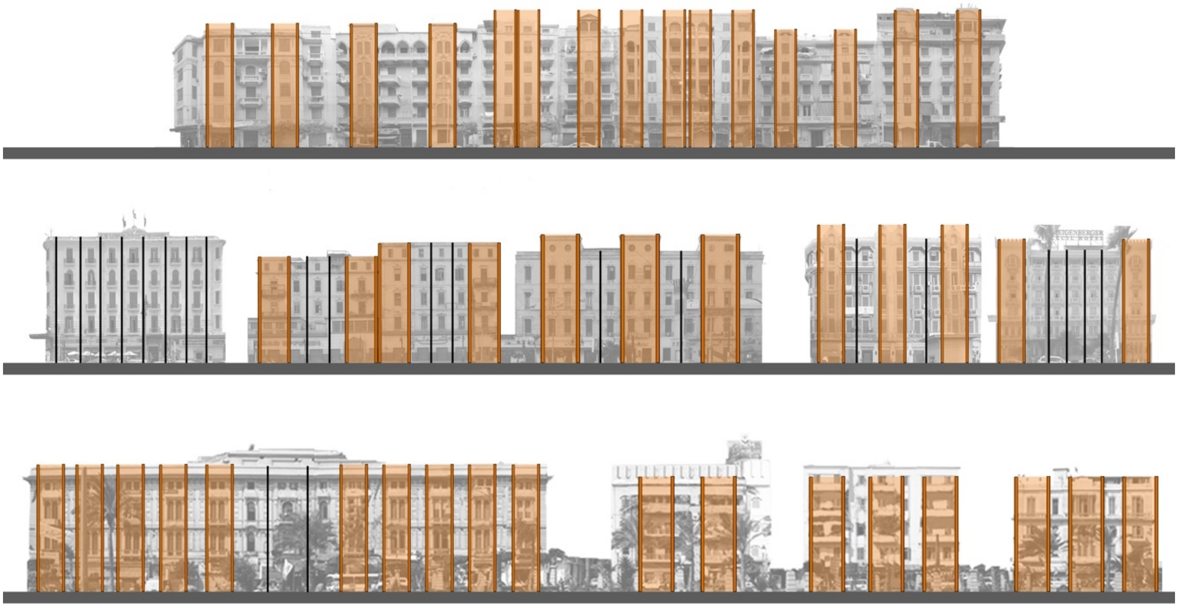

Figure 2-48 facade rhythm within the heritage context

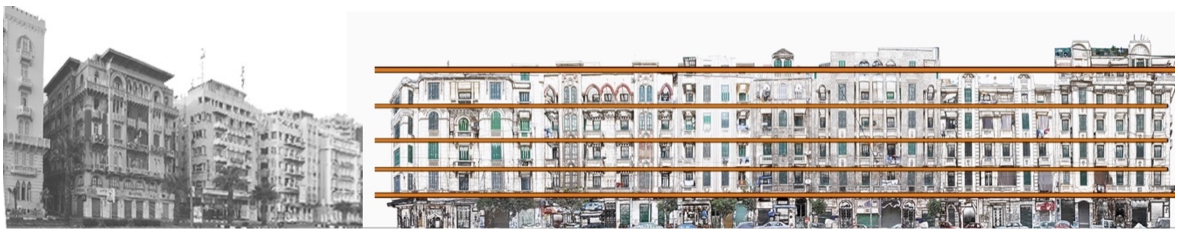

Figure 2-49 The stories heights form a datum within the heritage context

United Nations Educational, Scientific and Cultural Organization “UNESCO” defined heritage context as “groups of separate or connected buildings which, because of their architecture, their homogeneity or their place in the landscape, are of outstanding universal value from the point of view of history, art or science;” (UNESCO, 1972)

As stated by the charter for conservation of historic towns and urban areas organized by the ICOMOS “All urban communities, whether they have developed gradually over time or have been created deliberately, are an expression of the diversity of societies throughout history.” (ICOMOS, 1987) These international groups with assistance of different governments created lists of buildings and historical areas that must be conserved.

In conclusion the heritage context of cosmopolitan Alexandria is a group of homogeneous buildings, having an important significance whether in architectural style, historical and political. These groups of buildings include open spaces between them and other features such as street patterns, plot layout, and boundaries. The heritage context is formed mainly of a group of listed buildings, becoming a part of this historical context, creating its identity and style.

The quality and interest are considered within the whole context, rather than individual buildings, which should be the prime consideration in identifying the city’s heritage. The quality of the heritage context of the city will depend on the historic layout of property boundaries and streets, the contribution made by public and private spaces, such as gardens, parks and greens, trees and street furniture and the use of characteristic materials.

2.5.3 Threats facing the architecture heritage of downtown Alexandria

Despite the great value of richness and diversity of the city of Alexandria built heritage, is suffering many threats and problems, many buildings are a subject of partial or full deterioration. The city is subjected to intended demolition of heritage buildings, other buildings as a result of their deteriorated conditions faces partial collapse, beside the rapid destruction of valuable old villas (cairoobserver, 2014; Ezzat, 2017)

The deterioration of the built heritage is a result of many reasons, primary a result of the 1952 revolution and the confiscation of foreign and elitist property following the socialist changes of society in the 1960's, and a result of the result of the population change in Alexandria (Awad, 2008). The architectural heritage faces many problems as a result of its close association with the current conditions of society, indirectly related to the prevailing political, social and economic conditions. And directly related to the sever population density in the city. The new urban morphology and the infill of contemporary buildings within the heritage context deforming the existing urban fabric, informal growth and informal housing. Another important reason for the deteriorated conditions of the built heritage fabric in Alexandria is the weak awareness of the value of these buildings and the great benefits and potentials they can provide (NOUH, 2010).

The Egyptian government cancelled the endowment system “Waqf” in the early 1960s. Within this system, buildings were donated to the government and its revenue is used for charity purposes and the building can’t be sold, rented or inherited. Part of the income was dedicated to the preservation and the maintenance of the building, guaranteeing the building’s continuity (Ghazaleh, 2011). As a result of this system cancellation, the government wasn’t able to provide funds for these building’s maintenance (Khodeir et al., 2016).

The buildings and the surrounding context suffered from the consequences of neglect and deterioration resulted from; low maintenance and week management, weakness in enforcing law and policies protecting the built heritage, the renting laws and the relationships management between the landlord and the tenants and the low renting values, the absence of heritage value awareness of the owners, the misuse and improper additions to the buildings. The effect of natural factors of the weather like wind, rain and heat combined with the low maintenance increased the problem (NOUH, 2010).

The authorities neglect to document all aspects of heritage in the city, consequent to the lack of these buildings documentation for a long time, many changes are made to their original image, some other cases deliberate damage was done by the holders in order to demolish them for personal gain (AbdelNaby, 2017).

2.5.3.1 Demolishing of heritage buildings

Egypt currently has a critical issue with both heritage conservations especially with a number of heritage buildings being demolished (e.g Aghion villa demolished in 2013 after a great debate between the owner and environmentalists and heritage specialists Figure 2-50). Alexandria during this period, is facing its worst deterioration periods in which the absence of law lead to the demolishing of the city's heritage buildings which increased in the last five years. This resulted in demolishing more than 40 heritage buildings including small villas and low-rise buildings and changing them into towers exceeding twelve storeys, not just losing the heritage buildings, but also affecting the heritage urban fabric and the conservation streets (D. A. Elsorady, 2014).

The significant urban character of the city started to demolish. These effects did not meet any kind of resistance; however, these attempts have increased from the late seventies until the end of the 20th century. This deterioration increased rapidly in the beginning of the 21st century, to achieve more benefits in favor of concrete buildings against the urban heritage value. The future economic values of this urban heritage have been disregarded not sparing or preserving villas, residential buildings or palaces. Throughout the social change in Egypt, the state focused on low- income classes, up to open economy phase following the two wars 1967 and 1973. The authority has disregarded the condition and preservation of the architecture heritage (Osman, 2018).

Figure 2-50 the demolishing of Aghion villa

Currently 35% of the listed buildings in Alexandria are publicly owned by the Egyptian government or Alexandria governorate. Due to their public ownership and historic value, these listed buildings are restored and/or adaptively reused, the issue lies within the private ownership of heritage buildings. The remaining 65 % of the current listing of these properties are privately owned. The assumption within the within the market value that the heritage listing reduces the value of the property value (D. A. Elsorady, 2014).

listing of a building doesn't need the approval of the private owners of the buildings. If a listed property owner wants to make an alteration to the building, the plans are reviewed by the local authority, and the local authority makes the final decision. In the case the owner request to demolish a listed building, according the building law an application for demolishing permit is filed. This kind of permit is only granted if the building suffers from extreme deterioration, and its existence can affect the public safety according to law number 144 for 2006 (Urban-harmony, 2006) .

The negative impact perception on the real estate market of the listed building, owners and developers have followed some courses of actions; avoiding purchase of the listed building, attempts to delist the heritage building, or apply for a demolition permit for buildings damaged on purpose or left for deterioration (D. A. Elsorady, 2014)

In order to demolish these buildings, the heritage building has to be removed from the listing; firstly, people evacuate the current residents. Owners distort and erase the detective character of the building architectural style moldings are removed, columns capitals are changed Figure 2-51. Sometimes open water is left running in the underground floor for a week or more until the foundations are affected and the building is damaged. Buildings were even set into fire to lose their architectural identity (Elsorady, 2011).

Figure 2-51 deforming the architectural character practices of listed buildings, from left removal or ornaments, removing moldings, and changing the column capital (Elsorady, 2011)

2.5.3.2 Deformed heritage fabric

The coherent urban fabric of the city as a result of the continuous demolition of the existing heritage fabric was infilled with concrete structure disregarding the context’s morphology. The new additions disregarded all the planning features within and fragmented the heritage context including; the building masses, the extensive height disrupting the context hierarchy, and the use of unmatched materials and colors, Figure 2-52.

Figure 2-52 inappropriate infill to the heritage context of Alexandria

2.5.3.3 Façade treatments and the lack of maintenance

It is not just the economic factor that affects the heritage within the city, but also the cultural awareness of the public doesn't appreciate their importance. Many heritage buildings suffer from being abundant and neglected leading to their deterioration by time. This heritage value should be changed from an unused and mistreated asset into a cultural and a financial resource. Moreover, the inappropriate Façade treatments, additions and the lack of maintenance and awareness lead to the degrading of the urban heritage value and their cultural significance leading the city to lose its heritage identity (Khodeir et al., 2016), Figure 2-53 and Figure 2-54.

Figure 2-53 lack of maintenance and mal façade treatments

Figure 2-54 new addition to Majestic hotel (Forster, 2014)

2.6 Alexandria Cosmopolitan fabric climatic suitability for natural ventilation

Since the research will be concerned with natural ventilation as a passive cooling retrofitting technique with the heritage fabric of the city. The implementation of the strategy requires the complete understanding of the fabric and its compatibility with natural ventilation. A method was developed during the URBVENT research project, aiming to provide a methodology to assess the potentials for natural ventilation in the urban environments and building design. A range of variations were considered in order to assess the viability of natural ventilation (Germano et al., 2002; Ghiaus et al., 2003). Consequently, the heritage context of Alexandria common feature that was previously discussed was assed according to these variations.

Built up environment: As previously discussed, the initial planning of Alexandria planned by Dinoctratis 320 BC adopted the chess layout planning form considering the functions with the city. The orthogonal planning with street network parallel to the Mediterranean Sea has continued to be the dominant layout of the city center throughout its evolution across time and the different ruling periods.

With the new image of the city development during the reign of Mohamed Ali and the development of the modern cosmopolitan Alexandria 1805, the city's fabric was the main concern of the Municipal council. The main concern of this council was to improve the city's image and its urban planning. One of the main concerns of city's planning commission was concerned with the public health and the adaptation of natural lighting and ventilation within the fabric, through the imposed regulations (Reimer, 1993). The physical form of the urban fabric was characterized by the form of regular streets and squares. Main streets ran parallel to coast, while secondary streets perpendicularly intersect with them. The new city's extension to the east, west and south adopted the same pattern.

The council also was responsible into specifying the street width according to the specified classification with the context into three categories; major traffic routes having a width of not less than 14 meters, the second order routes of 10 -12 meters, and third order routes of 6-8 meters (Reimer, 1993). Combined with the heights approved within the heritage context with heights between 18.2-22 meters imposed by the council. Consequently, the canyon configuration within the heritage fabric is equivalent throughout the heritage context.

Heritage buildings typology: The eclectic neo-revival styles within the context commonly share the same building characteristics including; building materials, deep central compact masses, opening proportions, court linking the inner spaces to the roof, in addition to the similar internal spatial organization of the internal spaces.

The natural ventilation of buildings is affected by the urban environment, building configuration and the façade organization (Georgakis et al., 2004). From an architectural perspective, the European style courtyarded building layout according to (Givoni, 1998), this typical layout offers good potential for healthy indoor air replacement. However, further investigation will be conducted on the natural ventilation performance throughout the research.

Wind direction: The prevailing airflow direction within the street has a major impact on the wind distribution in the urban context, there is a great importance for passive cooling application in knowing the air speed inside the urban canyons (Niachou et al., 2007). The city's heritage fabric extends along the Mediterranean sea, with prevailing cold damp wind coming from the north-west direction (Weather and Climate, 2019). The prevailing wind is commonly characterized by its low temperature affected by the sea, contributing to moderate the city's atmosphere (Shalaby et al., 2017)

The linear city of Alexandria, is within the heritage fabric wind direction, generally divided into two regions; the waterfront zone which comprises the buildings that line up the shoreline and shape the waterfront facade of the city. This zone extends to about 400m depth in average, and follows the length of the shore line between the ends of the urban boundaries. The second zone's urban fabric is dominantly urban canyons organized at an angle of 20 degrees & parallel to the prevailing wind (NW). Moreover, freestanding buildings could be seen along the shoreline in a scattered manner and in rare occasions, figure 21. The case study building lies within inner fabric 1 with 21 degrees towards the prevailing wind Figure 2-55. The narrows streets perpendicular to the sea and the wide canyons parallel to the coast allows wind to penetrate the context depth within the urban fabric of the coastal city.

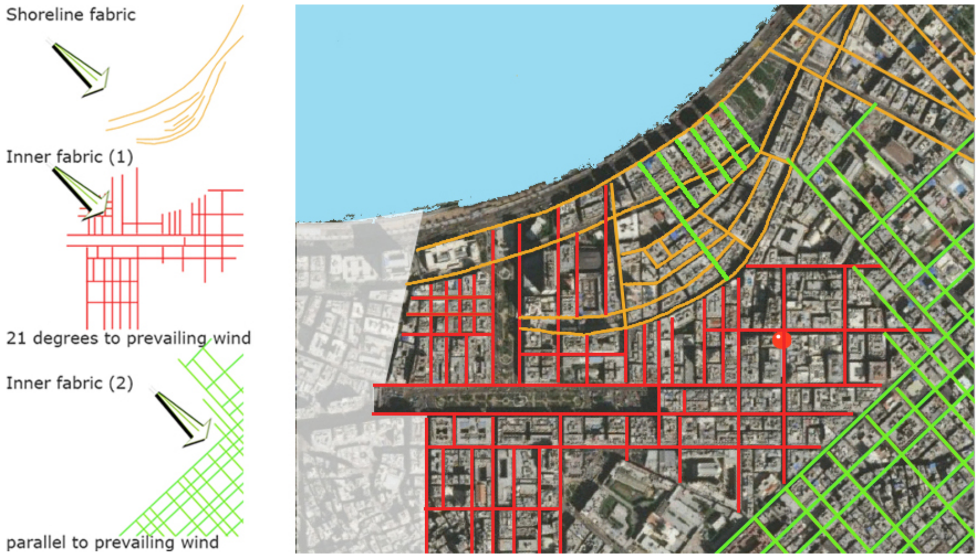

Figure 2-55 different urban fabric orientation with the heritage fabric of the city in relation to prevailing wind direction

Air velocity and airflow: The heritage context is extended parallel to the Mediterranean Sea, allowing a large volume of the sea's air mass to be received. According to the nearest weather station Typical wind speeds vary from 3.4 m/s (light air to moderate breeze), and rarely exceed 5 m/s gentle breeze), and the prevailing wind direction is strongly affected by the North-Western direction (Weather and Climate, 2019). Within the heritage context as a result of the perpendicular streets urban configuration to the sea front becomes stronger the wind speeds become stronger.

According to a field measurement performed by the department of Architecture, Alexandria university, the average wind speed in the context is 2.4 m/s. within the coastal line is recognized by its high wind speed, where the highest reading of air velocity reached 4 m/s and monitored air flow pattern 106 m^3/hr. penetrating deeper in the urban fabric the airflow pattern and air distribution changes and wind speed becomes slower, the airflow magnitude decreases gradually (Shalaby et al., 2017).

With air speed magnitude larger than 2 to 4 m/s, a correlation happens between the undistributed wind speeds in the street canyons. Which is the case within the heritage context. A vortex is developed when the wind direction is perpendicular to the canyons with a magnitude 2 m/s or higher. However, in the parallel canyon configuration parallel to the prevailing wind the magnitude becomes higher and conserved through the availability of open path (Ghiaus et al., 2005).

Temperature and relative humidity: Mean air temperature in the city ranges from 28.5^{o}C in September to 32^{o}C in August. Relative humidity typically ranges from 65% to 92% over the course of the summer months. (Weather and Climate, 2019). According to (Givoni, 1998) for the applicability of comfort ventilation in hot humid regions when the outdoor maximum temperature doesn't exceed 33 ^{o}C even on hot days. According to the ranges of external temperatures within Alexandria's context comfort ventilation is applicable.

Context constraints: The barriers of the context regarding the natural ventilation application, can be a major drawback of the application. Considering the urban constraints of pollution, particulate matter and noise. According to Niachou et al. (2007) the increased concentration of outdoor pollutants can seriously affect the indoor concentration. However, recent studies performed by Shalaby et al. (2017) indicated that the chess layout planning within the city and especially in the heritage fabric according to the municipality induced policies, has proved in reducing pollution and can provide good air quality. Regarding noise levels, the road traffic is considered the main source of noise, however, Shalaby have indicated the most noticeable noise levels within the city is very high along the Cornish road, while the noise rates are reduced within the city center.

In addition, the cultural factors and occupants' behaviour are commonly considered another barrier to natural ventilation in terms of privacy concerns. This is considered a critical criterion while adopting the sustainable conservation process, insuring the acceptability of the proposed measures.

The heritage context of Alexandria demonstrates a good potential for determining a potential for natural ventilation application. As a result of the air properties of the city; airflow, air velocity and the wind direction combined with the heritage fabric and building typology of the context.

2.7 The selected case study building

According to the research established aims in chapter 1 addressing the sustainable retrofitting of the heritage buildings within the context of Cosmopolitan Alexandria. the research seeks to consider potential case for the process, considering the potential of natural ventilation as a passive cooling method. Exploring more suitable, sustainable and effective ways to implement the natural ventilation retrofits.

The building selected for the study is a listed building which is sought to be a representative sample for the heritage buildings in Alexandria built during the same period and to same architectural style. The building was designed and built with traditional building materials and technologies as a residential four-story building located within the European district of Alexandria, Figure 2-56. The suggested criteria for choosing the case study building for the research are demonstrated in Table 2-6, according to the building's background, cultural values, heritage listing and the physical accessibility to the building.

It was intentional to choose a case study building, representing the majority of the current listing within the city, local level classification residential block (around 75 % pf the listing). Allowing the methodology can be applied on the wider range of the context as considered having the same typology and level of intervention. Moreover, results of the research to be valid within a certain level on the wider scale within the Cosmopolitan heritage fabric of the city.

The accessibility to the case study is an important factor in determining the case study in the Egyptian context due to social aspects. It can be considered hard to access homes, perform architectural survey, or install monitoring equipment. The research relied on personal relation with the building's occupants for accessing the case study.

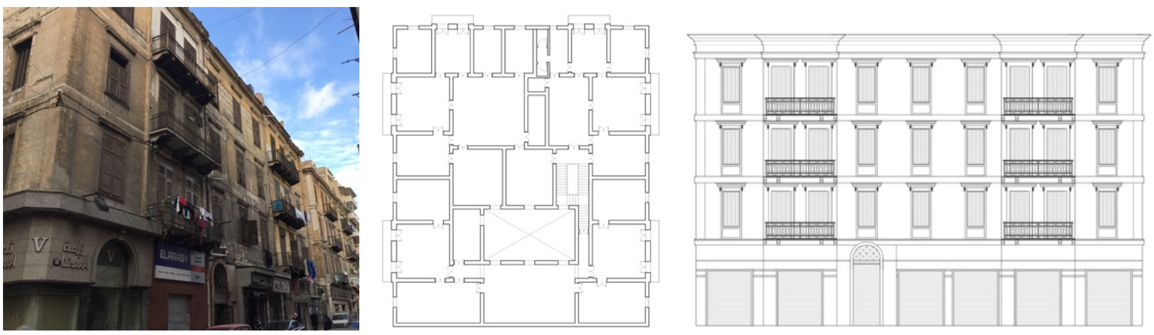

Figure 2-56 selected case study building, building image, plan, and façade from left to right

Table 2-6 Description of the case study heritage building

Criteria	Description		
Background	Date	1869	
	Original owner	Princess Najwan, currently owned by the government	
	Current use	Residential, ground floor commercial	
Cultural values	Social evidential	A representative place of social life of upper-class families who lived in Alexandria. It was an upper-class residential building	
	Architectural	Value	Represents the multi-cultural value of cosmopolitan Alexandria heritage context
		Style	The Neo-classic eclectic revivalist architecture style, the dominant style within the context
Context morphology	Building's mass	Expresses deep central quadrangular masses within the European city context typology.	
		The spatial organization of the internal spaces is composed of external spaces, internal spaces, and the inner court, typical layout within the heritage context	
		The building is composed of 4 floors with 19.2 m height, representing the typical typology	
	Building's surface	external finishing is paint, wooden windows frame and steel balcony similar materials used in the context	
		Windows and doorways share similar characters and have relatively equivalent linear proportions with the heritage context	
	spatial organization	The composition of the façade suggests a homogeneous continuity within the heritage context	
Heritage listing	Listing number	listed number according to the catalogue of 2007 by Alexandria Preservation Trust "108"	
	Listing grade	Grade (C) local level classification, representing 75 % of the city's heritage	
	location	The case study building lies within the heart of the heritage context of the city, located on Sizostriss and Msjid el Attarin, both are listed as conservation streets	

2.8 conclusion

The aim of this chapter is to represent the architectural heritage of Alexandria, the significance, evolution, threats as a part of the archival research, site survey, and data collection. In addition, assessing the heritage context applicability for incorporating natural ventilation strategies.

As discussed in this chapter, the city of Alexandria has a unique urban and architectural pattern, enduring many morphological changes in its urban evolution. Because of its historical background, a certain richness, historic meaning and importance are today associated with its built form. Different types of urban tissue currently co-exist, providing a particular morphology with its physical form and spatial structures. Together they accentuate the role of the city centre as a meeting point and the urban core of one of the most cosmopolitan cities of the Middle East.

The city centre heritage context of the incorporates the modern architectural history of the city (1807-1952) and the formation of the identified cosmopolitan fabric, listing this fabric of the city with its high architectural values and unique architectural styles. Consequent to the political, social changes and lack of awareness from 1952 to the present day these values within the urban and architectural context are suffering many threats and problems. The city is subjected to intended demolition of heritage buildings for economic reasons, deformed fabric from the new concrete expansions, buildings also suffer of deteriorated conditions from the lack of maintenance, mal façade treatments, and in appropriate additions.

The principles of environmental design for these heritage buildings typology have indicated the potentialities for comfort ventilation in the heritage context buildings, the combined effect of the Mediterranean climate of the city, and the heritage context morphology provides enhanced possibilities for promoting indoor thermal comfort. Finally, this chapter have a selected a residential case study representative for the heritage buildings in Alexandria built during the same period and to same architectural style.

The archival research and analysis presented in this chapter will be incorporated with the principles of sustainable conservation, that would be discussed in the following chapter. As an approach for conducting a natural ventilation retrofit, developing a balanced and culturally-responsive approach to the retrofitting and improvement of Alexandria's built environment.

Chapter 3 Heritage buildings sustainable retrofit

3.1 Introduction

Current research advocates incorporating green environmental design into the adaptive reuse of buildings (Asadi et al., 2012; Flourentzou et al., 2002; Xing et al., 2011). Although there can be little doubt that incorporating environmental design into the adaptive reuse of heritage buildings is one way to achieve low carbon emissions, addressing only the issue of environmental sustainability is not sufficient. All the other sustainability domains also significantly contribute to the extent to which heritage buildings are sustainable. In that context, this study attempts to identify a list of underlying factors, which contribute to the concept of sustainable development and retrofitting principles of the built heritage with concerns to natural ventilation as an aproach.

The issue in question here is how to incorporate a sustainable retrofitting framework addressing a heritage building for achieving sustainability, whereby natural ventilation as a passive cooling technique could be viewed as a means for respecting its integral aesthetics acquired by its architectural value. This environmental benefit, the energy savings, carbon emissions reduction and the social and economic advantages of preserving a valued heritage building, have been seen to make retrofitting heritage buildings an essential component of sustainable development (Department of the Environment and Heritage, 2004).

The chapter reviews the existing literature related to the area of retrofitting heritage buildings and related issues including current research, assessment criteria, and different retrofit approaches in order to achieve the research objective of establishing a heritage building retrofit framework and incorporating natural ventilation benefits. The chapter begins with an overview of the sustainable retrofit process, then discusses the difference when dealing with heritage buildings, reviewing different researches in the field. The incorporation of natural ventilation as a retrofit approach. This is followed by presenting the methodology for adopting the retrofit plan in accordance to heritage buildings.

3.2 Sustainable building retrofit

Sustainable retrofitting of buildings is a form of sustainable building regeneration. It promotes adapting the building to the challenges facing the need for carbon emission reduction and upgrading energy performance. This happens because it extends the building's life cycle and avoids demolition waste, encourages the reuse of embodied energy and also provides significant social and economic benefits. It embraces the different dimensions of sustainability. This method is one of the main approaches for achieving a sustainable built environment at a relatively low cost.

According to the statistical review of the world energy, global energy usage acceleration growth increased since 2013 by an average increase of 1.8% every year and reached 2.2% in 2017. This world trend of energy usage growth raised many concerns for future supply difficulties and environmental impacts concerns (BP, 2018).

While the building sector provides facilities for human needs and countless benefits to society, buildings also have had their negative impact on the environment during the last decades. Buildings are responsible for almost 40% of the global energy consumption and play a major role in the energy consumption market. They also have a significant influence on natural resources utilization (Nejat et al., 2015).

The residential building sector is responsible for 75% of total energy consumption, where there is great potential to improve energy efficiency. The energy consumption of these buildings differ according to the different regions of the world, there is an average fluctuation of 20% in developed countries to more than 35% in developing countries (Kelly, 2012; Yau et al., 2013).

The process of enhancement of energy efficiency in existing buildings is essential for the reduction in the global energy use and the promotion of environmental sustainability. This is due to the construction of buildings and their operation contributing to a large proportion of the total energy use worldwide. Many governments and international organizations have made tremendous efforts towards promising retrofitting and energy improvements for existing buildings. The UK Government for example set a strategy for reducing emissions from the household sector by 29% by 2020, with an up to 7 million British pound eco-upgrades plan (DECC, 2010). The US government, has provided a significant financial assistance in 2009 to support existing building retrofits (DOE, 2009). The International Energy Agency (IEA) has launched a set of Annex projects to promote energy efficiency of existing buildings (IAE, 2015). These different policies and guidelines provided financial and technical support for the implementation of energy efficiency measures in existing buildings.

A significant amount of research was carried out to develop and investigate energy efficiency opportunities in order to improve energy performance of existing buildings (Asadi et al., 2012; Xing et al., 2011). The results from these different researches have showed that energy use in existing buildings through retrofitting could be significantly reduced (Flourentzou et al., 2002). Retrofitting of existing buildings offers great opportunities for energy efficiency, better human comfort and reduced maintenance costs, reduced energy prices, it can also create job opportunities and make buildings more liveable (Sweatman et al., 2010). However, according to Tobias retrofitting of existing buildings has many challenges. The main challenge is that there are many changing variables, such as the existing building's condition, climate change, human behaviour change, different government policies and many more. All these different variables would directly affect the proper retrofit application. It is therefore important to address this issue regionally. Existing buildings are formed of many subsystems that work together to ensure the running of the building coherently, that different retrofit applications interact with the building's subsystems which makes the selection of the appropriate retrofitting application very difficult. Other challenges may include the economic factor for applying the different systems and their return revenue (Tobias et al., 2009).

Balaras and Droutsa relate the energy consumption of existing buildings according to their age and construction characteristics. According to their summaries, buildings built after 1990 used around 40 KWh/m^2 while a building built before that period, which are mainly considered heritage buildings have been generalised to presume that they each consumed around 170 KWh/m^2 (Balaras et al., 2005). This is clearly a problem as it is so imprecise a measure, covering all materials, construction technologies and climates, it is therefore necessary to undertake more detailed studies at the local level. The relation of heritage buildings to the principles of sustainability are theoretically not that far from each other. Finding a solution compatible with conservation potentially enhances long term preservation and sustainable management aspirations for our cities.

3.3 Sustainable retrofit of heritage buildings

Webb (2017) describes retrofits in heritage and traditional buildings in recent studies are commonly described as a "balancing act". This is where energy usage and conservation process are balanced against each other, achieving continued, long term use of the building. Heritage buildings retrofit differ from contemporary buildings in energy retrofits in two ways. The first difference comes in the physical characteristics. Heritage buildings have a different geometry, their envelope lacks insulation. There are methods and uses of natural non-standardized materials. In addition to that Cantin et al. (2010) mentioned that there are passive non-mechanical indoor climate management strategies such as the use of thermal mass and natural ventilation which are not generally calculated. The second difference according to Widström (2012) comes in the conservation principles. Retrofit strategies require a guided procedure, which secures the preservation of a building's fabric and character. Given these differences, energy retrofit strategies for new and modern buildings may not apply to heritage buildings. Inappropriate retrofit applications can cause damage to the historic character and the traditional construction, resulting in loss of the collective cultural heritage.

3.3.1 Heritage buildings versus contemporary existing buildings

Heritage buildings are an important factor contributing to the architectural character of any existing city and its evolution. The simplest way to define a heritage building is through the three essential attributes. It must have sufficient age, a relatively high degree of physical integrity and historical significance (GDNR, 2014). The first attribute is age; the building must be old enough to be considered as a heritage asset. In the USA, this means that the building must be at least 50 years old. However, this could be a general rule if the building is old enough to be studied by architectural historians so that it has a place in history. This allows some types of buildings to be considered as heritage even if they are less the 50 years old. The second attribute is integrity; in addition to having a sufficient age, the building should retain its historic physical integrity. It's essential to define character features that are relative to its significance. These features must be present still, such as, architectural features, structure and heritage site. The site must be recognizable to today's affiliated cultural groups and still used in some way. Finally, the significance attribute; the building must be significant to be considered as heritage. Significance is defined by three ways: the first is through the direct association with individuals, events, activities, or developments that shaped our history or that reflect important aspects of our history. The second is the spatial characteristics of an architectural style or type of a building, method of construction, or the artistic values or fine craftsmanship. The last way to identify significance is having the potential to give important information to our understanding of the past architecture.

With these attributes in mind in terms of heritage building retrofitting, the process of decision making must also obey conservation considerations, concerning retaining a building's original fabric and character. Certain aspects of a heritage buildings' treatment and potential modifications in order to comply with energy efficiency are treated differently according to their classification. For example, listed buildings in the UK are those included on the statutory list of buildings of special architectural character or historic interest. There are different grades of listing (A/B/C, international / national / local level and I / II / III according to the region). Permitted alteration to buildings in these classifications is progressively limited both internally or externally, constraining some retrofitting processes.

Buildings in conservation areas; as defined by "UNESCO" as a "groups of separate or connected buildings which, because of their architecture, their homogeneity or their place in the landscape, are of outstanding universal value from the point of view of history, art or science;" (ICOMOS, 1987). According to this approach alterations considered must be done in respect to protect the historic and architectural character of groups of heritage buildings. Emphasizing is on the preservation of the external façade, with surface materials and opening details, while alteration could be done internally.

3.3.2 Heritage buildings sustainable characteristics

According to Godwin Heritage buildings are considered a finite resource in their existence. It's not only for their embodied energy and carbon, but the spirit and the identity of a country. In the continuous pursuit towards sustainable achievement in heritage buildings, the local distinctiveness, and character should be retained. Bringing an old building to meet modern performance standards and sustainability requirements must be achieved with care to ensure preserving their value (Godwin, 2011).

Heritage Council of Victoria (2009) describes a building of heritage value generally shows examples of design, building techniques or materials that inform contemporary developments. One of the most important factors in terms of conservation is to retain the original fabric and character of the buildings. For example, in the nineteenth and some early twentieth century, masonry buildings have a very different characteristic than modern contemporary buildings. They differ in their moisture barriers, cavity wall and insulation. Optimizing the energy performance of heritage buildings may assist in achieving energy efficiencies and sustainability objectives.

Edinburgh World Heritage organization stated that the most important functional characteristic between heritage and contemporary buildings is commonly identified as their ability to 'breathe'. Heritage buildings masonry construction, and buildings with timber floors were designed to allow natural ventilation to reduce dampness. This feature makes them more porous and naturally ventilated with the use of soft and permeable materials. On the other hand, modern buildings are more reliant on mechanical ventilation with their sealed envelopes using impermeable materials. Old building components have lower thermal efficiency and systems tend to use more energy when compared to modern materials and systems (Changeworks, 2009).

The English heritage mentioned other positive considerations in heritage buildings for optimizing their performance including the consideration of thermal mass. Traditional masonry buildings have a high thermal mass which helps slowing down the heat transfer of the outdoor heat to the inner spaces of the building, allowing a comfortable inner temperature. The high thermal mass is useful for night ventilation and passive cooling. Heritage buildings, mostly passively designed, have the combination of building materials, orientation, sunlight and shade, and ventilation assist to maintain thermal comfort without the need for mechanical methods (English heritage, 2012).

The heritage buildings characteristics been addressed asserts on maintaining and retrofitting benefiting from them rather than the use of mechanical means. As the internal configuration of heritage buildings often has larger rooms with higher ceilings, which needs more energy to be cooled in hot humid climates.

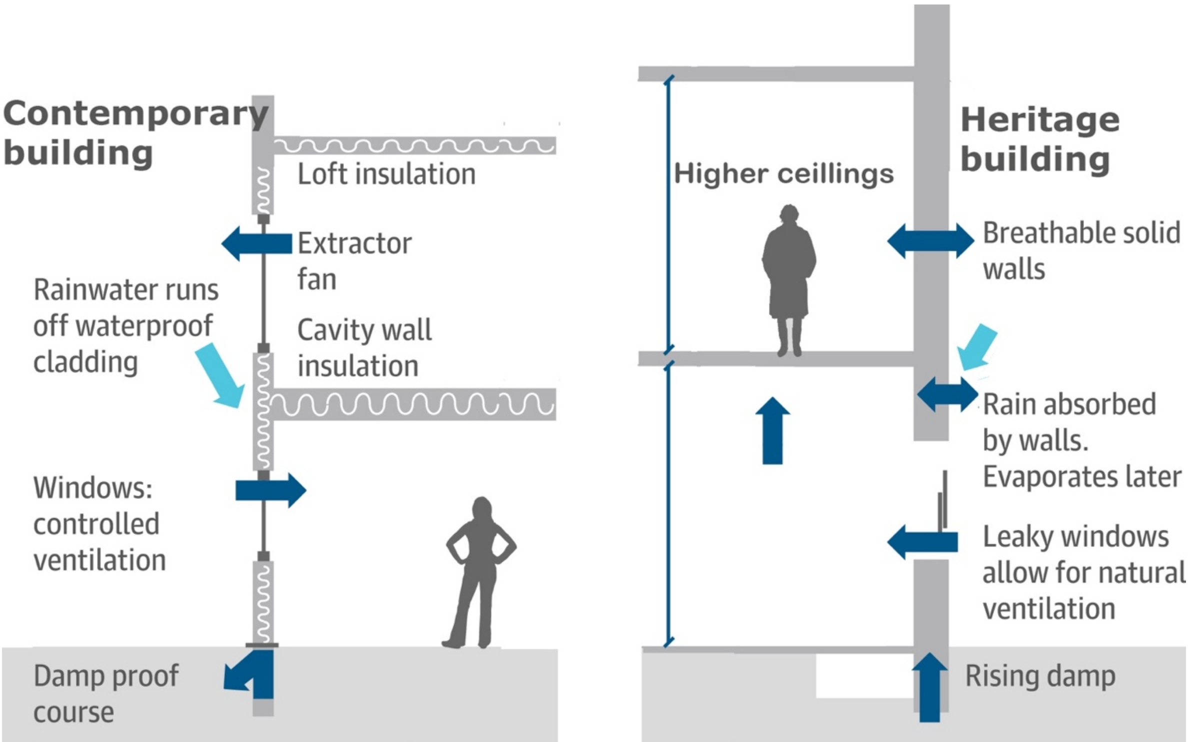

Figure 3-1 heritage vs contemporary buildings materials and internal configurations, adapted from English heritage (English heritage, 2012)

3.3.3 Retrofitting purpose of heritage buildings

Kohler et al. (2002) describes retrofitting as a method of extending the useful life cycle of a building by a combination of improvements. Energy saving, carbon emission reduction, and the social and economic advantages of recycling a heritage building makes the combined benefit of adaptation and reuse of a building an essential component of sustainable development. It is also important to understand heritage building retrofit as it doesn't only decrease the energy consumption but also improves the indoor thermal comfort conditions and the whole conditions of the building: The building's use, exterior, and comfort all serve to reduce negative impacts to the environment and enhance healthy environment.(Mickaityte et al., 2008)

The retrofitting process ensures that the heritage building could be comfortable, affordable and suited for contemporary lifestyles. Retrofitting allows an increase in the value of the heritage buildings, which results in solving their technical, economic and social problem (Sunikka, 2003). Retrofit, as defined by Power (2008) , turns the adaptation into an effective reuse of the heritage building. with the studies reviewed indicate retrofitting can be an essential component of sustainable development and has a positive impact on a wider scale. It sends a message that renewal and reinvestment will insure the long-term value and stability to heritage areas conservation, in return generating other investments.

3.4 Current heritage retrofit research and guidelines; a literature review

There is a no clear and consistent process for retrofitting heritage buildings. This is due to the lack of specific regulatory code. The energy retrofit approach has become an open question. Recent efforts have been made towards providing guidelines and decision-making processes for selecting appropriate retrofit methods for heritage buildings. Many organizations are starting to develop research programs for improving energy efficiency in heritage and traditionally constructed buildings. These include Historic England's guidance on energy efficiency and historic buildings (Heritage English, 2008), Historic Scotland's energy efficiency research program (Historic Scotland, 2012), the Swedish energy agency's save and preserve project (Claesson et al., 2019), and the society for protection of ancient buildings' (SPAB) energy efficiency research (SPAB, 2014).

The EU has recently sponsored several research projects concerned with energy efficiency and heritage buildings, which are summarized in Table 3-1. These projects have considered different approaches for the retrofit; solutions, climate protection, energy efficiency and the addition of renewable energies. The projects were done over several years with multiple partners, helped advancing research on this topic.

Table 3-1 Research projects in the EU

Source: Author

Project name	Dates	summary	Website
3ENCULT	2010–14	bridges the gap between conservation of historic buildings and climate protection	http://www.3encult.eu/
Climate for Culture	2009–14	investigating the potential impact of climate change on Europe's cultural heritage assets – particularly on historic buildings and their interiors.	http://www.climateforculture.eu/
Co2olBricks	2010–13	Investigating energy retrofit solutions in the Baltic sea region	http://co2olbricks.eu/
EFFESUS	2012–16	investigating the energy efficiency of European historic urban districts and developing technologies and systems for its improvement	http://www.effesus.eu/
New4Old	2007–10	Promotes the integration of Renewable Energy Sources into historic buildings in the EU.	https://ec.europa.eu/energy/intelligent/
NOAH'S ARK	2004–07	prediction of the impact of climate and pollution on cultural heritage and investigation of future climate scenarios	http://cordis.europa.eu/project/rcn/73915

These research programs projects have produced several retrofit guidelines handbooks as a part of their work. For example, "Energy efficiency solutions for historic buildings: a handbook" by the 3ENCULT research project (Troi et al., 2015), and "Improving the energy efficiency of historic buildings, a handbook of best practice examples" by Co2olBricks (D, 2013). In addition, a number of professional organizations (ASHRAE, AiCARR and CIBSE), governmental organizations (US department of interiors and culture heritage of Canada) and non-profit organizations (English heritage, European Committee for Standardization, and Historic Scotland) have as well produced a set of guidelines. A selection of these guides is listed in Table 3-2 guidelines on energy retrofits in heritage buildings.

Table 3-2 guidelines on energy retrofits in heritage buildings

Source: Author

Title	Date	organization
Guideline 34P: Energy Guideline for Historical Buildings and Structures	2016	ASHRAE (ASHRAE, 2016)
Building Resilience: Practical Guidelines to Sustainable Rehabilitation of Buildings in Canada	2016	Federal Provincial Territorial Ministers of Culture and Heritage in Canada (MTBA, 2016)
EN 16883 Conservation of cultural heritage - Guidelines for improving the energy performance of historic buildings	2015	CEN/TC 346 (CEN, 2015)
Planning Responsible Retrofit of Traditional Buildings	2015	STBA (N. May, 2015)
Energy Efficiency in Historic Buildings	2014	AiCARR (AiCARR, 2014)
Energy Efficiency Solutions for Historic Buildings: A Handbook	2014	3ENCULT (Troi et al., 2015)
Improving the Energy Efficiency of Historic Buildings – A handbook of best practice examples, technical solutions and research projects	2013	Co_2ol Bricks (D, 2013)
Short Guide 1: Fabric Improvements for Energy Efficiency in Traditional Buildings	2012	Historic Scotland (Historic Scotland, 2012)
Energy Efficiency and Historic Buildings Application of Part L of the Building Regulations to historic and traditionally constructed buildings	2011	Historic England (Heritage English, 2008)
The Secretary of the Interior's Standards for Rehabilitation & Illustrated Guidelines on Sustainability for Rehabilitating Historic Buildings	2011	U.S. National Park Service (A.E. Grimmer, 2013)
Energy Heritage – A Guide to Improving Energy Efficiency in Traditional and Historic Homes	2009	Changeworks (Changeworks, 2009)
Guide to Building Services for Historic Buildings: Sustainable Services for Traditional Buildings	2002	CIBSE (CIBSE, 2002)

These guidelines have many similarities, and mainly all of them are composed of the same structure, content and philosophy. They generally include background on conservation principles and how to apply them in the energy retrofit process, potential or recommended retrofit solutions, concluded by a set of case studies. However, they differ in their scope and purpose. Most of the guides take an approach considering the building type, few of them are composed by focusing specifically on the climate of a specific city or region.

These projects and guidelines have produced several retrofit strategies and assessment criteria, highlighting the main aims and intentions within the retrofit methodology adopted. The review reveals that in these guidelines, the main aspect of consideration regarding the retrofit process was considering the effect of different actions with maintaining the heritage value and character by defining elements and the context. However, the previous researches and guidelines have failed addressing the retrofit process at a large scale addressing the whole building performance in a holistic approach to heating, ventilation and energy efficiency, instead addressed the smaller scale interventions which were adopted regarding the envelope insulation alternatives; thermal bridges, and airtightness the approaches considered the different building components and construction details to make suitable junctions with different types of insulation.

The main components addressed were; openings with regards to their thermal performance, glazing, addition of secondary glazing or a complete replacement; external and internal walls in terms of their thermal mass, hydrothermal properties, and their insulation performance and the means to upgrade them, roofs were considered in terms of their insulation materials. The previous studies have only focused on flooring heat loss and only limited guidance to the insulation of traditional floors, with exception of Changeworks (2009) and the Historic Scotland (2012) have introduced the concept of modern floor coverings.

Fewer guidelines have incorporated the energy demand within the building's mechanical and electrical systems, addressed in "Building Resilience: Practical Guidelines to Sustainable Rehabilitation of Buildings in Canada", ASHRAE guidelines (ASHRAE, 2016), and English heritage (Changeworks, 2009), discussed energy saving measures applied to heating systems and mechanical ventilation systems (HVAC) approaches, regarding the upgrading or the installation of a new system, and the effect on the building's infra structure.

The applications of renewable energy, was addressed 3ENCULT European research project and the US's Secretary of the Interior's Standards, integrating solutions for electric and thermal energy production (solar technologies, wind energy, hydropower, etc), while considering physical impact of the applications on the aesthetic aspects of the heritage buildings.

The research projects and guidelines on the energy retrofit of heritage buildings have failed to address different climatic conditions. The current research to date has been influenced towards cold climates found in Europe and Northern parts of North America, it is likely as a result of the intensive research efforts in these areas, mainly concerned with thermal bridges, and airtightness. However, the different climatic conditions and building traditions in other areas must have a different approach in the retrofit process.

The hot climate of Egypt and the city of Alexandria, the main focus of this research requires a different retrofit approach, which would be more concerned with cooling and permeability rather than heating and insulation.

3.5 Heritage buildings retrofit assessment criteria – a literature review

Retrofits in heritage and traditional buildings in the recent studies are commonly described as a balancing act, where energy usage and conservation process are balanced against each other, achieving continued, long term use of the building while preserving its architectural identity. The two aims play the dominant role represented in a variety of criteria used to assess the impact of retrofit in heritage and traditional buildings. These can be grouped into five main categories: building fabric, energy generation, energy supply, indoor environment and economics.

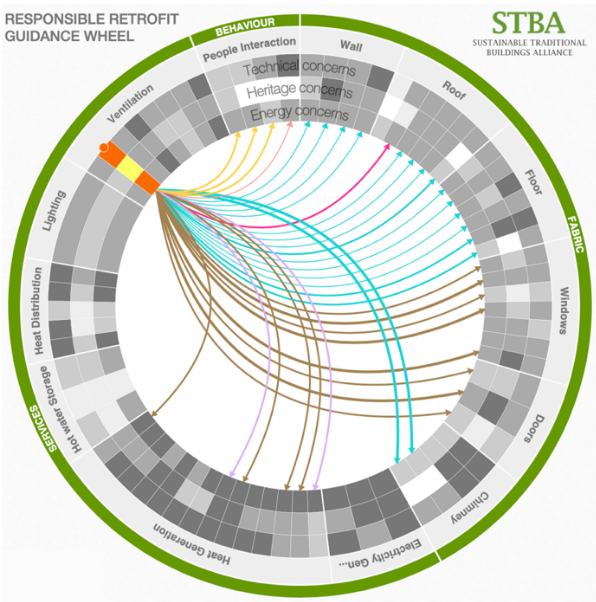

Figure 3-2 the STBA Green Wheel application (STBA, 2020).

Demonstrating the complexity of the assessment criteria, the Sustainable Traditional Buildings Alliance (STBA) identify the challenges of the heritage buildings retrofit regarding the complexity of interactions, and possible conflicting priorities and values of the proposed measures. Producing the Green Wheel designed to aid to decision making as a way of learning about traditional building retrofit, it aims to provide a systemic and holistic approach to retrofit design, application and use. The application reviews the different strategies and their impact on the different attributes within the building introducing the benefits, heritage concern, energy concerns, and all the related measures Figure 3-2, (STBA, 2020). Another similar application is OSCAR guides tool in the USA an initiative of the Association for

Preservation Technology (APT), guiding the process and offers strategies suited for the building's climate (OSCAR, 2020).

The retrofit criteria listed discuss a variety of alternatives, however, only or a subset of these are selected for any given retrofit project. The selection process must consider multiple, competitive criteria.

3.5.1 Building fabric

According to Drury et al. (2008) Conservation is the process of managing changes to a heritage buildings in a process that preserves its heritage values for present and future generations. Every heritage asset has its significance, with its own identity and distinctive character. Character refers to the visual aspects and physical features, the identify, and the appearance of the heritage building. The defining characteristics include; the overall shape of the building, its materials, decorative details, and interior spaces features (Nelson, 1988).

There is a set of guidance conservation principles as acknowledged by in order to preserve the heritage significance while dealing with heritage buildings, where energy retrofit decision making processes must also follow. These principles are acknowledged by ICOMOS (2013) as;

- Reversibility, changes should be reversible, and reversed when circumstances permit.
- Minimum intervention, seeking the option which reduces the impact on cultural significance,
- Authenticity, addition or changes should be identified from the original heritage set.
- Compatibility, respecting significance of heritage value involving no or a minimal impact.

(Wood et al., 2010) stated that the degree of applied treatment of a heritage building should be guided by its significance, this means heritage building classifications and different parts within the same building that differ can tolerate different levels of change.

Despite these common principles, there is a lack of coherent a methodology for using them to evaluate the retrofit impact on heritage values in practice. Some studies refer to principles according to common ICOMOS defined conservation criteria: reversibility, minimum intervention, distinction of addition, and new materials capability (Ascione, Cheche, et al., 2015), while others refer to the level of impact measures against the heritage significance evaluation: visual, physical, and spatial impacts on heritage value (Eriksson et al., 2014).

Embodied energy Historic England (2019) describes it as all the energy used for the building construction including extraction, production, delivery and installing the building materials, assed as the life cycle analysis. According to Munarim et al. (2016) It is considered a way to quantify the benefits of building reuse in a different way as it is usually discussed in terms of cultural and design values. Embodied energy can also represent the total energy consumed over the building's life cycle, which is usually between 10 and 20%. This percentage could increase or decrease according to the operational performance of the building (Ramesh et al., 2010).

Building on that as retrofit criteria, embodied energy can be considered in two ways; firstly, as criteria for comparing retrofit options to one another based on material related resource consumption. Secondly, as an extension of the conservation criteria, allowing a quantitative assessment of retrofit impacts against the removal of the existing building.

Embodied energy has a low impact on heritage building retrofit criteria, as the heritage value and the visual characteristics of the heritage building express a high significant value for the existing building preservation. However, it deserves to be another function in the sustainable retrofit.

Climate change vulnerability the vulnerability of a Heritage building to climate change can be defined into two aspects: risk of exposure and sensitivity to hazardous conditions and the capacity to adapt to the surrounding conditions. The potential for adaption of Heritage buildings to respond to climate change has become one of the most profound decisions faced by the different retrofit strategies, and can be considered an important criterion in evaluating the retrofit impacts. According to Cassar (2009) vulnerable heritage buildings are subjected to conflicted effects due to climate change, and might be at higher risk of inappropriate retrofits. Several studies deal with heritage buildings' vulnerability to climate change based on modelling simulations according to predicted future climate presented in a wide range of effects, Huijbregts et al. (2014) examined rainfall increase and flooding, also humidity Huijbregts et al. (2012) tested the changes in the outdoor temperature, while Lankester et al. (2012) simulated the changing environmental threats to tangible indoor heritage. With these issues being addressed it implies a proper retrofit could prepare the heritage building to remain in use under future climate changes.

Hygro-thermal behaviour heritage buildings control moisture by allowing the building fabric to "breathe", in other words, materials and assemblies absorb moisture and allow it to evaporate easily, in contrast with modern buildings. Modern buildings are designed to exclude moisture, using impermeable membranes, wall cavities and damp-proofing (Wood et al., 2010).

Many retrofits can change the moisture balance and drying capacity of the building fabric, increasing the potential of further damage or deterioration. These retrofits are applied to the building fabric, such as adding insulation, adding a vapor barrier, and air sealing, as well as changes to the building that have impacts on its fabric, like adding HVAC system, and altering the use of the building.

One of the most common applied retrofits affecting the building fabric is adding wall insulation, which improves the U-value of the building. This can improve occupant thermal comfort in addition to reducing the energy consumption of the building by creating a cooler or warmer wall surface temperature. Interior wall insulation has been more encouraged than exterior wall insulation since it greatly affects the building's appearance (Bleichen, 2012). However, according to Straube et al. (2007) interior wall insulation may result in poorer than predicted energy saving due the disruption of the moisture balance. Morelli et al. (2013) observed in the case of internal wall insulation, the temperature of the wall will decrease within the heating season decreasing the wall's drying capacity. Another point of view addressed by Wakili et al. (2014) considering internal wall insulation is that it gives less attention to durability and focuses more on the reduction of the U-values of the wall. Accordingly renovating any wall could be a potential risk to the durability of the building fabric, including freeze-thaw damage, interstitial condensation, and damages at the wooden beam ends embedded in the masonry

Window retrofit is another commonly used retrofit strategy impacting the urban fabric. The strategy includes the replacement of the heritage single glazed window with new, high performance windows reducing heat loss, but results in a loss of heritage fabric and an alteration of the building's visual character externally (Sedovic et al., 2005).

3.5.2 Energy demand

Energy consumption is typically measured in terms of annual energy savings as a result from the retrofit compared to the building's initial consumption and cutting down the greenhouse gas (carbon dioxide) and pollutants emissions (carbon monoxide, sulphur, and nitrogen oxides) (Alongi et al., 2015). In this way, the impact of different retrofit measures could be quantitively evaluated (Ascione et al., 2011). Retrofit studies evaluating the energy impact in heritage buildings are mostly dealing with modern buildings. Previous studies addressing energy demand failed for setting a criterion for dealing with heritage buildings, requiring the need to protect the building's fabric and visual character, limiting the types of interventions that could be used (external insulation, for example, is excluded due to its impact on the visual character).

Another consideration by Hensley et al. (2012) is to identify the inherited energy efficiency features of the building. Heritage buildings were often designed to take advantage of natural sources of heat, light and ventilation to respond to local climatic conditions (e.g. vents, shutters, courts, skylights). That contributes to better building energy performance.

Different strategies have considered a wide range of retrofits evaluating the energy consumption and means for reducing it, including different measures affecting building envelope (Ascione, Bianco, et al., 2015; De Berardinis et al., 2014), appropriate use of HVAC technologies available today (Alongi et al., 2015). However, one of the few retrofit studies examines the effect of the occupants' behaviour in heritage buildings. Ben et al. (2014) implied that modified occupant behaviour plays a major role in determining building energy use. It can provide an energy saving retrofit exceeding the physical retrofit alone. Other study by Geva (1998) mentioned the inherited energy efficiency features and taking advantage of these included characteristics and suggests a passive retrofitting measures to conserve energy (e.g. walls and roof insulation and air infiltration).

3.5.3 Energy generation and supply

A building's energy generation and supply can be retrofitted, altering its main source of energy, or can add energy production on-site. These two methods can use renewable energy sources, such as solar electric, solar thermal, wind and hydropower. The effectiveness of these retrofits is measured as a proportion of the total energy demand preserved through alternative energy production.

The main concern with energy supply retrofits in heritage buildings is their impact on the heritage building's visual character and how they could damage the urban fabric. The impact on the visual character could have different effects, for example, solar thermal collectors may disturb building's heritage character as they are highly visible (Henning, 2012). Another concern is the selection of the appropriate retrofit system which should be simply installed and robust in addition to its life span, which might be shorter than the life span of the building with a high capital cost (Changeworks, 2009; Kandt et al., 2011) . However, some energy supply retrofit strategies have a low visual impact on heritage building's character or fabric, for example fuel switching, combined heat and power and biomass boilers (Salata et al., 2014)

A main consideration is the negative impact on the heritage building's visual character and their effect on the urban fabric, as these systems have a large surface area and must be located on the building's exterior surfaces or site. Several studies tend to find new technologies that can minimize the visual impact of the retrofit for a minimum intervention, reversibility, and can hold a promising retrofit for heritage building's retrofit (López et al., 2014; Moschella et al., 2013).

3.5.4 Indoor environment

Building occupants there are five factors concerning the measurement of the indoor environment affecting the building's occupants according to Asadi et al. (2017): thermal comfort, indoor air quality (IAQ), privacy, light, and sound, which together form the indoor environmental quality (IEQ). For heritage buildings, there are two major IEQ considerations. Firstly, occupants' cultural context and behaviour changing over time, and indoor conditions at the time of the building was constructed which may no longer be deemed acceptable. Secondly, in some cases indoor quality may be viewed as a character defining feature of the retrofit.

Most IEQ studies in heritage buildings evaluate the acceptability of thermal comfort conditions taking two forms. In one form the goal is not to evaluate a retrofit measure, but to compare the performance of the heritage building against modern thermal comfort standards (Cardinale et al., 2013; Gou et al., 2015). Another case is examining the heritage performance versus modern buildings (Cantin et al., 2010; Nematchoua et al., 2014). Other studies predict whether indoor conditions resulting from a specific retrofit would result in thermal comfort (Ascione et al., 2011; Şahin et al., 2015). However, these studies not dealt with the level of achieved thermal comfort and IEQ after the balanced retrofit.

In addition, the cultural context in terms of privacy and occupants' behaviour. The preservation of the occupants'' way of life and the established privacy Is an important issue while considering the different retrofit strategy. Hence, the retrofit strategy adopted must consider the outcomes of the benefits of the retrofit on the internal environment improvement against the occupants need and behaviour, insuring the reliability of the retrofit strategy adopted and user's acceptance.

The other three IEQ have been less addressed concerning heritage buildings performance and possible retrofit strategies. The studies have primarily examined heritage buildings air quality, sound, and daylighting. (Hanna, 2002; Rohdin et al., 2012).

Collections In historic and heritage buildings housing collections and significant artefacts, the need to protect them is a critical consideration. The risk to collections can be estimated based on nine primary agents of deterioration: fire, theft, water, physical forces, pests, light pollutants, incorrect temperature, and incorrect humidity (Michalski, 1994). The last three are most directly relevant to energy retrofits.

There are several control strategies methods according to Tétreault (2003) that avoid or block pollutant sources, dilute or filter them through mechanical or natural ventilation and filtration. The most commonly retrofit research and application are on the effect of temperature and humidity on collections. Temperature and humidity are related agents of deterioration, and collections are affected not only by their level in space, but also by their fluctuations (Erhardt et al., 1994). However according to Brown et al. (1996) retrofit buildings with collections must not only consider the needs for collections, but also the conflicted outcome with human thermal comfort needs, building fabric damage risks, and building's energy consumption.

3.5.5 Economics

The monetary costs of building energy retrofits can include the initial cost of manufacture and installation, cost of operation, cost of maintenance, and cost of replacement. An important variable in the monetary costs is considering the time period (Cluver et al., 2010). According to Ma et al. (2012) the selection process of the retrofit process is a balance between capital investment and benefits from the measure implementation. Economic analysis weighs these retrofit measures against each other. These methods are generally paired with estimates of whole building energy consumption to provide an indication overview of retrofit alternatives for energy efficiency against cost effectiveness. The methods include: annual operational energy savings, capital costs, payback period, lifecycle costs (Ascione, Bianco, et al., 2015; De Berardinis et al., 2014). Most studies on the economic criteria have only focused on the return of a single building, with no economic vision for upgrading a heritage stock.

Most studies in formulating approaches to assessment criteria have addressed natural ventilation as a complementary means of improvement, these studies have failed to address natural ventilation and passive cooling strategies for heritage building as a holistic approach for improvement, needing a systematic approach rather than an element-based approach. However, the research project 'Between Heritage and Sustainability – Restoring the Palace of Westminster's nineteenth century ventilation system.' Focused on the ventilation system, constructing an approach based on the understanding of the historic system of the project, and formulating alternative scenarios for retrofitting the ventilation system (Schoenefeldt, 2016).

3.6 Natural ventilation a retrofit approach – a literature review

Demonstrating capacity for better levels of energy efficiency and thermal comfort has become a critical challenge for retrofitting heritage buildings and insuring their survival. Dealing with a hot climate like the city of Alexandria's heritage context requires a different retrofitting strategy rather than the main strategies established in the previously discussed guidelines.

According to Billington (1982) ventilation is an effective means of ameliorating the internal environment, which is usually achieved in three prime motive forces: mechanical means (fans, pumps, HVACS), heat (stack effect) and wind pressure. According to (SPAB, 2014) Research on the subject has been mostly restricted to mechanical ventilation specified as a part of energy retrofits, however such approaches heavily dependent on buildings being sealed to function properly. A study by Taylor et al. (2011) has found that there was no support evidence for improved performance considering mechanical means. Another major drawback of relaying on the use of mechanical ventilation system according to (Saurav et al., 2019; Teke et al., 2014; Zhang et al., 2013) is that it consumes a significant amount of energy in a building, ventilating and air conditioning system (HVAC) accounts for 40 to 60 percent of the total energy. Considering the rising fossil and energy costs and carbon reduction policies, people's awareness has increased and attention is focusing towards the use of an alternative solution. In the light of such concerns, natural ventilation becomes a viable and sustainable method in providing suitable environment and is increasingly considered in many building designs.

Wind driven natural ventilation in buildings is one way of reducing energy use by dependence on mechanical ventilation. It became a necessity to focus on the integration of passive cooling strategies for indoor climate conditioning and benefit from the natural resources as a retrofitting measure against mechanical strategies and reduce carbon emissions resulting from running a building.

3.6.1 Effect of natural ventilation on internal environment

The successful application of natural ventilation, can be defined by its cooling effect and the possibility to ensure adequate indoor air quality and thermal comfort with the reduction of the energy used and carbon emissions of the mechanical systems used. Achieving proper levels of occupant's thermal comfort and indoor air quality requires the control of air flow rate. Ghiaus et al. (2005) Determined that the building's internal environment in order to perform adequately in terms of natural ventilation, regarding passive cooling, acceptable levels of thermal comfort, and indoor air quality showed that it is dependent on the airflow rate factor. The adequate air supply provides the convection evaporative effect providing better thermal comfort, while the air changes per hour rate provides oxygen supply, odour and pollution removal. However, previous studies of natural ventilation have not dealt with a systematic approach for heritage building application.

3.6.2 Thermal comfort

Thermal comfort is defined as "that condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation"(Ashrae, 2013). There are several factors that can affect the thermal sensation, these factors can be categorized under three categorise; a) the environmental factors such as; temperature, mean radiant temperature, humidity and air velocity, b) personal or human factors such as; human activity level and clothing level, c) organic or contributing factors such as; age, gender, food, drink, human adaptation, colour of internal surfaces and lighting system. According to these factors the environmental and physical factors were the most effective, while the organic and contributing factors were reported by researchers that they provide a slight or sometimes neglected effect in relation to thermal comfort. (Allard et al., 2006) (McMullan, 2012).

Santamouris et al. (1996) states that wind is a major factor that an architect can use, air velocity is considered one of the most important factors that can greatly impact thermal comfort. In other words, good indoor air movement can provide sufficient air velocity to maintain an acceptable level of thermal comfort when temperature and humidity fail to do so, this air movement can be internally provided as natural ventilation. In addition, (Givoni, 1994, 1998; Watson et al., 1983) describes natural ventilation works within the convection mode of heat transfer, as the air with low temperature flows over a higher temperature surface and carries away heat reducing the surfaces temperature, this concept applies on both; human body and building fabric, which is the target of the strategic design level of natural ventilation. Through this thermal comfort can be promoted within warm and hot climates.

The studies indicate the main strategy that should be considered when designing for natural ventilation, "Comfort ventilation or daytime ventilation", is how a direct physiological cooling effect is delivered through increasing the air speed around the human body, providing by this mean heat loss and higher evaporation rate, which makes occupants feel cooler.

(Givoni, 1994) sets out the principles of Comfort ventilation as one of the simple behaviours by which humans can adapt themselves to the surrounding environment and its climatic conditions. The occupants can do that by using the available controls to them, in order to provide air movement. Givoni added comfort ventilation can improve the physiological comfort of occupant by creating airflow and does not allow to reach a certain temperature as the flow of outdoor airflow extends the upper limits of acceptable temperature and humidity. However, the application in climates similar to Alexandria when a building is cross ventilated during daytime hours the temperature of the indoor air and surfaces follow closely the ambient temperature. Therefore, there is a point in applying daytime ventilation only when indoor comfort can be experienced at the outdoor temperature, with acceptable indoor airspeed for optimizable use of daytime comfort ventilation. The effect of outdoor airflow on indoor daytime temperature depends on the temperature that the interior would have without the ventilation, depending on the design details of the building, its internal heat generation and the amount of penetrating solar energy.

Figure 3-3 shows the boundaries of the outdoor temperature and humidity within which indoor comfort can be provided by natural ventilation during the day and with indoor airspeed about 2 m/s after Givoni (Givoni, 1998).

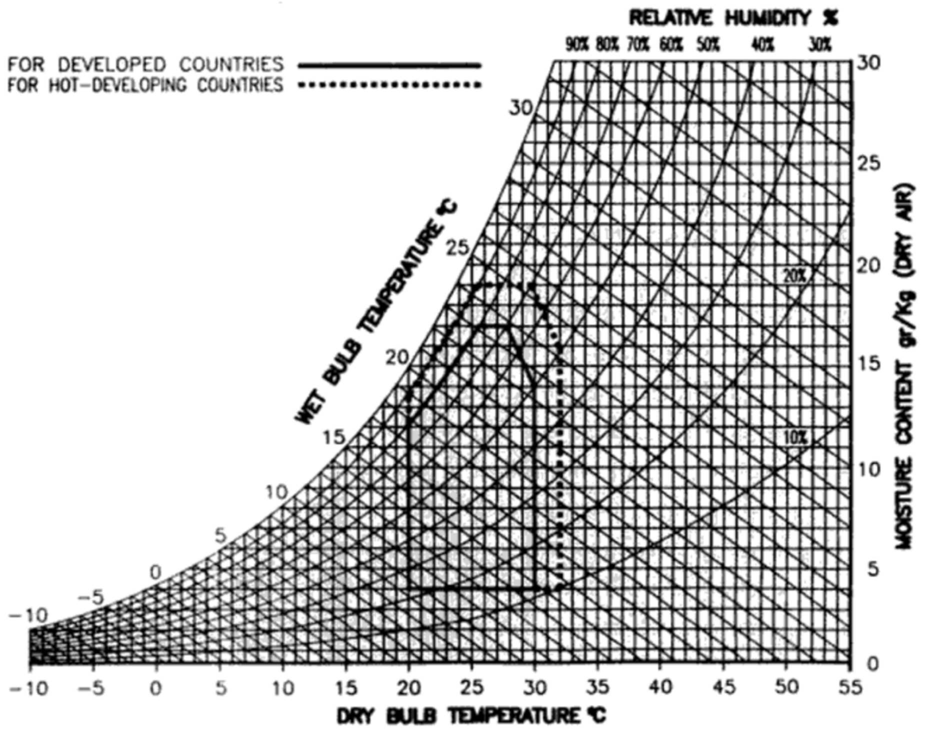

Figure 3-3 boundaries of the outdoor temperature and humidity within which indoor comfort can be provided by natural ventilation during the day and with indoor airspeed about 2 m/s after (Givoni, 1998)

The comfort ventilation is dealing directly with the human body. It is based on the theory that high airspeed around the human body accelerates the skin’s evaporation rate is improving accordingly the heat dissipation from the human body (Givoni, 1981; Santamouris et al., 1996). Which in useful in shifting up the comfort upper level providing direct cooling effect and decreases human discomfort due to skin wetness and high humidity level.

In comfort ventilation strategies, two different impacts on air velocity were determined by (Givoni, 1981); The heat exchange of the body that happens by conviction; Influences the evaporative capacity of the air. Many boundary conditions were found to have a great effect on comfort ventilation such as; humidity level, clothing and external temperature. However, Due to the variation distribution of air velocity within the space, comfort ventilation should always be defined in terms of velocity rather than change rate or supply. The optimum air velocity that fulfils different boundary conditions and considers the two impacts can be calculated using the equation of the index thermal stress assuming the sweat rate equal zero Equation 3-1, Equation 3-2 and Equation 3-3. The incorporated coefficients in this equation are given in (Givoni, 1981, 1998).

Equation 3-1

$$S = [\, M - 0.2(M - 100) \pm \alpha\, V^{0.3} (t_a - 35) \pm I_N K_{pc} K_{cl} (1 - a (V^{0.2} - 0.88))]\, e0.6^{(E/Emax - 0.12)}$$

where; S = required sweat rate Kcal/h, M = metabolic rate Kcal/h, α = coefficient depends on clothing, V = air velocity m/s , t_a = air temperature c°, I_N = normal solar intensity Kcal/h, K_{pc} = coefficient depending on posture and terrain , K_{cl} = coefficient depending on clothing, a = coefficient depends on clothing, e = the base of natural logarithms, E = required evaporation cooling Kcal/h;

Equation 3-2

$$E = (M-W) \pm C \pm R = M - 0.2\,(M - 100) \pm \alpha\, V^{0.3}\, (ta - 35) + IN\, Kpc\, Kcl\, [\, 1 - \alpha\, (\, V^{0.2} - 0.88)]$$

Equation 3-3

$$Emax = p\, V^{0.3}\, (42 - VPa)\ Kcal/h$$

where; Emax = maximum evaporative capacity of the air; P = coefficient depends on clothing, V = air velocity, 42 = vapour pressure of the skin at 35°C mmHg, VPa = vapour pressure of the air mmHg.

Table 3-3 coefficients for different clothing level and postures, after Givoni (Givoni, 1981)

Clothing	Coefficients				Posture	terrain	K_{pc}
	A	K_{cl}	α	P			
Semi-nude: bathing suit and hat	15.8	1.0	0.35	31.6	Sitting with back to sun	Dessert	0.386
Light summer clothing	13.0	0.5	0.52	20.5		forest	0.379
Military overall over shorts	11.6	0.4	0.52	13.0	Standing with back to sun	Dessert	0.306
						forest	0.266

3.6.3 Indoor air quality

. According to (Awbi, 2003) internal environments, the air is composed of more polluted chemical substances, including tobacco smoke, volatile compounds, radon, aerosols, and many more. Consequently, a poor ventilated space can be responsible for what is called a sick building syndrome which can affect the building's users in three ways; discomfort represented in bad odours, high humidity, carbon dioxide and high moisture levels; health effects in the form of transmission of airborne disease, burning eyes, and chest symptoms; chronic health effects.

(Ashrae, 2013; Germano et al., 2002) in their study concluded that, buildings have been designed to be more airtight and sealed for the preservation of heat, the lack of fresh air and poor ventilation can have a major influence on people's health and well-being. The indoor environment may have pollutants present, the source of some of these pollutants can be produced by the building itself, the furniture, occupants, equipment, and the flooring emissions such as radon and methane. In addition to the pollution coming from the external environment from vehicles emissions, process discharge, etc

These studies have shown that natural ventilation other than improving thermal comfort, it can promote for better indoor air quality and a better healthy environment, poor indoor environment or the sick building syndrome is directly related to the poor ventilation characteristics of the building. Token together, reducing issues related to building sickness (nasal blockage, dry throat, etc) and the environmental benefits for passive means of cooling, this approach would therefore seem to be a definite need for emphasizing.

3.6.4 Conditions for natural ventilation effectiveness

Internal environment thermal comfort can be promoted for occupants by the proper application of natural ventilation, wither by increasing the airflow rate and increasing the cooling sensation, or indirectly using night ventilation to cool down the thermal mass of the building, accordingly providing cooler temperature indoors during the daytime.

Several studies were performed on the effect of ventilation on heritage buildings in hot climates. Michael et al. (2017) investigated the influence of natural ventilation and its effect on the indoor environment in the vernacular architecture of Cyprus, examining the effect of day time ventilation in which the windows remained open, another study by D'Agostino et al. (2013) in Crypt analyzed possible ventilation scenarios corresponding to a combination of different outdoor climatic conditions and airflow inlets through the manipulation of the building openings simultaneously. Silvero et al. (2018) and Cellura et al. (2017) studied means for improving thermal comfort in historic center of Asuncion and Agrigento respectively, several retrofitting solutions for the building's envelope were assessed, while considering the natural ventilation both studies suggested an operational schedule for windows opening depending on the externa conditions. The studies indicate natural ventilation is an appropriate passive design strategy for the hot and humid areas, however they failed to address natural ventilation as a holistic system for improvement they have only focused on assess the optimal features of the indoor climate and different windows operation.

3.6.4.1 Climatic suitability for natural ventilation

The retrofitting decisions approach is dependent on the potential of the context expressed in either the external environment climate (external temperature, relative humidity, airflow speed and direction), and other factors dependent on the built environment (building mass, adjacency profile, building orientation, building size, façade design, and opening location and size.

The potential for application is related to several factors, Santamouris et al. (1996) indicated that every (0.15 m/s) increase in the air velocity can compensate 1°C rise in air temperature in moderate humidity (less than 70% RH). This is not an absolute rule as it is limited to the maximum accepted air speed by the occupants according to the Beaufort scale. However, for the acceptable indoor air velocity, ASHRAE guide (ASHRAE, 2005) has put an air velocity of 0.8 m\s as a maximum allowable airspeed indoors. However, this speed was considered by ASHRAE in air-conditioned office building specially to avoid disturbance of paper in the work places.

In terms for the maximum cooling effectiveness Givoni (1994) indicates increasing air velocity around the human body can be achieved at internal temperature up to 33 °C however, no significant effect on heat sensation along with significant effect in reducing discomfort due to skin witness was observed at internal temperature between 33-37 °C. in temperatures above 37 °C increasing air velocity negatively effects thermal sensation, but needed to reduce excessive skin wetness. (Faggianelli et al., 2014) demonstrated these outdoor climate conditions were the maximum air temperature does not exceed 33 °C and the temperature difference between day and night is less than about 10 °C. these conditions were found to be the typical climatic aspects found in worm humid climates.

Givoni proposed these internal climatic boundary conditions, in which the comfort ventilation is desirable and has an effect on thermal comfort depends on the assumption that the indoor airspeed is 1.5-2 m/s and without neglecting the humidity level. (Watson, 1983) added in hot climates, daytime temperature exceeds 35 °C increases the heat gain by convection and the dry air accelerates the evaporation rate from the human body in still air conditions, which makes comfort ventilation during daytime not preferable for convective heat exchange.

When comfort ventilation is, applicable there are some indication that can judge the efficiency of comfort ventilation strategy in a building, through; Indoor airspeed on the occupants' level (1 m above floor) reaches 35-50 % of the outdoor wind speed. Secondly a high mass building, a reduction of 2-3 °C in the internal temperature in comparison with the outdoor temperature (Givoni, 1998).

The diurnal temperature patterns of the low mass and the height mass buildings, the cooling of the building mass at night enabled it to absorb heat from the ventilation air during the day time hours, enough to lower the maximum temperature significantly. This means that the thermal mass can lower the daytime temperature and improve the comfort of the occupants in buildings ventilated day and night, provided that the rate of the night ventilation is sufficient to bring the indoor minimum temperature close to the outdoors's minimum.

Figure 3-4 demonstrates that the maximum temperature of the high mass building is continuously lower. The cooling of the building's mass at night enhances ventilation enabled it to absorb heat from the air during daytime hours, enough to lower the maximum temperature significantly.

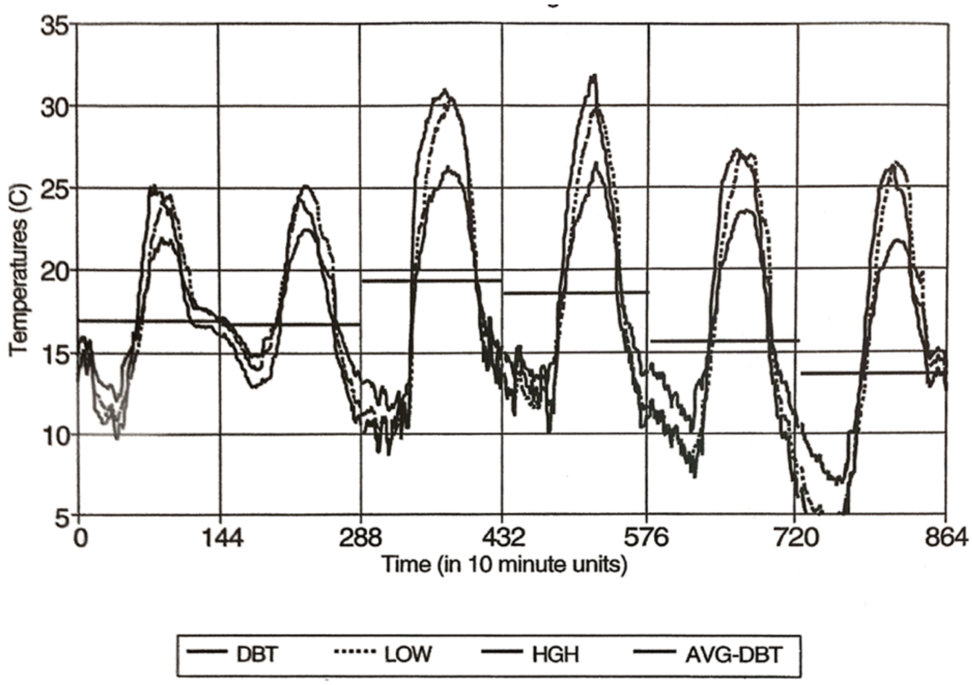

Figure 3-4 diurnal temperature patterns of the low mass and high mass buildings (Givoni, 1998)

3.6.4.2 External constrains for natural ventilation

The external urban environment can provide constrains for depending on natural ventilation. These constrains are pollution and noise levels. The level of these constrains can affect applying natural ventilation strategies according to URBVENT project can be specified quantitively and qualitatively. In addition the levels can be easier understood by the non-specialist and measured by subjective answered questioners (Ghiaus et al., 2005).

Outdoor air pollution can restrict the use of natural ventilation, as mechanical or air conditioning systems filters cannot be used. The indoor air quality is directly related to the outdoor air pollutant concentration, specified according to the air exchange rate and the pollutant reactivity (Hayes, 1991). The WHO (2006) stated the main external pollutants, which are usually monitored in large cities are (SO_2, NO_2, CO_2, O_3, suspended particle matter and lead), the levels of concentration of the pollutants in the internal environment is dependent on their reactivity. The ratio of indoor concentration is proportional to outdoor concentration and airtightness. However, the facade airtightness is a key factor and an important characteristic of natural ventilation property of the building. Hence the external air pollutant concentration is an important while considering the use of natural ventilation.

External noise is commonly considered as another barrier to natural ventilation. The most common source of noise pollution in the urban context is the road traffic. Germano et al. (2002) implied that the noise intensity is proportional to the street canyon size and number of vehicles per hour, and can be reduced with the building height. Methods of identifying noise levels in the urban context are critical if the potential of natural ventilation retrofit is assessed. The deducted noise levels can be compared at which building occupants can accept in order not to compromise the natural ventilation strategy.

Climatic studies in of Alexandria in section 2.6 indicated the potential applicability of natural ventilation there. However, an appropriate building design according to (Santamouris et al., 1996) can provide continuous direct high-speed airflow at the occupants' level through the building which enhances comfort ventilation. Hence, where sufficient wind speed is available, the question arises as to the building's natural ventilation strategies, for instance where large shaded windows along with high storage thermal mass are required in the design for an enhanced performance.

3.7 The methodology for the natural ventilation retrofits of heritage buildings – a literature review

The previous parts have addressed the purpose and beneficial gains of retrofitting heritage buildings, especially under the umbrella of passive cooling and natural ventilation and its impact on thermal comfort and indoor environment quality in Alexandria's heritage typology and climatic considerations. However, it is important to provide an approach and a procedure to make it possible to also recognize and integrate the cultural heritage values and energy retrofit application.

The building retrofit system optimization process is to acknowledge, implement and apply to achieve the most enhanced energy performance, providing indoor thermal comfort. This must be done in coherence with the existing building's characteristics and subsystems with the most cost-effective retrofit technology. These different issues must be the key factor in determining the most appropriate existing building retrofit project solution.

Heritage building retrofit is a complex process, balancing between the cultural significance of the heritage buildings and their energy performance. According to the different research and implementation regarding a sustainable building retrofit, previously studied and discussed, the process can be expressed in a number of phases having a clear vision towards the same approach and criteria of implementing the methodology. Here, the process established by (Galante et al., 2012; Khodeir et al., 2016; Ma et al., 2012; Webb, 2017) has been modified to address the sequence of considerations regarding natural ventilation strategies applied in three phases.

The process starts with the pre-retrofit activities, identifying retrofit options, and ends with the post-retrofit activities. Accordingly, each step of the process requires different strategic planning, methods and tools selection.

Initially the pre-retrofit activities would include; the initial heritage survey, through this phase a complete image is projected regarding the heritage significance and a complete understanding of the heritage building's fabric and historical context. This phase includes establishing the project targets and goals and sets an indication of the extent and limits of the proposed retrofit. Followed by the energy audit, with regards to the building characteristics and natural ventilation, this phase would analyse the data and the natural ventilation performance and on-site survey according to the intended retrofit strategy. The process would initiate strategies to be implemented.

The methodology would move on in accordance with the natural ventilation strategies to identifying retrofit options and strategies, considering the current performance and the building characteristics. Followed by quantifying the results through computer simulation models with regards to the heritage building's fabric, indoor environment, and economic impact then develop an action plan. The intended plan is then reviewed, in case of unsatisfying results other retrofitting, measures are considered again.

In case of satisfying results, the next step would be implementation and commissioning followed by the validation in the post-retrofit activities. In this step measurements and occupants' surveys are conducted to test the performance of the retrofit. However, in case that the results are not as required, possible amendments could be done to the implementation phase.

3.7.1 Pre-assessment of culture significance and building's performance

Through this phase, the scope of work and project targets must be defined. A proper understanding of the building's heritage character should be used to define the level of intervention. In addition to that, a survey is also required in order to understand the building's operational problems and the occupants' concerns.

3.7.1.1 Cultural significance and classification

The classification of heritage buildings can be considered a comprehensive indication of the extent of alteration possible. This part will discuss the main aspects of cultural heritage values and how to assess them depending on the level of cultural significance.

Dealing with heritage buildings has to start with a definition of the building itself and its association with cultural significance. The values of cultural heritage like historical, artistic, scientific or urban value. These values are usually the basis for heritage buildings to be entered into the lists of protection. Listed buildings and protected monuments are no longer limited to the classical hierarchy of heritage values, such as castles, town halls, churches, mosques and prestigious housed. In fact, the need for preservation is not depending on either its age or function.

The complexity of cultural values has been recognized as 'essential for cultural heritage'. This is discussed on many levels; international level, as indicated in recent charters and policy papers (ICOMOS, 1987) ,(UNESCO, 1972). On a practical level, it's not just the preservation of values but rather the care for elements those values are related to. While dealing with these types of cultural values, information about multiple layers of significance and subsequent practical consequences must be provided. This means a clear vision of what is to be preserved and what can be changed. Classification of heritage buildings can be considered very useful in finding solutions for a significant number of buildings with similar characteristics. Most buildings are listed because they have specific individual characteristics. However, dealing with architectural identity is not depending on a single building, the process should consider the conservation of the whole area identifying it as a conservation area. Consequently, it is very important that the assessment identifies the cultural values of the whole context, identifying different retrofitting criteria and interventions preserving these identified values.

Historical analysis and background

In addition to technical aspects, which is an important factor in terms of physical building issues, the historical analysis is a part of preliminary investigations. According to Troi et al. (2015) each retrofitting plan for a heritage building requires a precise knowledge of it. This knowledge also relates to an accurate information of the building's construction development. On the basis of the historical analysis, it is possible to define the heritage value of the building. The genesis of a building is usually represented in the various stages of construction, providing guidance for the appropriate retrofitting intervention. The level of details of the analysis depends on the available primary and secondary sources, and the available resources. In order to describe the building, the assessment is based on the following criteria; building description, history, environmental value, cultural value, and architectural value. The various methods of analysis and documentation are adapted to the building character in terms of reference. Several practical examples showed that a good preliminary investigation helps achieving better results with lower costs.

Building's heritage level (list of protected buildings)

The protected building list acts as a basis for the historical analysis for documentation and exploration of heritage buildings. The information is a necessity for a justification of cultural significance. It is collected in the form of texts, images and maps to justify the interest of conservation (ICOMOS, 2003).

The scope of data gathered by this stage can be very different according to the available data: from the simple compilation of a building to a comprehensive assessment of the cultural significance. Data are collected during a building survey partly in combination with archive information. This list of protected buildings is usually available in different countries according to their monuments' classification defining the level of intervention.

Building related documents

A specific information regarding the heritage building is needed, after performing the first stage. The nature and the scope of this analysis follows certain constructed related issues, allowing a specification of building's evaluation and therefore planning tailored to the specific needs of the heritage building. The aim is to understand the building as a record of history. In this regards, historic aspects, as well as building technology and construction issues. This analysis contains a graphic survey of the exact measurements of the building, carried out using traditional or advanced 3D methodologies, supplemented by building's observation, archival research. This task is complex, and requires a multi-disciplinary coloration including building researchers, conservators, historians and architects, depending on need.

However, the task is not only to collect the data, but also to interpret these findings within the historical context. The completion of this task is done in the form of texts, pictures, and drawings in line with their assessment (Troi et al., 2015). This approach has proved giving a comprehensive overview of the heritage building's structural changes, based on the findings it is possible to create reconstructive drawings of different historical changes.

Building geometric measurements

A retrofitting process requires a precise knowledge of the building fabric. The first step is accurate building geometric measurement which may also contain additional information on materials and constructions. This would be the basis for all further investigations. A good building plan usually contains information about the original construction process. According to Troi et al. (2015) these drawings would include direct observations from on-site survey of the construction resulting in additional valuable information. Interpretation will then flow from observation directly into the drawings shown in Figure 3-5and Figure 3-6. The method of building survey is applicable regardless of the age of the building. However, the level of the building's survey details depends on the nature of the building and the condition of the assignment. For buildings of the twentieth century, good floor plans are usually available in the archives depending on the country. These drawings if available must always be checked against the current state of the building.

The technical findings of the survey can range from a pure manual work to more advanced and computerized measurements, to 3D scanning with its post-processing. The measurements can also be completed by photogrammetric surveys, Figure 3-7. These represent the actual situation, but can also be created on the basis of contemporary photographs, just like the scan. As built plans might have gaps according to Prizeman (2015), for example in the case of non-visible areas, they can be completed by technical methods, such as endoscopic measurements, ground penetrating radar, and active infrared thermography (Troi et al., 2015). In some cases, core samples are required, but it is important to use non-destructive methods.

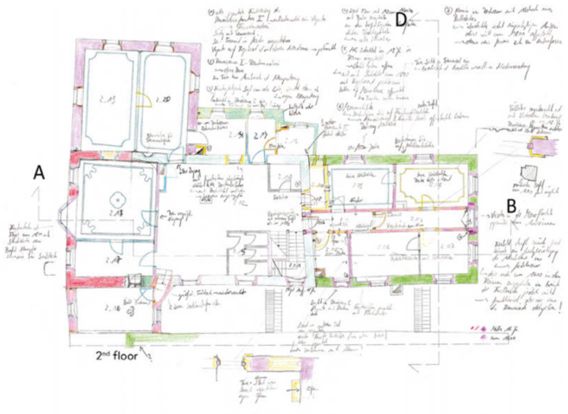

Figure 3-5 Plan showing the different construction phases of the Bolzano Waaghaus (Troi et al., 2015)

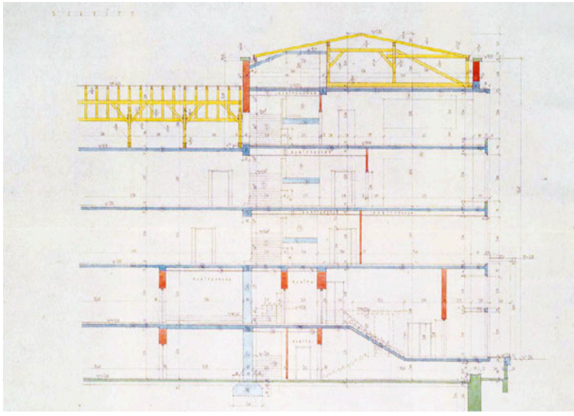

Figure 3-6 Original construction plan of hotting Secondary School, Innsbruck (Troi et al., 2015)

Figure 3-7 photogrammetric scan done by Agysoft photoscan software (researcher)

Reference method and historical sources

Designs and construction methods can be evaluated referring to architectural history and thus may indicate construction time and methods. Troi et al. (2015) implies for most of heritage buildings, an investigation of design elements and decoration is an essential. With such analysis, it is useful providing further information about time of origin, and can compare it to a similar structure of the same style and time period of construction. These studies can provide different information not only for visible layers but also covered design phases and materials. The results from such method investigation, inspection, and analyses require methodological and comprehensive interpretation.

In addition, a study of scientific literature is proven to be useful according to Troi et al. (2015), to get an overview of the building's history, its built environment, or its artistic evaluation. This covers text regarding the building itself, and scientific contribution to the building type, local construction history, and specific features in the construction, such as roof structures or ornaments. These information about the history of the building can be gained from:

- Pictorial sources such as artistic representations, plans, maps
- Text sources such as letters, documents, newspapers
- Material sources such as buildings, works of art, coins

The findings from these sources complement the results of the building's survey and can explain different findings. Plans of the construction phases can provide information about the causes of joints between various parts of the building, and a comparison with the existing construction documents makes dating possible.

Historic reconstruction

Considerations of how the building is currently used as opposed to how it was designed to be used are critical as they may raise further understanding and opportunities. The process involves using the building's historical analysis, archival drawings, reference methods, site investigation and technical analysis to deduce the design and the technical performance of the heritage building to reconstruct the performance of the building the way it was intended to perform in the original context.

According to Schoenefeldt (2018) the historic reconstruction method can improve the way of understanding the heritage building's technical operation and principles, in which can be reused and integrated in the retrofitting strategy offering a more sustainable approach.

The reconstruction method is mostly performed using computer simulation of the heritage building's original layout. In the case of this research inspecting the natural ventilation, computational fluid dynamics would be used (CFD). The results will later on compared with the building's current natural ventilation performance. Offering insights into the building's intended design concept and how its operation differed from current use.

3.7.1.2 Building performance and energy assessment: energy audit, performance assessment and diagnostics

The energy audit in general is used to analyse building energy data and identify areas of energy excessive use. It is also used to propose no and low-cost energy preserving plans. The energy performance through this phase is compared to energy benchmark criteria using performance indicators or green building rating systems. Through this phase improper control schemes and any malfunctions in the building can be identified.

The performance and energy audit according to (De Santoli, 2015) are one of the fundamental processes of energy upgrade for buildings. So, it is essential to clearly define the purpose and method of execution. It involves the inspection and analysis of the use and consumption of a site, building, or system. This can be done with the objective of identifying the potential for performance efficiency improvements.

While considering the natural ventilation as a passive cooling retrofit strategy the focus of this research, Ghiaus et al. (2005) describes the process with collecting continuous or spot measurements of thermal comfort parameters (air speed temperature, relative humidity, and mean radiant temperature) and compare them against the values of thermal comfort standards and the amount of energy saved from the reduction of using mechanical alternatives for ventilation. Here, considering monitoring indoor environmental conditions is a major aspect in considering heritage building retrofit criteria. It is used mainly to evaluate human thermal comfort.

The computer simulation is mostly performed when an input of parameters describing the building is given to a model to predict output variables of interest. In a retrofit process, a computer software is used to simulate the building's current performance, which serves as a baseline against simulated retrofit solutions. The software used is considered according to the retrofit model. In the case of this research inspecting the natural ventilation, computational fluid dynamics would be used (CFD), which would be discussed later on. However, according to (Blocken, 2015; Franke et al., 2010) a further use of environmental monitoring data is to calibrate building energy simulation tools ,computational fluid dynamics. Referring to the heritage building, the energy audit is a procedure aiming at defining the current performance of the building and identifying the possible recovery, improvement and solution for energy saving.

3.7.2 Identify retrofit options

Identification of retrofit options considering natural ventilation design strategies. This phase includes the use of appropriate energy models, risk assessment methods and economic analysis. knowledge and understanding the technical performance design and principles provided by historic research of the building can be used into retrofitting the current system, providing a more sustainable ventilation measures (Schoenefeldt, 2018). The different natural ventilation retrofit alternatives' performance can be assessed. These different alternatives could be later prioritized based on energy and non-energy related factors.

The energy retrofit measures and the incorporating of renewable energy sources criteria according to (Ma et al., 2012), are equivalent regarding all measures recognizing the built heritage and the impact of the results. In contrast with standardized energy efficiency guidelines the retrofit of heritage buildings must consider other aspects. The process should consider building's appearance, structure and existing materials and must consider that amendments follow the conservation principles. Consequently, the decision-making process must consider the cultural heritage in parallel with the energy retrofit alternatives and the structural issues. The impact of the amendments must be considered as a whole holistic approach enhancing the single elements and their impact. According to the scope of the research, initially a comprehensive list of the different natural ventilation design strategies including the passive systems for their application, will be demonstrated in the following chapter.

The heritage significance of the intended building for natural ventilation retrofit must be established for evaluating the impact of the amendments on the building and assess it heritage balancing process. However, previous researches failed to address natural ventilation passive systems applications selection process in terms of tailoring it towards and considering the unique characteristics of a specific heritage building.

Generally, the official heritage designation catalogues can be used as an indicator of the heritage level and significance defining the accepted level of intervention. However, these catalogues don't usually offer a detailed assessment criteria and character defining elements of a context or a building. Hermann et al. (2015) defined heritage assessment criterion evaluating the impact visually, physically and spatial on a variety of categories grouped into urban district, building exterior, and building interior, demonstrated in Table 3-4. With this structure purposed, the heritage impact of different retrofit strategies can be assessed in details, not only for an overall value of the building. Differentiation for significance can be made, and the proposed strategy can distinguish its impact wither its visual appearance, physical, or spatial configuration.

Table 3-4 examples of evaluating elements according to the categorized groups

Groups	Elements locations
Urban district	exterior spaces, roofscape, streetscape, street finishes,
Building exterior	balconies, exterior doors, external wall construction, external wall finish, and windows
Building interior	ceiling finish, floor construction, floor finish, interior doors, interior wall construction, interior wall finish

The retrofit options outcomes can then be qualified and quantified by a series of simulations of the different interventions according to their impact on the internal environment thermal comfort and the energy consumption reduction from the possible reduction of mechanical ventilation, as well as the impact on the heritage fabric.

3.7.3 Implementation and post intervention evaluation

The selected retrofitting strategy would be implemented on the existing building. The phase summarizes the process form the plan and the decisions of the retrofit option. The implementation is a result of the methodology adopted illustrating the particular retrofit intervention adopted with respect to the heritage values of the building. Tests would then be employed to ensure that the building and its services operate in an optimal manner and make sure that the retrofit measures do not interrupt the building and the occupant's operations.

The post intervention evaluation for the retrofit methodology in the heritage building must evaluate the architectural impact of the intervention, and the reduction achieved in the energy consumption. As the retrofit strategy is implemented and tuned, standard monitoring methods can be used to verify energy savings A post occupancy survey is also needed to make sure that the building occupants and owners are satisfied with the retrofit results.

3.8 Conclusion

the aim of this chapter is to identify the definition, development, reason and importance of sustainable heritage buildings retrofit. The chapter has reviewed different researches and guidelines concerned with the issues. It started with conceptualizing sustainable retrofit from a general definition to the context followed by the criteria for assessing heritage buildings, categorized as the needs for the building fabric, and collection. occupants have emerged as an important additional criterion, in addition to, economic, embodied energy, and climate change consideration. The chapter went through the benefits of natural ventilation as a retrofit approach and conditions of effectiveness. Finally, providing an approach and procedure of the natural ventilation retrofit.

As discussed in this chapter, energy retrofits are increasingly viewed as a protection tool, since upgrading and adapting historic and traditional buildings to meet current needs ensures that they will continue to be used, rather than neglected and demolished.

However, the chapter clearly demonstrates, through the overview of the different guidelines, that the main consideration is bias towards cold climates in Europe and North America, as a result of concentrated research and awareness in these regions. Different climatic conditions and building traditions in other regions would raise different issues. In the case of this research the heritage building in question fall under a hot humid climate for the heritage buildings of Alexandria, which requires different solutions other than the ones mentioned within this chapter (wall insulation, air leakage, and heating). The retrofit process would focus more on natural ventilation strategies as a passive cooling technique to achieve thermal comfort and reduce the dependence on mechanical ventilation.

The best heritage retrofit approach can be achieved by understanding the importance of preserving the significance of heritage buildings, regarding to its architectural, cultural historical and aesthetical values. It is also critical to fully understand the conventional or traditional materials and systems used the way it was built. Whereas the retrofit process is now considered as an opportunity to protect heritage buildings, and to respond to global environmental concerns.

The following chapter will explore the different strategies for applying natural ventilation and how it could be used on a retrofit strategy complying with the previous discussed framework. Identifying the different design criteria and their effect on the building performance and heritage significance of a heritage building, in addition to methods used to evaluate the application.

Chapter 4 Natural ventilation science and methods of application

4.1 Introduction

Natural ventilation can be considered a viable and sustainable method in providing suitable environment and is increasingly considered in many building designs. This chapter presents the related science to natural ventilation and airflow in terms of impacts and limitations. In addition, the strategic and methods of incorporating natural ventilation are explained. Finally, the chapter discussed the concepts and techniques commonly used in modelling and investigating the airflow around and inside a building, with emphasis on the computational fluid dynamics (CFD) modelling. Incorporating natural ventilation as a passive cooling approach in the heritage building retrofit application concluded in the previous chapter.

In general, the chapter aims to provide a critical review of the scientific background on which the methodology for the heritage buildings relevant to retrofit in Alexandria should be based. It clarifies the focus of the study, the level of intervention and the possible design measures regarding the heritage value of the building, and the different means for investigating and evaluating the building's performance in subsequent chapters.

4.2 Physics of air movement

It is necessary to acquire an understanding of the physical properties of the moving air itself. In this part, some physics associated with moving air will be addressed such as; airspeed and air flow patterns.

4.2.1 Air speed

Wind is the main source of air movement. Hence, the term "Airspeed" is used to refer to the wind speed. The airspeed is a major factor that affects that influences the air pressure on the building's surfaces, which in turn affects the wind driven movement through and outside the buildings.

Allard et al. (2006) indicated that wind driven force is effective when the wind speed is greater than 2.5 m/s. According to Bernoulli's equation the surface pressure due to wind is due to exponential proportion between the wind force and the wind speed squared Equation 4-1,

Equation 4-1 $$Pw = 0.5\, p\, Cp\, Vz^2$$

where; P_w = the surface pressure due to wind, p= the air density, C_p = the wind pressure coefficient at a given position on the building façade, V_2= the mean wind velocity at height (Z)

The natural airspeed lies in the range between 0 m/s to 25 m/s (McMullan, 2012). According to the different range *Blocken et al. (2004)* represented he different effects of various airspeed on human sensation and comfort the "Beaufort scale", Table 4-1. However, the scale indicates that the higher the airspeed isn't necessary associated with human comfort, as air speeds above 2.4 m/s can result in irritations to human perception.

Table 4-1 Beaufort Scale showing wind effects on people *(Blocken et al., 2004)*

Beaufort number	Description	Wind speed at 1.75 height (m/s)	Effect
0	calm	0.0-0.1	
1	Light air	0.2-1.0	No noticeable wind
2	Light breeze	1.1-2.3	Wind felt on face
3	Gentle breeze	2.4-3.8	Hair disturbed, clothing flaps, newspaper difficult to read
4	Moderate breeze	3.9-5.5	Raises dust and loose paper, hair disarranged
5	Fresh breeze	5.6-7.5	Force of wind felt on body, danger of stumbling when entering a windy zone
6	Strong breeze	7.6-9.7	Umbrellas used with difficulty, hair blown straight, difficult to walk steadily, sideways wind force about equal to forwards walking force, wind noise on ears unpleasant
7	Near gale	9.8-12	Inconvenience felt when walking
8	Gale	12.1-14.5	Generally, impedes progress, great difficulty with balance in gusts
9	Strong gale	14.6-17.1	People blown over

4.2.2 The atmospheric boundary layer (ABL)

The airspeed is by nature not a constant value it differs over the atmospheric boundary layer. Hence, it is expressed in terms of mean speed and velocity. The airspeed is directly proportional to the altitude from the earth's surface, as the altitude increases the airspeed increases as a direct effect of the air's friction with terrain roughness (Awbi, 2003).

The height from the earth's surface at which the wind speed reaches its maximum value is called atmospheric boundary layer ABL. This height is a variable that depends on the properties of the earth's surface over which the air passes and varies from 300 m to 500 m depending on if the surface is smooth of rough such as urban areas. In addition to the height and the surface roughness, the temperature also effects the air speed and turbulence within the ABL. Therefore, the profile of the mean airspeed over the earth and within the ABL is depending on the above variables which are presented by the empirical power law Equation 4-2, (Wei et al., 2005).

Equation 4-2 $$u / u_{\delta} = (z / \delta)^{\alpha}$$

where; u = the mean free stream velocity, u_{δ} = the mean velocity at $z=\delta$, z = the height from the earth's surface, α= coefficient depends on surface roughness, Reynolds number and the roughness length.

the wind speed is normally measured at 10 m height above the ground level at the meteorological station with an aerodynamic roughness length (z 0 = 0.03 m) and considered as a reference wind speed. It was also expressed the mean airspeed at specific height as a function in another power law, Equation 4-3 (Awbi, 2003; CIBSE, 2006).

Equation 4-3 $$V_z = V_m \, K \, z^{\alpha}$$

where; V_z = the wind speed at the building height (m/s), V_m = the wind speed at weather station (reference wind speed) , z = the building height, K, α= factors depends on surface roughness and terrain.

The value of the factor's "K" and "α" for different terrain conditions are given in Table 4-2.

Table 4-2 Terrain coefficients for Equation 4-3 after CIBSE

Terrain	K	α
Open flat country	0.68	0.17
Country with scattered wind breaks	0.52	0.20
Urban	0.35	0.25
City	0.21	0.33

4.2.3 Airflow patterns and turbulence models

Due to their complex nature, the air flow patterns are extremely complex to be accurately analysed (McMullan, 2012) (Awbi, 2003). The air flow patterns can be described into two major forms; Laminar flow and Turbulent flow.

Allard et al. (2006) indicates that most flows in nature that occur in nature are turbulent. For example, the atmospheric boundary layer, jet streams in the upper troposphere and cumulus clouds are all in turbulent motion. In fact, in fluid dynamics, laminar flow is exception.

Laminar flow, it is uncommon and only happens when the fluid has high viscosity and flows into a tiny section. It could be also called 'stream flow' mostly happens in nature near walls either inside or outside the space. the laminar airflow is characterized by: (Allard et al., 2006) (Alberto, 2004; McMullan, 2012)

a) The air moves in parallel layer with the same velocity and direction
b) The air molecules move in a constant distance from the wall within its layer
c) No layer crosses over another layer's path

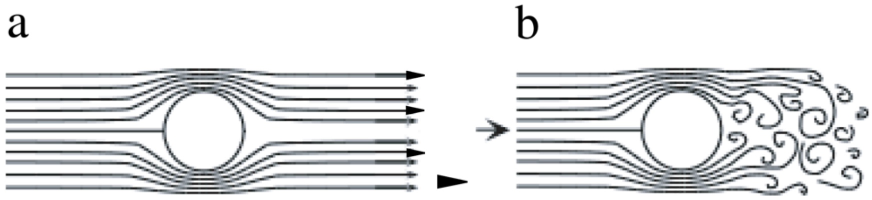

Figure 4-1 airflow models (a) laminar airflow, (b) turbulent airflow (Alberto, 2004)

The turbulent flow, is the normal airflow in nature and inside architectural spaces. The air moves randomly in chaotic flow and its molecules cross over other molecules path in a different speed. the turbulent airflow is characterized by (Allard et al., 2006; McMullan, 2012):

a) Irregularity and randomness: the turbulent flow is physically random and irregular in motion, time, speed and space
b) Diffusivity: the diffusive nature of turbulent flow increases the flow combination, the momentum rate and the heat transfer
c) Three dimensional: the flow is rational and has a high of repeatability
d) Dissipation: the flow requires energy supplement to mention its motion, provided by shear or buoyancy effect
e) A characteristic of flows: each turbulent flow has its unique characteristics which cannot be applied on other

The effect of turbulent air flow on human thermal sensation was found by Xia et al. (2000) that the preferred speed of airflow used by subject to gain the same level of thermal sensation is better in spaces with a lower turbulent airflow than a higher turbulent flow.

In order to determine the airflow, pattern a dimensional ration called "Reynolds Number" can be used according to Alberto (2004). The Reynolds Number can be calculated in any architectural space that has dimensions of: length L, width B and height H by using the equation, Equation 4-4 (Awbi, 2003).

Equation 4-4 $$Re = D_h \, U_r / V$$

where; Re = Reynolds number, D_h = the hydraulic diameter of the space= 2BH/ (B+H) , U_r = the equivalent room velocity= flow rate (Q) / cross section area (BH), V = the kinematic viscosity of air (m^2/s).

the value of Reynolds Number determines the type of the airflow inside an architectural space Alberto (2004) indicated, when Re is less then 100 the laminar flow inside the space was found to happen, however, when the value of Re for example is more than 1000 the flow is described as turbulent flow. Givoni (1998) elaborated according to the urban typology, describing the intensity of airflow turbulence is minimal in open rural areas 10 %, while it increases in urban areas to reach 30%. In conclusion, the airflow has less speed associated with high turbulence in urban areas.

4.3 Natural ventilation in buildings

Building ventilation, both mechanical and natural can occupy different roles such as insuring the indoor air quality. Faggianelli et al. (2014) indicated that the use of natural ventilation was neglected in practice since 1950's and disappeared from the construction system in favour of mechanical systems of ventilation and air conditioning. However, natural ventilation fits perfectly with the current issue of designing low energy buildings with low emissions of greenhouse gases. In addition, to improving thermal comfort in summer and reducing energy consumption to air conditioning. Natural ventilation is considered a free resource and easy to use if applied right as it improves occupant comfort simply by creating air movement in the building and by cooling the building structure at night with the lowest outdoor temperatures.

Passive means of ventilation can maintain adequate indoor air quality by replacing indoor air vitiated in the process of living and occupancy with fresh outdoor air. Indoor air quality is affected by living process and occupancy activities. Oxygen is consumed by breathing, carbon dioxide, vapour and bacteria are produced by occupants during the breathing process. Odour producing materials are given off by body. Smoking pollutes the air for both health and odour aspects. Therefore, there must be an accepted ventilation rate to maintain air quality that depends on the number of occupants per unit volume of the space, and their life style and sensitivity. According to Givoni (1998) a ventilation rate of about 0.5 air changes per hour as a minimum health ventilation rate in residential building with low occupancy density for maintain adequate indoor air quality, and can provide a very effective acceptable internal thermal comfort.(Santamouris et al., 1998)

Natural ventilation is considered a major passive cooling technique that can work within all climatic regions of the world (Santamouris, 2007). Its significant effect was found to be within hot dry and the hot humid climates, where its cooling effect is strongly needed (Cardinale et al., 2003; Givoni, 1994; McMullan, 2012). Accordingly, a well-designed natural ventilation system in the climate of Alexandria can reduce the energy consumption required for summer cooling and thermal comfort.

Awbi (2003) indicated that potential for ventilation depends on the wind speed around a building. The site's wind condition depending on; the urban wind approaching the site and the design details of the site's landscaping. Addressing the indoor environment (Lien et al., 2011) indicate that natural ventilation takes place mostly through windows, so opening design is then to a great extent a consideration for ventilation design and decisions concerning the location, number, size, orientation, and the design details of the windows.

However, this is an ideal case for applying natural ventilation in a new designed building. The difficulty ascends when addressing an established building, especially in the case of a heritage building with limited openings to which alterations can result in disturbing its preserved façade.

4.4 Natural drivers of natural ventilation

Natural ventilation mainly relies on the natural drivers of pressure variation. Davies (2004) explains the airflow movement either outside or inside buildings, due to the difference in air pressure. The pressure difference may be created naturally through the effect of wind forces and temperature difference, or be forced artificially through using fans and pumps. There are two main known physical principles according to Allen (2005) and Reznor (2001) that naturally drives the pressure differences. Firstly, the air moves from higher positive pressure regions to the regions of lower negative pressures. Secondly, the worm air is less dense than cool air so it rises and creates a difference in pressure which induces air movement, this phenomenon is called “The thermal buoyancy” and also referred to as “the stack effect” or “the chimney effect”. These natural drivers may work separately or in combination in order to form the airflow patterns inside the buildings.

4.4.1 Wind-driven natural ventilation

Wind-driven natural ventilation as described by Givoni (1998) and ASHRAE (2005) is initiated by wind blowing creating various types and gradient of pressure on the different building’s façades. The air in front of the walls facing the wind is compressed creating pressure zone. The façade which the wind blows on, a positive pressure “pressure zone” area is formed on that façade “windward”, while a negative pressure area “suction zone” is formed on the other side of the building’s “leeward side” along with the building’s side façades, this case if the wind direction is perpendicular on the building’s façade. The pressure distribution pattern differs if the wind blow angle is changed. The pressure distribution around a building in turn creates a negative pressure area inside the building that encourages air to move through the building and its openings. The air moves from the opening in the positive pressure façade to the opening in the negative pressure (ASHRAE, 2005; Awbi, 2003; CIBSE, 2006) .

Awbi (2003) indicated that the magnitude of air movement is a dependent factor on the pressure difference between the inlet and the outlet and proportional to the outdoor wind speed in front of the inlet. This conclude that the pressure difference is associated with several factors affecting the magnitude of the air movement through the building. These factors include; building geometry, wind velocity and direction, building location in relation to surroundings, terrain context and geographical location of the building.

The dynamic wind pressure on any specific position on a building’s surface can be calculated using the Bernoulli’s equation. In addition to that the pressure coefficient at a specific point on the building façade could be obtained by pressure measurement in wind tunnel, CFD models or measurement on a real scale building (ASHRAE, 2005; Awbi, 2003). Simple forms of buildings the values of C_p could be found in the tables of CIBSE (2006) guide A or in figures of ASHRAE (2005). Hence, the mean wind velocity at height Z could be calculated according to the building location and the given wind velocity measured at the weather station of that location. The rate of the wind airflow through an opening in a building depends on the air pressure difference across the opening's façade caused by their design and location. Givoni (1998) and ASHRAE (2005) classified wind-driven ventilation delivered to a building into two main techniques; single sided ventilation and cross ventilation.

4.4.1.1 Single sided ventilation

Single sided ventilation is a technique dependant on one side control through one or more opening in the same wall. Where the air enters from one opening and leave from the same opening or from another opening on the same side. The airflow in the single side ventilation is a wind driven airflow, unless a difference in height between the inlet and outlet openings within the same wall is provided and thus thermal buoyancy starts to occur (Awbi, 2003). The capability of thermal buoyancy in enhancing the airflow within the space is directly proportion to the vertical distance between the openings and the temperature difference between the indoor and the outdoor. An empirical model for measurement of this phenomena, Freire[1] et al. (2009) found an expression for the flow rate per Equation 4-5:

Equation 4-5 $$Qv = A/2\ (C_1 V_r^{\,2} + C_2 H * \Delta T + C_3)^{1/2}$$

where; Qv flow rate, A= opening area m^2 ,C_1 = 0.001 coefficient depending on window opening, C_2 = 0.0035 buoyancy constant, C_3 = 0.01 wind constant, ΔT = average temperature °C,

The effectiveness of single sided ventilation Awbi (2003) implies that it is limited and can only be effective within a distance of 2.5 H maximum. It was found that technique is more suitable for moderate climates. Single-sided ventilation is recommended in a space with a window area 1/20 floor area with depth of maximum 2.5 times the ceiling height.

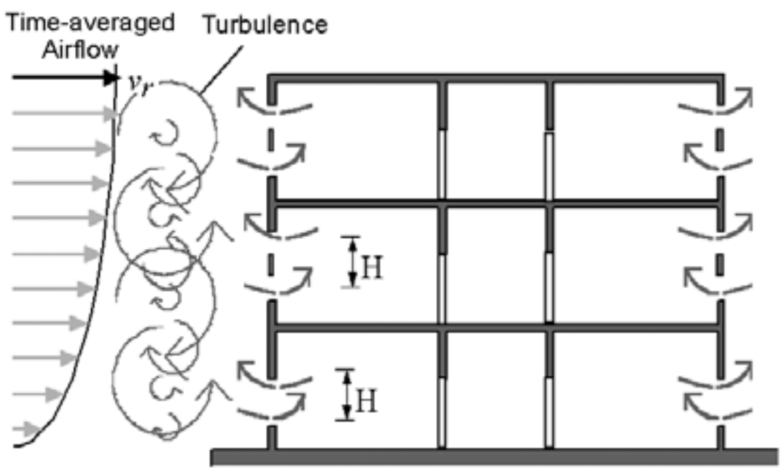

Figure 4-2 single sided ventilation, by turbulence influenced effects.(Axley, 2001)

4.4.1.2 Cross ventilation

Cross-ventilation is a dual side control technique through face to face opening. The air enters from one opening (windward wall) and travel across the space to leave from another opening (leeward wall). According to (Allard et al., 1998) cross ventilation can be considered the most effective natural ventilation techniques that can provide consistence large airflow with deep air penetration across the ventilated space. The airflow in cross ventilation is a wind driven airflow, unless a significant difference in height between the inlet and outlet opening is provided and thus thermal bouncy starts to occur (Awbi, 2003). The rate of wind driven airflow across any opening in the building façade can be calculated using Equation 4-6, (CIBSE, 2006).

Equation 4-6 $$Q = C_d A (2\Delta p / p)^{0.5}$$

where; Q = the volumetric airflow through the opening, C_d = the discharge coefficient = 0.61 for sharp edged opening, A =the area of the opening, Δp = the pressure difference across the opening), p = the air density.

The positive windward pressure ΔP_{ww} and the negative leeward pressure ΔP_{lw} are in fact the pressure difference from the ambient air pressure of the airflow. The pressure difference changes and varies with time and position, they may be related to wind velocity ,Equation 4-7, Equation 4-8 and Equation 4-9 (Allard et al., 2006).

Equation 4-7 $$P_{ww} = C_{p-ww} (Pv_r^2 / 2)$$

Equation 4-8 $$P_{lw} = C_{p-lw} (Pv_r^2 / 2)$$

Equation 4-9 $$\Delta P = P_{ww} - P_{wl}$$

where; ΔP =pressure difference, P = surface pressure, C_p = pressure coefficient, Pv_r^2 = kinetic energy per unit volume

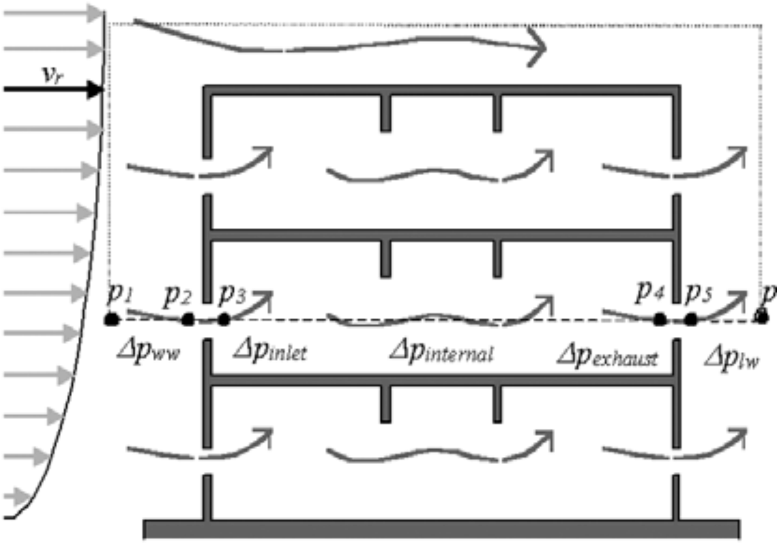

Figure 4-3 wind cross ventilation (Axley, 2001)

4.4.2 Buoyancy driven natural ventilation

Buoyancy driven ventilation is caused by the temperature variations creating pressure difference, either outside, inside the buildings or between the internal parts of the building itself generating airflow due to thermal buoyancy, as air density and pressure are reduced with height. Givoni (1998) describes he rate of this pressure drop depends on the air temperature, the higher the temperature the smaller the drop-in air pressure with height.

Faggianelli et al. (2014) stated the method is possible when there is a temperature difference between the inside and the outside. However, it does not achieve the high ventilation rates obtained by wind effect. Moreover, there must be a more accurate openings position as it is a necessary to have a lower opening and an upper opening. The airflow occurs mainly in the vertical direction through gaps or weak resistance points within the building such as stairwells, elevators, atriums and shafts. Awbi (2003) adds that the air flow patterns due to the stack effect between the building's parts performs differently. It is originated by the internal partitions and the degree of air tightness between the building stories.

The flow rate can be expressed directly in terms of height and temperature differences. It is calculated by Equation 4-10 ; (Givoni, 1998)

Equation 4-10 $$Q = K * A (h * d_t)^{0.5}$$

where; Q = the flow rate m^3/ (min.m^2), K = the effect of resistance coefficient, A =the net effective area of opening m^2, h = vertical distance between the centres of the upper and lower opening m, d_t = difference between indoor and outdoor average temperature.

When there is no effect of wind force and the thermal buoyancy is working separately, the level at which the level both indoor and outdoor temperature are equal the difference becomes zero is called "the neutral pressure level (NPL)" (Awbi, 2003) . the pressure difference created by the stack effect could by calculated by Equation 6-1 (CIBSE, 2006).

Equation 4-11 $$\Delta p = p_0\ g\ 273\ (h2-h1)\ (1/(t_0+273)-1/(t_i+273))$$

where; Δp = the pressure difference (Pa), $p0$ = the densty of the air at 0^{o}C (Kg/m^3) , g =the acceleration due to gravity (9.81 m/s^2), $h1$= opening 1 height above the ground level (m), $h2$= opening 2 height above the ground level (m), $t0$ = the outdoor temperature (^{0}C) , $t1$ = the indoor temperature (^{0}C).

Allard et al. (2006) affirms that large opening is needed to guarantee large amount of airflow rates, this should be larger in natural ventilation than for mechanical ventilation, where pressure difference may be 10 or even 100 times larger. Stack pressure is proportion to indoor outdoor temperature difference and to the vertical distance to the neutral pressure level. Therefore, the airflow rates increase with temperature difference and vertical distance between openings increase, Figure 4-4.

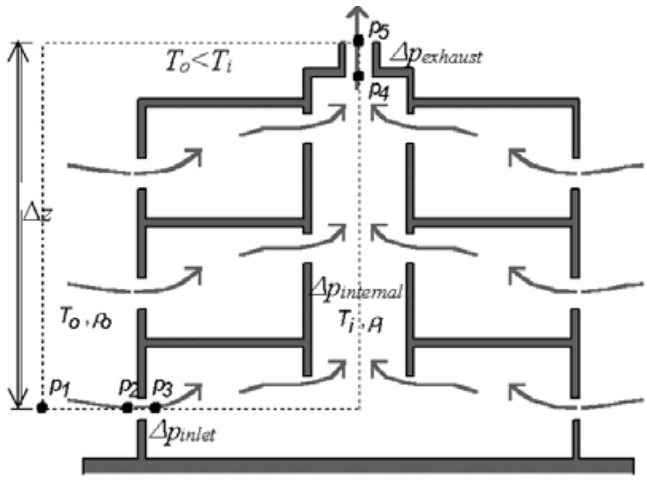

Figure 4-4 stack pressure driven natural ventilation (Axley, 2001)

The neutral pressure level NPL is a very important concept for the correct design of natural stack ventilation, Figure 4-5. This level sets itself so that the airflow rates that enter and leave the building are balanced. It depends not only upon size and location of openings, but also upon indoor and outdoor temperatures, wind and possibly fans. It places itself closer to the largest openings. When purely stack effect ventilation is used to cool high buildings, it is impossible to pass fresh air above the NPL location. The top opening should be as large and high as possible so that the NPL would be as high as possible within the building to supply fresh air to the largest possible area of the building. (Allard et al., 2006)

During warm periods, as outdoor temperatures approach indoor air temperatures, the stack pressure differences for all but very tall multi-storey buildings may be expected to be small relative to typical wind driven pressure difference. For a building of about 10 m height the difference between the indoor and the outdoor should be approximately 23 ^{o}C in order to obtain around 10 Pa pressure difference (Allard et al., 2006).

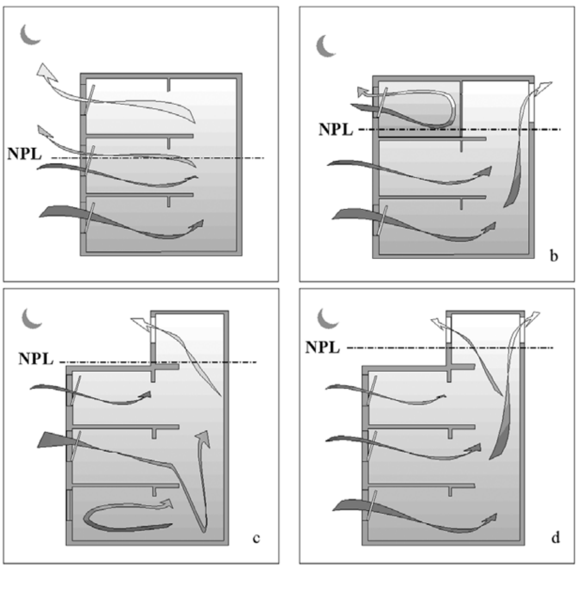

Figure 4-5 (a) poor cooling of upper level,(b),(c) and (d) various ways of improving cooling of the upper level (Allard et al., 2006)

4.4.3 Combined wind and thermal buoyancy forces

The airflow through any building is a result of combination of both wind pressure and stack effect. The direction and rate of airflow within the building and through its openings is the summation of the effect of both forces combined with any other ventilation system installed. The airflow could be enhanced if both stack and wind pressure forces work together in the same direction, for example the openings have the same sign (+\-). If the openings work with opposite signs the airflow will decline and might stop completely as a result of their equality. The maximum increase due to their combination could reach 40% more performance than the greater force alone, Figure 4-6 (Awbi, 2003; Givoni, 1981).

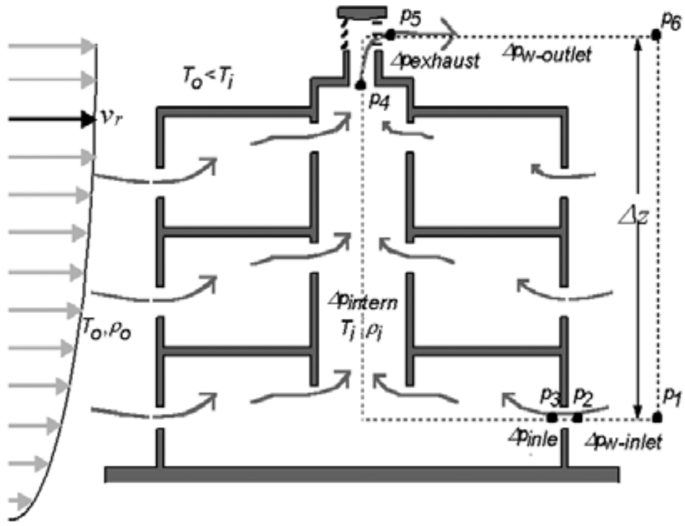

Figure 4-6 combined wind and buoyancy driven ventilation (Axley, 2001)

The combine force calculation method was developed by Walker and Wilson, in order to estimate the combined effect of wind forces and stack effect using the pressure addition method, Equation 4-12 (Awbi, 2003).

Equation 4-12 $$Q_t = (Qw^2 + Q_s^2)^{1/2}$$

where; Q_t = the overall ventilation rate, Q_W = the ventilation rate due to wind pressure , Q_S = the ventilation rate due to stack pressure.

The wind drives the airflow from the windward to the leeward side of the building. If the ventilation openings are located in an appropriate manner, the wind pressure is added to the stack effect and the ventilation is reinforced. However, if the top openings are on the windward side and the bottom opening on the leeward side, the stack effect and the ventilation is reduced and even suppressed for a specific wind velocity. It is therefore recommended by Allard et al. (2006) to locate the ventilation openings in naturally ventilated buildings according to dominate winds. Moreover, when the combination is properly designed, stack ventilation uses both wind and buoyancy driven pressure difference as shown in Figure 4-7.

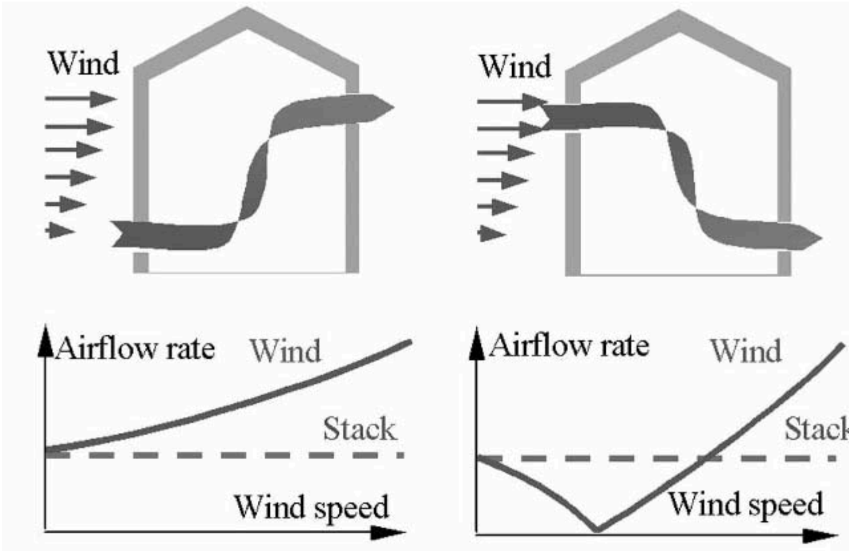

Figure 4-7 combined effects of wind and stack (a) adding the effect (b) opposite effects (Allard et al., 2006)

4.5 Design measures for natural ventilation

the performance of the natural ventilation strategies explained in the previous part is affected by the design measures incorporated in the building. The parameters of the different design measures affect the air movement in and around the buildings. The following part of the research the design measures that affects the natural ventilation strategies on the building scale, comprehensively studied examining the effectiveness of their parameters that identified by researchers is critically reviewed regarding their compatibility with the protected nature of heritage buildings.

4.5.1 Façade opening design

The effectiveness of natural ventilation is strongly depending on the properties of ventilation opening and their completability, these properties include size, position, number and type. This aspect is related to the façade design and its relation to the external environment (Prianto et al., 2002; Roetzel et al., 2010). Previous studies discussed in 4.4 indicated that the ventilation opening is considered the primary ventilation devices in most normal size buildings due to their low-tech and manual operation.

Ventilation opening size the size of the opening for ventilation purposes, there is no guidance for the maximum size of the opening. For worm humid climates its favourable to reach a 100 percent opening size virtually, but other consideration discussed by Aynsley (2014) comes in the design process such as sun control, security, privacy and potential heat losses in winter. The minimum size is usually specified by the building regulations.

The most outcome of windows size was observed in a cross-ventilated space, while a lower effect was observed when the space is single side-ventilated. Visagavel et al. (2009)

used numerical prediction of air velocities in cross and single-side naturally ventilated rooms considering the opening size, the air velocity was lower for the single sided ventilation in relation to the opening size. This was because of the gradient pressure over the window area.

The area ratio of the space is the most used method to express the suitable opening size. The ratios of internal and opening dimensions were considered as a limit for ventilation efficiency are; maximum of 40 % between ceiling height and room depth and a minimum of 5 % between window are and floor area (Awbi, 2003). Studies conducted by Tantasavasdi et al. (2001) aiming to produce guidelines in respect of opening size for natural ventilation design through quantifying several design parameters using CFD, the study involved different opening areas (5% to 30%) in different ventilation scenarios single and cross-ventilation on average internal speed. In general, the study showed increasing the opening area improves the average indoor air velocity, and the optimum opening size was found 1/5 of the room area.

While considering the opening percentage in relation with the external wall area by the difference of the air pressure difference across the building, the effective pressure difference provided by Aynsley (2014) tends to be higher when wall opening are about 15% to 20 % of the wall area have a potential of increasing the average wind speed through wall opening to be 18% higher than the local wind speed.

In the case when cross-ventilation is applied, the outlet area in relation to the inlet area (A_0 / A_i), studies indicated that a realizable increase in the interior air velocity when making a difference between their areas. The buoyancy effect is the main reason for the change of the flow cross section between the inlet and outlet area, resulting in an increase air velocity within the building (Prianto et al., 2002). According to (Allard et al., 1998; Aynsley, 2014; Givoni, 1981) the maximum internal air speed in a cross-ventilated internal spaces is acquired when the air outlet is larger than the inlet. The maximum internal airspeed is reached when (A_0 / A_i =3) with a minimum of (A_0 / A_i =1.5) for a reasonable average airspeed (Givoni, 1998).

However, Tantasavasdi et al. (2001) claimed that a larger inlet than the outlet is more preferable and improved the ventilation rate using the ratio of (A_0 / A_i =0.5). According to Givoni (1994), the choice on which should be larger is depending on the used space, as the internal average air velocity is dependent on the size of smaller opening, whether it is the outlet or the inlet it doesn't make a difference. The maximum air speed is dependent on the space inlet and outlet size and would increase with the (A_0 / $A_{i)}$ ratio, so in comparison a room with a larger outlet than inlet can experience a higher air velocity than a room with a reversed condition but this velocity is limited to the area near the inlet.

Opening position, the inlet and outlet position horizontally or vertically related to each other not only effects the internal airspeed, but also has a tremendous effect in the airflow pattern. Watson (1983) indicates the best air distribution and velocity lies within the location of the openings on the external façade, to manipulate the airflow to change its direction. He added the horizontal location of openings for maximum ventilation is determined by the positioning of the air inlets and outlets position within the façade, securing the maximum pressure difference between them, Figure 4-8. The airflow distribution and its effectiveness in the space can be determined by the relative horizontal position of the inlet and the outlet. Watson (1983) demonstrated the effect on the airflow pattern according to relative position of inlets and outlets. Accordingly, when positioning both openings in the centre of the windward and leeward facades, would result in the highest airspeed velocity through a narrow pass, regardless providing the highest air speed poor ventilation is provided Figure 4-9 (a). The opening position should be close to the thermal exchange surfaces when structural cooling is proposed Figure 4-9 (b,d,e). low air speed can be provided and short circuit accurs when the opening installed near to each other in lateral walls Figure 4-9 (c, f). which concluded for the best airflow distribution and higher air velocity, openings should be placed far from each other avoiding short circuit problems Figure 4-9 (e) (Tantasavasdi et al., 2007)

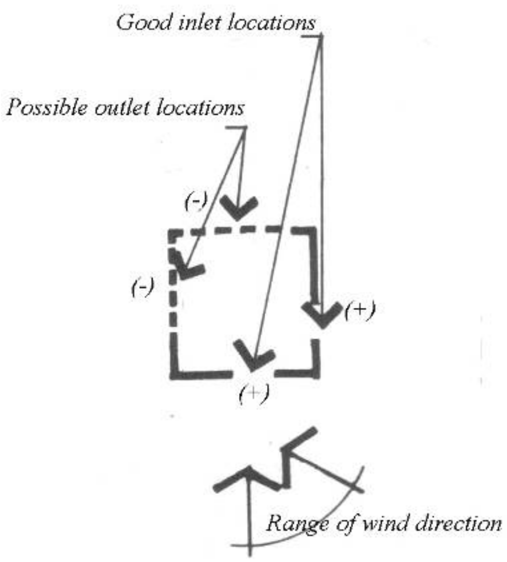

Figure 4-8 possible inlets and outlets position to achieve maximum pressure difference (Watson, 1983)

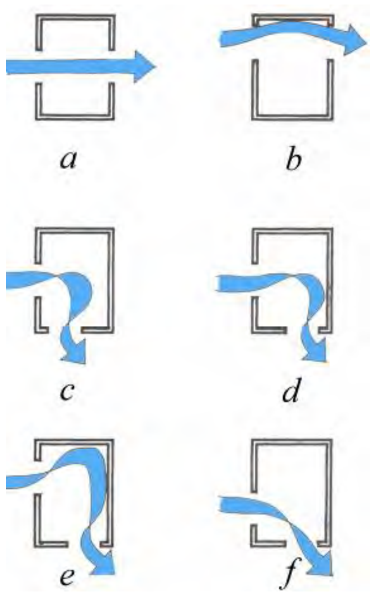

Figure 4-9 relative horizontal positions of openings and their effect on airflow patterns (Watson, 1983)

The vertical location of the opening is controlled by both wind-driven ventilation and stack-driven ventilation. In the case considering cross-ventilation Krishan (2001) demonstrates the vertical location of the inlet is more influential than those of the outlet position, having an almost neglected effect on directing the airflow. In the case of the inlet opening is at a high level, the main air stream flows at the ceiling height and is not affected by the low location of the outlet, providing poor ventilation conditions Figure 4-10 a. However, in the case of the inlet height placed at the occupant’s height Figure 4-10 b there is a good ventilation condition. Finally, in the case of a low outlet position a good ventilation conditions is also acquired Figure 4-10 c, (Allard et al., 1998).

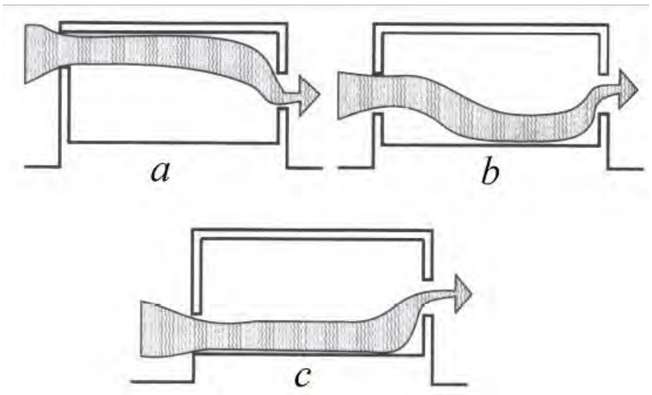

Figure 4-10 relative vertical inlets and outlets position and their effect on airflow

When considering the stack effect, the inlets and the outlets must be located at different heights and as far apart as possible to increase the effect of thermal buoyancy (Gratia et al., 2004; Heiselberg, 2004). In conclusion, for both wind and stack-driven ventilation, the outlet should always be higher than the inlets in order to avoid the conflict between both strategies.

Number of openings for an acceptable ventilation conditions at least two openings should be provided for the space acting as an inlet and an outlet (Tantasavasdi et al., 2007). In the case of single sided ventilation, two openings far apart from each other directed obliquely to the wind direction would create a pressure gradient over the external wall forcing the up wind opening to act as an inlet and the downwind opening to act as an outlet (Allard et al., 1998).

Opening type Allard et al. (2006) have described the role of the opening type in directing the airflow and controlling its speed depending on their operable type. There are many types operable openings, each type presents advantages and inconveniences;

The side hung casement window, rotates around a vertical axis allowing a complete opening but offers poor protection against rain. The hung can be placed on the bottom and top, the bottom hung can offer good ventilation potential for evacuating hot air as the largest opening is high, close to the ceiling while the top hung window offers good protection against the rain. Some windows can work with a mechanism and open either vertically or horizontally, having the advantages of these two types. These types of window openings can have good airtightness when closed. Providing a good seal.

Pivot- hung windows may also have their pivoting location on either the vertical or horizontal axis, having the feature of being able to be completely turned. The pivot-hung windows can facilitate the control of the airflow direction within the space interior. However, the horizonal pivot opening can offer a good ventilation potential through the stack effect.

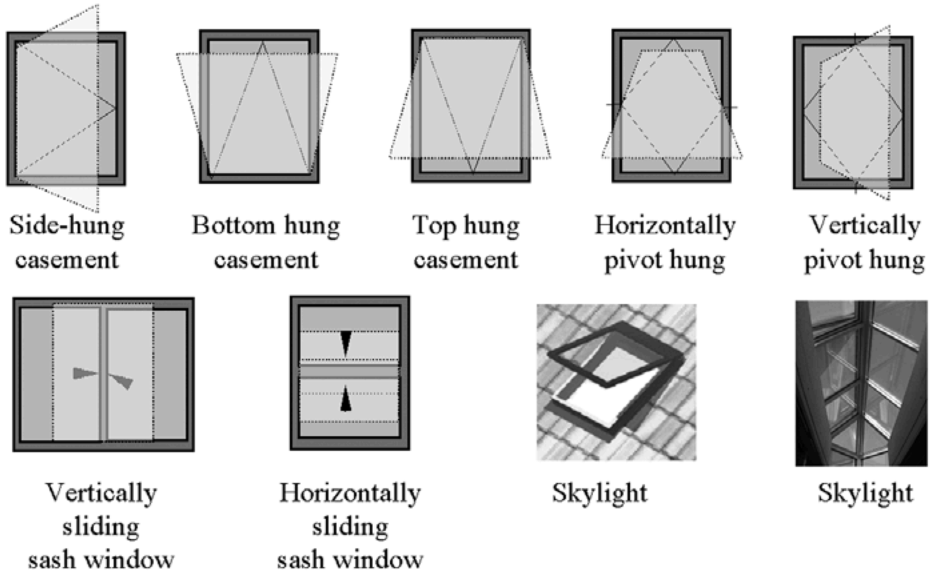

Figure 4-11 several types of operable windows (Allard et al., 1998)

Sliding windows can slide in a horizontal or vertical direction, allowing the control of the airflow rate. The main advantage of this type of opening mechanism is that it requires less active area space when opened. However, it reduces the active open area of the opening which could reduce the airflow rate.

Operable skylights or roof lights openings benefits from the stack effect and useful for evacuating hot air and to pull the neutral level up. Several opening types can be combined together in a window, thus taking the advantages of several opening types.

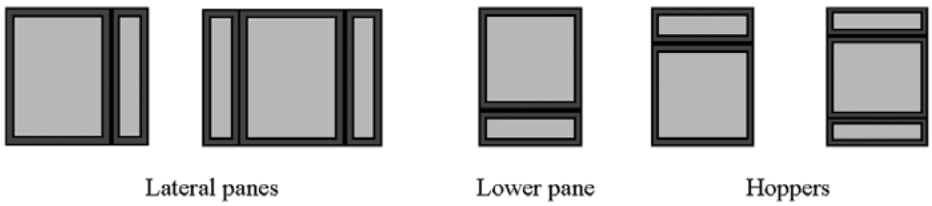

Figure 4-12 combination of openings in a window (Allard et al., 1998)

In order to comprehend with the external façade preservation of heritage building, the rule is to preserve its main features. When it comes to the opening size, position and number externally its very limited. However, externally the opening type depending on the heritage level of the building (grade 3 as an example) can be changed to a better performing type controlling the active area for natural ventilation and redirecting the airflow if needed.

The ventilation opening as discussed can have a tremendous effect on the internal airflow magnitude and distribution. According to dealing with an existing building with a heritage value that needs to be preserved some of the opening features needs to be compromised or can be neglected. For the different types of heritage buildings grading the external façade is one of the key features that needs to be preserved.

Internal openings on the other hand can have more flexibility according to the heritage level of the building and structure. As opening size, number, position and type can be enhanced more freely. These modifications can allow a better indoor environment benefiting from both wind and stack-driven ventilation, especially in the case of dealing with a multi connected spaces with an atrium or a courtyarded building.

4.5.2 Roof shape

The shape of the building roof can have a great impact on the size of downwind and the overall distribution of the wind pressure of the roof structure in terms of external airflow, either flat, single-slope, double-slope, dome or a vault. It's also discussed as having a significant role in inducing internal airflow, Figure 4-13 (Allard et al., 1998).

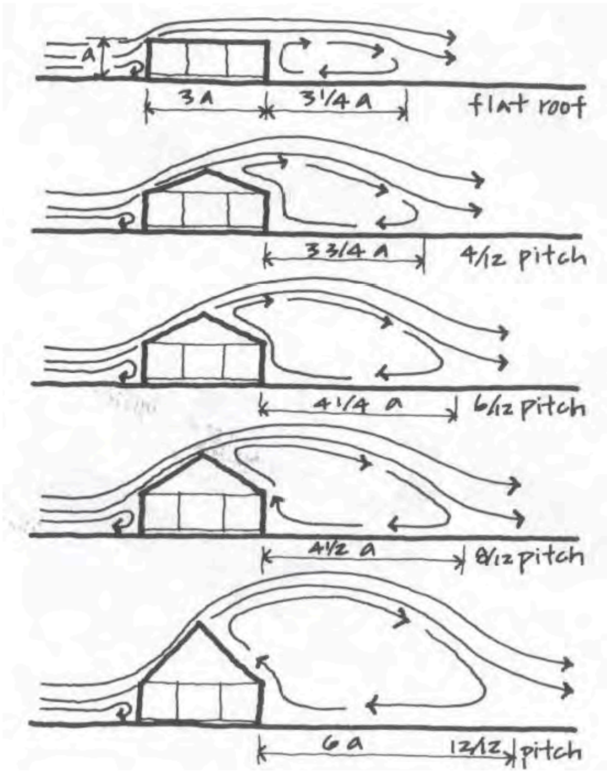

Figure 4-13 the effect of different roof shapes on downwind eddy size (DeKay et al., 2013)

A parametrical study was conducted by Grosso et al. (1994) on the air pressure distribution over the different types of roofs,. A flat roof, a single slope roof and a double slope pitched roof. The study tested the effect of the inclination angle of the roof slopes and the angle of wind incidence. Results shows that the inclination angles of the roof slopes and the angle of incident airflow have a tremendous effect on the pressure distribution on the roof surface, regarding the surface location either on the windward or leeward side. Consequently, the openings on the roof can have an inlet and outlet effect depending on these factors.

Another study performed by Sharples et al. (2001) testing the single slope and its effects of the ventilation rate of courtyard and atrium building. The experiment explored six models with different strategies with different incident angles; an open courtyard with no roof using a positive pressure ventilation strategy; single sloped roof with no opening using a positive pressure ventilation strategy; single sloped roof with 11.4 % openings of the façade area in the leeward side using a negative suction ventilation strategy; single sloped roof with 30.4 % openings of the façade area in the leeward side using a negative suction ventilation strategy; single sloped roof with 11.4 % openings of the façade area in the windward side using a positive driving ventilation strategy; and finally single sloped roof with 30.4 % openings of the façade area in the windward side using a positive driving ventilation strategy, Figure 4-14.

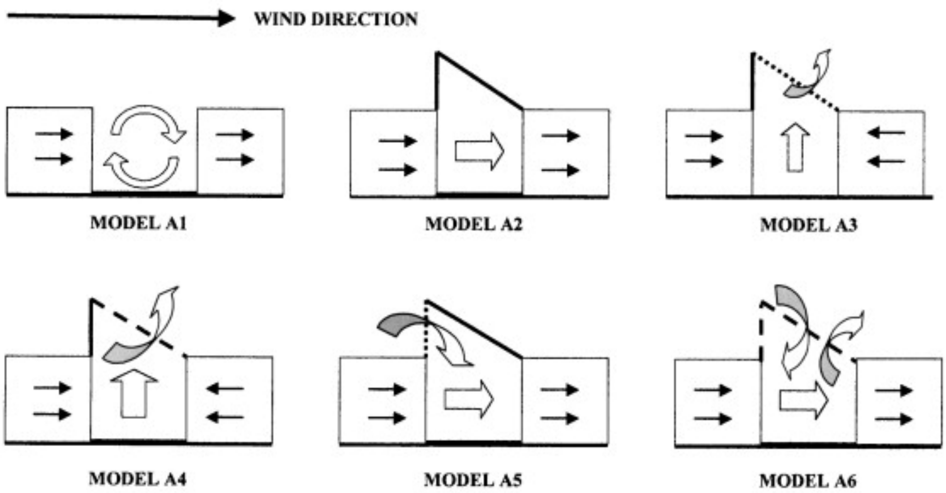

Figure 4-14 courtyard and atrium roof ventilation strategies (Sharples et al., 2001)

According to the study in the 0° incident angle, the open courtyard had the poorest ventilation conditions followed by the closed atrium with a slightly improved performance. The positive pressure strategy tested by placing the openings in the windward side resulted in a much better ventilation performance. However, the models performed under negative ventilation strategy placing the openings in the leeward side had the much-improved performance specially in the case of the larger openings. In the case of 45^0 incident angle the ventilation performance of all the models were increased. Concluding more efficient ventilation roof design may involve venture effects or vortex generation at roof edges to a much-accelerated airflow.

The issue has been addressed dependent on the heritage building's original roof form, changing the character of the roof from flat to inclined can change its characteristics and may be excluded as a possibility according to the building's level of heritage designation. However, applying this strategy as a retrofitting criteria strategy in previous studies indicated that improvements or additions can be applied to the existing characteristics of the heritage building performance. As is demonstrated in the heritage typology of Alexandria, in the case of atrium buildings. Here, improvements to the ventilation characteristics through additions to the roof might be used. The justification of the addition will be dependent on the heritage level of the building and how it would be affected visually.

4.5.3 Connected internal spaces

Airflow pattern, speed and ventilation efficiency can be deeply affected by the internal spaces' connection with the building. The horizontal and the vertical distribution of internal spaces can facilitate and have a great effect on wind and stack-driven ventilation respectively (Allard et al., 1998). Straight flow through the interiors can provide highest speed of airflow, while air circulation will be implemented when the flow has to change its direction many times inside the building in order to reach the outlet, as a result of the resistance by the internal obstacles. (Givoni, 1981; Watson, 1983).

For a maximum ventilation performance, Aynsley (2014) stated that resistance to airflow through the building has to be minimized. This means having large openings for the passage of air, and reducing the number of rooms through which the air has to pass to reduce resistance to the airflow. Givoni (1981) added, for a good ventilation conditions obtained in a residential building, by allowing the air to move through the different spaces by providing an opened connection between the different spaces. He indicated for a better performance can be provided when the internal separators are near the outlet rather than the inlet, emphasizing that upwind spaces should be larger than the other spaces.

According to the previous studies based on the optimum conditions for the best ventilation performance is the open plan (Allard et al., 1998; Awbi, 2003; Givoni, 1981; Tantasavasdi et al., 2007), recommending to present a balanced plan for the building internal spaces to incorporate ventilation and functional requirements. From this concept several architectural features were advised to be used facilitating the internal airflow and respect the internal functions; louvered doors, transom windows and louvered walls, demonstrated in Figure 4-15, Figure 4-16 (Watson, 1983). These architectural features can be useful avoiding the internal solid partitions. Louvered doors can also help enhancing the airflow without affecting the privacy of the spaces. The airflow potential can be improved due to thermal buoyancy through the connection of the horizontal spaces with the existing vertical spaces stair wells and atriums).

However, incorporating this ventilation strategy as a part of heritage building retrofit, several features must be investigated regarding the connection of internal spaces. As the addition of new vertical spaces would be challenging, the existing spaces should be explored in order to reach the maximum connectivity of internal spaces using the existing building's potential interconnective features such as atriums and stairwells. Depending on the level of heritage designation of the building targeted for retrofit, the flexibility of alterations to internal spaces which can be connected using transom windows or internal louvered walls to allow better conditions of ventilation.

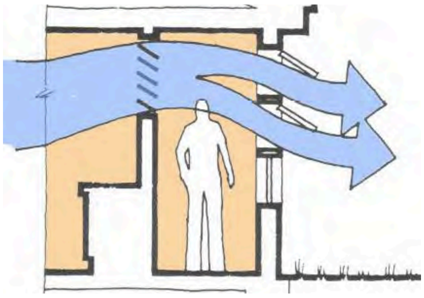

Figure 4-15 the use of louvred walls (Watson, 1983)

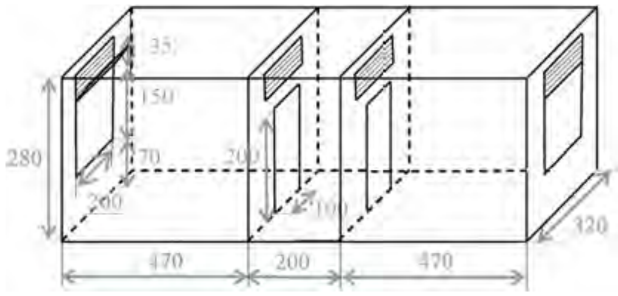

Figure 4-16 the use of transom windows (Breesch et al., 2007)

4.5.4 Double skin facade

Double skin façade DSF is the addition of a glazed skin on the exterior of the inner façade separated by an air cavity. The external skin act as an extraction of air with the spaces contributing to natural ventilation (Gratia et al., 2007). Three different types of double skin facades have been addressed by Boake et al. (2003) according to their ventilation method and the ability to reduce overall energy consumption; buffer system, acting as an insulator buffer sealed from the inside allowing fresh air intake at the base and exhausts at the top; extract air system, acting as a second layer of glazing placed on the interior of the main façade extracting the heat through the cavity while the outer layer is insulated with the intake of fresh air; twin face system, acting as a buffer and a source of air inlet allowing controlled natural ventilation though it , Figure 4-17.

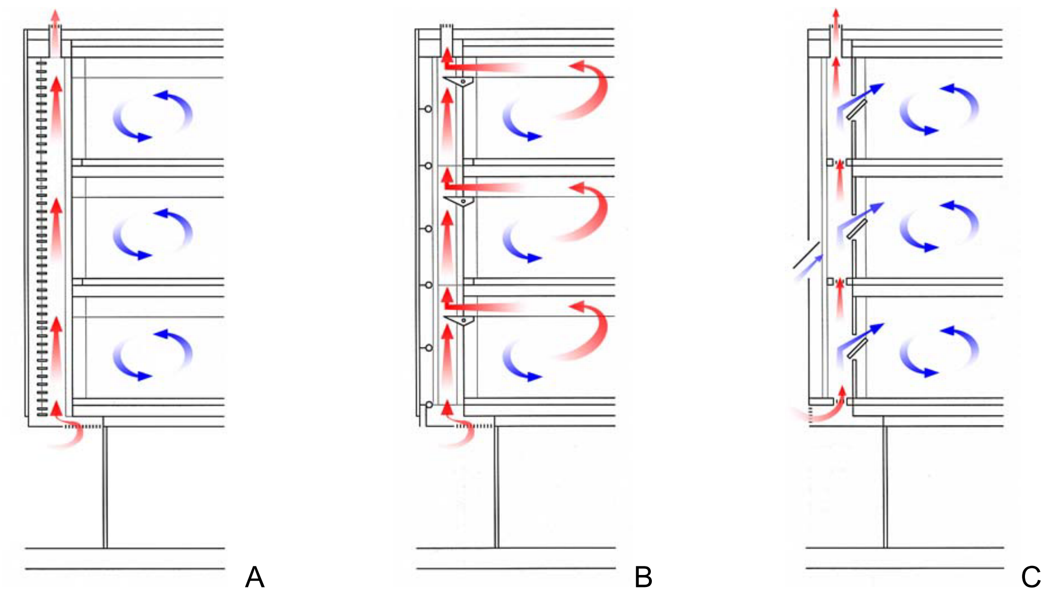

Figure 4-17 different types of double skin façade (Boake et al., 2003)

The main advantages of using this system it can provide a thermal and acoustic buffer between the interior and exterior spaces, and can be designed to induce airflow and ventilation driven by either stack or wind driven forces. The system application is mainly provided for tall buildings providing partial ventilation (Etheridge, 2011).

A study conducted by Gratia et al. (2007) on the double skin façade of a building, the study examines how the natural ventilation can be provided during the sunny summer day in relation to the orientation of the double skin façade. the study indicated the configuration and control of the openings is crucial to the effective operation of the ventilation system

Table 4-3 summary of guidelines to reach optimum cross ventilation with different orientation double skin façade (Gratia et al., 2007)

South double skin	Windward side	• Upper opening of the DSF oriented south • Lower openings of DSF can be opened or closed • Opening size must increase with stages
	Leeward side	• Upper opening of the DSF oriented north • Lower openings of DSF must be closed • Opening size must increase with stages
	Parallel to airflow	• Upper opening of the DSF oriented north or south • Lower openings of DSF must be closed • Opening size must increase with stages
North double skin	Windward side	• Upper opening of the DSF oriented south • Lower openings of DSF must be closed • Opening size must increase with stages
	Leeward side	• Upper opening of the DSF oriented north • Lower openings of DSF can be opened or closed • Opening size can be similar
	Parallel to airflow	• Upper opening of the DSF oriented north or south • Lower openings of DSF must be closed • Opening size must increase with stages

The main set back is the overheating risk of double facades in summer is evident but some tells that it can be minimized with well-dimensioned openings, a well-positioned shading device and an optimized space between the façade with increasing the building envelope costs (Etheridge et al., 2008).

However, applying this strategy to improving the ventilation of a heritage building depends on the nature of the application. The additions will alter the external appearance of the preserved building and change the heritage features of the façade, generally making its use as a retrofitting strategy be deemed to have a negative impact on a building's aesthetic value.

4.5.5 Ventilation shafts

The ventilation shafts are one of the widely used passive and ventilation and cooling system, the system have been traditionally used for many centuries until the present day (Santamouris et al., 2006). They are categorized by being a tall structure rising above the building to either capture the airflow or exhaust it out. The passive system can be categorized into several types according to its technical function; wind towers, wind catchers and ventilation chimneys. Where wind catcher functions as collecting airflow from above the roof and deliver them down the building. When this function is reversed as exhausting the air from the building's space to outside under thermal buoyance effect, they are called ventilation chimneys. Performing both functions the system is called wind towers and considered effective in creating airflow even when the wind outside is fairly calm (Yaghoubi et al., 1991).

The ventilation shafts through were used in a variety of forms especially within the area between North Africa at west and Pakistan at east, the system also been used 3500 years ago in the Egyptian context in the traditional housed with the local name "Malkaf" (Oliver, 2003; Watson et al., 1983).

Figure 4-18 traditional wind catcher (Oliver, 2003)

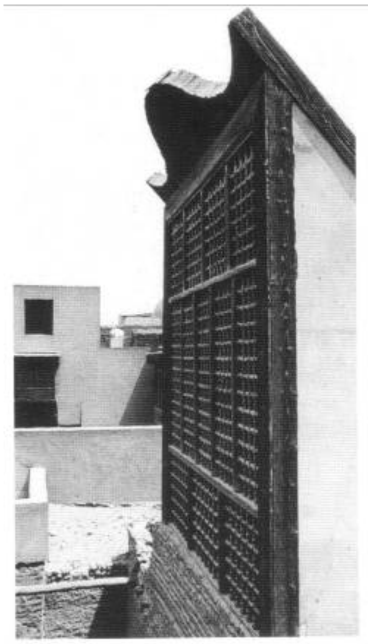

Figure 4-19 Malqaf, Cairo, Egypt (Oliver, 2003)

4.5.5.1 Ventilation chimney

For the ventilation chimneys, they are commonly used in modern buildings, especially in cold climates, to provide ventilation through stack effect and achieve reduction in energy consumption (Priyadarsini et al., 2004). Accordingly this suction effect is depending upon three primary factors; prevailing wind conditions, type of the discharge coefficient (cowl), and the flow rate (Santamouris et al., 2006).

The roof outlets or the exhaust cowls can perform in two strategies, Figure 4-20, Figure 4-21 .The first exhaust is designed to prevent downdraught into the chimney. While the second exhaust is used to prevent against birds, pest, insects, etc, but has a limited downdraught prevention capability (Khan et al., 2008).

The exhaust characteristics was investigated by Pfeiffer et al. (2008) for hybrid ventilation systems using CFD techniques. The study presented four models aiming the exhaust performance in terms of flowrate encountered in the ducts and the flow field on the roof due to wind induction only. A limited downdraught was used in the simulation with a dual characteristic. The results shown that the suction effect was a result of the wind speed and angle. It is essential in designing exhausts not to impede airflow too much as it will resist it and handicap the airflow. The investigation suggests that wind direction is a critical factor, therefore stationary devices lack the full capabilities to utilize the wind source.

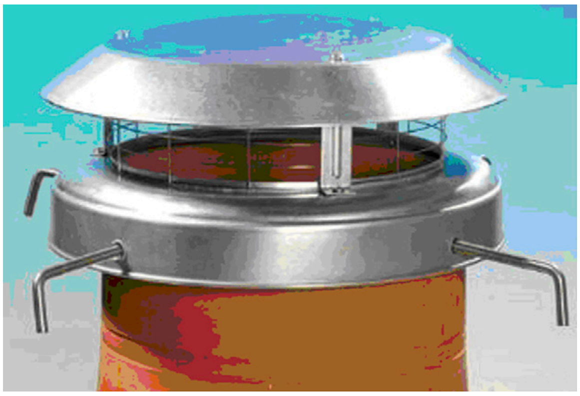

Figure 4-20 preventing downdraught exhaust (Khan et al., 2008)

Figure 4-21 limited downdraught exhaust (Khan et al., 2008)

4.5.5.2 Wind catchers

Wind catchers is considered a ventilation and cooling device that can deliver high rate of ventilation, where ventilation required. The highest cooling effect of the system can be found in the dense cities and humid regions where the dense urban fabric can act as a blocking factor for the prevailing wind thus ventilation through openings are not enough. The cooling capabilities of the wind catchers can be effective for up to 8 ^{0}c reduction of the building interior compared to the exterior temperatures (Elmualim, 2006)

The basic operational principle of the wind catcher system is that fresh air is drawn in the windward side and its directed into the building. Addition of louvers can protect the building's interior and volume control dampers are used to moderate flow. Stale air is extracted at the leeward side. The wind catcher head opening should be directed to the dominant wind direction and located high enough to trap the free streamline flow zone away from the surrounding obstacles (Elmualim, 2006; Watson et al., 1983). The deviation of the opening from the normal wind direction could make its ventilation less effective at an angle of 30^{o} and completely ineffective at an angle of 50^{o}. Many modifications were added to the wind catcher's design in order to increase its ability to capture the wind including; rotated heads controlled by vans and different shapes (Engineers, 1999).

Montazeri et al. (2008) investigated the best configuration and orientation for optimum natural ventilation performance of a typical wind catcher within an urban context, the investigation concluded the wind angle and the context have a deep impact on the airflow rate, direction and the pressure distribution over the wind catcher. They found that the maximum ventilation conditions were obtained, when the wind direction is perpendicular to the wind catcher's opening. In a more recent study Montazeri (2011) argued that the most effective design configuration to enhance the wind catcher's performance are; its height, cross section of its air passage and the head opening number and place. The research compared between the ventilation performance of circular wind catcher with 2, 3, 4, 6 and 12 openings and rectangular shaped ones with one or two openings, concluding the following:

- The airflow rate decreases by increasing the number of openings
- The sensitivity of the device to wind direction decrease with the increased number of openings
- The best performance of ventilation was found in the rectangular cross section wind catcher with one opening directed to the wind, the performance was better by four times

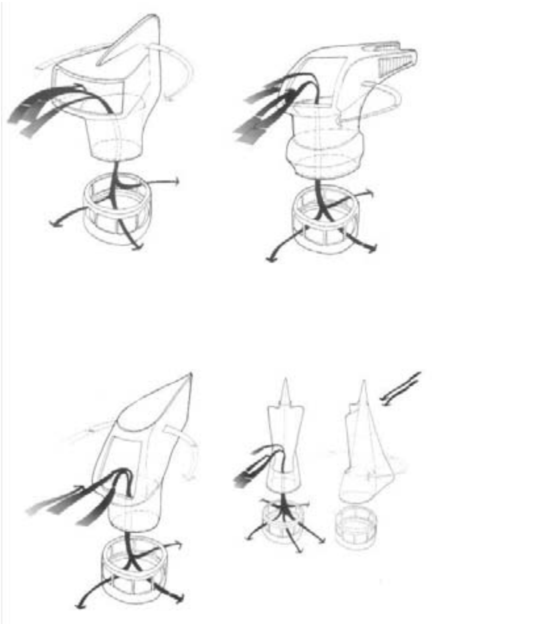

Figure 4-22 Modern design of rotated wind catchers (Engineers 1999)

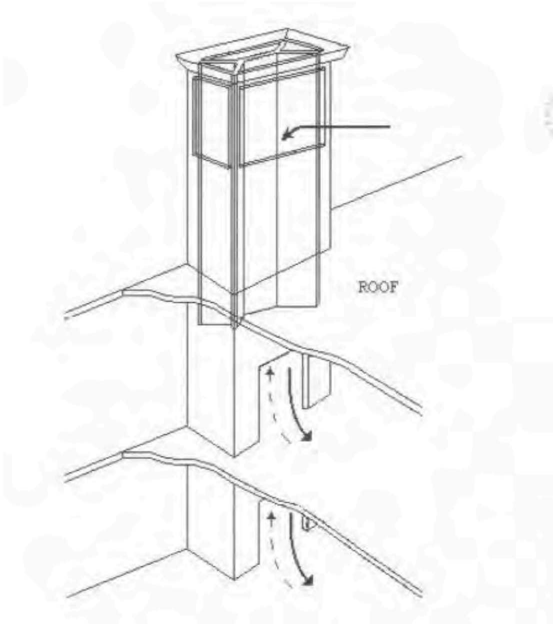

Figure 4-23 modern fixed wind catcher (Allard et al., 1998)

4.5.5.3 Wind tower

The wind tower performs both jobs of introducing the air down to the interior and exhausting it out through its multi opening configuration, as discussed by (Santamouris et al., 1998) there are three physical factors contributing to the control of the wind tower performance, Figure 4-24:

- Downdraught: when there is no wind, hot air enters the tower from its side, contacts it high inertia walls, cool down and the washes down to the tower bottom
- The wind effect: wind movement effect cools the air that enters the wind tower, as the tower is connected with the down spaces of the building that

have a leeward side, effective cross ventilation could be created. However, it is less effective during the night as the cool night air gains some heat from the tower wall gained during the day time and radiated during the night.

- The stack effect: during the night the heat released from the tower fabric can heats the air creating a low-pressure area at the tower's top, causing draught

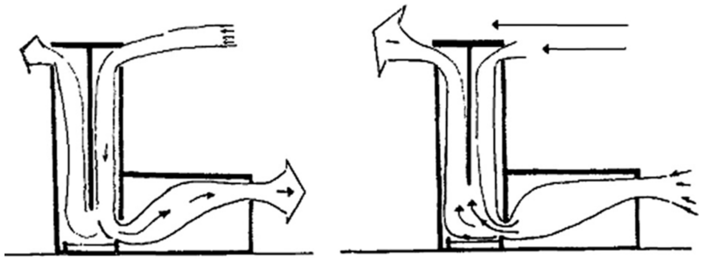

Figure 4-24 operating principle of wind tower (Khan et al., 2008)

Bahadori (1985) tried to improve the conventional "Baud-geer" tower design, in order to maximize its cooling effect and avoid some of its disadvantages by adding screens to the tower opening head to avoid dust, insects and small birds to enter. He avoided the problem of the loss of airflow due to the opposite openings opposite to each other in a multi- opening catcher's head by adding gravity dampers, allowing the air to move through the opening facing direction, while closing the dampers on the other direction. Finally, the addition of a clay grill to the top part of the tower to maximize the contact area with the air to enhance the heat transfer. Bansal et al. (1994) investigated the wind tower coupled with solar chimney design, the system consisted of a uniform cross section wind tower, solar chimney was used to enhance the stack effect for exhausts the study indicated the dominance of wind driven ventilation, but in the case for low wind speed the solar chimney dominates. The wind tower alone provided up a lower ACH which can reach to a higher rate with the use of the combined systems.

In terms of applying the system within a retrofitting framework, previous researches have indicated that ventilation shafts can act as discrete ventilation inlets or outlet sources enhancing the airflow rates and patterns within an existing heritage building depending on the building's scale and the complexity and number of its internal spaces. Higher mass buildings composed of several floors with a large number of internal spaces require more complex wind shaft strategies. This is especially true in the case of wind towers where a larger number of openings associated with each floor connect several internal spaces. These will require a large number of associated wind towers with a larger cross section and height above the ceiling level in order to increase the quantity of air induced. However, in the case of a single family or a small-scale building the addition of a system according to the designed ventilation strategy would not affect the preserved heritage value of the building. The system will require changes to the building's interior which may be acceptable, depending on its heritage designation level, the flexibility of interior modifications possible and also how the towers can be visually implemented in the urban context.

4.5.6 Building envelope projection

Building envelope projection could be vertical (wing walls) or horizontal (shading device and overhangs). They have a great effect in directing the airflow and its speeds inside the building (Watson et al., 1983), the concept is forming an air dam that blocks the air; regulating its pressure and deflects it to desired space.

The vertical projection, such as wing wall is usually for aiding single sided ventilation on windward facing windows. The main aim is to induce positive and negative pressures on either side of two projection originated from the window, thus improving the flow rate on already limited single sided space. The wing wall was first introduced by Givoni (1968) as an architecture feature that could enhance poor ventilation performance in single sided ventilation. The wing walls could be baffles, panels, hinged perpendicular shutters or solid structure walls (Watson et al., 1983).

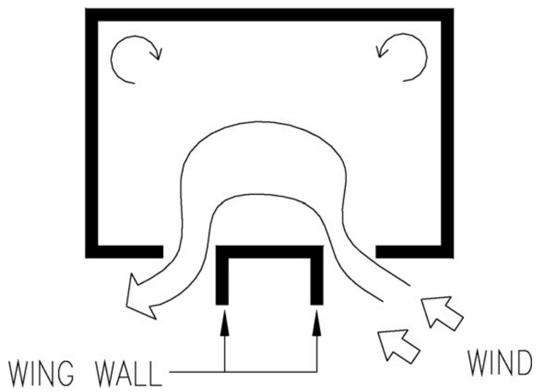

Figure 4-25 airflow enhancement due to wing wall (Mak et al., 2007)

Horizontal projection, such as shading devices and overhangs, create pressure pockets under their surfaces causes the funnelling of air trapped into the interior. In addition their use it also works as a solar shading, the increase of the overhang projection increased the positive pressure near openings under it, increases the airflow rate and velocity, and provide more shade (Santamouris et al., 1998). The airflow or the path can be directed, for example solid shading devices deflects air stream up to the ceiling, which won't have the best effect for occupants. This effect can be modified by adding a gap between the building wall and the projection.

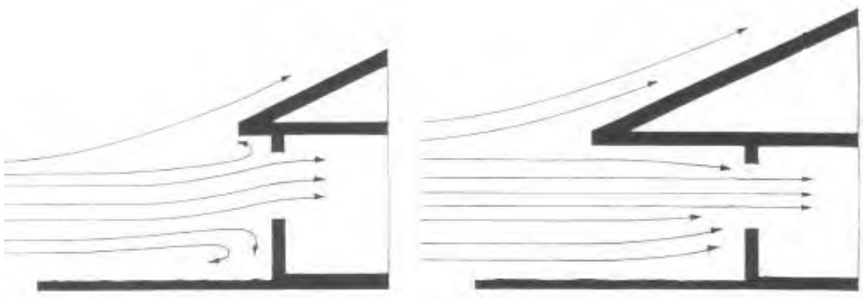

Figure 4-26 the effect of increasing the overhang size on the airflow through an opening (Santamouris et al., 1998)

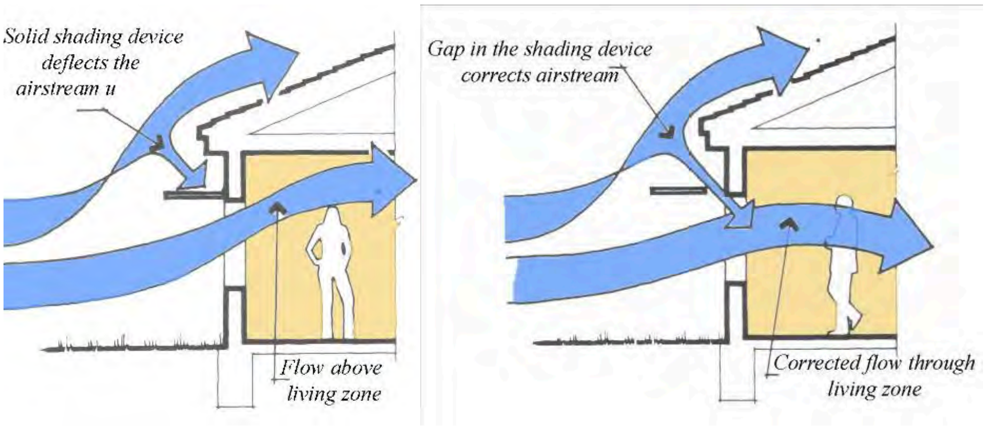

Figure 4-27 directing the airflow by adding gap in the shading device (Watson et al., 1983)

Mak et al. (2007) examined the application of the wing walls using CFD simulations, the results indicate using the wing walls it can enhance the average air velocity in the room by 40 % of the outside incident wind velocity whilst without one is only 15 %. The results also indicated that the relative size of a wing wall for a given window size reaches a value, above which any increase in size will not improve the performance.

Wing walls have been shown to be effective, although this type of inducer would have good results but the architectural integration of this process with would have a tremendous effect on the exterior façade. however, in the case of retrofiring heritage building and dealing with its architectural identity the use of building envelope projection would be unlikely used due to the change of the facades character for it to be applied.

4.5.7 Passive systems application on heritage building

Based on the study the study of passive systems applied for natural ventilation, previous researches have indicated their parameters were found to have significant positive effect for improving the building's performance in the matter of airflow magnitude and distribution. Improving natural ventilation some of these systems can be integrated together for a maximum performance depending on the ventilation strategy applied. Dealing with these systems may require physical changes to the existing physical form of the building intended for retrofitting. Some of these changes require modifications on the external façade with different extents, while other systems require interior changes.

The previous researches have not addressed the applications while dealing with heritage buildings as a natural ventilation retrofitting approach, as the physical modifications required for a retrofit can be limited by the preservation concepts and the building's heritage level. Dealing with heritage level 'A' modifications allowed externally and internally are very limited, heritage level 'B' more flexibility is allowed internally while same restrictions are forced on the exterior, finally heritage level 'C' maximum flexibility is allowed internally.

In order to consider these passive systems is dependent on their physical impact cross referenced with the heritage level of the building, Table 4-4 discusses the passive systems physical changes requirement and their applicability on different heritage grades.

Table 4-4 passive ventilation systems cross reference with the heritage grade completability

Passive system		Parameters	Application	Heritage grade compatibility		
			External / Internal	"A"	"B"	"C"
Façade ventilation opening design	Opening size	Modification requires changes to opening size • ratio of the served floor area • inlet and outlet ratio	External impact	○	○	○
	Opening position	Modification changes to opening position • horizontal position • vertical position	External impact	○	○	○
	Opening number	provide single or more than one opening on different or same external wall	External impact	○	○	○
	Opening type	Changes to opening type • influence active open area • manipulate airflow distribution	External impact	○	●	●
Roof shape		Depending on roof type and orientation • relocating inlet/outlet • roof additions	External impact	○	●	●
Connected internal spaces		Increasing internal spaces connectivity • connection between spaces • transom windows additions	Internal impact	○	●	●
Double skin façade		Addition on the exterior • double skin facade orientation • ventilation strategy	external impact	○	○	○
Ventilation shafts		Addition of wind tower, catcher, or exhaust • ventilation strategy • opening number, orientation and cross section	Internal and external impact	○	●	●
Building envelope projection		Addition on the exterior • horizontal projection • vertical projection	external impact	○	○	○

● Compatible ○ Not compatible

4.6 Natural ventilation auditing and evaluating techniques

The section below describes the concepts and techniques commonly used in modelling and investigating of the airflow in the investigation of the airflow around and inside a building. It firstly discusses a brief of the different methods on site field measurements and reduced scale wind tunnel. Finally, an emphasis on the computational fluid dynamics (CFD) modelling. Discussing the different steps taken to perform a reliable (CFD) simulation process and attaining confidence in the results, backed up different verification and validation requirements using different CFD model using examples from the literature.

Characterization of the airflow is a very complex process and requires several tools for understanding the flow. According to Van Hooff et al. (2010) there are three main approaches can be distinguished;

- On site field measurements
- Reduced scale wind tunnel
- Numerical modelling with computational fluid dynamics (CFD)

The importance of understanding of the airflow patterns lies in the purpose of deciding a retrofitting solution adopting the building's performance audit in the strategy, there are two types of analysis required; the analysis of existing situation, and the analysis of planned retrofit. For the first type analysis, field studies are the best way for obtaining information, but because of its high cost and long study it is not possible to study the full range conditions. Airflow comes as a detailed alternative without extensive field measurements.

The modelling of the airflow is even more important in the second analysis for understanding the wind patterns in order to evaluate the environmental issues of a specific built environment. The importance of this evaluation lies in understanding the wind potential of the built environment and how it can affect a successful retrofit and the need for future improvements. It also gives an understanding of how the air changes and patterns could affect the indoor air quality and the achievement of passive cooling.

According to (Plate, 1999) performing the field studies are not the best technique for wind analysis. On the other hand, it can be used mainly as a way of monitoring the environment, providing information for setting initial conditions, or model calibration or verification.

4.6.1 On site field measurements

In order to make an accurate airflow field measurement, there several aspects need to be considered depending on the type of airflow;

- Airflow within a room or zone
- Airflow between different rooms or zones
- Airflow between building and outdoors

Many techniques have been developed to measure these different types of airflow in buildings. These techniques according to (McWilliams, 2002) can be divided into four categories according to the field being tested in natural ventilation; air velocity, envelope air leakage, and tracer gas (single zone and multiple zone).

The airflow measurement that would be used in this research is the velocity and direction of the air flowing past a given point in space at a given time. This type of measurements is having two main difficulties; firstly, in a low flow area, as the device used can affect the air stream, the problem itself increases when measuring several points close to each other. The second difficulty is measuring enough point to determine the airflow.

The most common used device for measurement is the hot wire anemometer. Mueller et al. (1994) describes the advantages and the disadvantages of this technique. The advantages are that the equipment comes in a low price compared to other equipment's like laser-optical equipment, it provides high resolution in time and space, being able to measure velocity and turbulence intensity. However, the device itself can disturb the airflow, and they have a spatial resolution disturbance dur to the wire dimension.

Karimipanah et al. (1996) performed experimental and numerical analysis of the flow field in a room to determine the room ventilation effect on occupants' comfort level. They used a hot wire anemometer to measure the velocity for a consecutive time in different locations, the measured turbulence intensity didn't represent the actual turbulence as the hot wires were not able to measure large fluctuations.

Due to the limitation error of the hot wire anemometer Liu et al. (2012) conducted a new prototype formed that microelectromechanical systems (MEMS) sensor based anemometers can be low in cost for mass production. And due to its ultra-thin filaments and fine structure, a MEMS-based hot-film sensor also has the potential to outperform traditional hot-wire or hot-film sensors. Having a probe structure mounted with three MEMS based hot film sensor can detect both airflow speed and direction with high sensitivity. However, the data represented by field measurements represent an average over 10 min or 30 min time intervals. Longer intervals are no applicable to present reliable field experiment data, as the meteoritical conditions changes within 30 min.

4.6.2 Reduced scale wind tunnel

Another means for monitoring airflow is physical models applied as a method of airflow investigation in a wind tunnel chamber. It is considered a method of studying the airflow without extensive field measurements. Models are even come handier while studying the impact of future development, which is not possible in the field studies.

The wind tunnel consists of inlet fans, flow straighteners, such as screens, a turbulence generator, an airflow adjustment, the test section itself and finally an outlet surface. The most important input to the experiment is modelling the boundary layer and establishing a nature like boundary layer along the wind tunnel floor (Cermak, 1975).

Wind tunnel physical models are models which are a reproduction of an urban situation to be studied at a small scale, which implies it is more effective on the urban scale analysis due to it nature.(Plate, 1999). Mitchell et al. (1977) suggested that the effectiveness of natural ventilation models is suitable to use under isothermal conditions, when the difference in temperature between the inside and the outside of the study is negligible, they have done several applications using a basic 2D model.

Figure 4-28 wind tunnel model of the new York trade center astudy by Dr. J.E.Cermak and A.G.Davenport in the Colorado State (Plate, 1999).

Choiniere et al. (1994) conducted a wind tunnel study of wind direction effect in a naturally ventilated swine buildings, using a smoke in a wind tunnel to visualize three-dimension airflows patterns. According to the study smoke tended to take more time to disperse, these zones of slow smoke dispersion could be attributed to the transports of smoke from one region to another or lower local air exchange rate. Another study was conducted by Ernest et al. (1992) presenting an application study of assessing the surface pressure data measured with a wind tunnel on a sealed building envelope and how it could be used to predict induced indoor air velocities in buildings. Then the indoor air motion can be used to predict the thermal comfort to be expecting in a naturally ventilated building. Despite the effectiveness of the method on the urban scale, the wind tunnel measuring the airflow in the internal environment of a building will present a challenge for acquiring a reliable outcome, suggesting the use of computer simulation models for the internal environment (CFD).

4.6.3 The computational fluid dynamics (CFD) simulation

Computational fluid dynamics (CFD) is one way of investigating airflow in and around buildings. The software provide computer based numeric solution for the governing equations for the fluid flow, and asses a space in the matter of the airflow and temperature (CIBSE, 2006). The use of CFD software helped on the process of solving problems involving turbulent flows in steady and dynamic time.

The increase use of CFD for the airflow study can be attributed to the strong interaction between the outdoor wind flow and indoor airflow when natural ventilation occurs through large openings, as using the analytical or imperial models are difficult to predict ventilation through an enclosure. Straw et al. (2000) examining cross-ventilation study that the use of pressure coefficients didn't result in accurate flow rate in comparison to measured volume flow rates (deviation of 28-32%), while the coupled CFD simulation in the same publication provided far more accurate results, with a deviation of only (3-9%) from the measurements.

The software conducts numerical analysis for the problem using the Navier-strokes equation for energy, mass and momentum, with addition to the transport equation for turbulence components (Awbi, 2003) . the disguising factor of CFD that it has the capability to deal with complex shaped walls and other boundary conditions using flexible fine scale grids in addition, the CFD includes advanced turbulence treatment schemes.

4.6.3.1 Defining the target values

The first step should be the definition of the target variables as mentioned by (Schlünzen, 1997) and (Menter et al., 2002). The variables representing the target of the simulation should be included combined with those that can be compared with the corresponding experiments. The computer-based tool can predict the following variables;

- Internal and external air movement patterns and air flow path
- Building behaviour in ventilation studies
- Stack and wind pressure inside and outside the building and their interaction
- Heat transfer within the building

4.6.3.2 Governing equations and approximate forms

The governing equations are the three laws of conservation used by computational fluid dynamics to solve fluid problems. These equations are derived from the basic conservation and transport principles; (a) conservation of mass (continuity) equation, (b) conservation of momentum (Newton's second law) and (c) conservation of energy (first law of thermodynamics)(Vardoulakis et al., 2003).

While the term Navier-Strokes (NS) covers the Newton's second law, in CFD it is generally used to refer to the entire set of conservation equations (Blocken, 2015). The equations of the standard K–ε model is:

For continuity:

Equation 4-13 $$\frac{\partial \mu_\iota}{\partial x_\iota} = 0$$

For momentum:

Equation 4-14 $$\frac{D\mu_\iota}{Dt} = -\frac{1}{\rho}\frac{\partial \rho}{\partial x_i} + \frac{\partial}{\partial x_j}\left[(v + v_t)\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right)\right]$$

For turbulent kinetic energy:

Equation 4-15 $$\frac{DK}{Dt} = \frac{\partial}{\partial x_j}\left[\left(v + \frac{v_t}{\sigma_k}\right)\frac{\partial K}{\partial x_j}\right] + P_k - \varepsilon$$

For energy dissipation:

Equation 4-16 $$\frac{D\varepsilon}{Dt} = \frac{\partial}{\partial x_j}\left[\left(v + \frac{v_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right] + \frac{\varepsilon}{K}(C_1 P_k - C_2 \varepsilon)$$

Where: C_1, C_2 model constants of K–e model, K turbulent kinetic energy, P mean pressure, P_k production of turbulent kinetic energy t time, U_c convection velocity, U_i mean velocity in the direction, U_j shear velocity, ε turbulent energy dissipation rate, ρ density

Additional terms can be added to these equations, e.g. the gravitational acceleration and the buoyancy terms. The equations of state optioned through the thermodynamics equilibrium assumption and the Newtonian model of viscus stresses are also enlisted to close the system numerically. Initial and boundary conditions have to be specified, the atmospheric turbulent models need to be modelled.

4.7 Towards accurate and reliable CFD simulation steps

As discussed above the software conducts numerical analysis for the user defined problem. However, the results for the problem are depending on the user accuracy and understanding of the problem. Several publications where dedicated towards guidance for the best practice steps to be taken to acquire a reliable result from a CFD simulation. Since the start of the application in the 70s and 80s, researchers have been testing the different choices that can be made by the users and their impact on the results (Baetke et al., 1990; Murakami et al., 1989; Stathopoulos et al., 1990). Franke et al. (2010) provided a set of specific recommendations as "The best practice guideline for the CFD simulation of flows in the urban environment" included; the target variables, approximate equations, geometrical representation, solving domain, boundary conditions, computational grid, choice of numerical approximation, time step size and convergence criteria. In addition, the architectural school of japan conducted an extended cross comparison between the CFD simulation results and a high quality wind tunnel measurements to support the development of the guidelines for practical CFD application and published " All guidelines for practical application of CFD to pedestrian and environment around buildings" (Tominaga, Mochida, Yoshie, et al., 2008). The steps according to the different guidelines for acquiring a valid CFD results can be categorized as follow; (Blocken, 2015; Franke, 2007)

- Defining the computational model: this step includes the definition of the target variables, computational domain design (including 3D modelling, domain size, blockage ratio, boundary conditions) and the problem characteristics is decided.
- Solver setting and simulation: which first approximate numerically the unknown flow variables, discretizes the governing equations using these approximations, and finally solves the problem
- Verification, validation and output: The CFD simulation has to be verified and validated, the final output is produced as plots, vectors (wind velocity and direction) and contours and can provide animation for the result display.

4.7.1 Defining the computational model

The Computational domain

It is the process of generating the volume the defines the outer limit of the examined simulated case. The enclosure set by the computational domain cuts of the surroundings, which in turn must be represented by the appropriate resemblance of the simulated environment, and not interfere with the fluid flow. The following recommendation should be applied to formulate a computational domain; geometry creation, domain size and the boundary conditions.

The approaches employed for wind induced natural ventilation are the whole domain and domain-decoupled CFD modelling (Jiru et al., 2010);

- Whole-domain approach: in this approach the outdoor and the indoor are modelled simultaneously within the same computational grid, through this the calculation of airflow around and inside the building.
- Domain-decoupling approach: this approach separates analysis the external fields outside and internal flows inside the building. Simulation is conducted for a sealed building to determine the airflow around the building, then boundary conditions at the building surface are collected. Using the collected boundary conditions airflow simulation is conducted inside of the building.

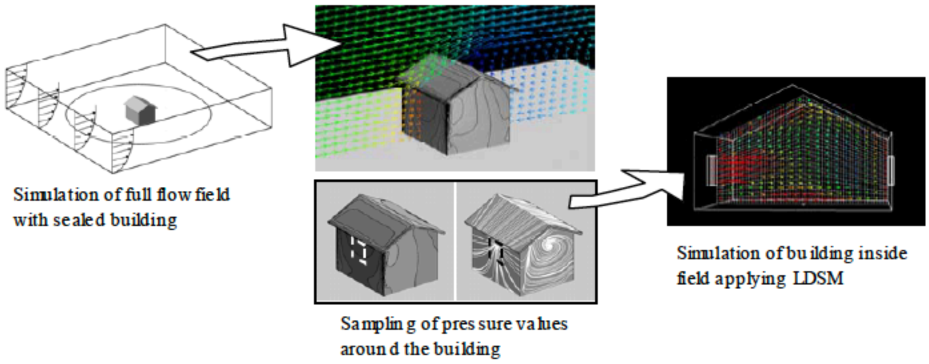

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Figure 4-29 Domain-decoupling approach (Kurabuchi et al., 2008)

Geometry creation

Building up the geometry representing the built environment, building and obstacles have a great impact on the wind flow patterns. However, the level of details required is dependent on the problem solution of interest. Details of the facades and roofs are of secondary importance as the geometry should be simplified as possible without affecting the wind flow.

The level of details of a single building is dependent on their distance from the central building of interest. The central building at which wind effect are the main interest requires a great level of details, and any feature bigger than 1 m should be represented. Buildings further away in the urban environment can be represented as simple blocks. (Pontiggia et al., 2011) (Tominaga, Mochida, Yoshie, et al., 2008). However, Franke et al. (2004) indicates the level of details is dependent on the application and the tested variables. For example, if the internal airflow of a building is the question, it needs to represent the internal layout of the building are more critical than if the pedestrian- level wind speeds are required.

The above recommendations indicates that the central area of interest should be modelled with as much details as possible, doing that increases the number of cells that are used to resolve the details. the level of details can be limited by the available computational resources and the mesh required. In some cases, it is possible to decide the simplification of different details effect the results.

Domain size

The used represented area on the boundary conditions is responsible for the size of the entire computational domain in the vertical, lateral and flow direction. The built area (e.g. buildings or structures) represented in the computational domain extent, depends on the influence of the features on the region of interest. In general, only the bottom of the computational domain responds to an actual physical boundary. The side and the top faces are non-physical boundaries, should be located away from the region of interest to avoid artificial acceleration.

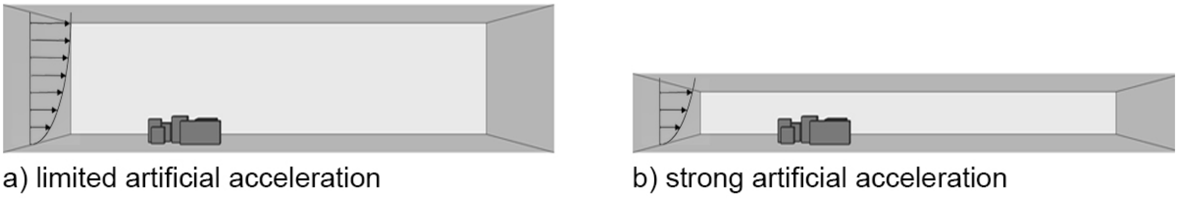


Figure 4-30 the effect of domain height on artificial acceleration

Based on best practices guidelines research, three guidelines have been established to determine the size of the computational domain; imposing the minimum distance between the region of interests and the boundaries of the domain, imposing a maximum allowed blockage ratio, and finally a combination of the previous two methods (Blocken, 2015).

The blockage ratio is defined as in wind-tunnel testing Janssen et al. (2013) provided the ratio of the projected frontal (windward) area of the obstacle to the cross section of the computational domain, and in CFD simulation is it required at a percentage less than 5%.

Equation 4-17 $$Blockage\ ratio = \frac{A_{building}}{A_{domain}}$$

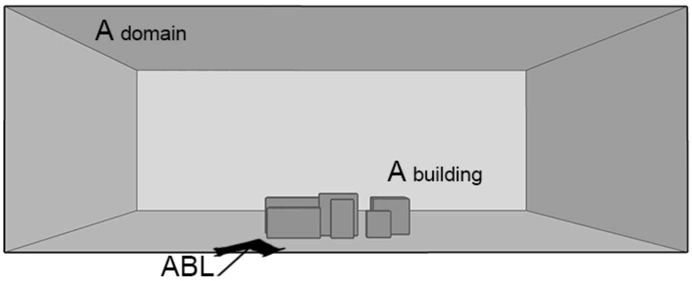


Figure 4-31 view in stream wise direction in computational domain and the definition of blockage ratio

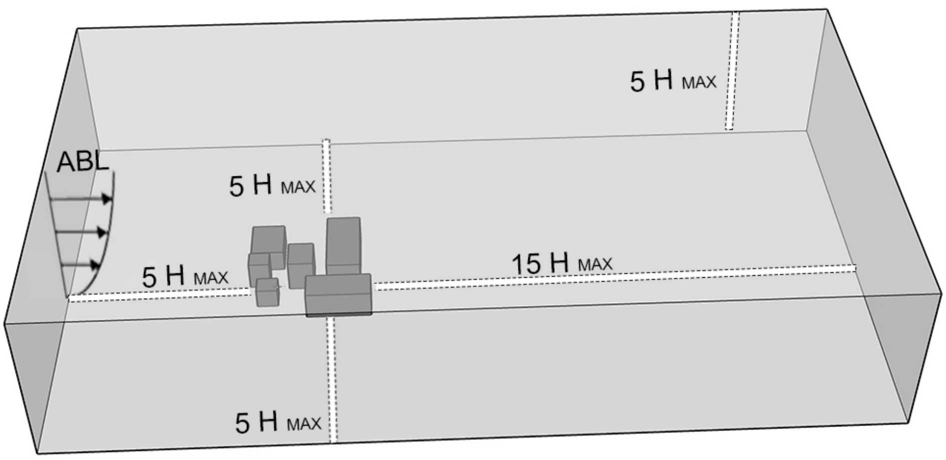


Figure 4-32 size of computational domain according to (Franke, 2007)

Based on guidelines by Baetke et al. (1990) and Hall (1997), the dimensions are a factor of the maximum height of the simulated case H. The vertical extension of the domain should be at least 5H. the outflow boundary should be at least 15H_{max} away from the group of modelled buildings, allowing a full flow development. The lateral boundary of the domain to be at least 5h_{max} away, the distance between the inlet boundary and the model to be equal to the upwind area.

The computational grid

The computational grid defines the resolution of the units in which the simulation resolves the problem in order to achieve realizable results in the CFD. The grid used to discretize the computational domain has a critical impact on the simulation results. The grid should be designed in a way that it doesn't introduce too large errors. Therefore, the grid resolution must be fine enough to capture the important physical phenomena like shear layers and vortices. Grid stretching and compression should be small in regions of high gradients, to keep truncation error small. The expansion ratio between two consecutive cells should be below 1.3 in these regions (Franke et al., 2004).

There are various shapes or units that constitute the base elements of a mesh; tetrahedral, hexahedral, pyramid, wedge, or polyhedral cells, or a combination of these types (Ansys, 2017). with regard to the shape of the computational cells the most commonly used are hexahedral and tetrahedron. However, Hirsch et al. (2002) indicated hexahedral cells are preferred over tetrahedral cells, as hexahedral are known to display better iterative convergence and introduce smaller truncation errors.

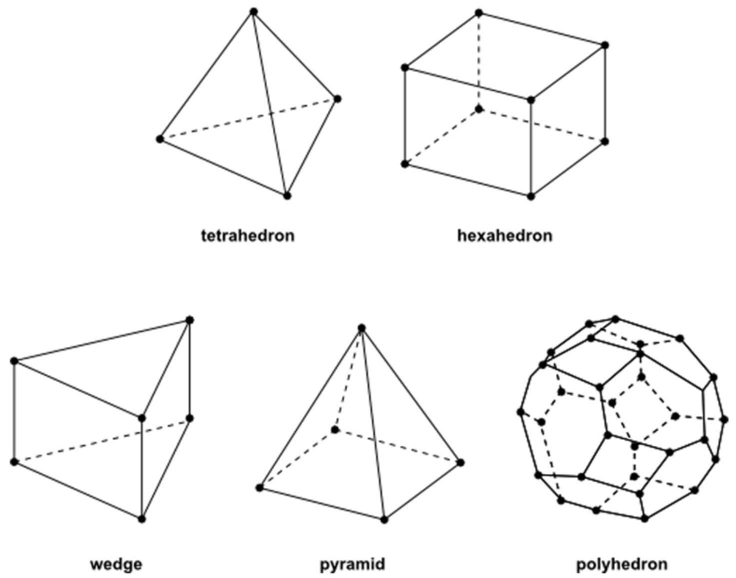


Figure 4-33 Ansys fluent 3D mesh cell types (Ansys, 2017)

Previous researches and guidelines showed that it is impossible to determine the necessary resolution in advance as this is a problem dependent. If the simulation uses the logarithmic wall model, positioning of the first computational node should be placed in the logarithmic region, corresponding to a non-dimensional wall distance at least 30. The wall distance must comply with the wall roughness. As for the built area resolution it should be at least 10 cells per cube root of the building volume (Casey et al., 2000). This is the least minimum grid resolution. Further analysis will be done by using grid refinement. This is considered the initial grid resolution minimum requirements; the resolution will have to be analysed by using grid refinements.

Grid dependent solution

In order to assess the influence of the grid quality on the solution a grid convergence study must be made. As discussed by Ferziger et al. (2012) at least three systematically and substantially refined grids should be used, with a ratio of cells for two consecutive grids should be at least 3.4. Using the Richardson extrapolation the error in the solution on the three grids can be estimated, if the grids are fine enough to yield results in the range (Roache, 1997; Stern et al., 2001).

Accordingly, grid refinements should be done for the local values in the area of interest. The refinement is dependent on the computing capacity and its ability to refine the grid, if it didn't allow the refining of the whole grid if the grid is not fine enough, local grid refinement based on some refinement's criterion can be used to estimate the grid refinements solution instead of refining the whole grid.

4.7.2 Solver settings

Setting the boundary conditions

These conditions represent the influence of the cut- off surroundings by the computational domain. The top boundary usually prescribed by symmetry, enforcing a parallel flow. The same is applied to the lateral boundaries. Therefore, the blockage ratio should follow the recommendations that was set in the previous section to prevent a strong artificial acceleration to the flow.

The outflow boundary is used at the boundary behind the model, where almost all of the fluid leaves the computational domain. The outflow boundary is responsible of all flow variables to vanish, corresponding to a fully developed flow. Therefore, this boundary should be far away from the model as possible.

The inflow boundary is usually set at a distance of 5H. the mean velocity is obtained from the upwind terrain via the roughness length from the corresponding logarithmic profile using the power law. The nearest meteorological station can provide the wind speed information at the reference height.

The solid walls the no-slip boundary condition is used to simulate reasonable roughness especially at the bottom of the domain. Also, symmetry boundaries are used when simulating the geometry and flow are symmetrical along one of the domain axes.

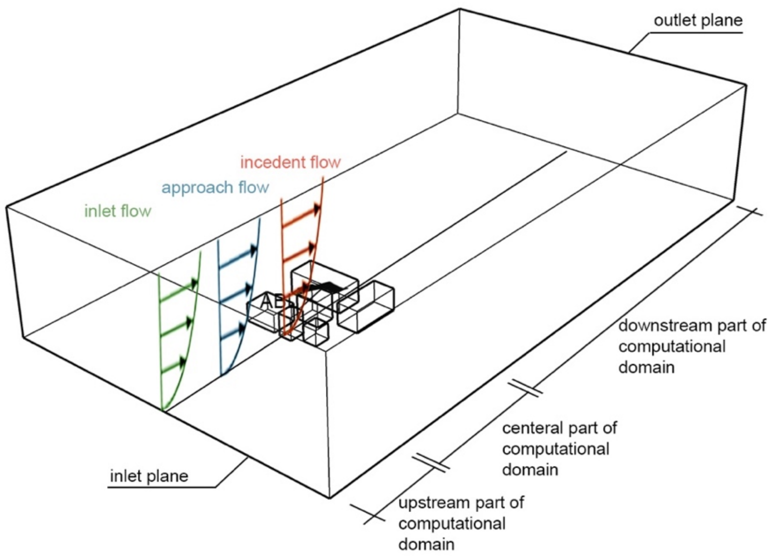


Figure 4-34 computational domain with building models for CFD simulation of ABL flow

Iterative convergence

Most of the CFD software use iterative methods to solve the algebraic system of equations. Starting from the input value of the flow variables to be calculated in every iteration until each equation is solved up to an user specified error (Franke et al., 2010). As recommended, there are two targets to judge convergence; the first is, residual momentum, continuity and supplementing turbulence variable (e.g. ε) drop no less than 4 orders of magnitude. The second target, the user should monitor an important variable of the simulation (e.g. velocity) to insure the stability of the iterations. Monitoring the solution progress and the residual plot can give a clear view for the status of conversion, if the solution is still seeking conversion or stabilized. Stopping the calculation at an early stage can cause inaccuracy in some of the results, both criteria and prudence have to be adopted in order to decide when to stop the iterations without compromising the outcomes.

Turbulence models

The turbulence model is the description of the turbulent fluxes or Reynolds stresses as a function of the mean flow variables. Approximate forms of these equations are solved in two categorize in the urban physics; (I) the classical models based on Reyonolds averaged Navier-strokes (RANS) flow equations (the k-ε standard model, RNG k-ε and realizable k-ε models) and (II) the Large Eddy simulation (LES) models, (which is computationally very demanding).

The RANS equation is derived by averaging the NS equations. With RANS equations, only the mean flow is solved while the turbulence is approximated. The averaging process in the RANS equations results in unknowns and don't form a closed set which need approximations to achieve closure, these approximations are called the turbulence model.

While improved performance for several parts of the flow field could be obtained (Baskaran et al., 1989; Mochida et al., 2005; Murakami et al., 1993), the main limitation of steady RANS modeling remained. RNG k-ε and realizable k-ε models both are improvements of the RANS specific applications. The RNG k-ε model has an improved accuracy on strong flows and swirls from the added terms for the turbulent dissipation rate. The realizable k-ε models enhanced the sharp edges separation and the reattachment by reviewing the viscosity turbulence equations (Ansys, 2017).

In the LES approach, the NS equations are filtered in space, by removing only the small turbulent eddies. The large-scale motion of the flow is solved, while the small scaled motion is modelled. The LES approach in general shows a better performance in general against RANS (Tominaga, Mochida, Murakami, et al., 2008). This better performance comes at a price as the process requires more computational power and large amount of data is generated as many researches compared between the two process on a single building (Liu et al., 2016; van Hooff et al., 2017).

4.7.3 CFD results verification and validation

while performing a CFD simulation acquiring a reliable data requires various means of controlling errors and uncertainties that are known to occur in numerical simulation results, these sources of error can be controlled and quantified by the user while solving the problem. There are several classifications of well-known errors and uncertainties. For the evaluation of the CFD results it is a necessary that all these errors and uncertainties that can cause results to deviate from the true and exact values to be identified and treatment separately. While performing validation simulation it is important to quantify and reduce the different errors according to the previously discussed in the CFD simulation steps (Coleman et al., 1997);

The CFD results has to be verified and validated to make sure the work is related to a certain software is reliable and suitable for the application, the software's supplier provides this information. The modelling process needs also to be verified and validated to make sure of the results are reliable and accurate to the conclusion. Even when all the steps of the CFD process have been followed there is a window of uncertain results.

Validation of the CFD results to attain confidence in the airflow assessment in the case is acquired by comparing the outcomes from the simulation with either a benchmark results, wind tunnel experiment or field measurements (CIBSE, 2006). The literature is emphasizing on the validation according to the turbulence models in producing airflow speed, direction and turbulence levels using the whole domain approach, and comparing the results obtained either to a wind tunnel experiment of field measurements using different turbulence models RNG k-ε, realizable k-ε models, standard k-ε and LES models used and validated in several researches.

Blocken et al. (2015) presented a CFD model simulation model validated by field results for a natural complex terrain, the aim of the study was to evaluate the accuracy of 3D steady Reynolds-averaged Navier-Strokes (RANS) simulations. The field measurements have been made using two dimensions ultrasonic anemometers at five different positions for four months. The results show a good agreement, with deviation with 10-20%. Using a standard k-ε model Nishizawa et al. (2004) calculated the indoor airflow inside a simple building model that was strongly influenced by external conditions, comparing the results with a wind tunnel experiment and validated air flow field and the wind pressure distribution. However, the results showed the calculated values of the pressure coefficient was lower than measurements. Kindangen et al. (1997) have checked the confidence in analysing the effect of wind direction roof shape and height on airflow inside a building. Using a wind tunnel previous experiment study by Givoni validation Mak et al. (2007) showed that the wing walls can increase natural ventilation air change and the mean indoor air speed as the experiment, but there was an average deviation in the internal velocity distribution in the CFD simulation of 25%.

Kim et al. (2010) analysed the ventilation performance of eleven design for arcade markets alternatives and showed that the height of the surrounding buildings and the arcade height, roof shape and ventilation openings can affect the ventilation performance. Using k -ε model to verify the results a CFD simulation was carried out with the same scale-down model under the same conditions of a wind tunnel experiment, the patterns of airflow showed some differences in some cases as the k-ε model could not predict the strong velocity fluctuation through the opening on the roof and the crossroads.

Using RNG k-ε and realizable k-ε models, Yang et al. (2006) using a full-scale field experiment data under various conditions, validated a coupled external and internal airflow in a cubic building with two dominant openings, RANS model predictions are reliable when wind direction are near normal to the ventilation openings, the negative sign indicates that the modelled airflow rate is less than the calculated one.

Comparing the different turbulence models, Stavrakakis et al. (2008) applied three RANS models; standard k-ε, RNG k-ε and realizable k-ε models to study wind and buoyancy induced natural ventilation validating the results using an experimental built room, it concluded that all turbulence models applied agree relatively with the experimental measurements with better agreement with the standard model. Same results were obtained using cross ventilation, single-sided (windward and leeward opening) configuration. The results were confirmed using full-scale measurement. For the accuracy of the RNG k-ε turbulence model compared to the standard k-ε model by Evola et al. (2006), using cross ventilation, single-sided (windward and leeward opening) configuration. The results were confirmed using full-scale measurement with more accurate results acquired by the standard model.

In the case of LES turbulence models, Jiang et al. (2003) demonstrated the accuracy of LES in modelling the wind driven natural ventilation using three natural ventilation cases single sided ventilation with an opening in windward wall, single sided ventilation with an opening in leeward wall and cross ventilation models. The results were measured by wind tunnel and tests compared to LES results for model validation. The numerical results from LES are in good agreement with the experimental data, in particular with the predicted airflow patterns and velocities. Hu et al. (2008) stated that using LES in comparison to other models proven to give a better result in the case of fluctuating flow rate for wind directions normal and parallel to openings, using an experimental wind tunnel validating the outcomes.

According to the previous studies, RANS equations are the most common used approach in CFD for urban physics, according to Blocken (2018) researchers and practitioners used the available computational power to perform RANS simulation for a larger and more complex problems and very time consuming simulations, against less extensive problems by LES. However, as indicated above regardless the turbulence model used the results and outcomes must be validated against an actual monitoring or a wind tunnel experiment and following the practice guidelines to insure the confidence of the acquired results.

4.8 Conclusion

This chapter reviewed the science for natural ventilation in correspondence to the previously discussed heritage retrofit methodology. Introduced in the study of the different natural ventilation strategies in this chapter form the base, on which the selected case study heritage building in the evaluation part will be analysed. Also, the different design measures associated with improving the natural ventilation, their studied performance cross referenced with the different building’s heritage grade compatibility will help in formulating the proposed design measures in enhancing natural ventilation performance inside the case study. In addition, this chapter discussed the different techniques used for auditing and evaluating natural ventilation performance. In general, the chapter introduced the different retrofitting methods regarding natural ventilation strategies with the theories of conservation, integrating cultural significant and environmental retrofit into a unified framework.

Chapter 5 Case study analysis

5.1 Introduction

This chapter presents the methodology adopted for assessing the case study building representing the eclectic revivalist style of the late nineteenth and early twentieth century architecture heritage of Alexandria. It is concerned with the internal natural ventilation performance of the building, as a part of the retrofit framework steps formulated in Chapter 03. In order to achieve the objectives stated in Chapter 01, various methods of research on the case study's architectural style and heritage value were applied.

Retrofitting a heritage building in the matter of improving its natural ventilation performance to perform at a satisfactory level involves the previous analysis of its architectural style, heritage value, level of classification, structure, current conditions and analysis of its relation to the airflow field in the external environment. This is necessary to determine its current performance potentials and deficiencies in order to apply this technique. Thus, the potential is subject to the level of intervention that could be applied to the building according to its heritage listing level and current conditions.

The retrofit process can be described in terms of several steps involving the heritage value of the building and its physical performance. For this reason, the relationship between these important factors is the key derivative of the investigation for the case study building which is considered a represented sample for the heritage buildings in Alexandria built during the same period to the same architectural style.

5.2 The case study building heritage background

The following part introduce the case study building in terms of its history, architectural survey and building's layout, structure system, and its current conditions. Conducting a proper understanding of the building's heritage character defining the level of intervention and limits.

5.2.1 Heritage value and architectural listing

The building selected for the study is an example of the Neo-classic eclectic revivalist architecture style located within the downtown heritage node of Alexandria "the European quarter" Figure 5-1. This style expresses architectural pluralism and the pro-European cosmopolitan city of Alexandria. This style was the early modern style introduced by the Italian architects during this period with its decorative style -the Neo-Renaissance- was considered the favourable expression of the era (Awad, 2008). This part of the city represents the major part of the city's conservation areas.

Figure 5-1 case study building, source: the researcher

The building lies within the heritage list of the city within the local level classification, with a listed number according to the catalogue “108” as a local level heritage building. As mentioned earlier in chapter two the local level heritage classification is around 75 % of the heritage listing in the city of Alexandria which means that this building heritage level lies within the major category of the city’s architectural heritage.

According to the listed building location, it lies within two conservation streets; “Sezostreis” street and “Masjid EL Atarin” street. this means that the listed building is sought to be a representative sample for the heritage buildings in Alexandria built during the same period and to same architectural style.

The building by itself doesn’t have that much architectural significance as a local level heritage classification which means that this building’s type is mainly a part of a group of listed buildings having an architectural expression. Each building by itself doesn't have a heritage value but they became a part of this historical context of the conservation street, creating its urban identity and style, as described by the Venice Charter (Charter, 1964).

The conservation streets “Sezostreis” and “Masjid EL Atarin” have a very coherent urban form and architecture style. The building’s masses are in a regular geometrical form with equivalent heights of 19.2 m and kept on four floors. Elements within the existing context are proportioned together and have the same size and materials. The configuration of the building composition and defining elements together create a homogeneous material, building mass scale, openings and articulation.

Figure 5-2 case study building location within the heritage classification and conservation street map, source: the researcher

Most of the original context buildings (Eclectic Style) have the same materials features; all the external finishing is paint, wooden windows frame, shutters and steel handrails. Openings within the context share similar characteristics and have relatively equivalent linear proportions sharing the same window frames and balconies character. The ornaments and articulations might be slightly different but they share the same characteristics including: the decorative elements, cornices have the same proportion and materials, and the balconies steel work.

The rhythms between buildings are seen through the repetition of the vertical projected windows' bays. This rhythm is continued through both conservation streets. The datum is clearly seen through the storey's height forming a continuous line together, the height of the first floor through both streets is 5.5 m, while the height in the rest of the stories is the same at a height of 3.7 m.

Figure 5-3 case study building in relation to the surroundings in Masjid El Attarin street

Figure 5-4 case study building in relation to the surroundings in Sizostreis street

5.2.2 Case study building ownership and current use

The listed building according to the heritage catalogue (Alex-Med, 2008) was previously owned by princess Najwan, one of the previous Egyptian royal family and inherited by her daughter princess Shwikar after her death in 1941. The building was confiscated with other properties owned by the princess after the 1952 Egyptian revolution after a judicial conflict between the princess and the Egyptian government (Hussien, 2015). The building is now owned by the Awqaf (Ministry of Religious Endowments) and the building's current users are renting the different units.

The case study building current use is residential commercial. The ground floor is composed of twelve commercial shops while the first, second and the third floors of the building are composed of residential flats. Each residential floor plan is composed of three flats occupied by three families, which makes it a total of nine families occupying the listed building.

5.2.3 Architectural survey

Due to the lack of the heritage archives in Egypt, the name of the architect and the building's architecture drawings were not available. A complete architectural survey was done by the researcher in order to produce a reliable drawing that can be used to perform the research.

Talking to the occupants was really helpful and some of them gave permission to enter the premises and perform the metric measurements for the typical floor layout with its accurate measurements. However, doing the external survey within the street level including the external elevation measurements and the streets dimensions was much more difficult due to the trust issues between the public and the government. Another challenge was the photography, due to security reasons set by the government which lead to the use of a laser scanner being impossible.

Overcoming these challenges was not easy but it was possible to do the survey according to the means available producing the set of drawings which would be later used in the research Figure 5-5 ,Figure 5-6, and Figure 5-7.

The building spatial layout was very familiar with the Italian architecture present within the heritage context of the city. The spatial layout was of rooms around a central space mainly used as a living area and a court in the centre of the building where all the different flats are around it. Also, the familiarity is presented in the presence of the thick walls 0.6 m and 0.4 m for external and internal walls respectively used as a bearing structure for the building.

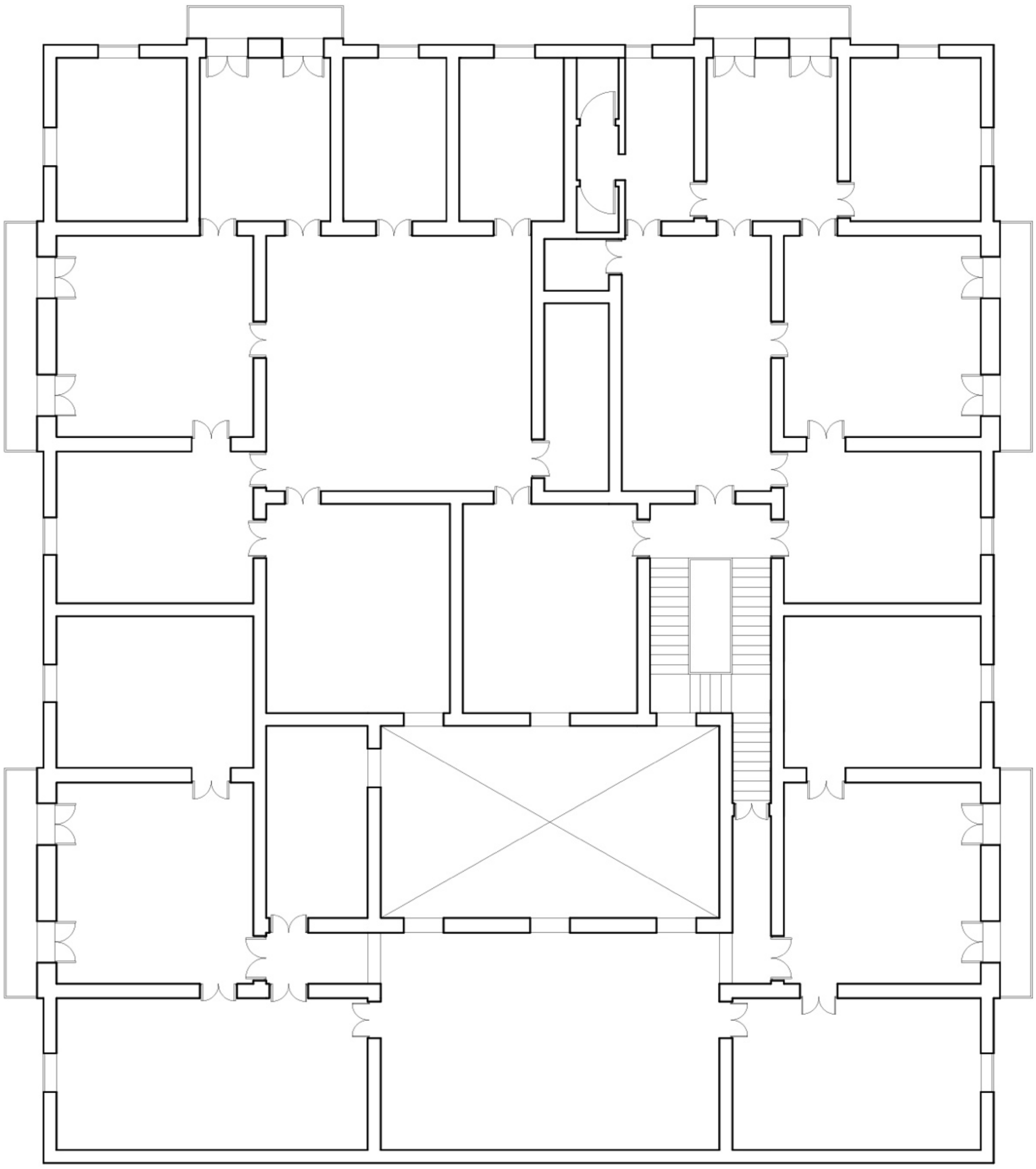


Figure 5-5 typical floor plan, source: the researcher

Figure 5-6 Elevation on Masjid El Attarin street, source: the researcher

Figure 5-7 Elevation on Sizostreis street, source: the researcher

The building design is very modular. The building external elevation reflects the internal architectural layout. There is a very noticeable rhythm throughout the organization of the openings and the balconies giving the external appearance its symmetry which was one of the key features of the neo-eclectic style. This rhythm can be seen through the repetition of the vertical projected windows and the balconies module. The building's both facades were composed of the vertical window module combined with the balcony module with two doors, Figure 5-8and Figure 5-9.

As a reflection of the eclectic Italian style within Alexandria, the building design is a very regular geometrical form, with a height matching the surrounding conservation street 19.2 meters. The stories heights form a line together on both conservation streets. The height of the first storey is 5.5 m in the whole street, while the height in the rest of the stories is of 4.2 m and the handrail of the roof is of a height of 1.2 m, Figure-10.

The building is composed of several architectural motives that reflect the neo-eclectic style with the conservation context of Alexandria. These architectural decoration motives are mainly seen in the building's entrance wooden door with the gypsum decoration around it, the steel work of the balcony's handrail, the parapets above the wooden windows and the main parapet at the building's roof, Figure 5-11, Figure 5-12 and Figure 5-13. All these elements were considered the architectural expressions that were adopted by the Italian style.

The buildings used materials are considered the mostly used materials with the heritage context of the European city of Alexandria (Eclectic Style) having the same materials features thus, were very similar to those erected in Italy, in their use of stone, plaster decoration, gypsum cornices, wooden openings (windows and doors) and the use of metal work decoration (El-Habashi, 1994; Khalil et al., 2018), Figure 5-14. The internal finishing for the entrance flooring is made of marble, and increasingly elaborate iron-work for the stair handrail. Within the residential flat interior, all openings including doors and windows are made of wood. There were not any significant details or decoration for the interior spaces, the interior walls were plaster finished which were modified according to the occupants. Most of the interior doors had a transit window above that was closed using wood panels by the occupants, Figure 5-15.

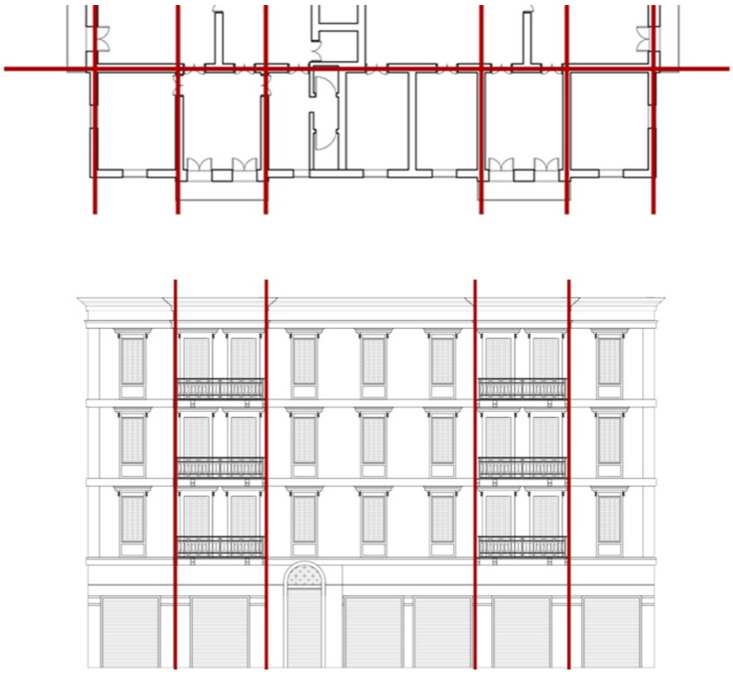


Figure 5-8 case study building external façade rhythm throughout the design with relation to the internal layout, source: the researcher.

Figure 5-9 balconies module within the case study building façade with the two doors openings, source: the researcher.

Figure 5-10 case study building height configuration, source: the researcher

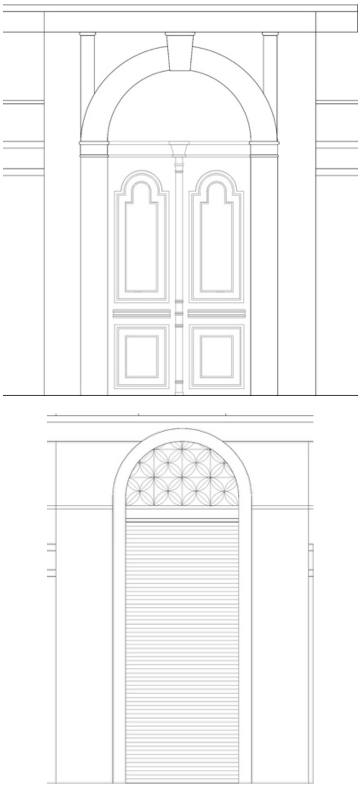


Figure 5-11 entrance doors wooden work decoration and decorative gypsum, source: the researcher

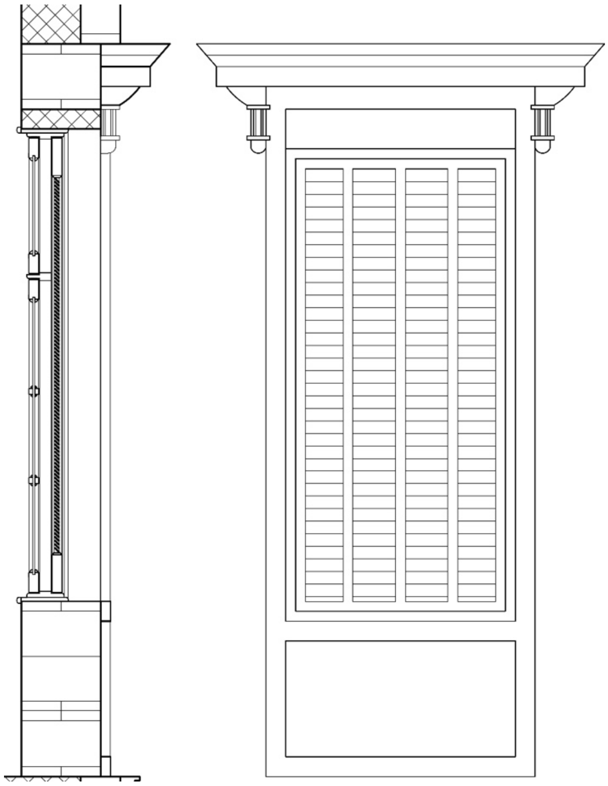


Figure 5-12 opening details with external wooden shutters surrounded by decorative gypsum Cornish, source: the researcher

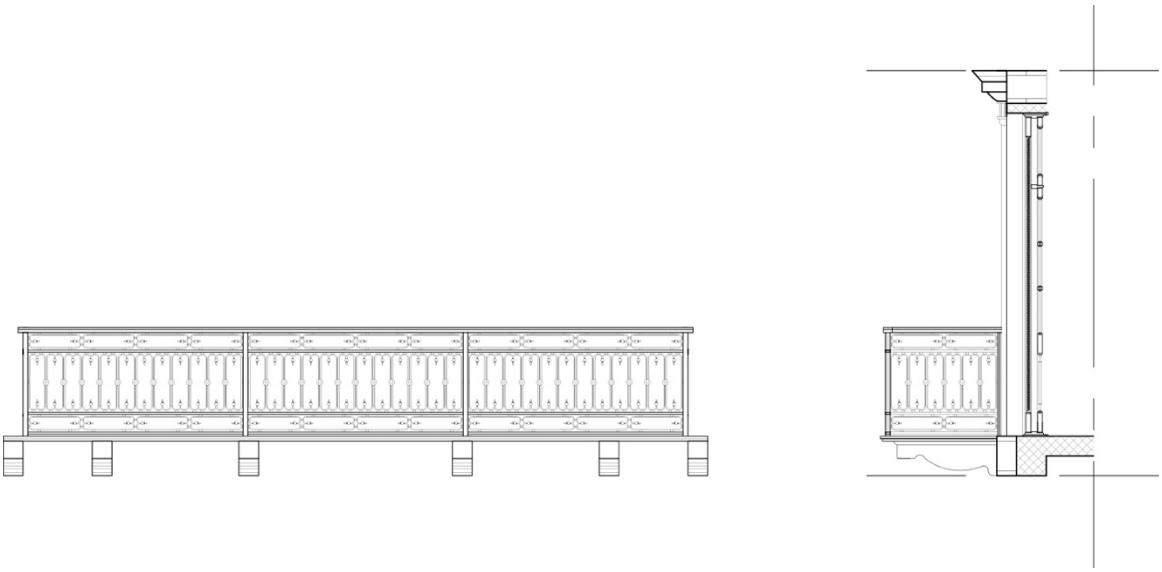


Figure 5-13 balcony’s metal steel work handrail, source: the researcher

Figure 5-14 the different external finish materials and their application

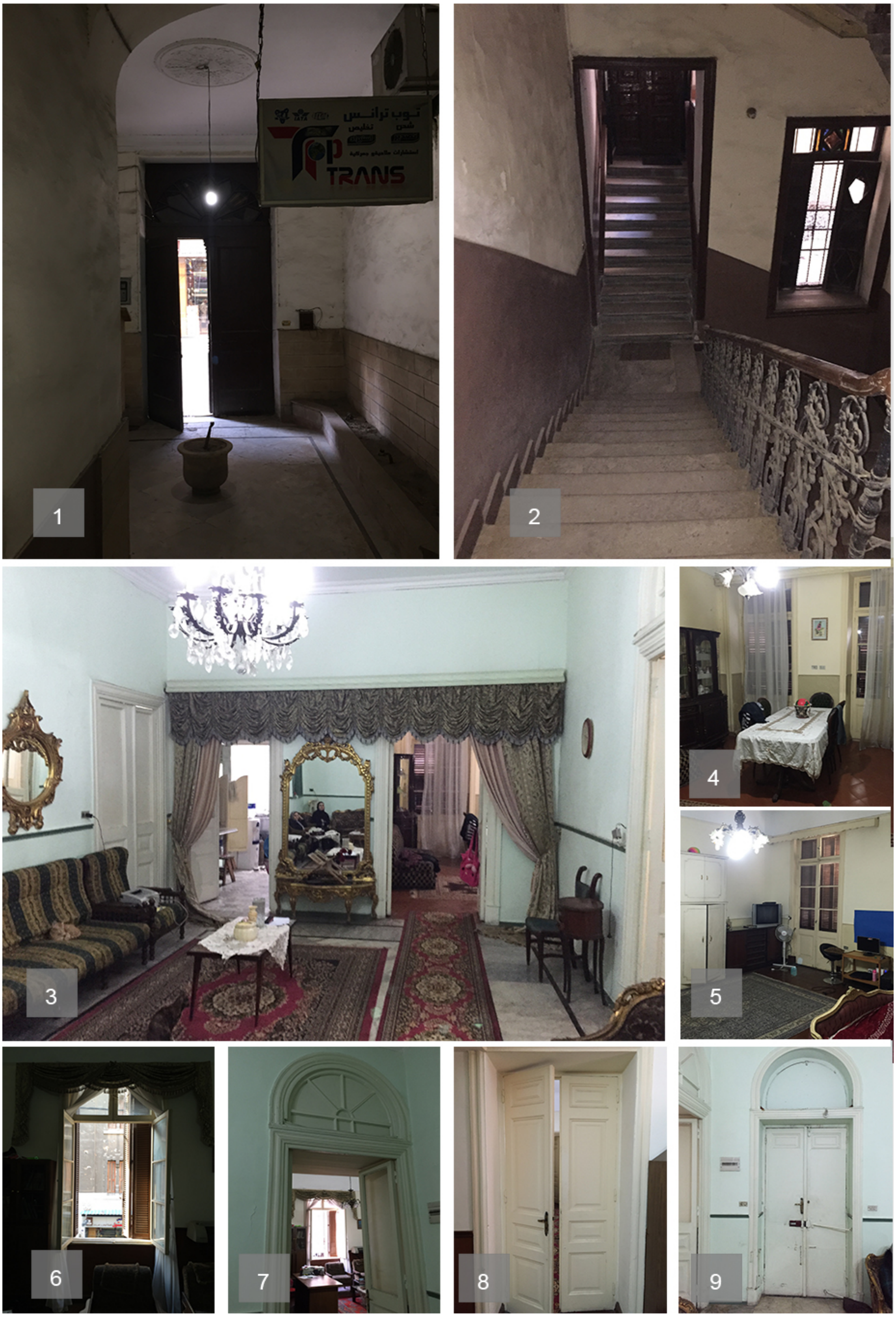


Figure 5-15 the different interior spaces and finishing, 1) buildings main entrance with marble flooring, 2) internal stair case with marble finishing and steel work handrail, 3) main internal living space with plaster finish, 4) dining room, 5) bedroom, 6) external wooden opening, 7) internal wooden door on the main living space, 8) internal door between secondary spaces, 9) main entrance door

5.2.4 The structural system

Within this survey process there were not any archive documents for the building demonstration of the exact structure system used for this specific building. The methodology used for conducting the structure system used was based on referencing to other buildings built during the same time and field observation.

The field observation indicated that the building's main structure system is a load bearing structure, due to the presence of the thick walls as observed during the field survey. The walls thickness ranges from 0.4 m to 0.6 m and there weren't any columns within the building. The formation of the bricks is very obvious in the external elevation at the parts where the external plaster has been deteriorated. In addition to that, the regular vertical geometry of the openings also indicates this conclusion, Figure 5-16. From the literature, data emphasize that according to this building style and time of erection the reinforced concrete wasn't yet introduced to the Egyptian construction methods (El-Habashi, 1994; Khalil et al., 2018; Turchiarulo, 2009).

The brick walls supported a wooden beams structure ceiling, as the construction method being used at this time. Due to the unavailability to see the ceiling exact structure Figure 5-17 shows different ceiling structures of buildings with the same style and erected during the same period(Khalil et al., 2018). The openings lintels (doors and windows) are supported by a concrete block hung over the brick structure of the building as been observed, Figure 5-18. Figure 5-19 is a complete strip section showing the complete structure and materials.

Figure 5-16 the thick walls of the building, source: the researcher

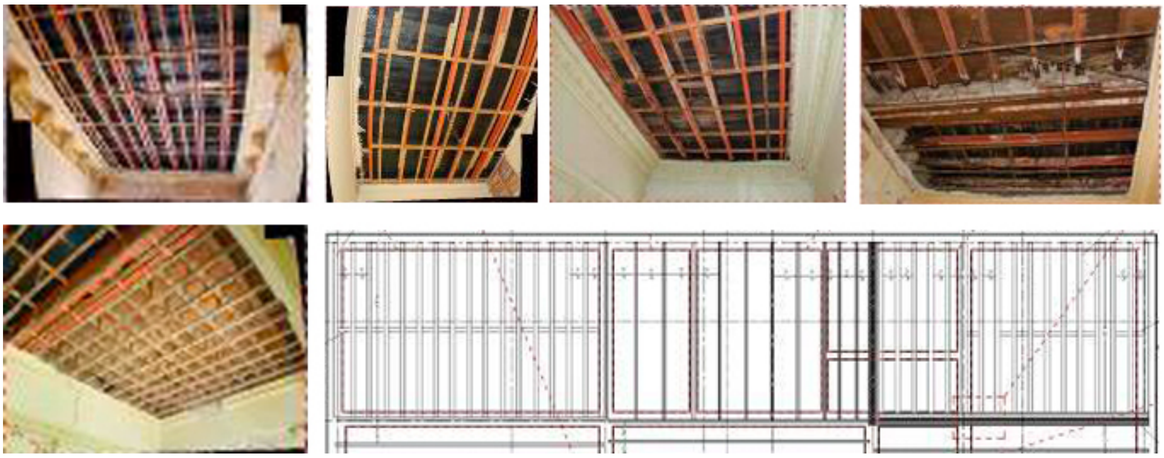


Figure 5-17 different examples of wooden structure ceiling from a similar style building erected during the same period after (Khalil et al., 2018)

Figure 5-18 the openings lintels are supported by a concrete block hanged over the brick structure, source: the researcher

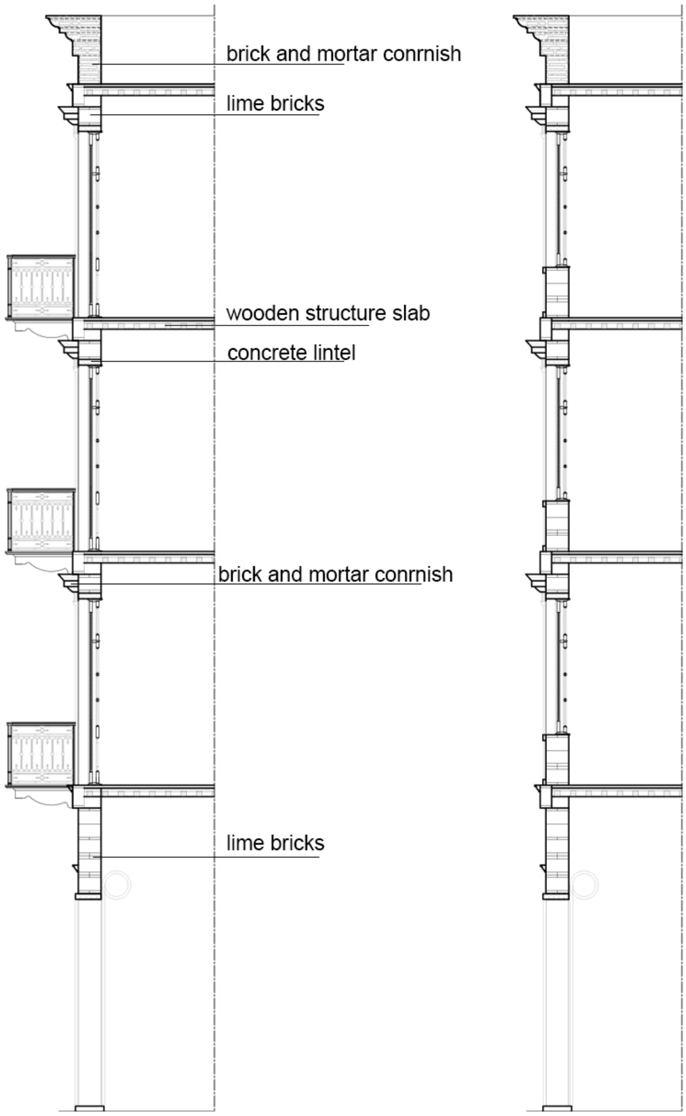


Figure 5-19 strip sections through the building external facade demonstrating the structure system and materials, source: the researcher

5.2.5 The building's current condition

The façades are composed of plaster and gypsum cornices with some areas in very bad condition that required restoration including replacing damaged areas using similar materials in addition to the deterioration of the wooden elements forming the windows shutters and the balconies handrail.

Occupants and shop owners have a major impact on the external façade. The occupants changed the external plaster colour according to their desire in a part of a self-restoration process but considering their own flats only. There was an observed random additions of air conditioning air handling units and piping on the external façade. all that is in addition to shop owners who have used different materials and colours according to their desire, Figure 5-20.

The current conditions and the different random modifications to the building, as discussed in the literature review are not specific to this building but it's a general case that faces the architectural heritage of the city which needs to be resolved.

The current conditions and the different random modifications to the building, as discussed in the literature review is not a specific case to this building but it's a general case that faces the architectural heritage of the city which needs to be resolved.

Figure 5-20 the case study building current conditions, source: the researche

5.2.6 The building's original lay out

According to the archival research of the building's history, as mentioned was confiscated from its previous owner princess Shwikar after the 1952 revolution. According to the previously discussed changes to the Egyptian political, economic and social fabric in Chapter 2. the building's occupants where composed of the city elitist and foreigners with their migration and the rural relocation toward the city. With the high-density growing population, the building's original layout was altered which was a common case with the heritage fabric of the city.

The original layout of the building typical floor was changed from one flat occupied by one family for each floor to be divided into three flats and occupied by thee families, the current building's layout and usage, Figure 5-21. The ground floor usage was the same as the current layout composed of commercial shops. The flat original layout was spacious accommodating the city elitist. The spatial configuration of the flat was composed of large reception and dining area in the centre, occupants' bedrooms and guest hospitality rooms located on the main streets, while the services including kitchen, storages, and servant's accommodation are found on the back area with a separate entrance. The surrounding context have been slightly changed with the erection of higher new buildings after the recent transformation of the city after 1952.

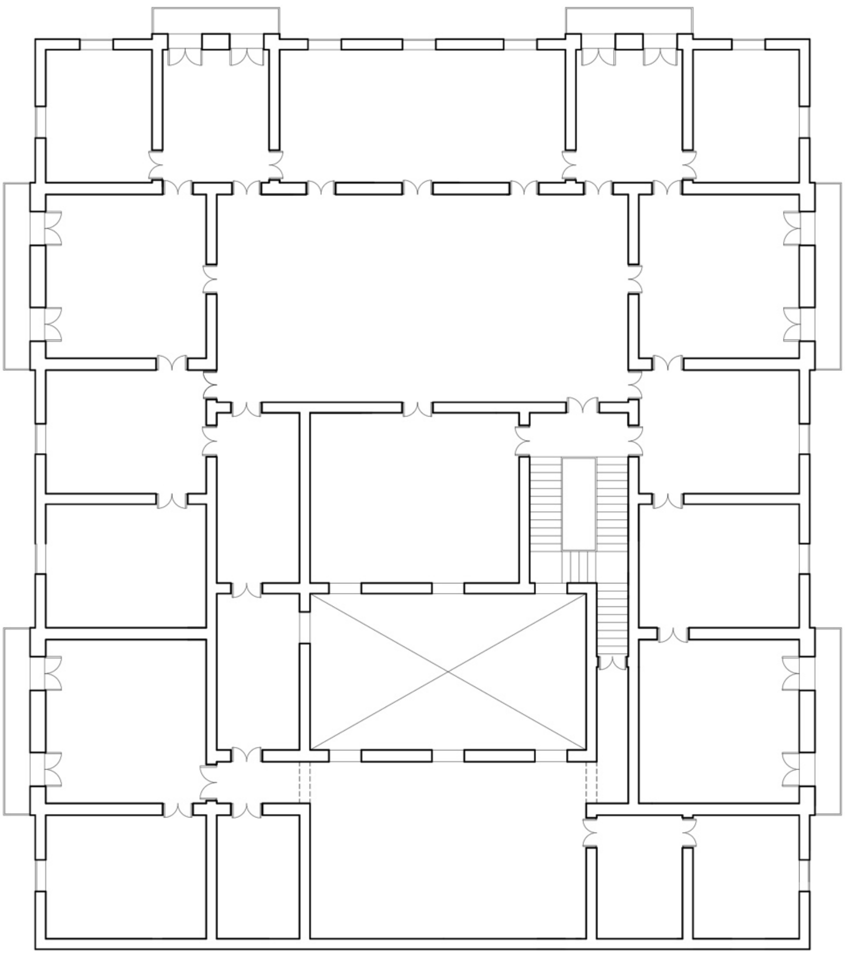


Figure 5-21 case study building layout before modifications, source: the researcher

5.3 The case study building in relation to natural ventilation parameters

In the following section the case study would be analysed in terms of the natural ventilation parameters and design measures that could possibly affect and drive the air movement in and around the building for ventilation purposes. These measures and parameters are; Alexandria's climate and urban fabric.

5.3.1 Alexandria's climate and urban fabric

Alexandria is characterized by moderately warm and humid summers and mild wet winters. It induces specific energy needs in buildings, air conditioning needs being the most significant specially in the summer season. Considering the climate during summer and its consequences in terms of thermal comfort is a characteristically Mediterranean problem (Ghrab-Morcos, 2005). Mean air temperature in the city ranges from 28.5°C in September to 32°C in August. Relative humidity typically ranges from 65% to 92% over the course of the summer months. Typical wind speeds vary from 3.4 m/s(light air to moderate breeze), and rarely exceed 5 m/s gentle breeze), and the prevailing wind direction is strongly affected by the North-Western direction (Weather and Climate, 2019).

As mentioned in Chapter 2, Alexandria is a linear city, the cities extend parallel to the Mediterranean Sea. The fabric of the heritage context is divided into two regions; the waterfront zone which comprises the buildings that line up the shoreline and shape the waterfront facade of the city. This zone extends to about 400m depth in average, and follows the length of the shore line between the ends of the urban boundaries. The second zone's urban fabric is dominantly urban canyons organized at an angle of 20 degrees & parallel to the prevailing wind (NW) (Gomaa, 2015). Moreover, freestanding buildings could be seen along the shoreline in a scattered manner and in rare occasions, Figure 5-22. The case study building lies within inner fabric 1 with 21 degrees towards the prevailing wind.

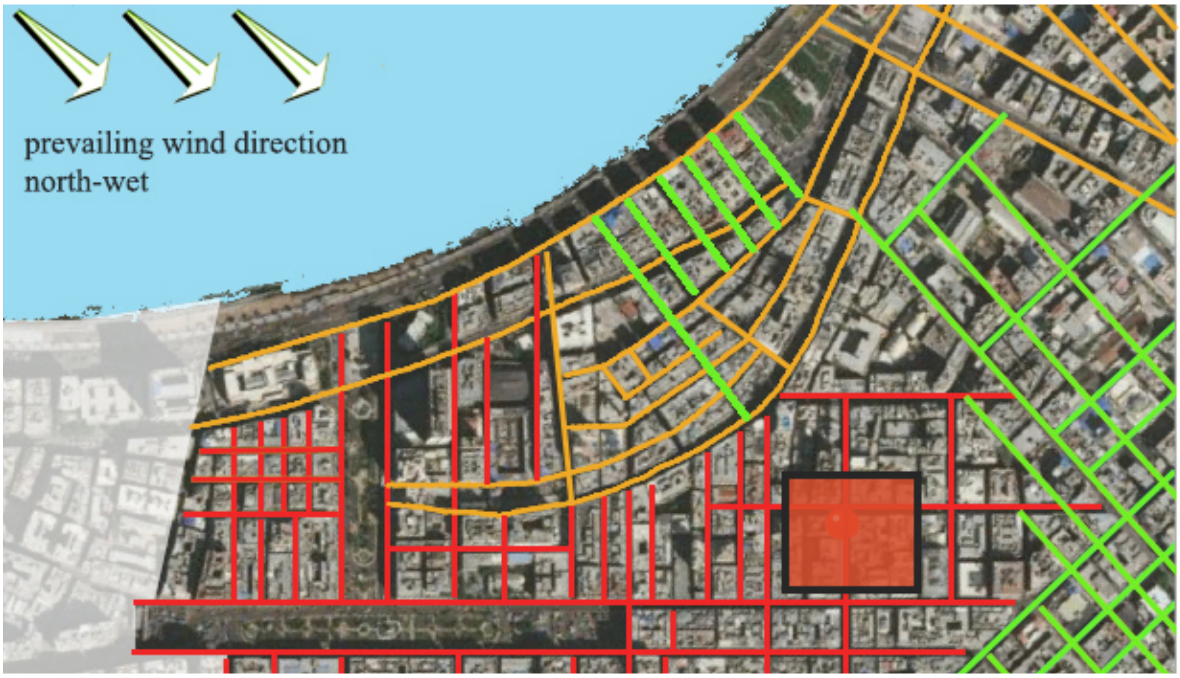


Figure 5-22 case study building in relation to prevailing wind direction

5.3.2 Heritage context adjacency profile

The urban fabric of the city's heritage centre is a dense urban fabric with attached buildings. Therefore, all blocks are found in rows that line the street from both sides (double loaded corridor). The case study building is completely attached from the north side, while the other three sides are detached. According to literature having more than one side gives the opportunity to provide openings in both windward and leeward sides, which could enhance natural ventilation performance.

Figure 5-23 the compact fabric of the heritage part of the city, source: the researcher retrieved from google maps

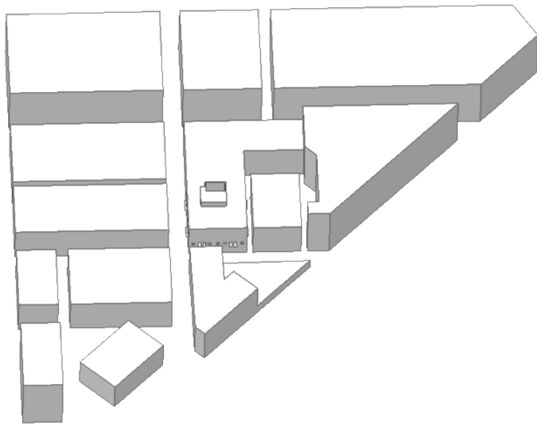


Figure 5-24 3D demonstration of the case study building adjacency profile, source: the researcher

5.3.3 Building mass, wind orientation and canyon configuration

The block is a compact deep mass with a dimension of L=34 m, W=30 m and h= 22m and a W/L 0.882. The block consists of four storeys high with footprint area of 1020 m2 and volume of 22440 m3. The block contains a court penetrating the mass with 57.75 m2. This court is used to provide light and ventilation to the inner spaces. The nature of deep plan design of the block is against the recommendation derived by the literature and may reduce the potential of using ventilation, Figure 5-25.

Wind angle of attack is south west, with an angle of 112 clock wise. Although the prevailing wind in the Alexandrian context is directed from the north-west direction, Figure 5-26. The urban canyon configuration for Sezostreis street and Masjid EL Atarin street are H/W 1.96 and 1.78 respectively having a deep configuration on both streets, enhancing the natural ventilation potentials Figure 5-27.

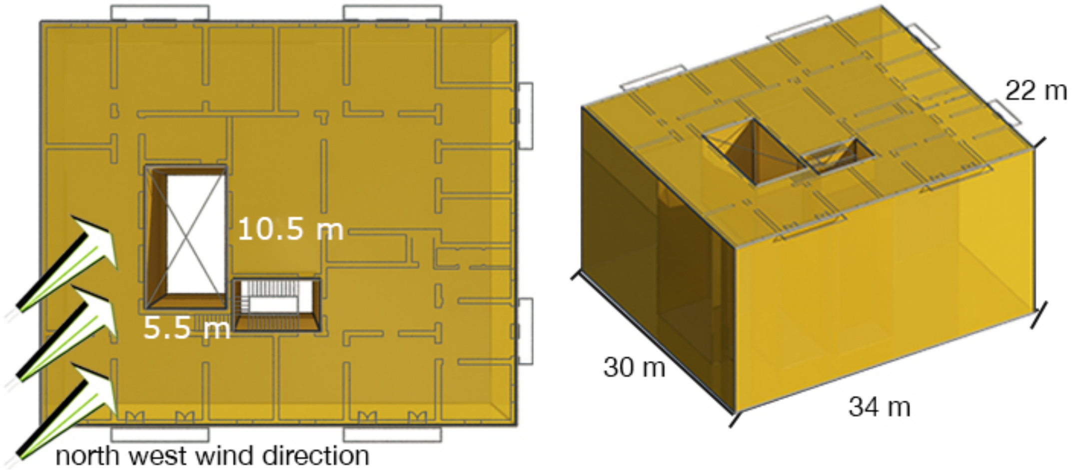


Figure 5-25 case study building form and mass, source: the researcher

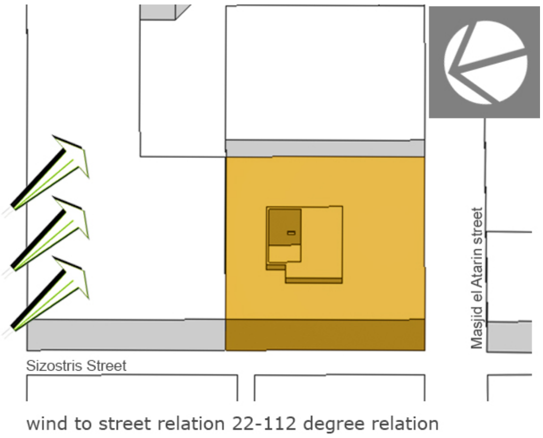


Figure 5-26 wind to street orientation 21-112 degree to prevailing wind direction, source: the researcher

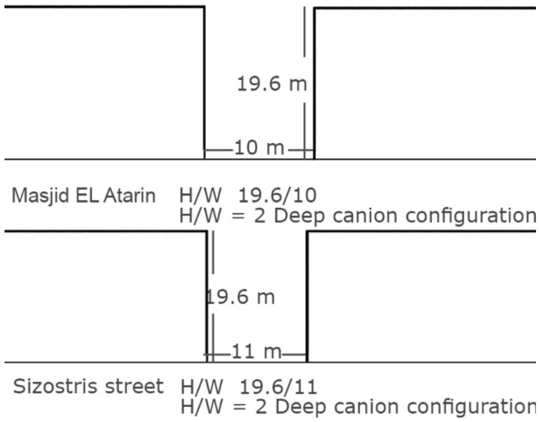


Figure 5-27 urban canyon configuration, source: the researcher

5.3.4 Building envelope and internal openings

The case study building has a flat roof with no vertical projection designed for ventilation. There is an introduced court to drive air pressure and induce the air into internal spaces. In terms of openings design, the size, position and the morphology of openings were analysed. Two different sizes are identified with inlet percentage in relation to the inner spaces, ranges from 5 to 36 percent. In terms of position, the windows are located in the Centre of the space, the balconies openings are two and also located in the Centre of the space, Figure 5-28.

Morphologically, as case study openings are vertical-vane openings type with double-side hinges all windows and balconies openings have external venetian shutters. In addition, all internal doors are solid timber frame with a high-level transom opening which were modified and closed by occupants' Figure 5-29.

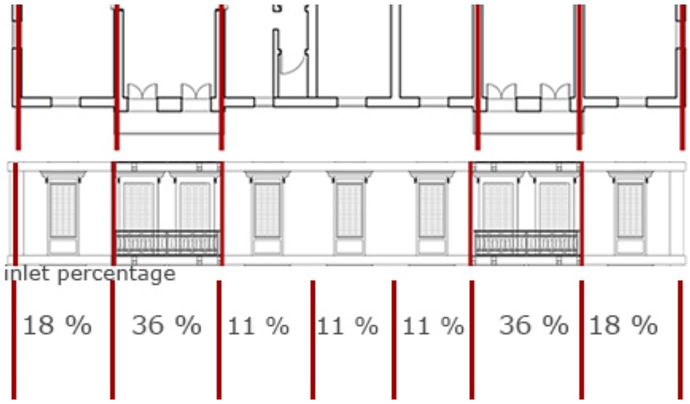


Figure 5-28 opening position arrangement and opening percentage in relation to the space

Figure 5-29 external and internal opening types

5.3.5 Internal space categorization

The applied assessment in the research would focus on the internal airflow patterns and magnitude. However, the inner spaces formulating the building have different characteristics according to their location, use and relation with the external environment, it was preferable to categorize the spaces according to different variables and to study the efficiency of each space ventilation according to them.

The case study building is composed of four floors, ground mainly used for commercial use, the three consecutive floors are of a typical residential layout and finally the roof. The typical floor plan according to the current layout of the building, composed of three flats, as discussed earlier.

The block itself has the dimensions LxWxH =34x30x22 m, with a foot print area of 1020 m^2. The building contains a light-well (dimensions = 10.5 x 6 x 22 m). The building envelope is composed of different sized vertical windows with the percentage of opening in relation to inner spaces ranging from 5 to 36 percent. On plan, windows are positioned central to indoor spaces. Indoors all internal doors have high-level openings yet site survey showed that they are permanently boarded by occupants, Figure 5-30.

In order to analyse the airflow implications of the three different flats' layouts, inner spaces where categorized in a depth map according to their inlet position with the external environment. This categorization would help recognizing the airflow pattern and how it affected by the external and internal environment. The zones categorization Were as follows;

- the zone labelled 'S1' has direct openings with the external environment, rooms within the zone donated
- the zone labelled 'S2' have no openings to the external environment, by contrast, their openings are located on inner shafts.

according to the architectural organization of the flats, the areas labeled S1 are currently used for bedrooms, office spaces and dining areas, while the area labelled S2 is used the living spaces. This makes it important to insure a sufficient airflow magnitude and pattern influence these zones. The categorization of the rooms would help in studying the airflow behaviour inside each space and how it affects the attached space, Figure 5-31.

In addition to categorizing the depth map auditing points were placed different zones. The points were used for CFD monitoring for specifying the airflow speed within each zone to achieve a complete survey of the detailed floor plan internal spaces, Figure 5-32.

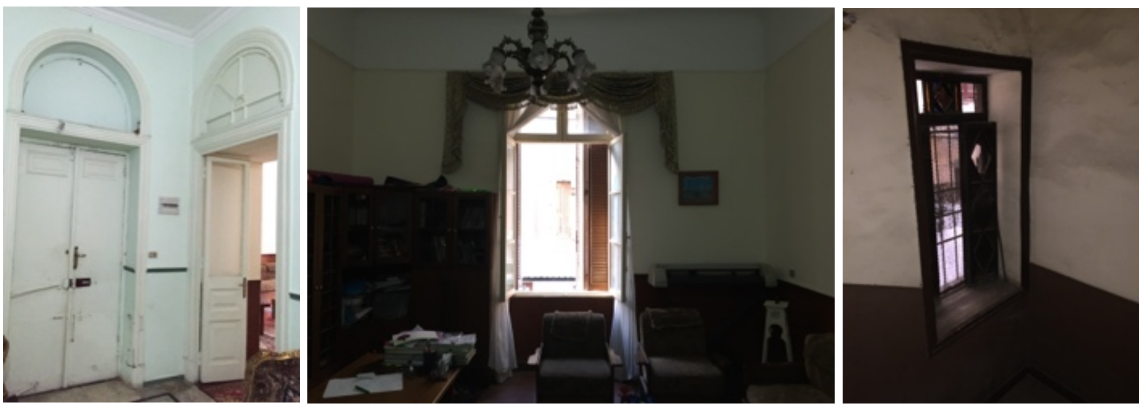


Figure 5-30. inner openings

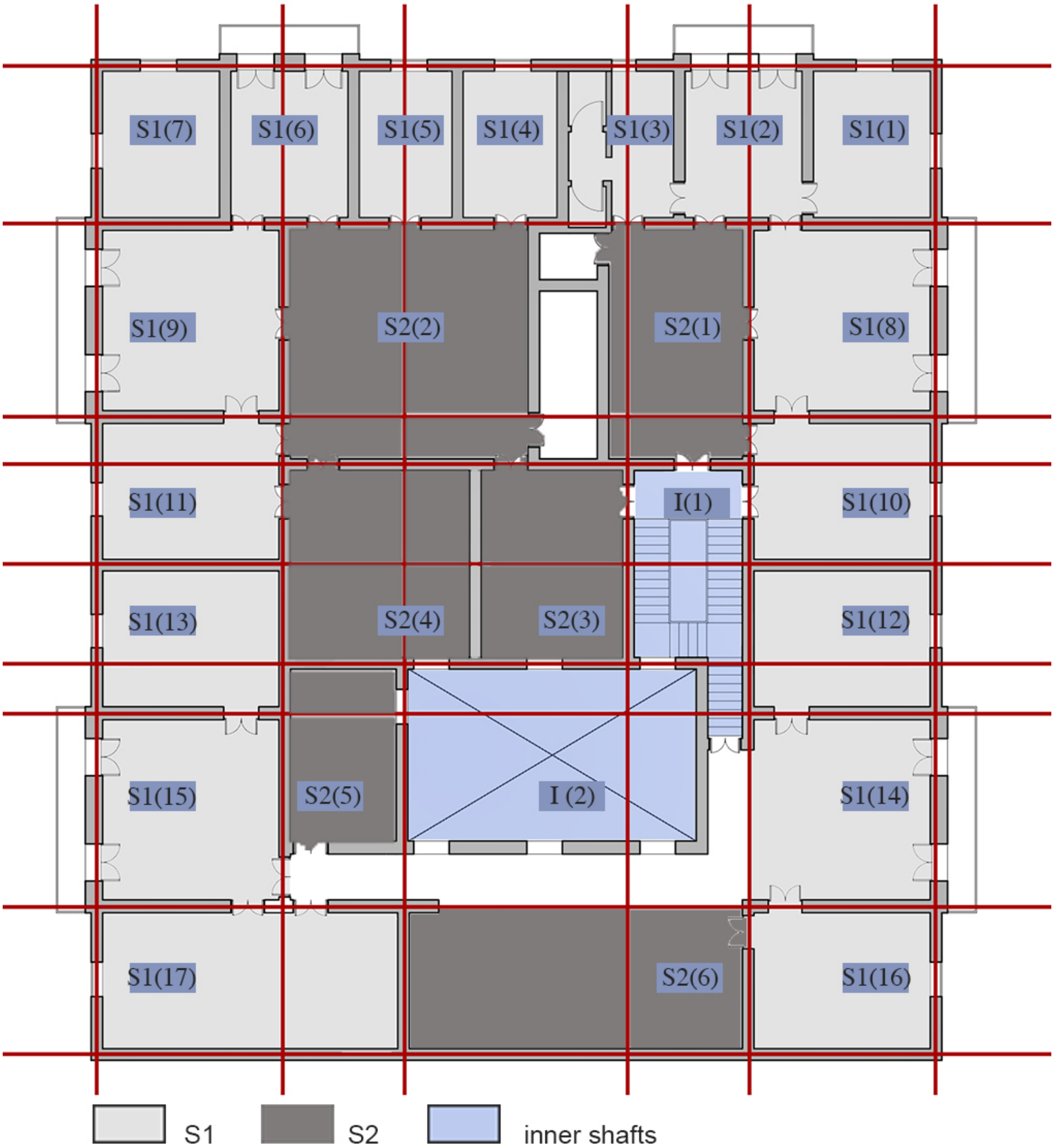


Figure 5-31 different zones categorization, source: the research

Table 5-1 the different zone categorization properties

Zone		Dimension (m)	Opening (ext.) no.	Opening to space ratio (%)	Opening direction	Function
S1	1	4.0 x 5.1	2	18	South west, north west	Bedroom
	2	4.0 x 5.1	2	36	South west	Dinning
	3	3.2 x 5.1	1	11	South west	kitchen
	4	3.2 x 5.1	1	11	South west	Kitchen
	5	3.2 x 5.1	1	11	South west	Dinning
	6	4.0 x 5.1	2	36	South west	Dinning
	7	4.0 x 5.1	2	10	South west, south east	Bedroom
	8	6.1 x 6.2	2	19.5	North west	Bedroom
	9	6.1 x 6.2	2	19.5	South east	Bedroom
	10	6.1 x 4.7	1	6.5	North west	Office
	11	6.1 x 4.7	1	6.5	South east	Bedroom
	12	6.1 x 4.7	1	6.5	North west	Office
	13	6.1 x 4.7	1	6.5	South east	Office
	14	6.1 x 6.2	2	19.5	North west	Bedroom
	15	6.1 x 6.2	2	19.5	South east	Bedroom
	16	7.7 x 4.7	1	5.5	North west	Bedroom
	17	9.6 x 4.7	1	4.5	South east	Bedroom
S2	1	4.4 x 7.9	-	-	-	Living space
	2	8.2 x 7.9	-	-	-	Living space
	3	5.1 x 6.4	-	-	-	Living space
	4	6.1 x 6.4	-	-	-	Living space
	5	3.1 x 5.9	-	-	-	Kitchen
	6	10.2 x 4.7	-	-	-	Living space
I	1	3.7 x 6.5	-	-	Top	Stair well
	2	10.5 x 5.9	-	-	Top	Inner court

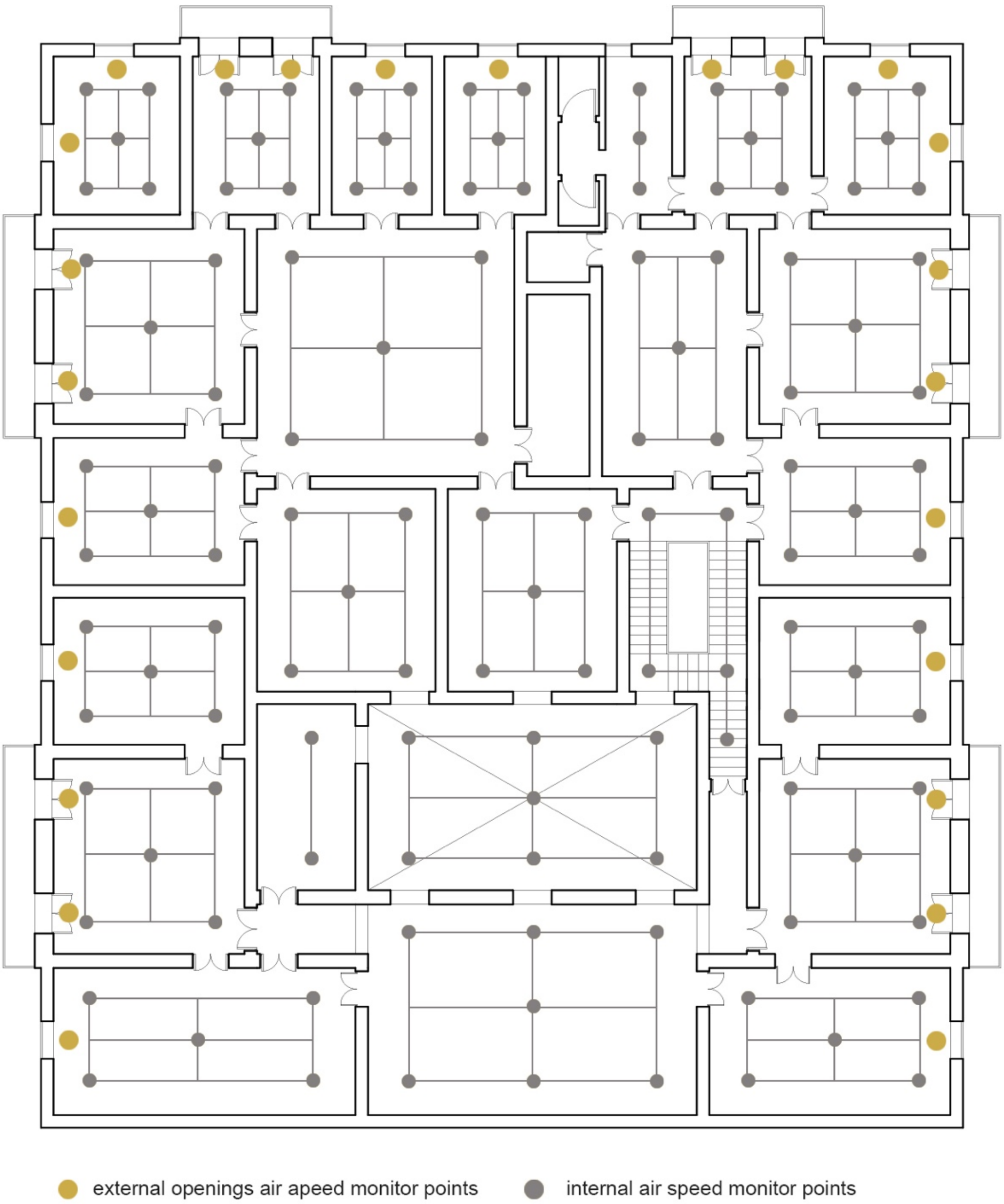


Figure 5-32 case study detailed floor plan highlighting the monitoring points

5.4 Conclusion

The chapter introduced the representative case study to be used in this research. Identifying its heritage significance, and how it falls within the Alexandria heritage listing as a grade 3 heritage building (local level classification). The selected listed building was completely surveyed producing a complete architectural drawing, showing the internal spaces layout, architectural style, and its gematrical coherency with the surrounding heritage context within both conservation streets Sizostris and Masjid el Atarin streets. The survey also included the external and internal finishing materials, opening types included, the structure system, the building's current conditions and its original layout. The procedures performed within this chapter as a part of the archival research and site analysis within the pre-retrofit activities, understanding the building's fabric and context.

The case study building's survey showed how the selected case study can be used as a represented building of its heritage typology nature, architecture common style within this period and the heritage context of the city, and the building's internal spatial layout of the inner spaces. Which is composed of external spaces around internal spaces mainly used as living areas with imbedded inner court.

Furthermore, the case study was analysed in this chapter in terms of identifying the properties of its design measures which could possibly affect the airflow and natural ventilation performance. This analysis included the case study building in relation to the urban fabric, heritage context adjacency profile, wind orientation, street canyon configuration, and external envelope opening ratios.

According to the analysed data the research proposed an internal spaces categorization as a depth map of the detailed floor plan based on the internal spaces' characteristics according to their location, use and relation with the external environment, which can be considered a common layout within this heritage listing profile. The proposed depth map will be used in the flowing chapter recognizing the airflow patterns and how it is affected by the external environment and the relation of the internal spaces together, identifying the natural ventilation performance considering airflow patterns and magnitudes inside the case study building.

Chapter 6 The assessment of natural ventilation inside the case study building

6.1 Introduction

This chapter presents the methodology adopted for assessing the case study building represented in the eclectic revivalist style of the late nineteenth and early twentieth century architecture heritage of Alexandria, as a part of the retrofit methodology. Considering internal natural ventilation performance the focus of this thesis. Firstly, the objective assessment methodology including the monitoring experiment design and the computer-based assessment study are set out. Secondly, the results of the objective assessment are shown, discussed and analysed according to the methodology as set out. The discussion starts with the results of the case study monitoring and then proceeds to show the air movement simulation results.

6.2 Methods of natural ventilation assessment

Assessment was conducted in two parts. The first part used detailed monitoring approach for the magnitude of the airflow inside and outside the case study building for validation purposes. The second part employed a Computational Fluid Dynamics (CFD) software; ANSYS Fluent; in two stages:

- Stage 1: Verification, and validation of the input parameters of the CFD models. CFD results and field testing are compared to ensure that the quality and the reliability of the numerical simulations in reproducing airflow. The comparison between the results aim at spotting the accuracy and the consistency achieved in the CFD simulations undertaken, since the input and calculation parameters will serve as a basis for subsequent more complex investigation using the same CFD parameters.
- Stage 2: Study of the case study building with simplified volumetric shape simulated in CFD. CFD simulation was employed to investigate the airflow in and around the case study building to expand on the measurement's findings, through modelling a coupled domain combining the external calibrated environment with the internal environment of the case study building. The simulation is validated through air speed field monitoring. This step focuses on identifying both the airflow magnitude and patterns inside the case study building through conducting an in-depth evaluation according to the internal space categorization in order to bring out its current performance deficiencies and potentials.

Since this research makes use of CFD calculations for a large part of the analysis, the comparison of the results of the different methods gives the opportunity for providing the confidence and the demonstration of the reliability of the results achieved. All the used techniques are utilized for the same case study building and the urban environment. Moreover, the steps for the CFD modelling and the methods used in the verification and validation process were demonstrated earlier in the literature.

6.3 Field monitoring

field measurements were held to assess the performance of natural ventilation. The aim of monitoring the case study was to validate the proposed methodology in the realistic environment. Monitoring is also used to demonstrate quantitively the influence of the outdoor urban environment and to provide data that can be compared to CFD simulations. For this purpose, the set of measuring points that were employed in testing will be utilized later in CFD to ensure consistency across the different parts of the study.

Measurements was undertaken during the month of July, which is considered the hottest weather of the city of Alexandria according to weather data. Due to limitations on the number of anemometers available for this study a total of four points were assessed, on the first floor and the roof were a granted access was acquired for the measurement which would be the detailed in the CFD model. The measuring points positioning dependent on the case study building external façade orientations; north west and south west. For each of these sides two monitoring points were used.

6.3.1 Field equipment and set up

Two hotwire anemometers, manufactured by Airflow model TA 2 anemometer/ thermometer, where deployed to measure the wind speed with a stated accuracy $\pm$ 3%. Due to the limited number of hotwire anemometers available, it was decided to monitor only the spaces in relation to the external environment S1 (2), (10) monitoring points P1, P2.

The field monitoring was undertaken at several locations in spaces in relation with the external façade of the case study building (north west and south west). The hotwire anemometers locations are indicated in Figure 6-1. Their positioning was distributed between the first floor of the case study building and the rooftop.

In order to specify fixed points within the inner space of the case study building and, on the roof, to calculate the U and the Uref speeds; two hot wire anemometers were placed in the inner space of the study (P1, P2) at around 7.5 m above the ground level, and the other two were placed on the roof (RP1, RP2), 22 m above the ground level. The hot wire anemometer was used in pairs combining the results of P1 and RP1 (both on the north west direction) and P2 and RP2 together (both facing the south west direction).

The measurements were undertaken with the condition that was set by a specified internal door opening openings, the external openings were all opened to see the maximum potential for natural ventilation airflow. This setup will be later on simulated for inner and outer openings specified in the CFD simulation, to validate the acquired results.

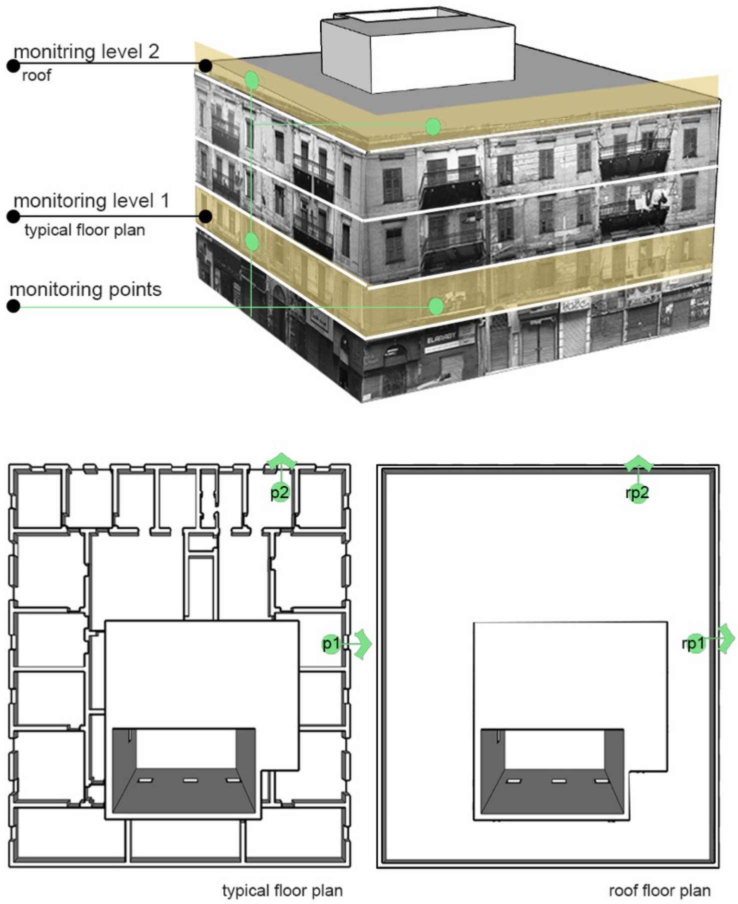


Figure 6-1 (above) case study building isometric showing different monitoring levels and points, (bottom left) the location of the monitoring points in the first-floor plan, and (bottom right) the location of the monitoring points in the roof floor plan.

The researcher was notified by the occupants not to put any nails, screws or sticky tapes on the wall as this could affect the internal finishing. The only method that was suitable for installation of the devices was attaching them with a sticky tape to a chair because it was not going to be affected by the sticky tape. The anemometers were placed at a height of 1.35 m from the floor level. The anemometer setup was fixed during the whole time of the field measurements. The occupants were so helpful for keeping it the way it was during the experiment time.

Figure 6-2 placement of hotwire anemometer over the roof

6.3.2 Measurement schedule

The field measurement was set during the month of the summer July, to insure the reliability of the results the airflow velocity magnitude was measured for a consecutive week (seven reading days), in a specified reading time for each day throughout the week (4:00 pm and 4:30 pm) for both pairs (P1, RP1 and P2, RP2) respectively. The measurement time for each pair was set for 30 minutes and the time interval for each velocity magnitude input was logged for a 30 second time interval, which is the adequate time needed for getting the average magnitude according to the literature.

However, due to a lack of available data loggers, the data were collected manually from the direct reading of the hot wire anemometers screen directly in an organized spreadsheet labelled for each point of measurement, specifying time and date. At the end of the monitoring period, these data were later on digitalized into a spreadsheet file and then analysed accordingly, in order to get an average velocity magnitude and direction for the measuring points and be correlated with the data from the nearest weather station (ELnozha airport weather station) and contrasted with the CFD simulation results.

6.4 Case study heritage building (CFD) simulation

This part of the objective assessment aims to evaluate the air movement patterns and speeds in and around the case study building. This is important as it allows the best understanding to the airflow profile of the case study building. Three methods of evaluating airflow patterns and speed were considered which are; monitoring (Awbi, 2003; Levermore, 2013), wind tunnel or computational fluid dynamics (CFD). Using the monitoring methods could be performed using different techniques such as tracer gas for measuring the rate and data loggers. This evaluation technique was limited to the researcher due to the unavailability of the expensive equipment to the researcher. Moreover, the tested building was occupied by residents which caused a problem to get their approval. For the wind tunnel, it required physical modelling of the case study. Through the model, the airflow in and around the case study were tested visually and quantitively. The wind tunnel facility was not available to the researcher. Therefore, it was decided to conduct this study using one of the computational fluid dynamics (CFD) software, as a result of the unavailability of either the required equipment to monitor the airflow patterns in and around the case study, or wind tunnel facility. It is known that the simulation research methods can be used effectively where the experimental work in the real world cannot be performed due to occupants, economical or dangerous restriction (Groat et al., 2002).

Computational fluid dynamics (CFD) technique uses a complex mathematical model which is represented and solved by a computer program. The results are graphically presented mostly by a 3D model. The computer based tools can predict the following variables (Clements-Croome, 2002);

- Internal and external air movement patterns and airflow path

- Building behaviour in ventilation studies
- Stack and wind pressure inside and outside the buildings and their interaction

6.4.1 Adopted CFD software

Several CFD software were considered. Regardless of the interface, the CFD software that would be implemented must use mathematical fundamentals: Solving physical equations such as Navier-stoke equation, the energy equation, the transport equation for turbulence and its scale and turbulence's model type. All incorporated to control the result's accuracy. Since the work is concerned with studying the wind driven airflow in and around the buildings and estimating the internal airspeed for thermal comfort ventilation, it was necessary to select CFD software that can meet certain criteria and capabilities;

- Allow a replica of the selected slice of the real world to be modelled as accurately as possible including the boundary layer conditions with wind profile and airflow turbulence
- The physical configuration of the simulated environment could be constructed
- Have an architectural user-friendly interface, which is easy to model, edit and navigate around.
- It should have an efficient and clear way of introducing results that can allow the user to manipulate easily and effectively
- The software license should be available

The commercial numerical simulation code Fluent 18.1 was found to fulfil the above outlined criteria for choosing the simulation tool. Although it is recognized that CFD results are subject to uncertainties and approximations, the achievement of consistency is related to the control of a number of input parameters. This is usually achieved by performing pre-test simulation for calibration, verification and validation of the results. The calibration, verification and validation used in the CFD investigation were by comparing the airflow around specific points and contrasting the results with those of the field measurements. The setup of the field measurements has been described earlier in this chapter.

Fluent uses the computational fluid dynamics (CFD) technique, through which the calculation of the airflow patterns and speed rely on the conservation laws that are implemented in a partial differential from Navier-Stokes equations. These equations are converted from the volume to be solved by finite volume methods. As the volume form is required for the calculation purposes, a simulated slice of the real world is modelled in the volumetric space form the "solution domain". This solution domain is then divided into a number of cells presented in the model. As the cell number increases the better the outcome results are obtained, but this will increase the solution time. The conservation process within Fluent, as in several CFD software, is solved in an iterative manner, until the errors within them are at an acceptable level and a steady state solution in converged (Ansys, 2017). The simulation process within Fluent is user-dependent and starts from defining the requirements, setting up the mathematical modelling parameters, constructing the geometry, adding a solution grid, solving the domain and finalized by displaying the results (Ansys, 2017).

6.4.2 Validating the CFD modelling

As been discussed earlier that CFD results are a subject of uncertainties and approximations, the achievement of consistent and reliable solution depends on the input data and the calculating parameters. The standard procedures and performing pre-test simulation for the verification and the validation of the results were followed during this research.

The calibration, verification and validation of the parameters used in the CFD investigation were attained by the calculation of the airflow around the simplified urban area of the targeted building of investigation and contrasting the results with those of the field measurement experiment. The field measurement experiment was described earlier in this chapter. These actions were applied to make sure of the consistency of the CFD calculations undertaken; the calibration of the CFD input and modelling parameters, and the assessment of the airflow inside the case study building.

6.4.3 CFD pre-simulation parameters

As mentioned earlier the CFD results are susceptible to approximations. The reliability of the results is related to a number of input parameters. To insure the consistency of the CFD simulation, a number of guidelines were undertaken. The simulation process was considered in three stages; the pre-processing, solving and post processing.

In the CFD pre-simulation phase, the 3D model has to specified. This phase includes creating the domain and specifying its size, verifying the boundary conditions and the mesh type and size, the fluid properties, the cell blockage ration and other problem description that could have an impact on the results. These steps are described in the following part with illustration from the CFD simulation done.

6.4.3.1 Geometry creation

The geometry built in this model is a simplified version of the urban environment surrounding the case study building. Buildings including the case study building are represented using simple blocks. The section of the environment used is representing the urban environment of the case study building with the surrounding buildings and the urban canyons.

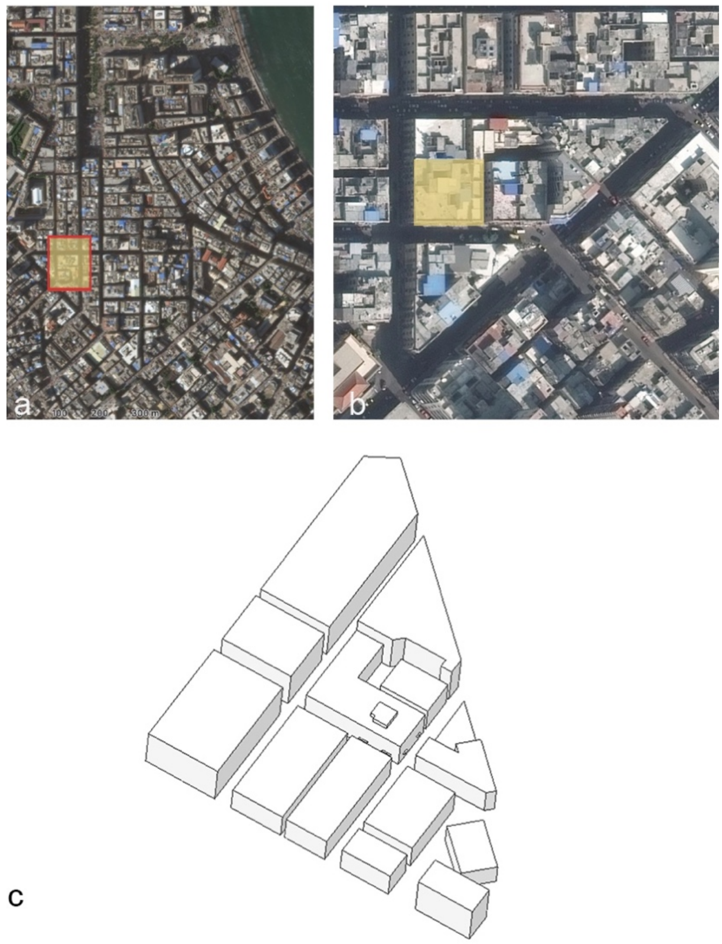


Figure 6-3 (a) the historic context of downtown Alexandria marking the case study location source: Apple maps, (b) case study building with the surrounding context, source: Apple maps and (c) the geometry created for the CFD simulation, from the study

6.4.3.2 Domain size

The domain for the CFD simulation model, is subdivided into three different volumes. The domain was classified as: inlet, centre and outlet. This allowed different cell treatment in different zones, ensuring the meshing accuracy was performed according to the zone without compromising the final outcomes or calculation time.

According to the guidelines, the domain size is according to the dimensions of the area of experiment. The case study height H = 20 m which means the vertical extension of the domain is 5H (100 m), the outflow boundary is 15H (600 m), the inflow distance to the model 5H (100) and the lateral boundary of the domain 5H (100) from each side. The total dimensions of the domain are (560 x 365 x 100 m).

The CFD domain has been designed for minimum blockage ratio with an average value of 3.0% and a maximum of 4.2%. The total length and the volume adopted for the domain has proven to be sufficient to allow full development of the airflow without affecting the target area’s flow pattern.

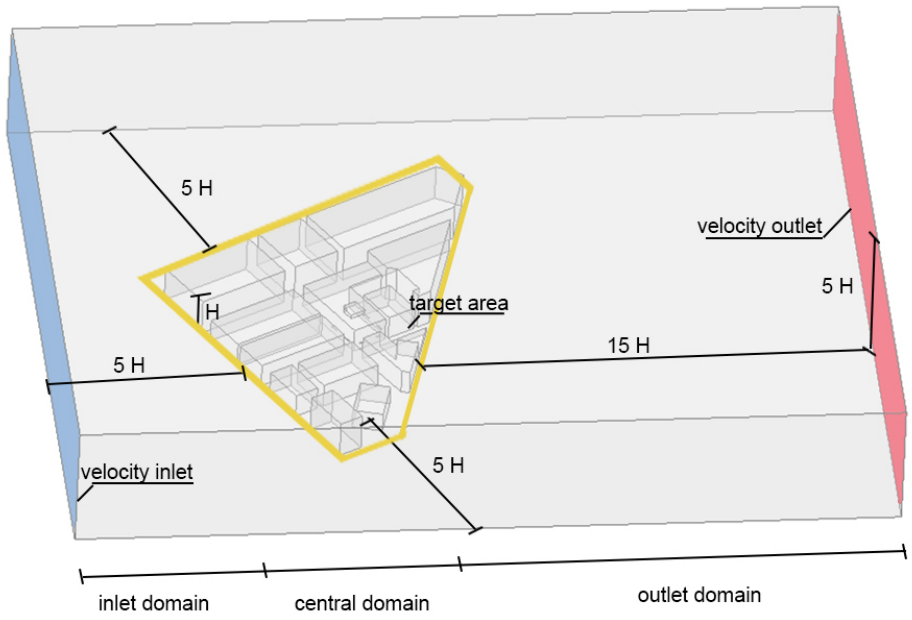


Figure 6-4 case study domain size and boundary description

6.4.3.3 Setting the boundary conditions

The boundary conditions represent the influence of the cut-off surroundings by the computational domain. The boundary types used in the CFD simulations performed in this research are; velocity inlet (applied to the boundary facing the model providing the airflow), interface, non-slip walls (applied to solid walls to stimulate reasonable roughness) , Symmetry (applied to top and lateral boundaries), and outflow boundaries (applied to the boundary behind the model where all the fluid leaves the domain).

The fluid was set for air at constant density (1.225 kg/m^3) and viscosity (1.79e-05kg/m-s). The operating pressure conditions of the domain were kept at 101325 Pa. The gravitational acceleration was set at -9.81 m/s^2. Moreover, the fluid to blocked cell ratio was kept at a low average of 3.0%.

The upstream boundary was set at velocity inlet and through this surface the ABL is added to the model. A velocity magnitude was related on the surface as a result of the airflow normal to the boundary, reproducing the ABL calculated by the logarithmic profile for a given terrain roughness according to Reynolds numbers as per equation 5-1. Velocity was corrected to allow for terrain as per equation 5-2 (CIBSE, 2006).

Equation 6-1 $$u / u_{\delta} = (z / \delta)^{\alpha}$$

where; u = the mean free stream velocity, u_{δ} = the mean velocity at $z=\delta$, z = the height from the earth's surface, α= coefficient depends on surface roughness, Reynolds number and the roughness length.

Equation 6-2 $$V_z = V_m K z^{\alpha}$$

where; V_z = the wind speed at the building height (m/s), V_m = the wind speed at weather station (reference wind speed) , z = the building height, K, α= factors depends on surface roughness and terrain.

In which Umet is the velocity of wind from the meteorological data, K and a are the coefficients of the terrain. The variables K and a were assigned the values of 0.21 and 0.68 for the dense urban site. Free wind was set flowing from the north west direction (incident angle = 22 degrees). The outlet boundary was set as outflow with flow rate equals to 1. All the blockage walls and ground were considered stationary with no slip shear conditions, a wall roughness height of zero meters and a roughness constant of 0.5.

6.4.3.4 The computational grid

The CFD uses unstructured features for solving. The computational grid and meshing define the resolution of the units to achieve reliable results. Since the grid used to discretize the computational domain has a major impact on the simulation results, hexagonal and tetrahedral mesh types were employed in the model, according to the need. The rectangular shape of several volumes that form the domain, and through the domain where the blocked cells are orthogonal to the grid, hexagonal meshes were used. On the other hand, tetrahedral meshes were used in the target area mostly in the meshing of non-orthogonal shapes. It occurred due to the shape complexity or the rotation of the model in order to simulate 22^o wind direction.

For acquiring a reliable result in the CFD simulations, simulations are carried out modelling the urban surroundings and the case study model as simplified cubes in the environment shown in Figure 6-5, aiming to assess the impact of the mesh structure on the Cp output of tetrahedral or hexagonal meshes. Cp contour plot results on the windward face of the blocks were compared to examples in the literature. An initial group of CFD simulations was carried out showing how the mesh type, coarseness and refinement level affect the results. The coarseness of the meshing procedure relates to the sensitivity of monitoring the fluid and directly relates to more accurate results and calculation time. Three sets of simulations were done for each type of cell meshing hexagonal and tetrahedral structure. The set of simulations included (A) (B) and (C) according to the level of refinement of the mesh structure, where (A) is coarser and (C) is more refined.

Initial mesh (A) is too coarse and results are not accurate in both meshing options. Throughout the first refinement (B), the uneven cell distribution in the tetrahedral mesh solution becomes more obvious, affecting the even distribution of the pressure and the nature of the airflow. The refinement (C) has much-improved results specially in the hexagonal meshing as the results show the shape of pressure distribution and the airflow patterns found in the literature. Further adaptation did not improve the results through increased simulation time, as the hexagonal cell meshing adaptation improves the results until reaching a certain limit of adaptation. For the chosen cell size, two refinements proved to be enough to allow results become mesh size independent.

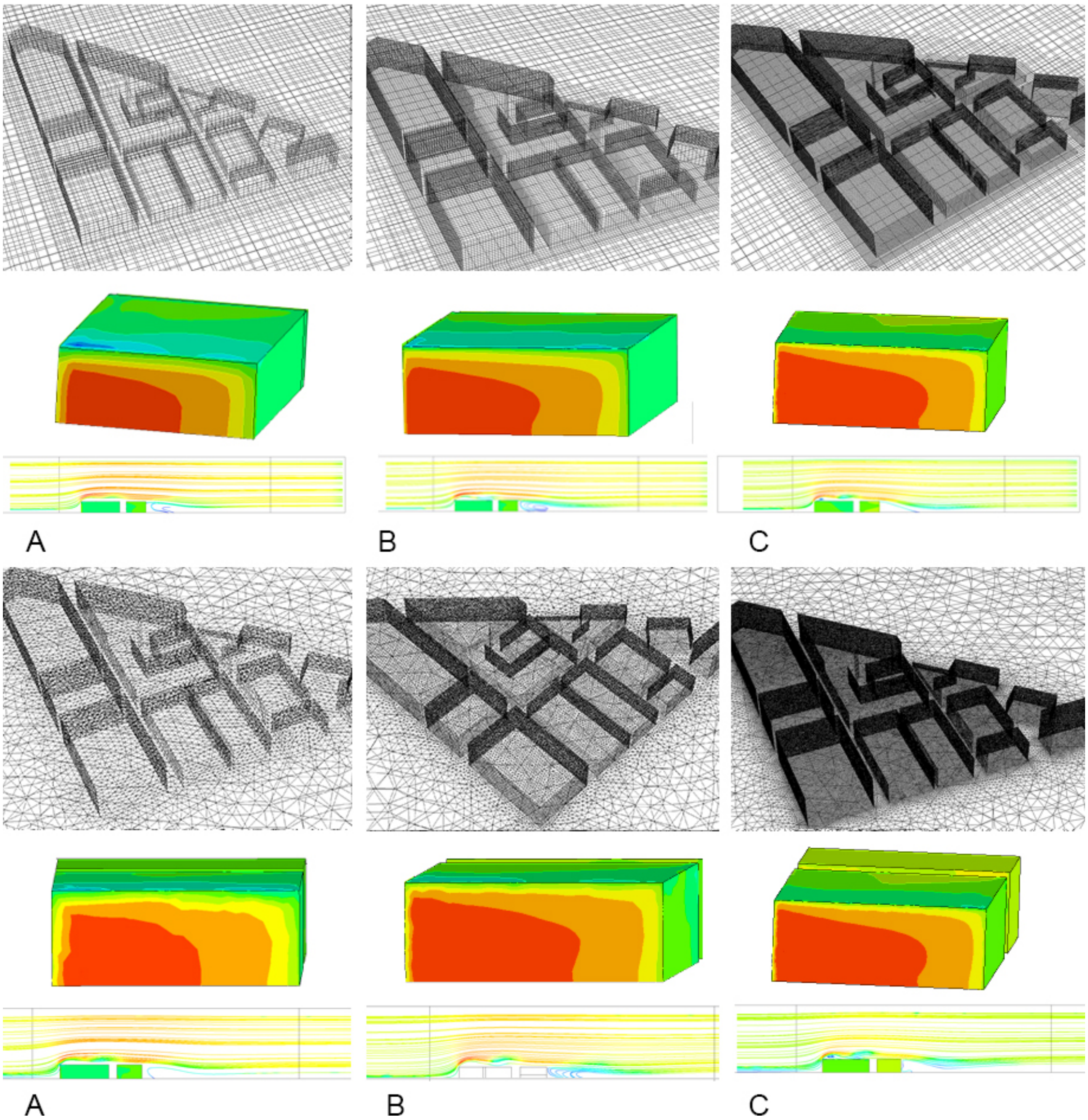


Figure 6-5 impact of mesh refinements on the surface Cp and the airflow for hexagonal (above) and tetrahedral (below) mesh type

Table 6-1 mesh refinement characteristics

Grid type	Number of cells			Volumes (m^3)			
	Initial	Added	Final	Domain volume	Max. cell	Average cell	Min. cell
Hexa-gonal	96255	-	96255	20,440,000	8.27	8.17	4
	96255	132723	228978	20,440,000	8.27	7.17	2
	228978	545761	774739	20,440,000	8.27	6.67	1
tetra-hedral	202534	-	202534	20,440,000	16.55	11.115	4
	202534	511150	713684	20,440,000	16.55	10.115	2
	713684	1985415	2699099	20,440,000	16.55	9.615	1

Based on these previous simulations and results some procedures were adopted for all the following CFD models meshing simulations later in this research. The initial parameter adopted for the cell size and volume for the subsequent steps on this research was that a drawing unit was equivalent to one meter. A cell of 1 x 1 x 1 has a volume of 1 $m^{3.}$ For the more detailed part of the study a further cell refinement for the target area of investigation was undertaken. Using the maximum level of mesh refinements equal to one and setting a minimum cell volume of 0.008 m3 in the openings. The total number of cells in the CFD models used, ranged from 96255 cells for the urban prototype model to 2699099 cells for the complex urban geometry in the case studies with the detailed building model. Accuracy in the results has proved to be reliable with the mesh refinements of this scale of simulations.

6.4.4 CFD solver setting

The imposed CFD problem calculation is presented during the solving stage. The solution control parameters require some choices that may interfere with the quality of the simulation and attain reliable results. These choices include; the choice of the time mode; thermal mode; turbulence model; solution controls; monitoring solution progress; and residual plot. The parameters for the solution in the CFD adopted simulation are described in the following software window. The solution was set as pressure based, the linearization was set on steady-time parameters and gravitational acceleration of -9.81.

6.4.4.1 The turbulence models

The most common used approach for CFD modelling the turbulent viscosity for urban physics is K- ε standard RANS models and was adopted by this research. A number of simulations were carried out for the purpose of testing the results of the standard turbulence model used with the K- ε realizable, K- ε RNG, and the LES outputs.

the CFD solver simultaneously solves the governing equations in each mesh cell in the domain and updates the different properties of the fluid flow. CFD can iterate this process for as long as the user requires.

The simulations of the different turbulence solver were applied for the same urban model with a symmetrical boundary domain and then compared the results with the literature. Throughout the results shown inFigure 6-6 , K- ε RANS turbulence solver was reasonably close to the ones presented in the lecture by (Cook, 1985). While the K- ε realizable created a major turbulence on the top of the building, and the K- ε RNG created the same turbulence but on a smaller scale. The Large-eddy Simulation LES computational time was 12 times greater than those of the other models. Regarding the CP plot results, all the turbulence models were close to the results of the literature.

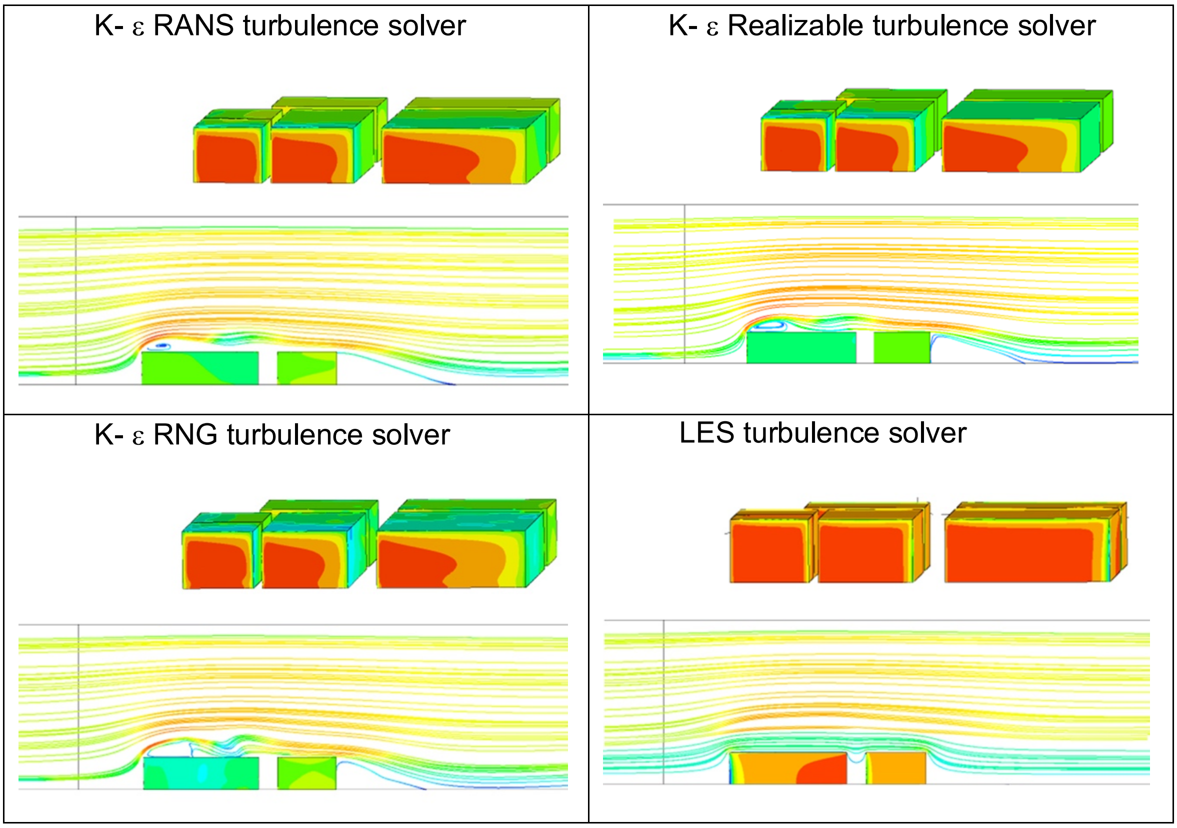


Figure 6-6 results obtained from different turbulence solvers, source researcher

The choice of K- ε standard RANS model solver is the most suitable for modelling external and internal airflow in a coupled domain. According to previous researchers RANS and realizable k-ε models show an adequate level of accuracy when compared to LES models simulations (Stavrakakis et al., 2008; Tominaga et al., 2009). Comparison of RANS models; concluded that all turbulence models applied agree relatively with the experimental measurements. However, the standard k-ε model performed relatively better. RNG k-ε model in some researches, showed the results of calculated values of the pressure coefficient were lower than measurements and the modelled airflow rate is less than the calculated one. (Nishizawa et al., 2004).

RANS remain the main CFD approach up to the present day. In many focus studies and in many practical studies it has often been applied with a satisfactory degree of success. Researchers and practitioners used the available computational power to perform RANS simulation for larger and more complex problems, against less extensive problems by LES (Blocken, 2018). For LES, the better performance comes at a price as the process requires more computational power and a large amount of data is generated as many researches compared between the two processes on a single building (Liu et al., 2016; van Hooff et al., 2017).

6.4.4.2 Convergence criteria

The convergence criteria for continuity, velocity, turbulence, and viscosity equations were set at four orders of magnitude. The convergence monitor allowed the observation of the results and ensured the reliability of the results. Confidence in the results is achieved when the monitored residuals plot criteria drops in three or more orders. From monitoring the plot, they were considered stable. The convergence history plot was based on the following criteria; air velocity magnitude (m/s); turbulence kinetic energy (k); and static pressure (Pa). the solution was converged in 872 iterations.

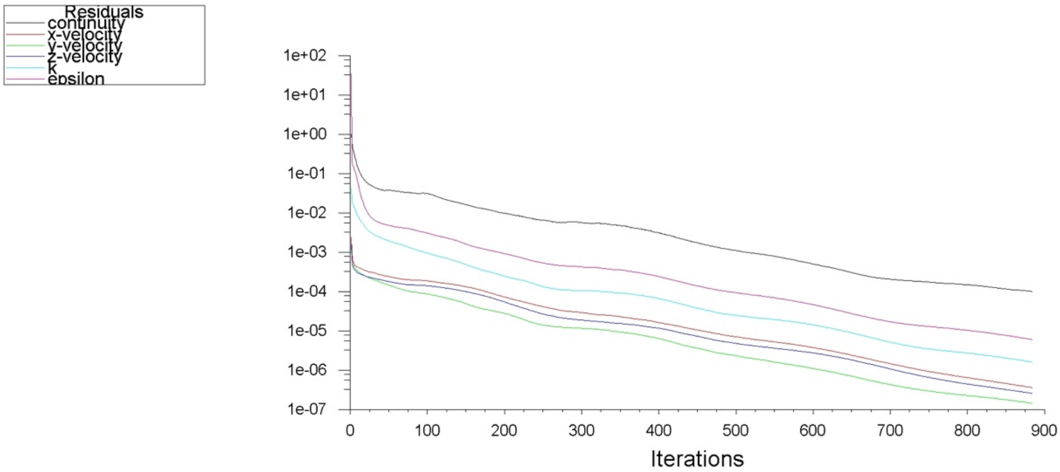


Figure 6-7 residual plot from the urban prototype, source: the research

6.4.5 CFD post-simulation

The CFD post processing phase is responsible for presenting the output information form of the simulation and organizes them to be analysed and displayed. The CFD software used (ANSYS) allows different graphic presentation tools and exports data format for the results, and the proper adjustment of these tools ensure the proper understanding of the CFD results. The reliability of the visual and the numerical data analysis is dependent on the choice of different parameters.

The visual output analysis is the display of data related to; velocity (magnitude, x, y, z vectors); pressure (static, dynamic, relative, total, absolute, Cp); turbulence (TKE, intensity, dissipation, viscosity), and several other results. The results can be displayed in different formats according to the setting as contours, vectors and path lines either in a 2D or a 3D format. The visual output is released with a range and scale of results to be shown, and the style of the output can be adjusted with line width, colour ranges and the crossness scale. Achieving good results in the visual output requires different trial and error methods for combining these properties together.

The numerical data analysis can be analysed by means of tables, graphs, averages and total values, and can be exported from a point, line, plane or volume within the model domain. The accuracy of the data is dependent on the mesh refinement of the domain.

6.4.5.1 The visual output

The CFD results were analysed based on contour plot lines and airflow visualization path lines were used for the visual output information. Contour plots were used for comparing the Cp results on the block surfaces and the velocity magnitude from the CFD simulations. Velocity magnitude path lines were used to demonstrate the airflow field around and inside the case study building. The path lines were released from the domain inlet and either presented in a 3D or 2D output on several vertical and horizontal planes at a 8 m, 21 m distance from the ground representing the flow in the detailed area of the study and the roof respectively.

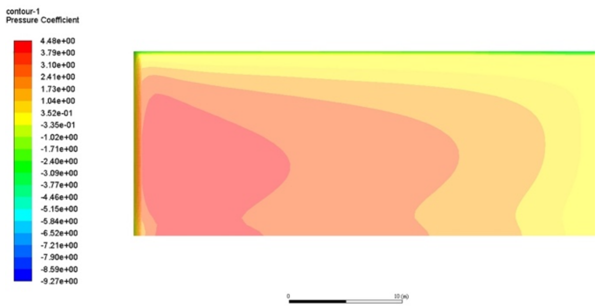


Figure 6-8 contour plot image Cp example, source: the researcz

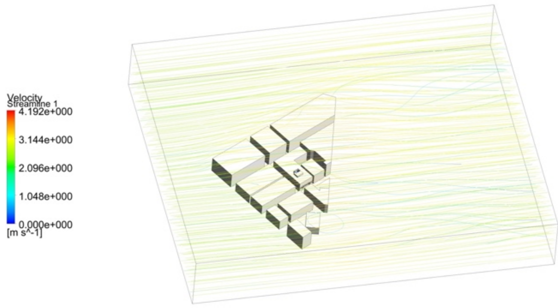


Figure 6-9 airflow for velocity magnitude, source: the research

6.4.6 The case study building detailed floor CFD simulation

The next step of the CFD investigation is to construct the simulation on the case study building. The process will require a coupled domain including the urban surrounding of the building and its interior configuration of the typical floor plan, representing the focus of the investigation.

The coupled domain different phases pre-simulation, solver settings and post-processing would be according to established parameters already set in the previous section. These parameters were CFD simulations for the same urban domain of the surrounding context for the wind direction from north-west, with a total 16 different simulations acquiring confidence in the CFD results (domain size, meshing, and solver settings). Further validation would be done after obtaining the results by contrasting the CFD results with the data acquired from the field experiment for the case study building.

6.4.6.1 The case study building geometry

A model for the case study building and the surrounding building blocks was constructed using all the surveyed data and drawings done in the previous part of the research. All surrounding blocks were placed as a solid block except for the monitoring block, which was modelled in detail.

The detailed case study building block was modelled in three parts. In the first part, the first floor of the block was completely modelled in details with all internal walls, as the built conditions with the same dimension between the walls creating the same zones inside. The building openings were composed of external and internal openings, both were modelled with the same dimension, aspect ratio and their location, allowing natural ventilation through it as the built conditions. The second part was the ground floor which was adding the staircase and the inner atrium which had to be modelled throughout the whole building mass vertically from the ground to the roof, to see the interaction of the detailed floor with the surroundings. The final part was the addition of the ground and the rest of the typical floors till reaching the roof which was a solid part without inner details. But in the case of the ground floor, the relation between the building entrance and the inner staircase and atrium were placed to complete the airflow cycle. The conditions of the outer and inner windows and doors different level opening status (opened or closed) were modelled according to the physical survey of their actual conditions according to the building's occupants.

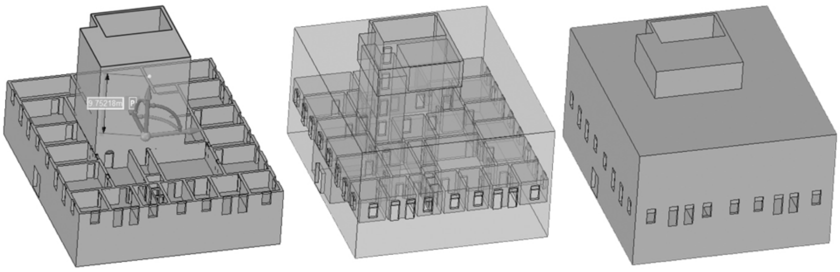


Figure 6-10 case study building detailed modelling

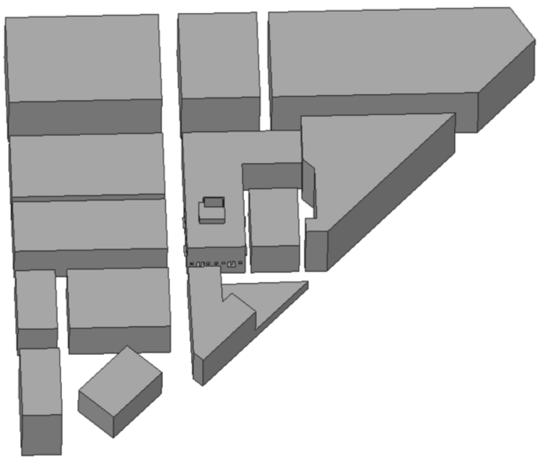


Figure 6-11 surrounding environment modelling

6.4.6.2 Solution domain and meshing

The dimensions of the solution domain were set according to (Blocken, 2015) dimensions of H inlet direction 5H from the outflow direction and height, where H is the model height (643 x 532 x 100 m). The domain total volume is $3.42E^{+7}$ with a fluid volume of $3.35E^{+7}$ with a blockage ratio of3.3%. The inlet and outlet positions were specified in Table 6-2.

The final step in building the CFD model is to define the solution grid within which the Ansys Fluent performs its calculations. Fluent has the ability to specify a different grid's configuration (denser) over a specific geometry in the model.

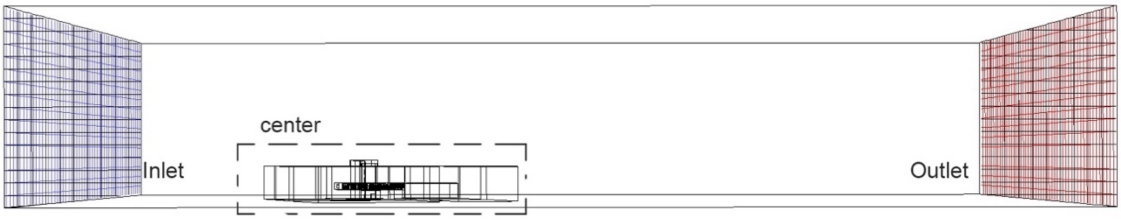


Figure 6-12 domain zone and target area of study

For acquiring a reliable result in the CFD simulations carried out, modelling the detailed floor plan cell meshing size aiming to assess the impact of the mesh structure on CFD results. An initial group of CFD simulations was carried out showing how the mesh type, coarseness and refinement level affect the results. The coarseness of the meshing procedure relates to the sensitivity of monitoring the fluid and directly relates to more accurate results and calculation time. Three set of simulations were done for each type of cell tetrahedral structure. The set of simulations included (A) (B) and (C) according to the level of refinement of the mesh structure, where (A) coarser and (C) more refined, Figure 6-13. Simulation with cell meshing (B) acquired results difference of more than 20 percent from meshing case (A). The more refined simulation (C) took an extensive time for simulation than simulation (B) meshing, with result difference less than 1 percent, concluding the use of mesh refinement (B) within the further CFD simulations.

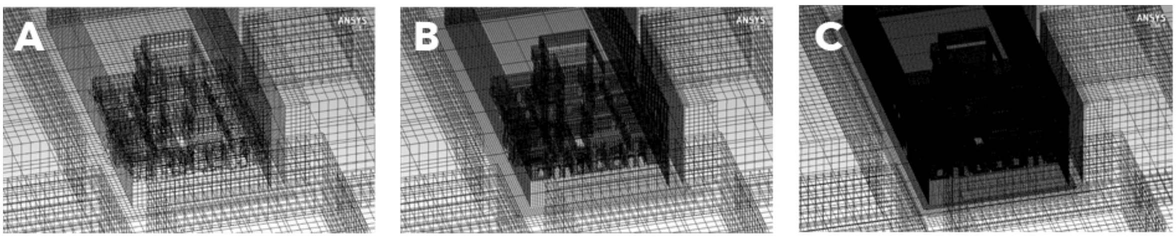


Figure 6-13 detailed floor plan different mesh sizing refinements

The meshing procedure, in order to reduce the time required for the solution to be converged, reduce the complexity of the calculations, and insure the accuracy of results over specific parts of the model, three different grid levels were used. These three levels are; the base grid, the surrounding building grid, and the detailed floor plan grid demonstrated in Figure 6-14, the specific grid levels are specified in Table 6-3.

Table 6-2 domain and mesh information

Domain zone	Domain extent (m)			Total volume (m^3)	Fluid volume (m^3)	Blockage %	Type of cells	No. of cells
	x	y	z					
Total	643	532	100	$3.42E^{+7}$	$3.31E^{+7}$	3.3	HEX	1,074,572

Table 6-3 the solution grid level and their specifications

	Base grid	Surrounding buildings' grid	Detailed floor grid
Max. grid size	6.4	2	0.2
Min. grid size	0.1	1	0.1
Inflation outside the assembly	-	Inflation of 5 layers outside the assembly with max. cell size of 1	Inflation of 10 layers outside the assembly with max. cell size of 0.4

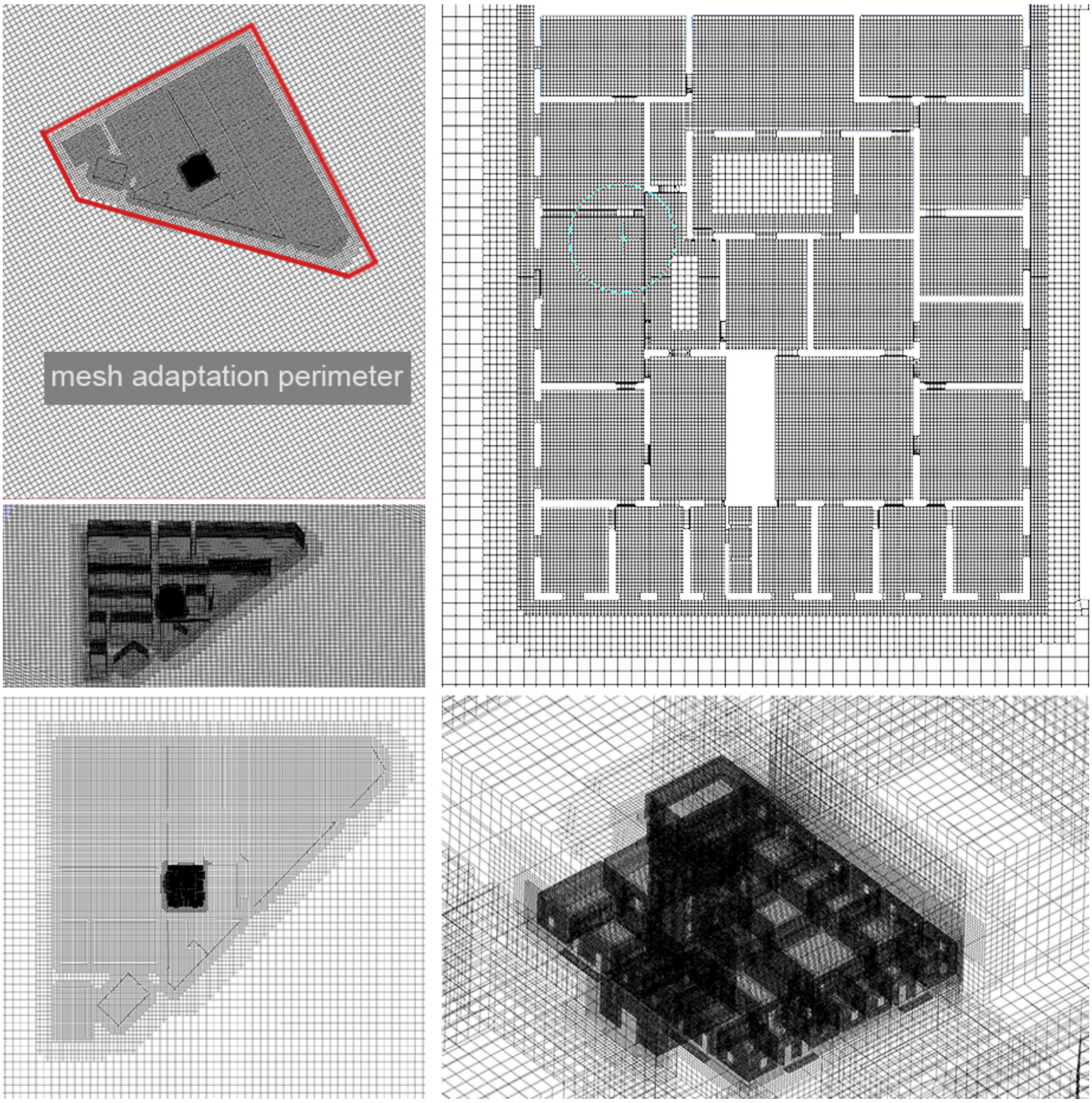


Figure 6-14 mesh adaptation for the case study building top left the whole domain, bottom left zoom on the mesh adaptation perimeter, top right the case study building mesh adaptation, and bottom right 3D view of the case study building mesh adaptation

6.4.6.3 The model's boundary conditions

After building the case study's model, the boundary conditions of the model had to be specified. The boundary conditions include the solution domain configurations, the ambient conditions, the system's fluid properties, the turbulence model, the solution type and the wind boundary profile. The following ambient conditions were attached to the solution domain:

- The turbulent model used is standard 3D RANS model with standard wall treatment
- The gravitational in the normal value of (9.81 m/s^2) and the normal direction (-Y)
- Ambient temperature of 32.5^{o}c in July (according to the nearest weather station)
- The fluid was set for air at constant density (1.19 kg/m3) and viscosity (1.79e-05kg/m-s).
- the operating pressure conditions of the domain were kept at 101325Pa
- The dimensions of the solution domain (642 m, 532 m, 100 m)

The boundary types used are velocity inlet, interface, non-slip walls, and outflow boundaries (Franke et al., 2010). The upstream boundary was set at 'velocity inlet', an ABL profile was imposed with the ABL calculated by the logarithmic profile for a given terrain roughness according to Reynolds numbers. Free wind after correction flowing from the north west direction was with an incident angle of 22 degrees.

As this research is investigating the wind driven natural ventilation only, the solution type was set to calculate the flow only rather than calculating the flow and heat transfer. In addition, the steady state solution approach had been selected to be conducted in the three dimensions multi-grid coupled domain option.

After the setting of the boundary conditions, the problem was initialized, the monitoring plot was set for monitoring four critical points in the model in addition the pressure coefficient on the case study building to insure the reliability of the solution.

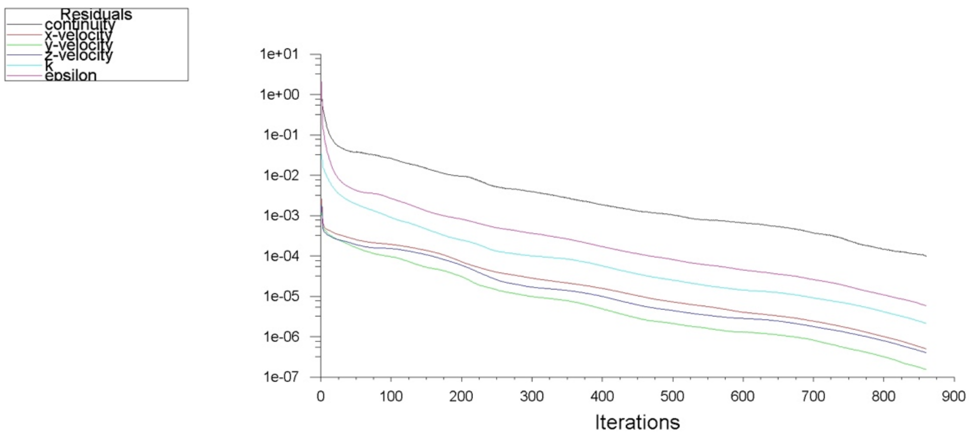


Figure 6-15 simulation convergence plot, source: the research

The results reviled that a value of four orders of magnitude convergence was obtained, the steady state solution was converged in 7 hours and 47 minutes with 872 iterations. The visual and the numerical results of the airflow patterns and airspeed in and around the case study were then extracted and analysed as follows:

- The airflow quality and distribution over the site were analysed in several heights; the person's height (1.75 m above the ground level) and at the mid windows' height in each storey (1.75m, 7.5m, 11.5m, 15.5m, and 19.5m)
- The airflow quality, sources paths, and distribution inside the detailed floor were analysed
- The airspeed was volumetrically presented within the main living space in the detailed floor in each of the monitored points

6.5 Historic reconstruction (CFD) simulation

Historic reconstruction simulation is designed as a part of the pre-retrofit stage of the retrofit. The simulation was set according to the building's original spatial layout of a floor compromised as demonstrated in Section 5.2.6, the modifications are represented in Figure 6-18. The surrounding context building heights are modified according to the established heights for the archival research not exceeding 22 m, Figure 6-19. the aim of this part is to establish a critical understanding of the building's natural ventilation performance the way it was intended to operate and compared to the current performance after modifications.

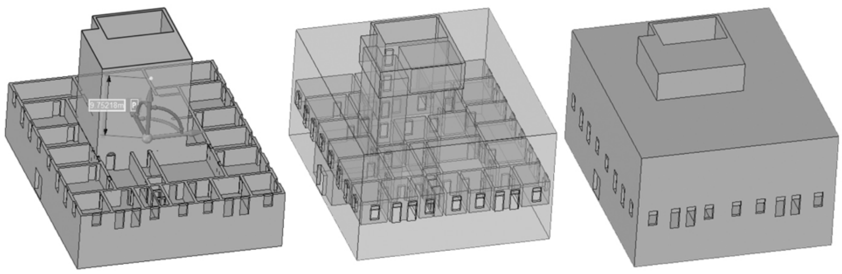


Figure 6-16 historic reconstruction building detailed modelling

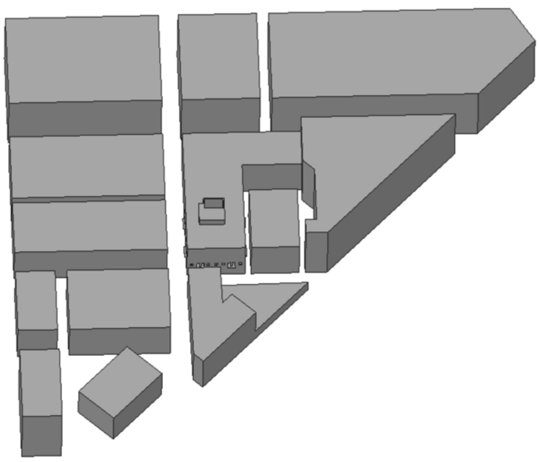


Figure 6-17 historic reconstruction surrounding environment modelling

The CFD pre-simulation, solver settings and post-processing employed for all these simulations were very similar, all based on the findings of the previous step method. These parameters were CFD simulations for the same domain with wind direction from north-west. The 3D model was modified according to the building's original layout before any modifications, and the surrounding building's heights was set as the original context. Solution domain was kept the same and meshed with the same values specified in Table 6-4 showing the domain and mesh details.

Table 6-4 Historic reconstruction domain and mesh information

Domain zone	Domain extent (m)			Total volume (m^3)	Fluid volume (m^3)	Blockage %	Type of cells	No. of cells
	x	y	z					
Total	643	532	100	$3.42E^{+7}$	$3.31E^{+7}$	3.1	HEX	1,249,349

The boundary conditions of the parametric study simulations were set with the same conditions, including the ambient conditions, the system's fluid properties, the turbulence model, the solution type and the wind boundary profile. Finally, the simulation was calculated and converged in 887 iterations approximately 7 hours.

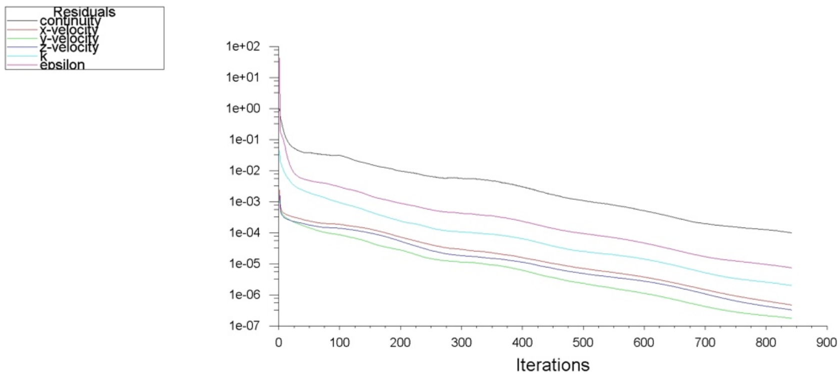


Figure 6-18 Historic reconstruction simulation convergence plot, source: the research

6.6 Results and discussion

The results of applying the assessment of natural ventilation, which were explained earlier in this chapter, are discussed. Two main results are interpreted in this section; the monitoring results and the air movement CFD simulation results. It also includes the field monitoring results of the specific points using the hot wire anemometer as a method of validating the CFD results.

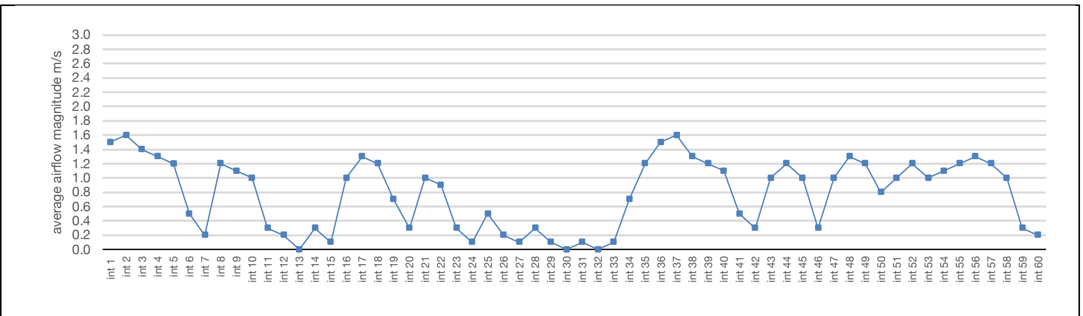
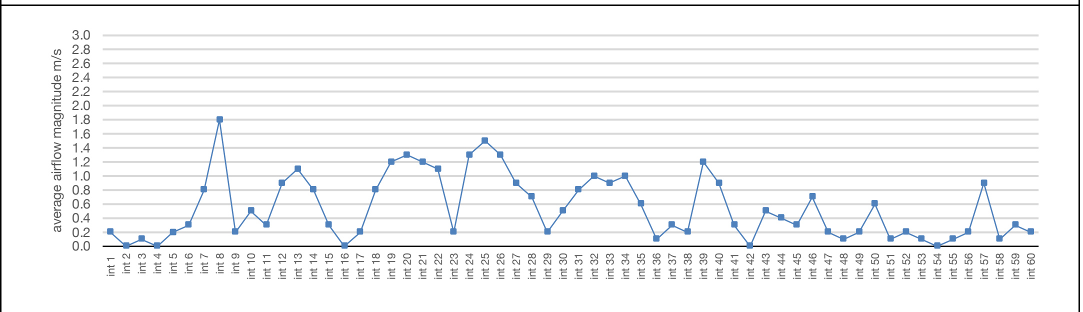
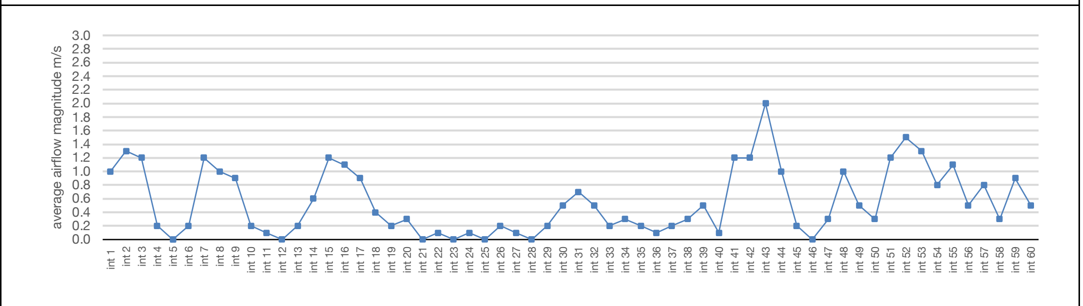
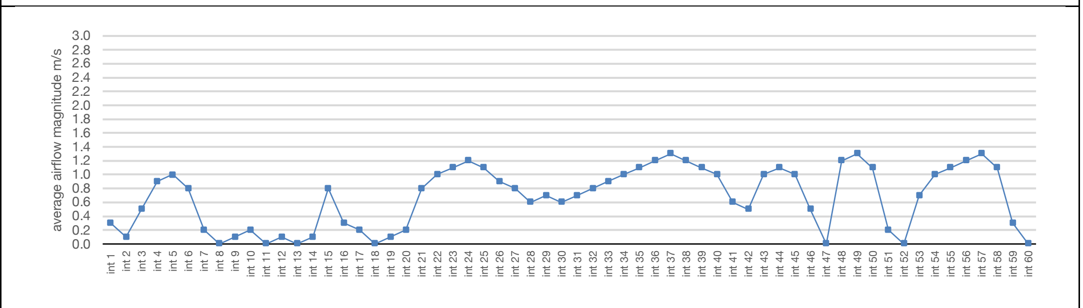
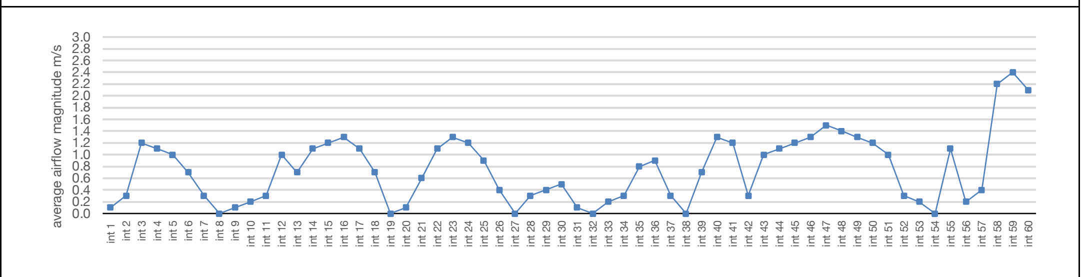
6.6.1 Field Monitoring results

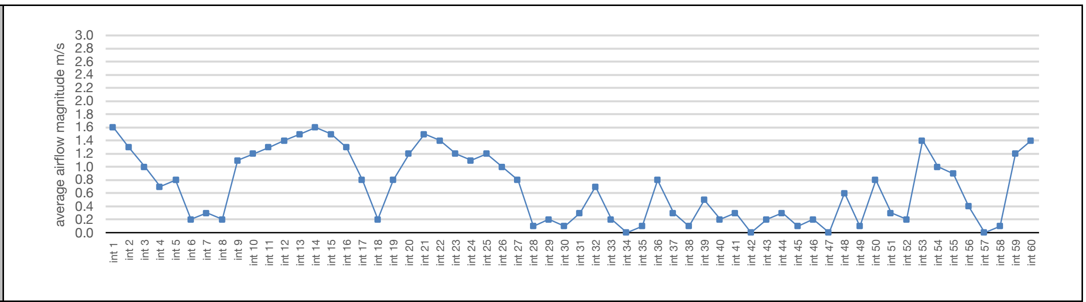
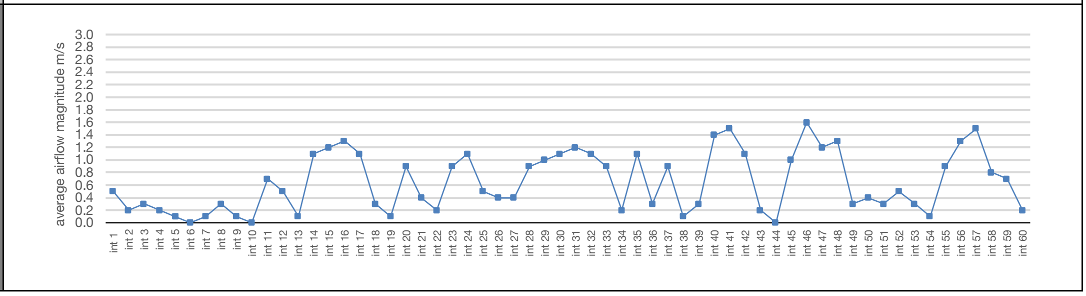
The monitoring results of the airflow velocity magnitude of the monitored points, as discussed previously. The monitoring was undertaken on a specified week of July for four days with two readings per day. The monitoring specified fixed points P1, P2 within the second-floor inner space of the case study building on Masjid el Atarin and Sizostriss street respectively, and on the roof to Rp 1 and Rp2 on both streets Masjid el Atarin and Sizostriss street respectively. The results are displayed in the following section, demonstrating the monitored days and intervals according to each point.

6.6.1.1 Point 1 results

Table 6-5 demonstrates the monitoring results of P1 point located on the second floor of the case study building Masjid el Atarin, results are plotted according to the monitoring intervals specified. The average magnitude of the monitored point is calculated to 0.69 m/s.

Table 6-5 P1 monitoring results

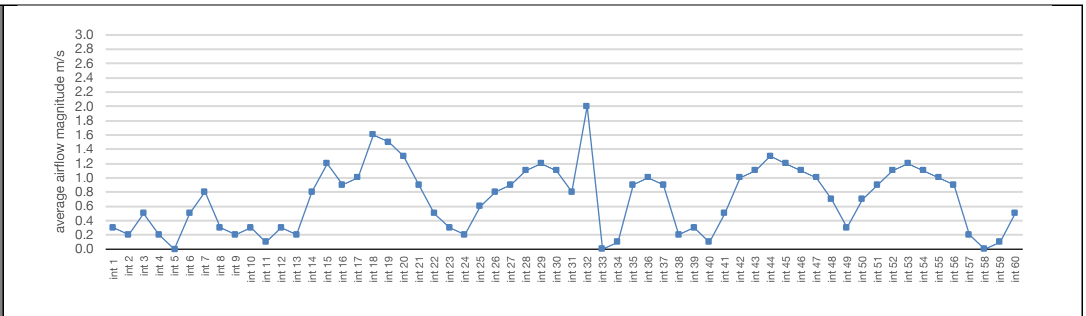
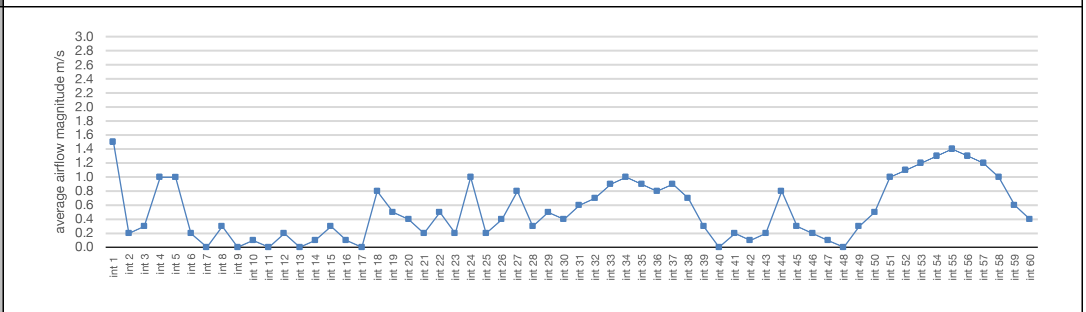
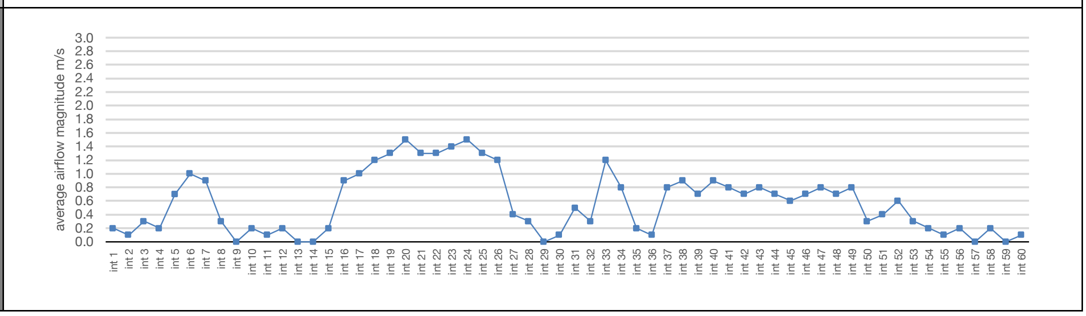
Day 1	
Day 2	
Day 3	
Day 4	
Day 5	

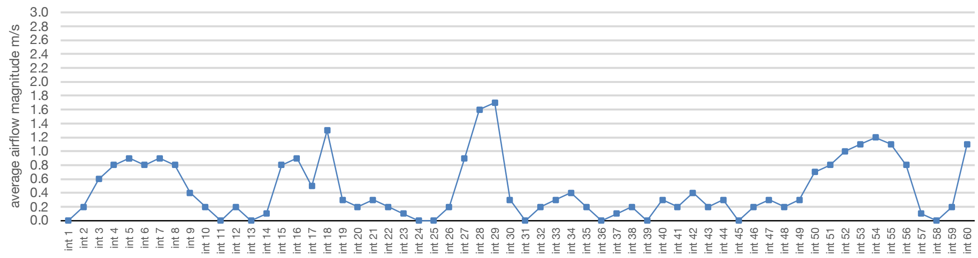
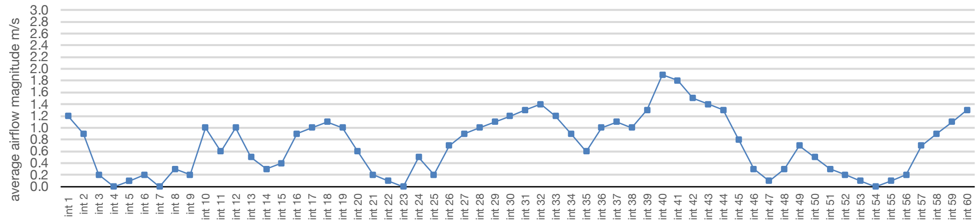
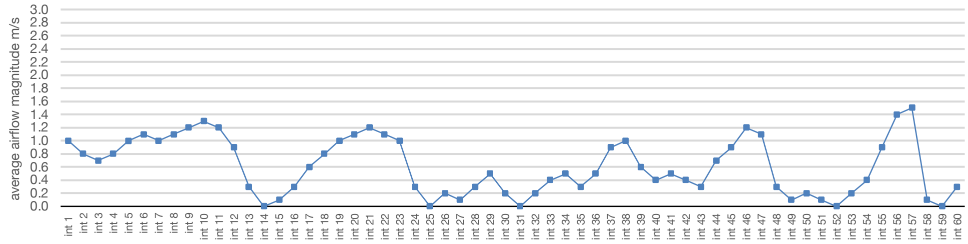
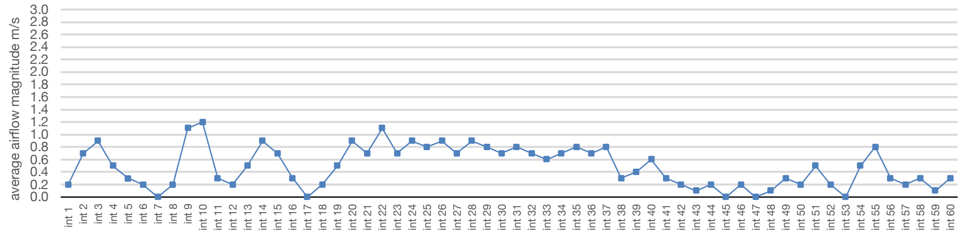
Day 6	
Day 7	

6.6.1.2 Point 2 results

Table 6-6 demonstrates the monitoring results of P1 point located on the second floor of the case study building Sizostriss street, results are plotted according to the monitoring intervals specified. The average magnitude of the monitored point is calculated to 0.59 m/s.

Table 6-6 P2 monitoring results

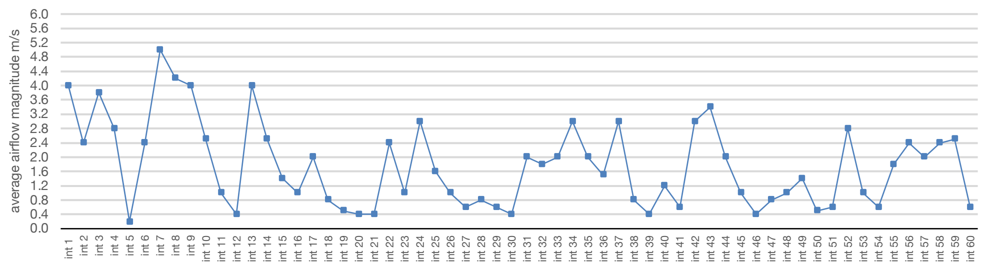
Day 1	
Day 2	
Day 3	

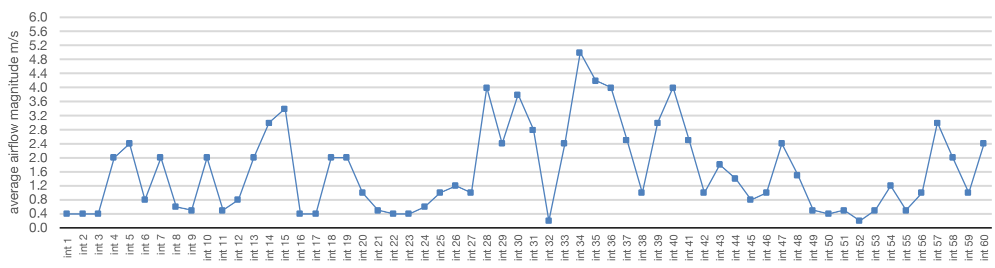
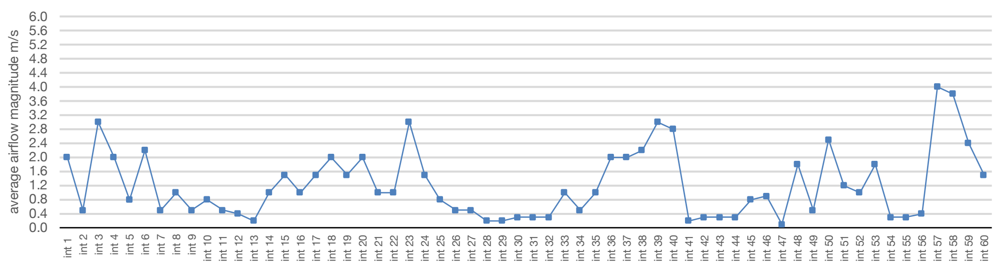
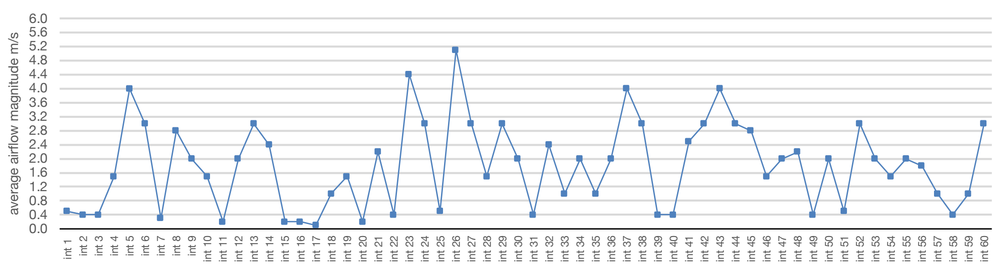
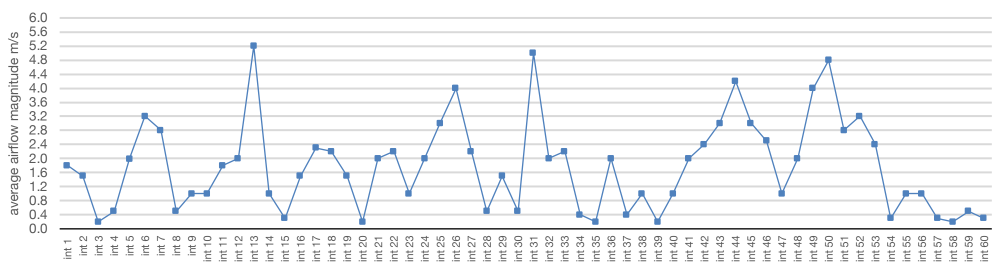
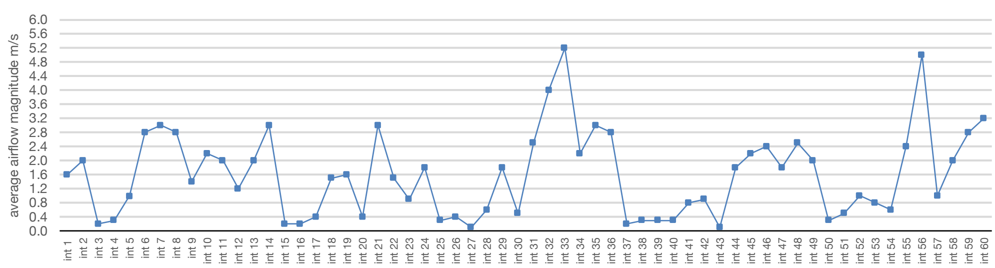
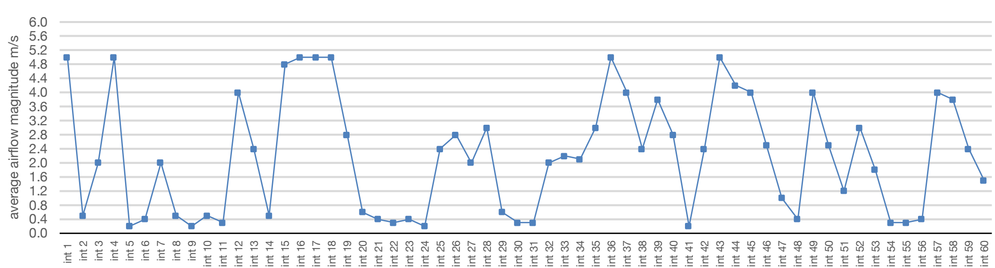
Day 4	
Day 5	
Day 6	
Day 7	

6.6.1.3 Roof point 1 results

Table 6-7 demonstrates the monitoring results of RP 1 point located on the roof of the case study building Masjid el Atarin, results are plotted according to the monitoring intervals specified. The average magnitude of the monitored point is calculated to 1.71 m/s.

Table 6-7 Roof point 1 monitoring results

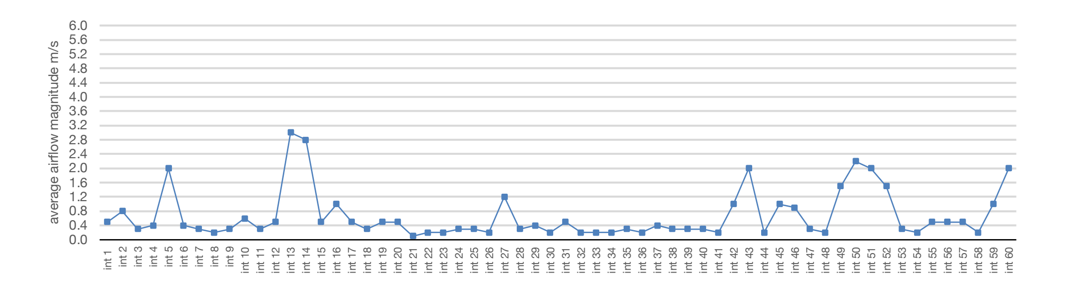
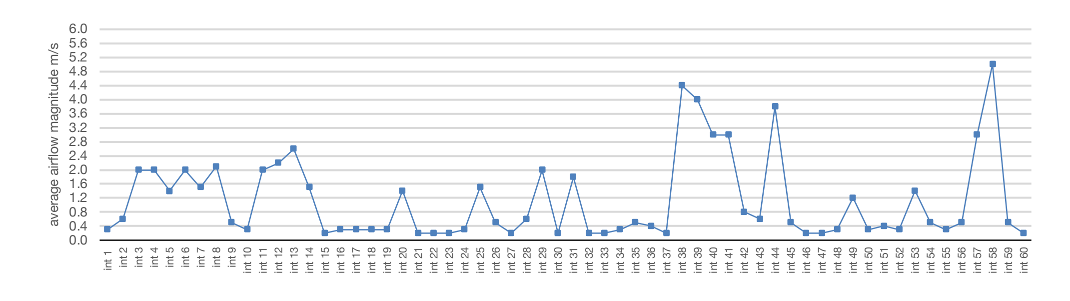
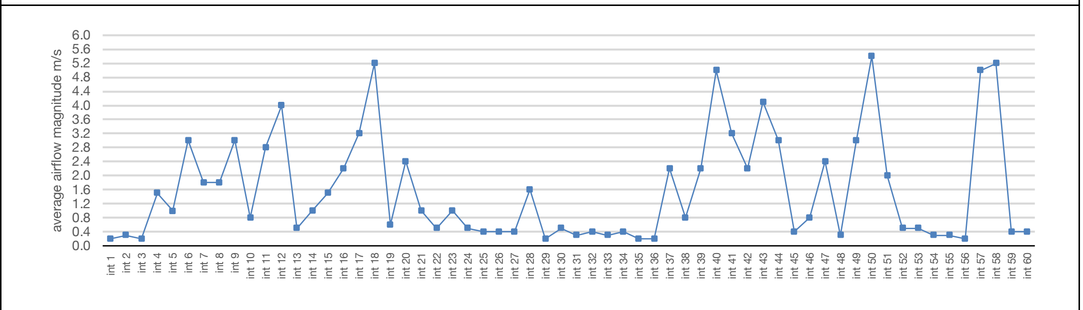
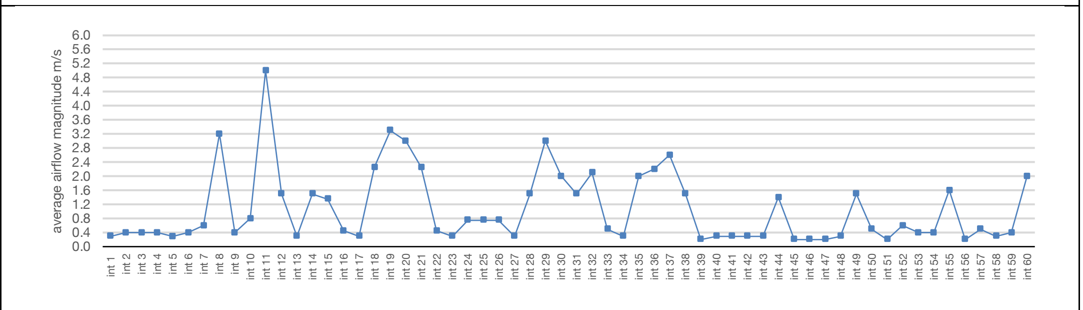
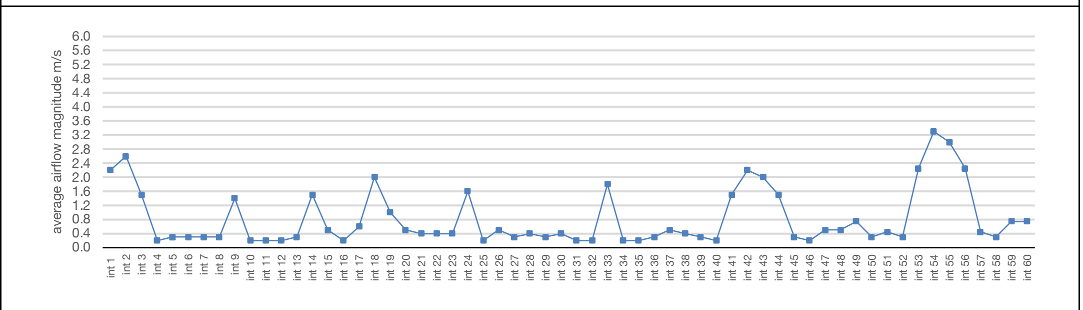
Day 1	

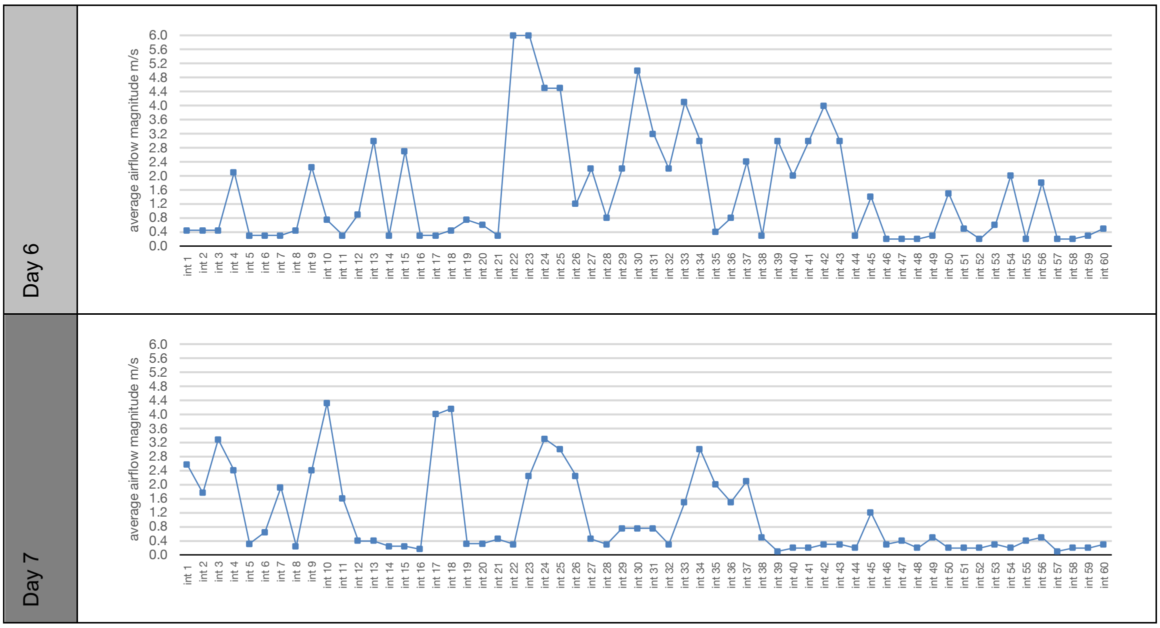
Day 2	
Day 3	
Day 4	
Day 5	
Day 6	
Day 7	

6.6.1.4 Roof point 2 results

Table 6-8 demonstrates the monitoring results of RP2 point located on the roof of the case study building Sizostris street, results are plotted according to the monitoring intervals specified. The average magnitude of the monitored point is calculated to 1.12 m/s.

Table 6-8 Roof point 2 monitoring results

Day 1	
Day 2	
Day 3	
Day 4	
Day 5	



6.6.2 CFD results

6.6.2.1 CFD validation

The complete and comprehensive validation for the model is generally not possible. There is no model proven complete accuracy. According to the CFD simulations carried out, the results where compared to the actual monitoring data gathered from P1, P2 and roof point (1) and roof point (2) monitor, by comparing the results of specified points on both simulation and monitoring with the same conditions of the internal opened doors.

CFD simulation was carried out with the same condition of external openings and internal doors. The simulations were carried out using the different turbulence models the K- ε standard, K- ε RNG, and the K- ε realizable. The results for the velocity magnitude for the monitoring points compared with the actual field measurements with are shown in Table 6-9. The results from the comparison showed a good agreement between the field measurements and the CFD results of the K- ε standard model, with a difference not exceeding 5%.

Table 6-9 points velocity acquired from the CFD model with field monitoring results

Monitoring point	*Physical monitor Airflow velocity m/s*	*Simulation RANS model's airflow results m/s*		
		K- ε standard model	K- ε RNG Model	K- ε realizable model
Roof point (1)	1.71	1.68	1.32	1.56
Roof point (2)	1.12	1.15	1.45	1.15
P1	0.69	0.72	0.58	0.70
P2	0.59	0.57	0.22	0.45

6.6.2.2 Context analysis

The CFD simulation results of the airflow quality and distribution over the case study's site were at several heights; (1.75m the person's height above the ground level), at the mid windows' heights in each storey (3.5m, 7.5m, 11.5m, 15.5m), and the roof height (19.5m) are shown in Figure 6-19, Figure 6-20, Figure 6-21, Figure 6-22 and Figure 6-23 respectively.

From the analysis of the figures, the airflow takes the same routes across the site. These routes are created by the parallel nature of the arrangement of the blocks in the site, which in turn forms straight higher speed streamlines of the airflow that penetrate the context between the case study building and the surroundings' rows.

The airspeed in these routes increases when going to the higher levels plans of the context as a result of the wind speed increase due to the boundary layer. Apart from these airflow routes, the site was found to have adequate airspeed with the blocks' wind shading areas (recirculation regions) ranging from 0.3 to 2.6 m/s, but this is not the case for the ground levels. At the ground level of the site, large vortexexes are formed and create large areas with airspeed almost 0.2 m/s (almost still air) at the leeward sides of the blocks. In the case of the case study block, this vortex is formed on the façade facing Msjed El Atarin street reducing the airflow speed in this area and the maximum airflow magnitude appears in Sizostris street, Figure 6-24. The area of these still air regions decreases as the height increases until they disappear completely as shown.

The above described airflow profile over different levels of the site show the majority of the blocks are exposed to the airflow in a minimum of two sides. The urban canyons are at 22^0 angle on the sides of the buildings in the context, while the urban canyons at the wind meeting facades, the back facades of the blocks and the following row have higher pressure difference than that for the urban canyons.

Airflow configuration could have the ability to provide reasonable ventilation potential for the flats' internal spaces as the air infiltrates the facades of the blocks, and the availability of enough pressure difference. Moreover, the form of the blocks mass (cuboid volumes) paired with their orientation could provide a ventilation potential for the inner spaces in each floor, Figure 6-25. The case study's internal courtyard showed the potential of having an effective role was observed. This was due to the even arrangement and orientation of the blocks towards the airflow direction, Figure 6-26.

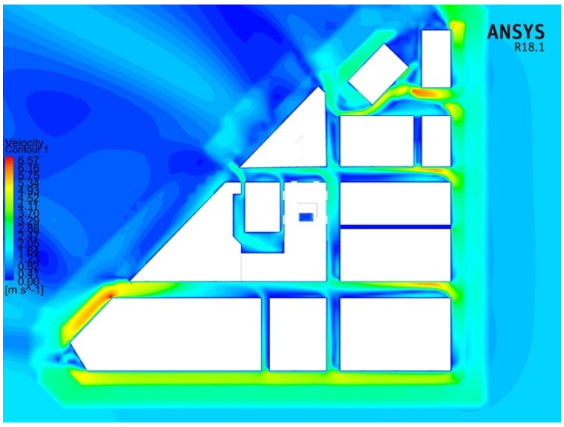


Figure 6-19 The airflow pattern over the site at 1.75 m above the ground level

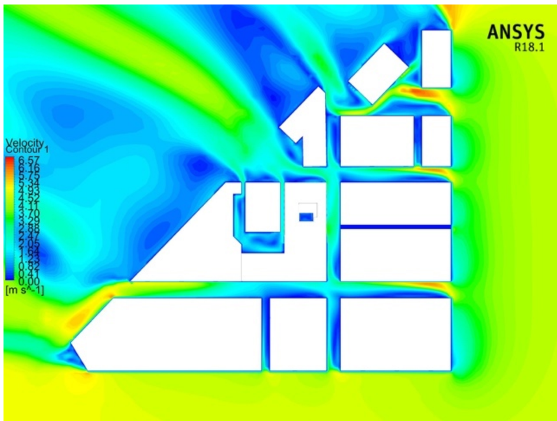


Figure 6-20 The airflow pattern over the site at 7.5m height of the first-floor window

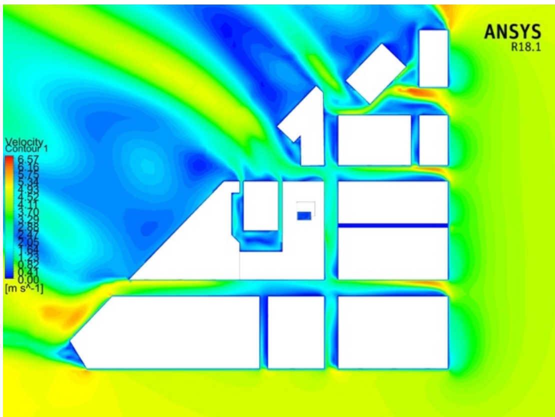


Figure 6-21 The airflow pattern over the site at 11.5 m height of the second-floor window

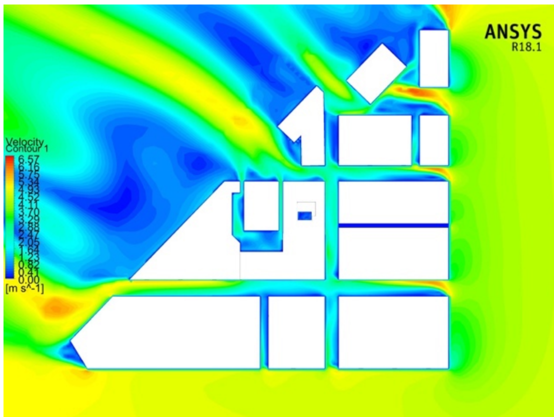


Figure 6-22 The airflow pattern over the site at 15.5 m height of the third-floor window

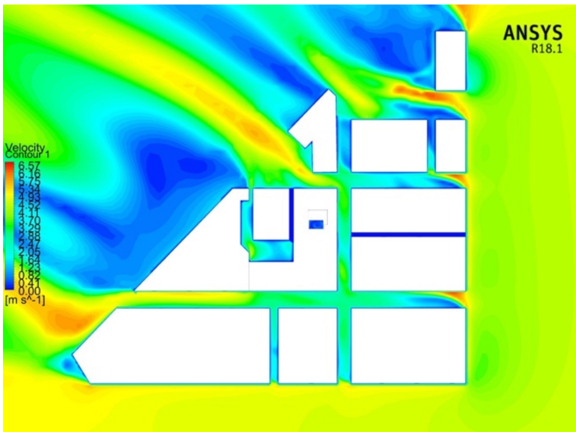


Figure 6-23 The airflow pattern over the site at 19.5 m (person’s height on the roof)

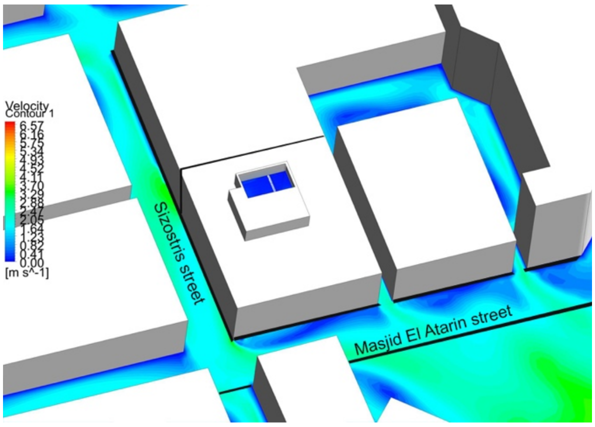


Figure 6-24 airflow magnitude around the case study building block

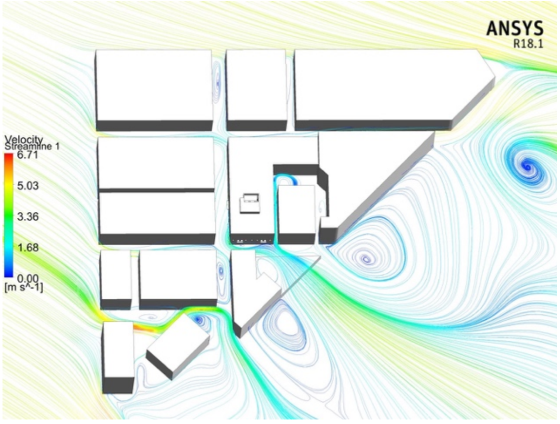


Figure 6-25 the block orientation and its form effect on the airflow

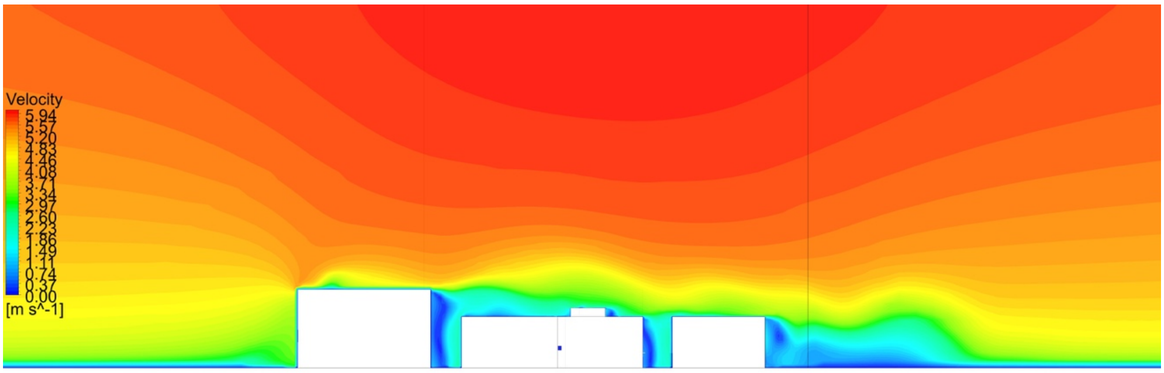


Figure 6-26 contour plot of airflow magnitude around context’s cross section

The velocity magnitude of the airflow surrounding the case study block streets Sezostris and Masjid El Atarin street are shown in Table 6-10 according to the point location of Figure 6-27. The average airflow magnitude on the street level (1.75m) showed that the average wind speed on Sizostris street is slightly higher than Masjid El Atarin street 1.35 m/s against 0.40 m/s respectively. However, as the measuring level increases the magnitude of both airflows increases and the average speed difference is lowered, reaching a maximum of average airflow magnitude of 3.03 m/s on Sizostris street and 1.39 m/s on Masjid El Atarin street at street level of (19.5m). According to the wind direction and the simulated block orientation Figure 46 the façade on Sizostris street would act as the surface of positive pressure and the façade on Masjid El Atarin street would act as the negative pressure surface.

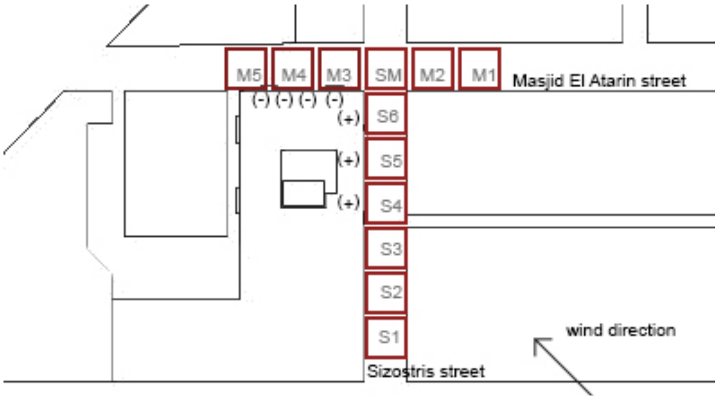


Figure 6-27 case study block surrounding streets monitoring points and wind direction

Table 6-10 airflow velocity monitor points magnitude at different heights

	Sizostris street							Streets intersection	Masjid El Atarin street					
Monitoring level (m)	monitoring points (velocity m/s)						Average (m/s)	(velocity m/s)	monitoring points					Average (m/s)
	S1	S2	S3	S4	S5	S6		SM	M1	M2	M3	M4	M5	
1.75	1.66	0.28	0.39	1.35	2.18	2.25	1.35	1.82	0.15	0.12	0.72	0.52	0.50	0.40
7.5	2.19	0.86	1.94	2.80	2.20	1.90	1.98	1.97	1.53	1.21	1.82	1.00	0.80	1.27
11.5	2.28	1.70	2.70	2.40	2.11	1.97	2.19	2.08	2.37	2.01	2.21	2.15	2.13	2.17
15.5	2.24	2.45	1.93	2.13	2.23	2.10	2.19	2.16	2.05	2.18	2.31	2.61	1.64	2.16
19.5	3.22	3.57	2.00	2.79	3.25	3.39	3.03	2.90	1.88	2.14	2.97	3.37	2.85	2.65

The airflow analysis of the case study's context showed a good potential airflow pattern in different levels. In addition, the analysis indicated good block's arrangement and orientation which could possibly indicate the possibility of available airflow patterns. These patterns can enhance infernal spaces ventilation with the upwind side of the block lying on a good airspeed area, while the downwind side of the block lying in a negative pressure area.

6.6.2.3 Case study building internal airflow depth map analysis

The airflow inside the first floor of the monitored block was further analysed using the outcome from the CFD simulation. The building's external openings are not facing the direct airflow. The velocity magnitude of the prevailing wind direction according to the City of Alexandria is north west. The simulated building has three external elevations north west, south west and south east. As a result of the urban configuration, the north west and south east elevation openings are acting as a positive pressure opening, however, the north west elevation allows a higher magnitude of wind velocity than the south east elevation. The south west elevation is acting as a negative pressure opening.

The airflow inside the first-floor detailed plan of the monitored block, which is exposed to the optimum airflow conditions, was included as a coupled model during the simulation.

The simulation was conducted according to the internal setting of the occupants in relation to opening and closing of external openings and doors. The simulation was conducted with all external openings opened, while the internal doors were simulated according to the occupant's behaviour according to the privacy of spaces. The CFD results are shown in Figure 6-28, Figure 6-29 and the magnitude is shown in Table 6-11.

In general, the airflow inside the typical floor is very poor as there is a great separation being noticed between the S2 spaces, S1 spaces, the inner courtyard, and the stairwell. The main sources of air are the S1 spaces on the outer boundary of the building having external openings. The airflow circulates inside these spaces, however, there isn't any cross ventilation throughout the whole building floor between the external openings and the inner courtyard, due to the unavailability of any connections between the different zones according to their classification.

The S1 spaces performs better due to their direct relation with the external environment in the monitored typical floor. The main sources of airflow are the openings on the S1 zones. Their performance may vary according to the number of openings in each space, as some spaces have two openings creating a cross ventilation and other spaces have one opening which results in single sided ventilation. The airflow that comes from these spaces' openings, most of it rotates inside the space forming a vortex and exists from the spaces through the same side.

While the S2 spaces which are considered the main living spaces inside the building are very poorly ventilated as a result of its complete separation between these spaces, the outer environment and the inner courtyard. The resulted airflow within these spaces where almost still air is found, the airflow pattern inside it indicates poor potential of using comfort ventilation. The maximum obtained air speed inside the S2 spaces is found to be 0.21 m/s and can be low at some spaces at a magnitude of 0.04 m/s.

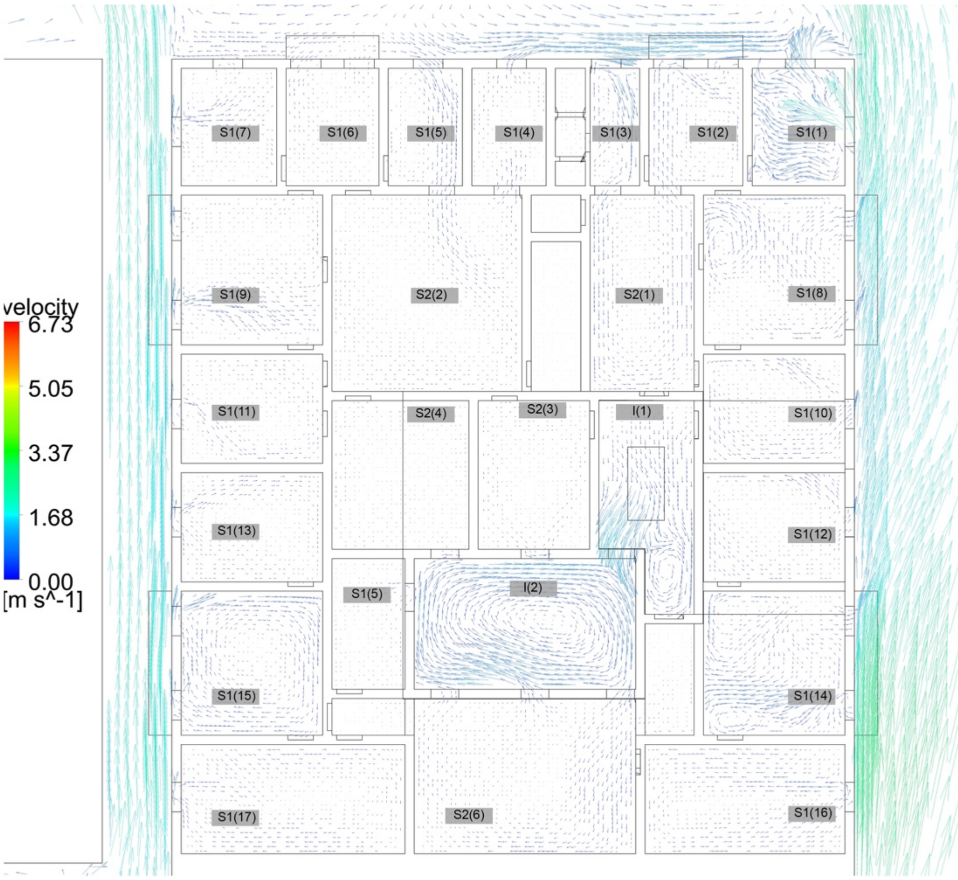


Figure 6-28 the airflow pattern inside the detailed floor of the monitored case study building

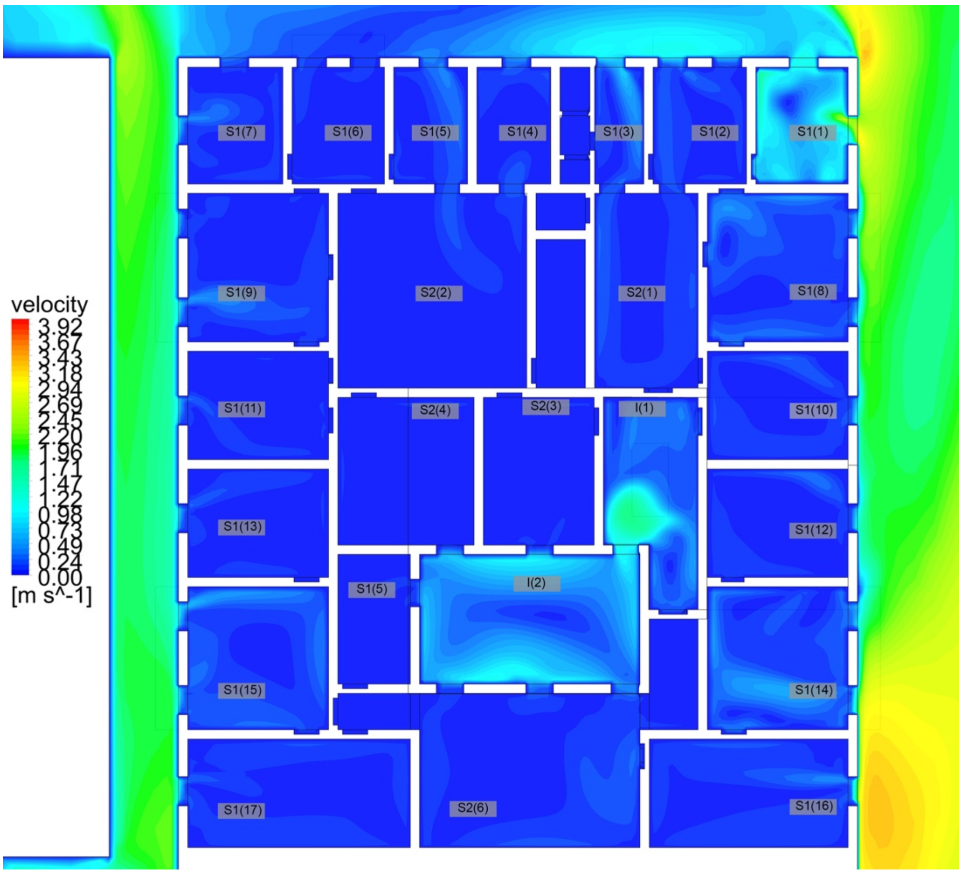


Figure 6-29 the airflow speed profile of the detailed floor of the monitored case study building

Table 6-11 internal airspeed inside the detailed floor plan spaces

Zone		Inlet airspeed (m/s)	Internal airspeed (m/s)		Average airspeed (m/s)
			max	min	
S1	1	2.1	1.35	0.77	1.41
	2	0.13	0.19	0.07	0.13
	3	0.32	0.19	0.13	0.21
	4	0.28	0.25	0.08	0.21
	5	0.37	0.18	0.09	0.21
	6	0.12	0.13	0.07	0.11
	7	0.39	0.33	0.12	0.28
	8	0.42	0.15	0.18	0.25
	9	0.48	0.18	0.05	0.23
	10	0.33	0.19	0.05	0.19
	11	0.32	0.15	0.05	0.17
	12	0.35	0.11	0.08	0.18
	13	0.24	0.19	0.06	0.16
	14	0.24	0.23	0.17	0.21
	15	0.3	0.28	0.12	0.23
	16	0.28	0.23	0.14	0.22
	17	0.12	0.11	0.07	0.11
S2	1	-	0.16	0.11	0.14
	2	-	0.21	0.04	0.13
	3	-	0.07	0.03	0.05
	4	-	0.04	0.03	0.04
	5	-	0.04	0.03	0.04
	6	-	0.16	0.06	0.11
I	1	-	0.84	0.35	0.59
	2	-	0.62	0.18	0.41

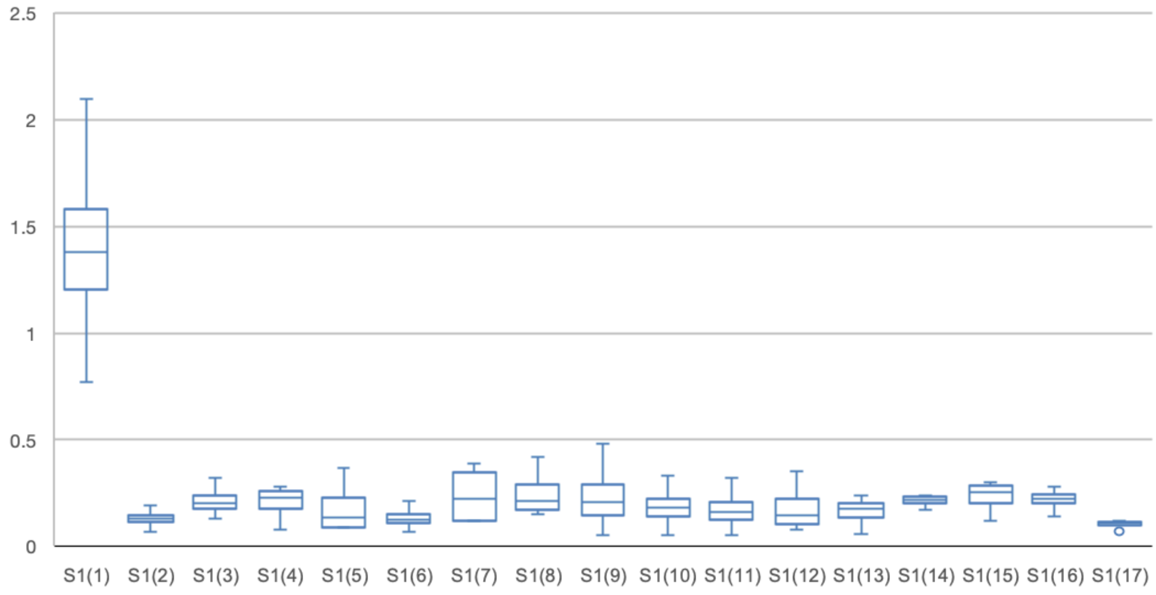


Figure 6-30 average velocity m/s for the S1 spaces

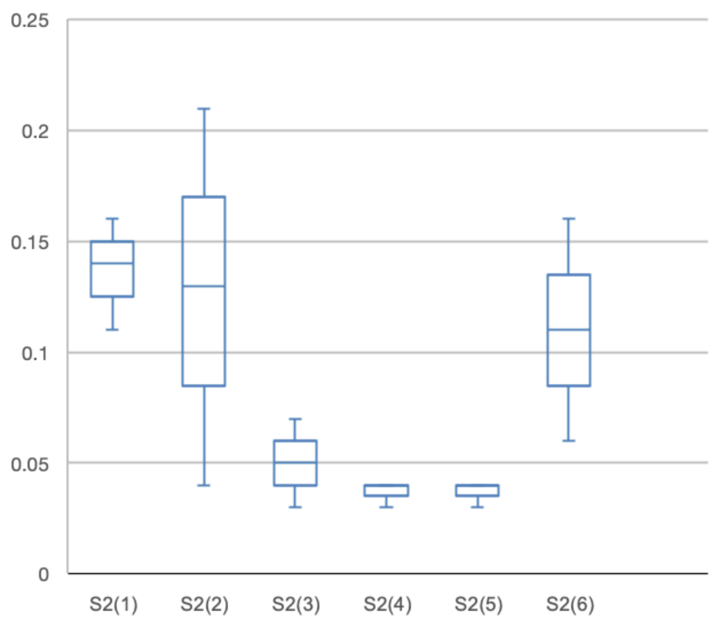


Figure 6-31 average velocity m/s for the S2 inner spaces

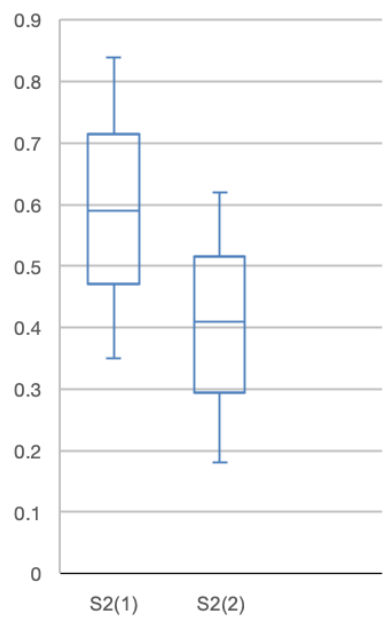


Figure 6-32 average velocity m/s for the Inner shafts' spaces

According to the depth map of the internal space's categorization and the monitoring points previously demonstrated in this chapter, the different spaces in the detailed floor plan were analysed according to their categorization and the different patterns of airflows. In the detailed floor plan as mentioned, the S1 spaces are the main source of airflow inside the internal spaces.

The S1 spaces on Sizostris street airflow patterns and magnitude are as follows; the S1(1) room includes two vertical openings, one on the NW façade while the other on the SW façade, not connected to any other rooms. The air enters the room from the NW opening with velocity 2.10 m/s creating an upper and lower vortex before leaving the room from the SW opening with an average air flow magnitude of 1.41 m/s. The S1(8) room is not connected to another room, has two door openings on the NW façade. The air enters the room from the first opening creating a vortex on the upper left side and leaving from the second opening with an average airflow magnitude with an inlet airspeed of 0.25 m/s. The S1(10) room is not connected to other rooms, the room has one vertical opening for inlet and outlet having a vortex on the upper left side of the room with an average airflow magnitude of 0.19 m/s and the air enters the opening with a speed of 0.33 m/s. The same features are adapted by S1(12) room including one vertical opening acting as inlet and outlet having a vortex on the upper left corner, having an average airflow magnitude of 0.18 m/s and the air enters the opening with a speed of 0.35 m/s. The S1(14) room is not connected to another room, has two door openings on the NW façade. The air enters the room from the first opening creating a large vortex on the upper left side and leaving from the second opening with an average airflow magnitude of 0.21 m/s with an inlet airspeed of 0.24 m/s. The S1(16) room has a deeper layout and not is connected to other rooms. The room has one vertical opening for inlet and outlet, having a smaller vortex on the upper left side of the room, having an average airflow magnitude of 0.22 m/s and the air enters the opening with a speed of 0.28 m/s.

The S1 spaces on the SW façade (Masjid El Atarin street) airflow patterns and magnitude are as follows; The S1(2), S1(3) and S2 (1) are having connected doors creating an airflow passing through the rooms. S1(2) space has three openings and two vertical openings on the SW façade. The air comes from the connected door between the space and the S2(1) space and leaving through the outer vertical openings with an average airflow magnitude of 0.09 m/s. The S1(3) space has one vertical opening acting as an inlet and the connected door with the S2(1) space acts as the outlet with an average airflow magnitude of 0.21 m/s and the air enters the opening with a speed of 0.32 m/s. The S1(4), S1(5) and S2 (2) are having connected doors creating an airflow passing through the rooms. S1(4) space has two openings, one vertical opening on the SW façade, the air comes from the connected door between the space and the S2(2) space with airflow magnitude of 0.28 m/s and leaving through the outer vertical opening with an average airflow magnitude of 0.21 m/s. The S1(5) space has one vertical opening acting as an inlet and the connected door with the S2(2) space acts as the outlet with an average airflow magnitude of 0.21 m/s and the air enters the opening with a speed of 0.37 m/s. The S1(6) space is not connected with any other rooms. The space has two vertical openings on the SW façade, and the left opening performs as an inlet, creating a swirl on the lower side of the room and leaving from the right opening with an airflow magnitude of 0.12 m/s having an average airflow of 0.11 m/s. the S1(7) space is a corner space having two vertical openings on the different sides. The opening on the small alley acts as the inlet with airflow magnitude of 0.39 m/s and the opening on the Masjid el Atarin street acts as the outlet, creating two swirls on the upper left and the lower right of the room with an average airflow magnitude of 0.28 m/s.

The S1 spaces on the SE façade (small alley) airflow patterns and magnitude are as follows; The S1(9) room is not connected to another room having two door openings on the SE façade. The air enters the room from the first opening creating a vortex on the upper left side and leaving from the second opening with an average airflow magnitude 0.23 m/s with an inlet airspeed of 0.48 m/s. The S1(11) room is not connected to other rooms. The room has one vertical opening for inlet and outlet, with a vortex on the upper left side of the room, having an average airflow magnitude of 0.17 m/s and the air enters the opening with a speed of 0.32 m/s. The same features are adapted by S1(13) room including one vertical opening acting as inlet and outlet, having a vortex on the upper left corner, and with an average airflow magnitude of 0.16 and the air enters the opening with a speed of 0.24 m/s. The S1(15) room is not connected to another room and has two door openings on the SE façade. The air enters the room from the first opening creating a large vortex on the upper left side and leaving from the second opening with an average airflow magnitude 0.23 m/s with an inlet airspeed of 0.30 m/s. The S1(17) room has a deeper layout and not connected to other rooms, the room has one vertical opening for inlet and outlet having a smaller vortex on the upper left side of the room, having an average airflow magnitude of 0.11 m/s and the air enters the opening with a speed of 0.12 m/s.

The internal spaces (S2) airflow patterns and magnitude are as follows; The S2(1) space is ventilated from the connection of the S1(2) and S1(3) spaces having an average internal airflow magnitude of 0.14 m/s. The S2(2) space is ventilated from the S1(4) and S1(5) having an internal air speed of 0.13 m/s. The S2(3), (4) and (5) are connected to the inner court with an average internal airflow magnitude of 0.05 m/s,0.04 m/s and 0.04 m/s respectively. The S2(6) space is more ventilated with the inner court with three windows having a better performance of 0.11 m/s with a noticeable airflow inside the space.

The inner shafts are composed of the inner court and the stair case which are acting as a negative suction throughout the building with an average airflow magnitude of 0.59 and 0.41m/s respectively. The shafts are connected together throughout the whole building floors through a window on each floor.

The overall performance of the inner spaces concerning the airflow magnitude and patterns are very poor. Some of the zones reached an average airflow of 0.04 m/s almost still air, especially in the main living spaces zones (S2). The main observation is that the spaces are not connected together not allowing a cross ventilation circuit to occur.

6.6.2.4 Historic reconstruction internal airflow results

The airflow inside the first floor of the monitored block, the simulation was set according to the building's original spatial layout before the current modification. The reconstructed floor layout included spacious internal spaces and the presence of internal transom windows above the internal doors. The results of this simulation are analysed and compared to the current natural ventilation performance of the case study building.

The main noticeable difference in the spatial layout, is that the whole floor act as one apartment with multiple spaces where divided in the current building's layout. These spaces are seen in external spaces S1(3), S1(4), and S1(5) are now on space. While in the internal spaces S2(1) and S2(2) are connected, and S2(3) and S2(4) are one space. Throughout the simulation cross ventilation patterns between the different spaces is obvious as a result of the connected spaces.

In general, the building's original performance the way it was intended to operate has an improved average internal airflow patterns and magnitude throughout the different spaces. Figure 6-33, Figure 6-34, Figure 6-35, and Figure 6-36 illustrate the difference to airflow shown in the detailed floor plan. the external and internal spaces are more spatially connected allowing airflow to circulate within the internal spaces with a higher magnitude, as a result of the large spaces and their connectivity.

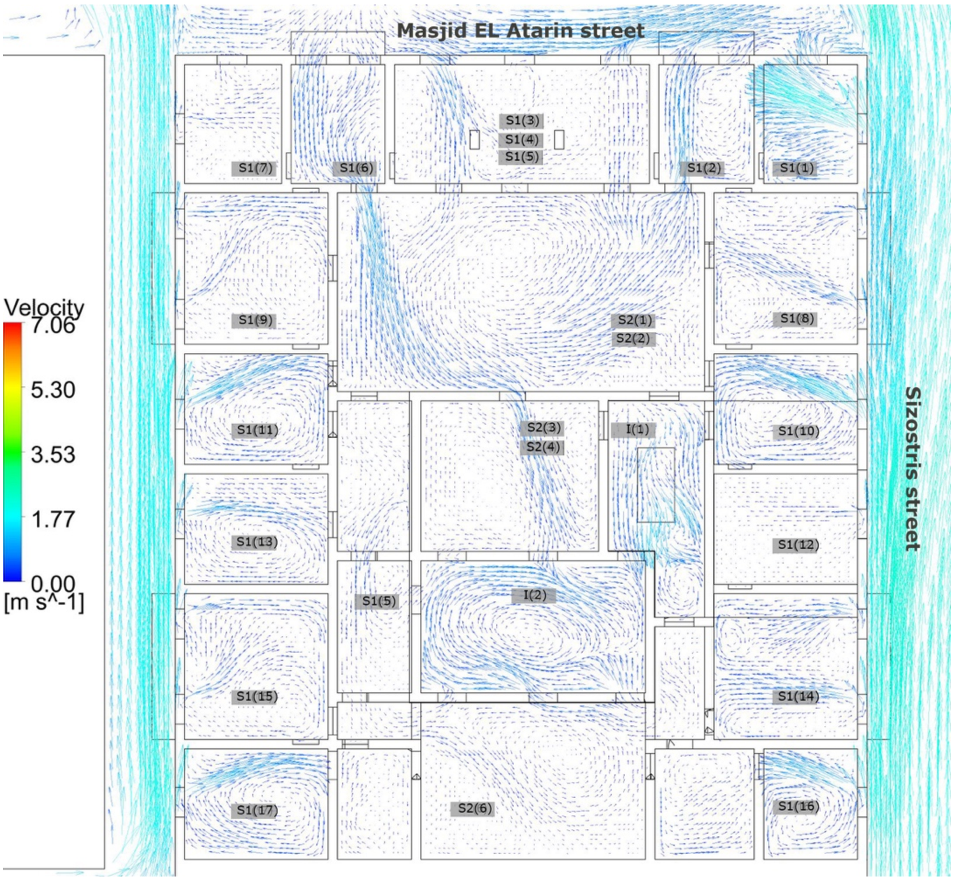


Figure 6-33 historic reconstruction detailed airflow pattern

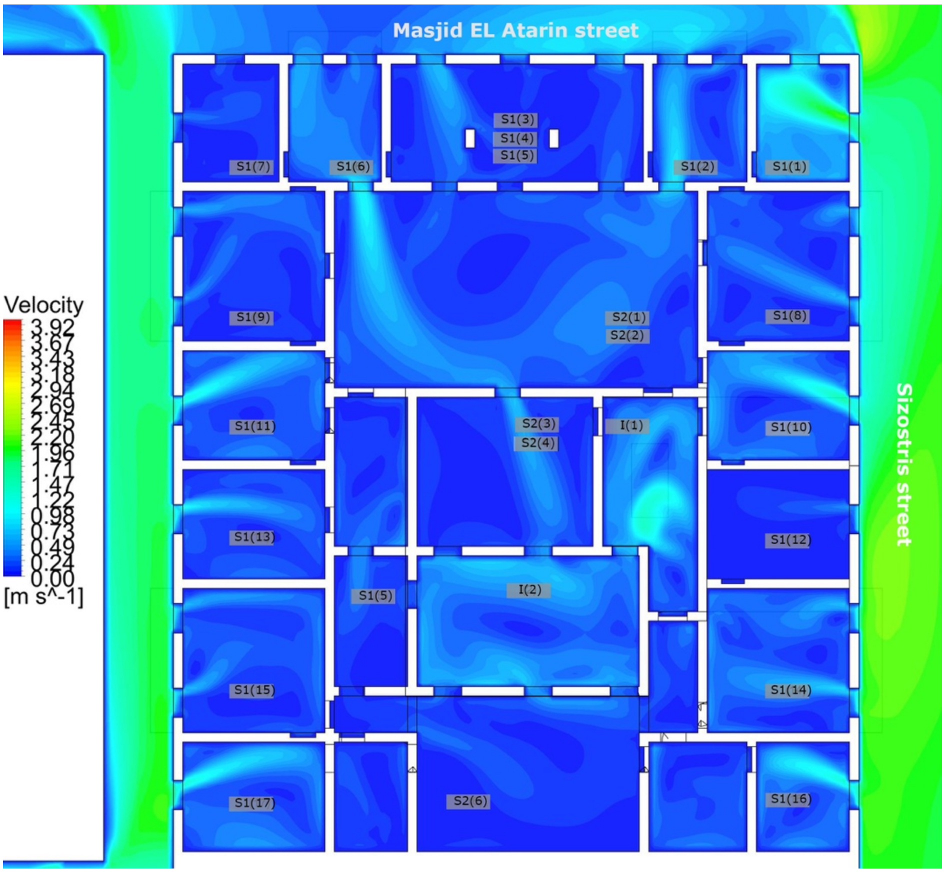


Figure 6-34 historic reconstruction airflow speed profile

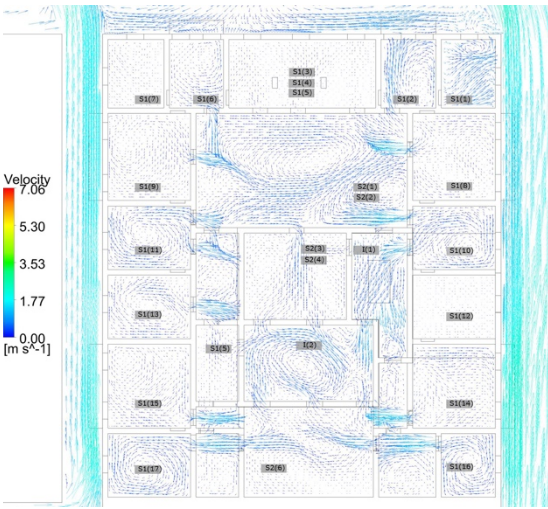


Figure 6-35 historic reconstruction detailed airflow pattern at height 8.6 m

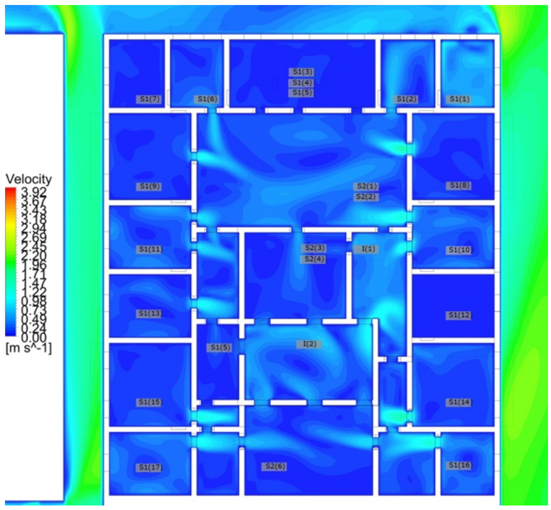


Figure 6-36 historic reconstruction airflow speed profile height 8.6 m

Table 6-12 internal airspeed inside the detailed floor plan spaces

Different cross-ventilation patterns were created as a result of reverting exiting transom windows, opening S1 (8), S1 (9), S1 (10), S1(11) and S1 (13), as an inlet for the internal spaces, the airflow is reaches the internal spaces S2 spaces S2(1,2), S2(3,4) contrasted against still air observed in the current performance of the building. While the external spaces on Masjid El Atarin street S1(2), S1(3,4,5), S1(6), combined with the internal court are acting as an outlet. Another main cross ventilation pattern is observed between the S1 (14), S1 (16) rooms overlooking Sizostris street and S1 (15) and S1(17) overlooking the small alley acting as an inlet passing through the inner space S2(6) and the inner shaft acts as the pressure outlet.

Table 6-13 illustrates the different internal airflow magnitude within the different space in the original building's layout and compared to the actual current performance of the case study building, Figure 6-37, Figure 6-38 and Figure 6-39. The external S1 spaces perform better than the actual performance case due to their connection with the internal zones resulting in increasing the average internal air speed reaching to 0.57 m/s against 0.26 m/s. Meanwhile, the internal S2 spaces which are considered the main living spaces inside the building are more ventilated from the outer S1 spaces the air flow patterns increased with a maximum internal airspeed reaching to 0.44 m/s against 0.08 m/s.

Table 6-13 internal airspeed inside the detailed floor plan spaces

Zone		Inlet airspeed (m/s)	Internal airspeed (m/s)		Average airspeed (m/s)
			max	min	
S1	1	2.2	1.61	0.94	1.58
	2	0.81	0.64	0.44	0.63
	3	0.73	0.47	0.32	0.51
	4				
	5				
	6	0.49	0.66	0.32	0.49
	7	0.53	0.39	0.16	0.36
	8	0.55	0.55	0.36	0.48
	9	0.66	0.26	0.20	0.38
	10	1.97	0.64	0.29	0.96
	11	1.15	0.56	0.27	0.66
	12	0.36	0.22	0.16	0.25
	13	0.81	0.62	0.39	0.61
	14	0.63	0.88	0.42	0.64
	15	0.43	0.39	0.26	0.36
	16	1.12	1.74	0.81	1.22
	17	0.64	0.48	0.35	1.47
S2	1	-	0.92	0.58	0.75
	2				
	3	-	0.57	0.28	0.43
	4				
	5	-	0.31	0.17	0.24
	6	-	0.42	0.27	0.35
I	1	-	0.96	0.46	0.71
	2	-	0.79	0.34	0.57

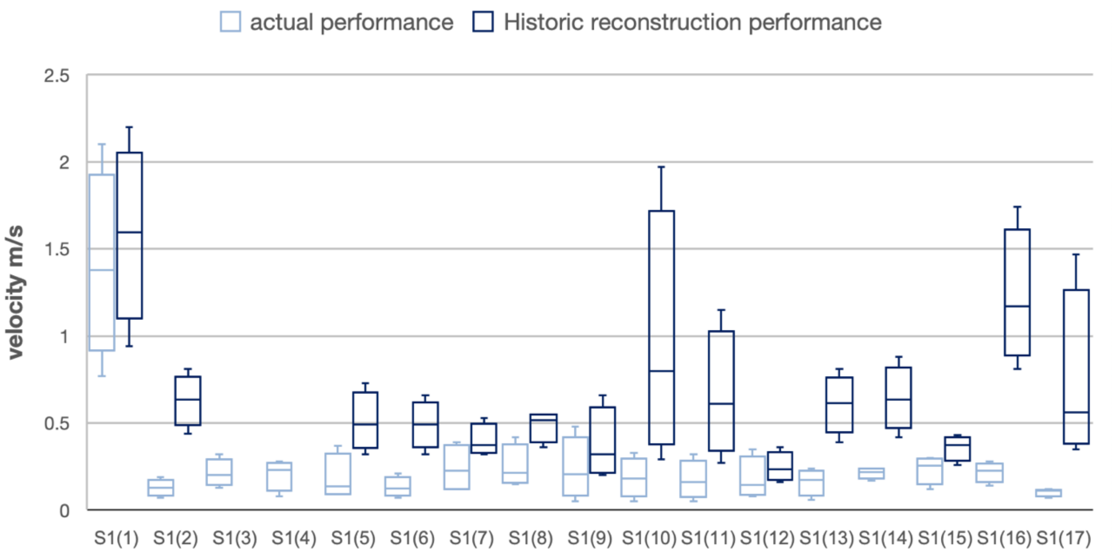


Figure 6-37 average velocity m/s for the S1 spaces scenario 3

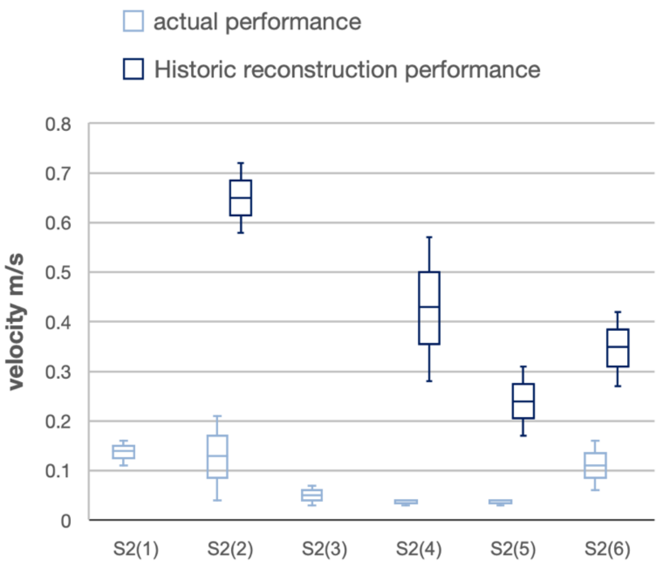


Figure 6-38 average velocity m/s for the S2 inner living spaces scenario 3

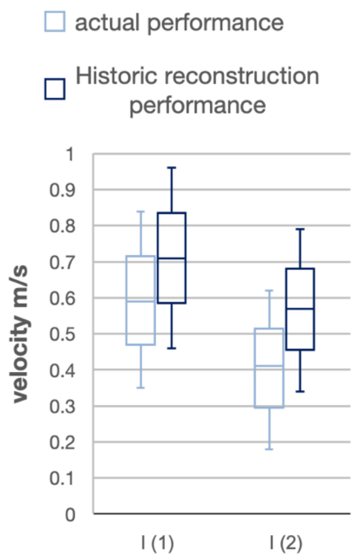


Figure 6-39 average velocity m/s for the Inner shafts' spaces

6.7 Conclusion

This chapter provides a clear demonstration for the current natural ventilation performance, and a critical understanding the way the building operated within its original layout for a typical heritage building located in the city of Alexandria. The principles of environmental design for this heritage buildings typology have indicated the potentialities for comfort ventilation in the case study building, the combined effect of the surrounding environment, inner space height, inner shafts and 17 % opening ratio.

The main aim is to reduce cooling loads and energy consumption in summer. However, in modelling and measuring the current occupation of the building and compared to its original layout and features, the results obtained demonstrate the current unacceptable conditions for indoor comfort. This failure is evidently due to a combination of factors including occupants' behaviour and modifications to the functional environmental principles of the building's original design. Alterations include the blockage of upper openings which have negatively affected the induction of cross ventilation and the stack effect throughout the building. Results show a detailed example of how a deficiency of performance in natural ventilation is created in the case study building.

The next chapter will study the different natural ventilation strategies and alternatives will be explored to assess how indoor air flow could be improved

Chapter 7 A Parametrical approach to enhance natural ventilation in the case study

7.1 Introduction

The work in this chapter aims to formulate strategies towards the possible approaches for natural ventilation retrofit measures to enhance the performance inside the case study building. The strategies are formulated according to the retrofit methodology adopted as identifying retrofit options. The strategy is backed up by the pre-retrofit activities performed in the previous chapters, concerning cultural significance in Chapter 05 and the natural ventilation performance assessment in Chapter 6. The parametrical approach would put into consideration the quantitative and qualitative impact on the heritage value of the case study. Following the literature review in chapter 4, this chapter will use passive systems retrofit measures that are believed to have a positive impact effect on the natural ventilation performance inside the building. It will analyse the measures applicability to the selected case study building with respect to its heritage value.

7.2 The parametric study method

The computational parametric study is conducted here to attain two objectives. First, the study aims to evaluate the effect and derive a scientific understanding of acceptable thermal comfort in choosing the appropriate retrofit strategy to efficiently improve the indoor natural ventilation airflow magnitude and patterns in Alexandria's cosmopolitan heritage buildings represented by the selected representative case study listed building. Second, it aims to evaluate the effect of each strategy on the building's cultural and heritage identity.

Compared with applied studies focusing on natural ventilation performance in internal spaces, the current parametrical approach obtains the natural ventilation performance with generic changes to the building's configurations. In the parametric study, cross-comparing the effects of different retrofitting strategies is made easier by observing the changes in natural ventilation performance in a number of different testing scenarios, thus identifying the effects of the different retrofit parameters. The details of conducting this study, in terms of the selection of the applied measures and the procedures of conducting the parametric analysis, are as follows;

- The applied changes to the building configuration would be based upon a selective criterion of the different measures that can be used to enhance the internal natural ventilation within the case study building, according to the ventilation strategies deficiencies in ventilation performance that were evaluated in the previous part of this research. The different measures would be applied or excluded from the study according to the level of the intervention of each measure and the impact on the heritage features of the case study building.

- The computational parametric study of the proposed retrofit measures uses ANSYS Fluent computational fluid dynamics (CFD) simulation software, in which each parameter measure will be applied to the base case study model. The accuracy of the simulated results is based on the same settings, grid configuration and the same boundary conditions settings used in the validated base case study model for ensuring reliable results.
- The effectiveness of each parameter of these measures will be compared with applied studies focusing on both the average airspeed across the internal spaces and the quality of air movement pattern. These results are presented to show the steps in enhancing the airspeed and the air movement inside the spaces maximizing the use of comfort ventilation strategy and the cooling effect.

7.3 Selected measures for the natural ventilation retrofit

According to the review in chapter 4, it was established that different passive systems can be applied to enhance the natural ventilation inside a building. These measures are: modifying the design of façade openings; including size, position, number and type; modifying the roof shape and additions; connecting internal spaces; introducing double skin facades; introducing ventilation shafts; and finally adding a projection to the building envelope.

The results from earlier modelling and measuring of the current building's natural ventilation performance demonstrate unacceptable conditions for indoor comfort. Results show a detailed example of how a deficiency of performance in natural ventilation is created in the case study building, including the inability of the building to induce cross ventilation and the stack effect principles throughout the building affecting the airflow distribution and magnitude. The building previously would have performed better but modifications by the occupants to the interior have reduced its ability to provide adequate function.

These results have indicated the need to reintroduce passive retrofit strategies in order to upgrade the natural ventilation performance of the case study building. However, the heritage nature of the case study limits the use of some features of the passive retrofit criteria in the enhancement process. The nature of this research context is a balancing act between these retrofit criteria and the heritage value of the building, which needs to be preserved. Therefore, these different measures should be discussed, filtered and modified in order to formulate the list of measures that would be applied to the case study and their effect on the heritage value and natural ventilation performance of the case study in any proposed enhancement process.

The case study building was classified as a grade III heritage and a local level classification. According to this heritage classification alterations to the external façade are limited to changes that won't affect its value and image, while changes internally are very flexible. These alterations are also supported by the legislative controls' minimum requirements and that although the interiors are not protected by law, decisions approach to any proposed alteration should be adopted. The research would apply to modifications bearing in mind the preservation of the internal spatial configuration and the building's load bearing wall structure. The filtering process will be conducted based on the actual performance of the case study building and contrasted with its architectural identity and heritage value level.

Facade opening design, include the opening design (size, position, and number of openings), any changes to the size of the openings, changing their location, or the addition of any new openings regardless the performance benefits, and their manipulation, would affect the external appearance of the building. This is not proposed to be changed. Therefore, the parameters of these aspects in the retrofitting measure were excluded from the choice. However, according to the heritage level of the case study building, the opening type can be modified to increase the inlet size.

The original case study opening type is composed of two parts; a double-sided casement, with a top fixed pane, Figure 7-1. The imposed parameters could increase the inlet area through modifying the opening type enabling the top fixed pane to be opened. The research can quantify the effect of the different opening types and test their effect on the internal airflow. An experimental simulation can be applied according to the different upper window type opening types exploring the effects as follows;

a) Single side hung casement upper window

b) Top hung casement upper window

In terms of the impact of this strategy to the building's heritage value, this would be considered a minimum intervention to the external building façade. As this intervention will not change the physical appearance of the preserved façade to be an acceptable intervention.

Figure 7-1 the layout of the existing windows showing the fixed top part

Roof shape, proposals for the case study building for being enhanced are made considering its features including its flat roof shape, which is not proposed to be changed considering its effect on the flat roof heritage context of Alexandria. However as discussed earlier, additions could be implemented in the open courtyard imbedded within the case study building.

The study can test the impact of a single slope addition and its effects on the ventilation rate of courtyard case study building. In order to evaluate the effect of this retrofit measure on the wind-driven natural ventilation, a range of mono-pitch roof additions will be added to building's central courtyard opening to produce a range of ventilation strategies. Each proposed roof addition was limited to 2 meters in height to be invisible from the pedestrian level, giving a roof pitch of 16°. The computational modelling will explore three models with different strategies while fixing the incident angle parameter according to the case study building context orientation. This different criterion would be tested using the recommended measure of setting the openings area equivalent to the openings area of a detailed floor plan at a percentage to the facade openings of 24 %, as shown in Figure 7-2;

(A) Negative suction pressures on atrium roof openings ventilation strategy, addition of atrium mono pitch roof with openings in leeward side.

(B) Positive driving pressures on atrium roof openings ventilation strategy, addition of atrium mono pitch roof with openings in windward side.

(C) Positive and negative pressures on atrium roof openings ventilation strategy, addition of atrium mono pitch roof with openings in leeward and windward side.

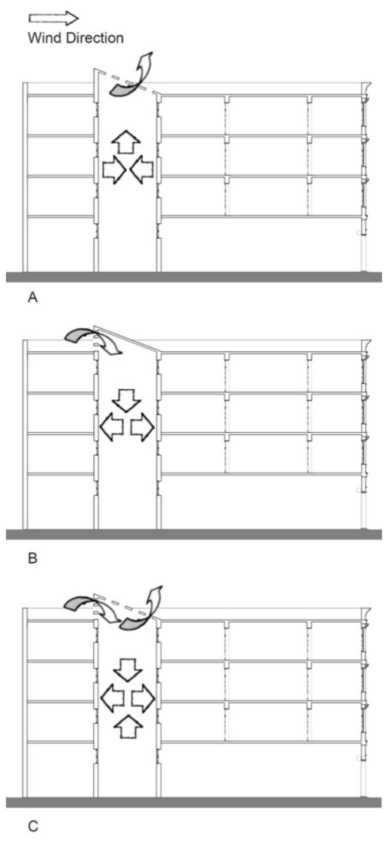


Figure 7-2 Different roof shape applied parameters; (A) openings in the leeward side, (B) openings in the windward side, (C) openings in the leeward and windward sides

According to the impact of this strategy on the building's heritage value, the different chosen parameters won't have a visible impact on the pedestrian level line of sight. Accordingly, this strategy could be implemented in the retrofitting process.

Connected internal spaces, one of the main observations from the current building's performance in Chapter 6 is the occupants' behaviour and modifications to the functional environmental principles of the building's original design. Through a series of alterations and the blockage of upper openings to closed wood panels which have negatively affected the induction of cross ventilation and the stack effect throughout the built. These alterations were made as a result of the divided ownership within the detailed floor plan into different apartments. The internal space categorization analysis showed that the reliability of some of the internal spaces (S2 spaces) for ventilation is dependent on (S1 spaces) for ventilation, in addition to the availability of the inner court and staircase acting as vertical connected spaces.

According to the internal space categorization analysis for the internal spaces either vertically or horizontal, the building configuration design could allow the facilitation of the internal airflow through the availability of connected spaces S1, S2, inner court, and staircase which is a positive point through the availability of transom windows. The unavailability of connected horizontal or vertical spaces due to the blockage of the available transom windows has shortened the cross-ventilation circuit, leading to a very poor ventilation performance of some spaces and degrading the benefits of stack effect ventilation that can be available through the inner court and the staircase.

The proposed parameter in this case is, the reverting of the existing transom windows within the case study building. This consequently will increase the internal spaces' porosity through providing the connection between the different horizontal and vertical spaces. The reversion process would be applied according to the separation of the apartments by restoring the transom windows within each apartment separately, considering the privacy of the different ownerships and other safety issues that emerge such as fire risks. The parameter is not imposing the connection between the different ownerships that can have an effect on the current tenancy and the building's use, Figure 7-3.

With regard to the heritage value of the building, this parameter won't be changing any of the heritage characteristics of the building. As a matter of fact, it would be restoring it to its original context. Depending on that and the importance of connected spaces within a structure for natural ventilation, this parameter would act as the base case for the other parameters for comparison.

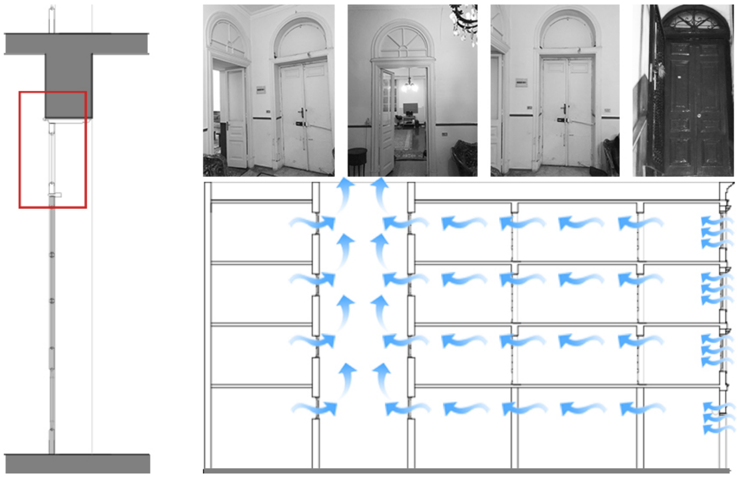


Figure 7-3 the transom windows opening strategy for enhancing the airflow

Double skin facades, adding an external skin layer to the building's façade to facilitate stack effect and wind-driven ventilation. The effect for this application was reported to be more suitable for cold climates rather than hot climates. Moreover, this retrofitting strategy would directly affect the façade's external physical appearance disturbing the intended preservation of the urban heritage context. Considering these two factors affecting the heritage significance and the climatic considerations of the context this retrofitting parameter would therefore be excluded from the choice of the retrofitting parametrical study.

Ventilation shafts, the parameter can be used to boost the internal airflow within the internal configuration of the case study building. However, the use of this strategy would require changes to the physical appearance of the external façade appearance of the building due to the addition of the external shaft up to 4 m above the roof level affecting the massing coherency between the building mass within the urban environment. These changes according to the preservation plan of the case study building (preserving external façade as a grade III heritage) the parameter would be excluded from the choice of the retrofitting parametrical study.

Building envelope projection, the parameter can be used to direct and enhance the internal airflow with the induction of wind-driven ventilation. However, the use of horizontal or vertical projections would require changes to the physical appearance of the external façade. These would require additions of a wing wall or horizontal shading which would include the use of different materials and the introduction of a different architectural language to the building. These changes according to the preservation plan of the case study building (preserving external façade as a grade III heritage) meaning that the parameter would be excluded from the choice of the retrofitting parametrical study.

These retrofitting measures and their parameters were selected to be applied to the case study in order to quantify their effects according to the building's heritage grade and the different scale of intervention with the building's structure. The summary of the proposed measures and their parameters to be applied to the case study in the enhancement process are listed in Table 7-1. The effectiveness of the proposed measures and their parameters there will be quantified according to the enhanced methodology.

Table 7-1 the proposed retrofitting measures for ventilation enhancement

Retrofitting measure	Proposed parameters
Façade opening design	• Changing the external window type with a single hung casement upper window. • Changing the external window type with top hung casement upper window.
Roof shape	• addition of atrium mono pitch roof with openings in leeward side. • addition of atrium mono pitch roof with openings in windward side. • addition of atrium mono pitch roof with openings in leeward and windward side.
Connected internal spaces	• The restoration of the physical properties of existing transom windows by opening them according to the separation of the apartments.

7.4 The computational parametric study

The computational parametric study structured in this research, while cross-comparing the effects of the selected measures for natural ventilation retrofit conducted in the previous part, is simulated in order to observe the changes in natural ventilation performance in the case study building in different testing scenarios. Thus, identifying the effectiveness of each measure and the best proposed parameter within each measure.

The enhancement process will deal with the retrofit plan in three measures; façade opening design; roof shape and connected internal spaces, compromising 12 testing scenarios, as the proposed testing parameters based on best practices. Accordingly, each group of the selected measures is composed of a different number of testing scenarios related to the best practices that could be applied for each measure. Façade opening design is composed of two different scenarios of two different types of openings, roof shape additions is composed of three different scenarios of roof additions to the atrium, and connected internal spaces is composed of one scenario; which is restoring the building's original layout.

The proposed measures will be applied in a different order than that of Table 7-1. This was to facilitate creating an airflow inside the case study spaces that are not exposed to airflow, have still air inside, and have connected internal horizontal and vertical spaces. As there is no point of enhancing the stack effect by roof additions while the internal spaces are not connected to the inner court. In addition to that, most of the used measures do not take their significant effect until cross-ventilation is provided, such as an opening's size. In general, the proposal of the parametrical study is allowing cross-ventilation between spaces before testing the other measures. For this reason, the parametrical study would start with treating the connected internal space measure first and then would be combined with the other measured parameters scenarios; façade opening design; roof shape; and ventilation shafts, in order to serve this purpose.

The parametric study of the research would be conducted in three consecutive levels testing the performance of the selected measures separately and combined as one system, Figure 7-4 and Table 7-2.

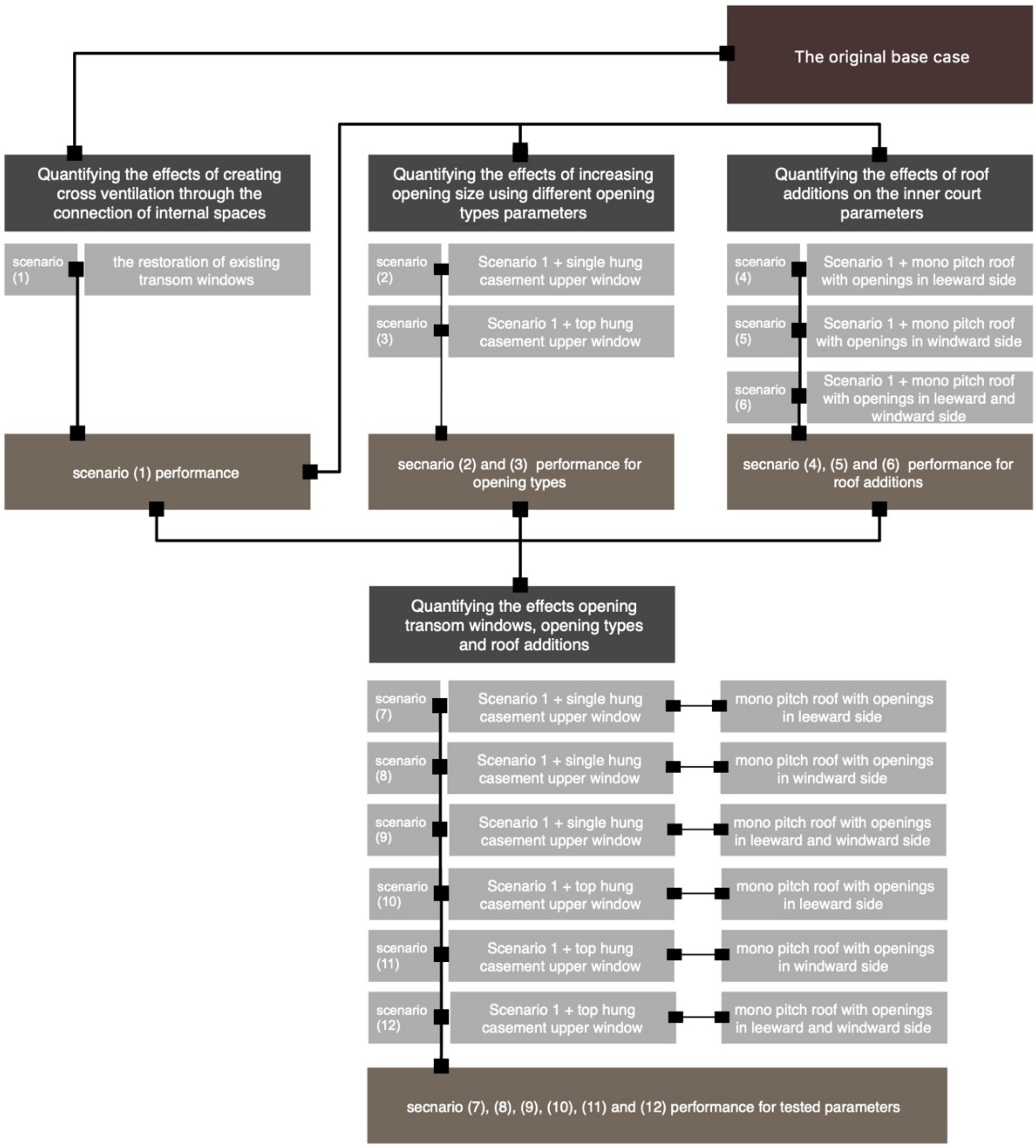


Figure 7-4 the methodological flow and stages of the parametrical study

Table 7-2 the simulation scenarios for quantifying the enhancements effects

Level	Scenario	Description	Proposed measure to be quantified	Base case	Result case
Level 1	(1)	The restoration of the existing transom windows according to the separation of the apartments	Quantifying the effects of creating cross ventilation through the connection of internal spaces	Actual building performance	Performance of internal connected spaces
Level 2	(2)	single hung casement upper window + Opening transom windows	Quantifying the effects of increasing opening size using different opening types parameters	Scenario (1) performance	performance of changing opening type
	(3)	top hung casement upper window + Opening transom windows			
	(4)	mono pitch roof with openings in leeward side + Opening transom windows	Quantifying the effects of roof additions on the inner court parameters	Scenario (1) performance	performance of different roof additions
	(5)	mono pitch roof with openings in windward side + Opening transom windows			
	(6)	mono pitch roof with openings in leeward and windward side + Opening transom windows			
Level 3	(7)	single hung casement upper window + mono pitch roof with openings in leeward side + Opening transom windows	Quantifying the effects of the different parameters used in the retrofitting strategy combination together (opening types, roof additions, and internal connected spaces)	Scenario (1) performance	performance of the combination of the different strategies internal connected spaces, opening types, and roof additions.
	(8)	single hung casement upper window + mono pitch roof with openings in windward side + Opening transom windows			
	(9)	single hung casement upper window + mono pitch roof with openings in leeward and windward side + Opening transom windows			
	(10)	top hung casement upper window + mono pitch roof with openings in leeward side + Opening transom windows			
	(11)	top hung casement upper window + mono pitch roof with openings in windward side + Opening transom windows			
	(12)	top hung casement upper window + mono pitch roof with openings in leeward and windward side + Opening transom windows			

The first level is about testing the restoration of the building's transom windows as scenario (1) internal S1, S2 and internal shaft spaces, conducting the effect of this measure effect on the building's natural ventilation performance. The effect of this measure would be set as the base case for the following scenarios to be applied.

The second level combines the effects of scenario (1) with the selected measures of "façade opening design" of increasing opening size by changing opening type with an operable top opening is composed of; scenario (2) single hung casement; scenario (3) top hung casement. Followed by combining the effects of scenario (1), the selected measures of roof additions in the form of a mono-pitch roof to the inner court is composed of; scenario (4) roof openings in the leeward side; scenario (5) roof openings in the windward side; scenario (6) roof openings in the leeward and windward side. This level would conduct the effect of each measure separately on the building's performance combined with opening the internal transom windows.

The third level tests the effect of the different measures combined together, to evaluate the systems performance and coherence composed of; scenario (7), (8), and (9) which combine the effects of opening transom windows, single hung casement upper window with and the addition of mono-pitch roof with openings on the leeward side, windward side, and finally with openings on the leeward and windward side respectively. Scenario (10), (11), and (12) combine the effects of opening transom windows, top hung casement upper window with and the addition of mono-pitch roof with openings on the leeward side, windward side, and finally with openings on the leeward and windward side respectively. This level would conduct the effect of the selected measures performance combined on the building's internal natural ventilation performance.

7.4.1 Quantifying the effects of the retrofitting measures

In terms of quantifying the effect of the selected measures in the retrofitting plan, the results of the tested parameters 12 scenarios will be analysed according to the proposed internal space categorization as follows. Firstly, the airflow quality, sources, paths and distribution inside the detailed floor will be analysed according to their categorization (S1 spaces, S2 spaces, and inner shafts). Secondly, the airspeed will be averaged within the spaces on the different monitoring points in the detailed floor plan. These results will form the datum line that the enhancement process results will be compared with accordingly, in order to quantify the effect of applying the proposed retrofitting strategies in enhancing natural ventilation performance in the case study building.

This method of analysis will be applied to retrofitting measures in different scenarios. The scenario that will achieve the higher average airspeed and better-quality airflow pattern in most of the detailed floor plan spaces will be considered the best scenario in the retrofitting parameter. The results of each scenario will be compared to the performance of the different scenarios in the same level in order to quantify the enhancing effect of the simulated retrofit measure. The research is intending to reach the maximum enhanced case by combining the different scenarios of all retrofit measures in one case and cross-compare the final results with the actual performance quantifying the effect of the parametrical study representing the final output of this research.

7.4.2 Retrofitting measures CFD setup

The three selected measures, comprising 12 scenarios, are set up according to the established modelling parameters already set in chapter 6 for the case study building's current performance. These scenarios were CFD simulated for the different retrofitting natural ventilation measures. The process will require the incorporation of a coupled domain including the urban surrounding of the building and its interior configuration of the typical floor plan, and is the focus of the investigation.

The CFD pre-simulation, solver settings and post-processing employed for all these simulations were very similar, all based on the findings of the previous step method. These parameters were CFD simulations for the same urban domain of the surrounding context for the wind direction from north-west, with a total of 12 different simulations. Each testing scenario uses a building model matrix, the building model design, computational modelling of the testing scenarios, and boundary conditions for the CFD simulation used.

I. Parametric study building geometry

Twelve building models are designed to test the effects of the different case study building retrofitting measures conducted in Section 7.4. The summary of these scenarios is presented in Table 7-1. The base case study model configuration remains the same, while modifications will be applied to it.

To evaluate the effects on the internal airflow natural ventilation, the model for the case study building and the surrounding building blocks were constructed using the same parameters used on the previous simulation of the actual performance of the case study building. The surrounding blocks were modelled as a solid block and kept with the same dimensions of the base case simulation. The monitored block case study building will be modelled with the same configuration with the detailed first floor plan, same internal space configuration, connected to the inner courtyard and the stair well.

Alterations made to the models are based on the tested parameters according to the workflow in Table 7-2, configuring the tested parameters including, alteration to the internal spaces' connection, changing the opening types and the additions to the roof court.

II. Parametric study solution domain and meshing

The dimensions of the solution domain are kept the same throughout the twelve testing scenarios according to the established results of the previous simulations of height (642 x 532 x 100 m). The domain total volume is $3.42E^{+7}$. The fluid volume and the blockage ratio vary according to the different alterations applied to the model. The inlet and outlet positions were set in the north-west orientation normal to the domain geometry.

The solution meshing and grid configuration is applied according to the mesh refinement applied in chapter 6 base case simulation, using hexagonal structure. Three different grid levels were used. These three levels are; the base grid, the surrounding building grid, and the detailed floor plan grid. The specific grid levels are specified in Table 7-3.

Table 7-3 the solution grid level and their specifications

	Base grid	Surrounding buildings' grid	Detailed floor grid
Max. grid size	6.4	2	0.2
Min. grid size	0.1	1	0.1
Inflation outside the assembly	-	Inflation of 5 layers outside the assembly with max. cell size of 1	Inflation of 10 layers outside the assembly with max. cell size of 0.4

III. Parametric study boundary conditions

The boundary conditions of the parametric study simulations were set with the same conditions, including the ambient conditions, the system's fluid properties, the turbulence model, the solution type and the wind boundary profile. The following ambient conditions were attached to the solution domain:

- The turbulent model used is standard 3D RANS model with standard wall treatment.
- The gravitational in the normal value of (9.81 m/s^2) and the normal direction (-Y).
- Ambient temperature of 32.5^{o}c in July (according to the nearest weather station).
- The fluid was set for air at constant density at (1.19 kg/m3) and viscosity at (1.79e-05kg/m-s).
- The operating pressure conditions of the domain were kept at 101325Pa.
- The dimensions of the solution domain are (642 x 532 x 100 m).
- The boundary types used are; velocity inlet, interface, non-slip walls, and outflow boundaries (Franke et al., 2010). The upstream boundary was set at 'velocity inlet'. the ABL profile was imposed calculated by the logarithmic profile for a given terrain roughness according to Reynolds numbers. Free wind after correction flowing from the north west direction of (incident angle = 22 degrees).

7.4.2.1 Scenario 1 (CFD) simulation setup

Scenario 1 shows quantifying the effects of creating cross ventilation through the connection of internal spaces, through the restoration of the existing transom windows within the detailed floor plan according to the apartment's separation, and reverting modifications applied by the occupants. The transom windows were located above the internal doors between the outer spaces (S1) and the internal living spaces (S2), with a height 2.6 m above the floor plan and a height of 0.6m. The 3D model was modified according to the tested parameter. The solution geometry was simplified while attaining a high level of accuracy, Figure 7-5. Solution domain was kept the same and meshed with the same values specified in Table 7-4 showing the domain and mesh details. Finally, the simulation was calculated and converged in 892 iterations approximately 7 hours.

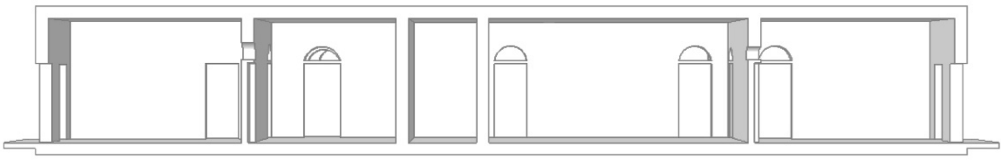


Figure 7-5 scenario 1 3D model opening transom windows

Table 7-4 scenario 1 domain and mesh information

Domain zone	Domain extent (m) x	y	z	Total volume (m^3)	Fluid volume (m^3)	Blockage %	Type of cells	No. of cells
Total	643	532	100	$3.42E^{+7}$	$3.32E^{+7}$	3.1	HEX	1,174,269

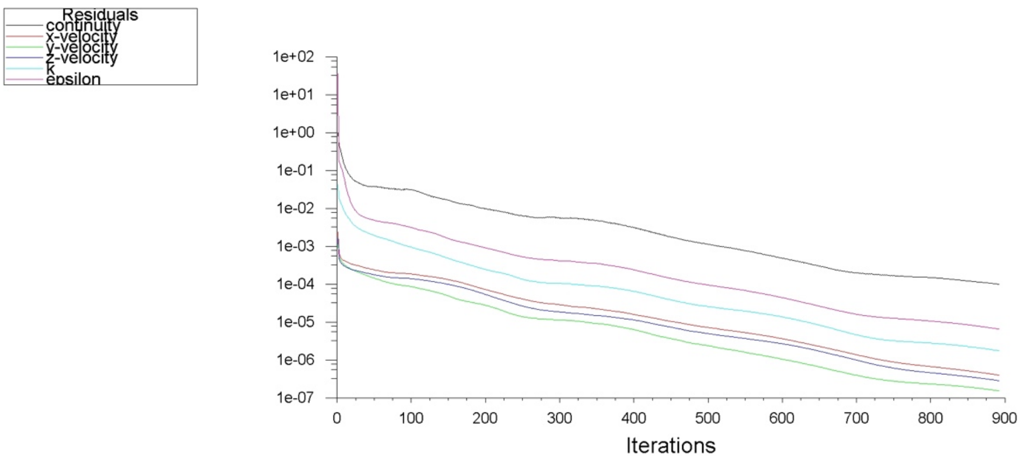


Figure 7-6 scenario 1 simulation convergence plot, source: the research

7.4.2.2 Scenario 2 (CFD) simulation setup

Scenario 2 quantifies the effects of increasing opening size using different opening types parameters, using single hung casement upper window and the opening of the existing internal transom windows. The existing window type is composed of a double hinged window opening with a height of 1.65 m with a fixed upper window with a height of 0.7 m as demonstrated in chapter 5. The 3D model was modified according to the tested parameter, Figure 7-9. Solution domain was kept the same and meshed with values specified in Table 7-5, showing the domain and mesh details. The simulation converged in 884 iterations approximately 7 hours.

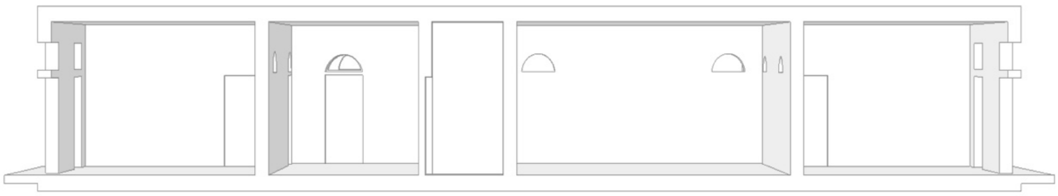


Figure 7-7 Scenario 2 3D model single hung casement upper window

Table 7-5 Scenario 2 domain and mesh information

Domain zone	Domain extent (m) x	y	z	Total volume (m^3)	Fluid volume (m^3)	Blockage %	Type of cells	No. of cells
Total	643	532	100	3.42E^{+7}	3.36E^{+7}	3.1	HEX	1,689,885

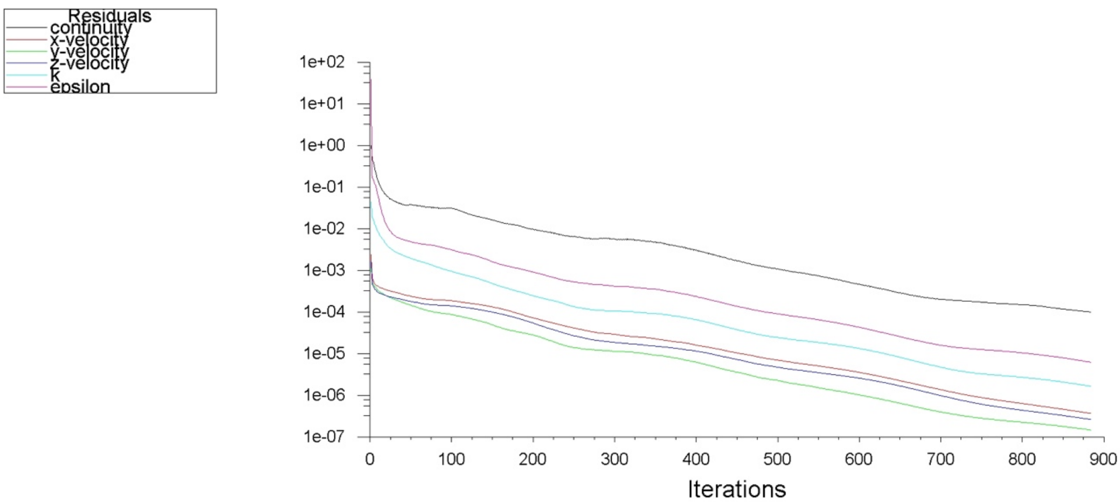


Figure 7-8 scenario 2 simulation convergence plot, source: the research

7.4.2.3 Scenario 3 (CFD) simulation setup

Scenario 3 quantifies the effects of increasing opening size using different opening types parameters, using operable top hung casement upper window and the opening of the existing internal transom windows. The existing window type is composed of a double hinged window opening with a height of 1.65 m with a fixed upper window with a height of 0.7 m as demonstrated in chapter 5. The 3D model was modified according to the tested parameter. The solution geometry was simplified while attaining a high level of accuracy, Figure 7-9. Solution domain was kept the same and meshed with the same values specified, Table 7-6 showing the domain and mesh details. The simulation converged in 886 iterations approximately 7 hours.

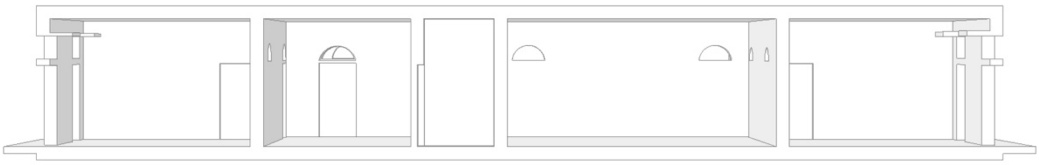


Figure 7-9 Scenario 3 3D model top hung casement upper window

Table 7-6 scenario 3 domain and mesh information

Domain zone	Domain extent (m) x	y	z	Total volume (m^3)	Fluid volume (m^3)	Blockage %	Type of cells	No. of cells
Total	643	532	100	$3.42E^{+7}$	$3.36E^{+7}$	3.1	HEX	1,753,665

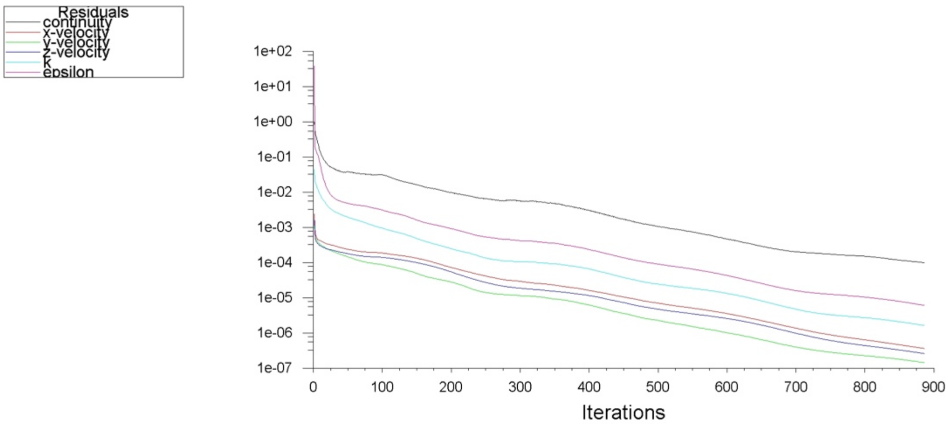


Figure 7-10 scenario 3 simulation convergence plot, source: the research

7.4.2.4 Scenario 4 (CFD) simulation setup

Scenario 4 quantifies the effects of roof additions on the inner court of the case study building using a mono pitch roof with inclination angle of 15^0, and in the case of this scenario placing the openings in the leeward side. The openings area was set equal to the area of the floor openings 24 m^2 as demonstrated in chapter 5 analysing the case study building's features. The 3D model was modified with simplified, Figure 7-11. Solution domain was kept the same and meshed with the same values specified, Table 7-7 shows the domain and mesh details. The simulation converged in 841 iterations approximately 7 hours.

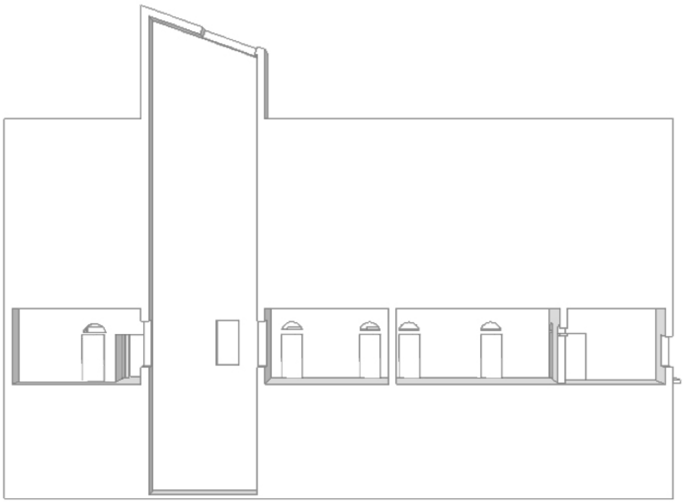


Figure 7-11 scenario 4 3D model for the mono pitch roof addition with openings on the leeward side

Table 7-7 scenario 4 domain and mesh information

Domain zone	Domain extent (m)			Total volume (m^3)	Fluid volume (m^3)	Blockage %	Type of cells	No. of cells
	x	y	z					
Total	643	532	100	$3.42E^{+7}$	$3.36E^{+7}$	3.1	HEX	1,705,177

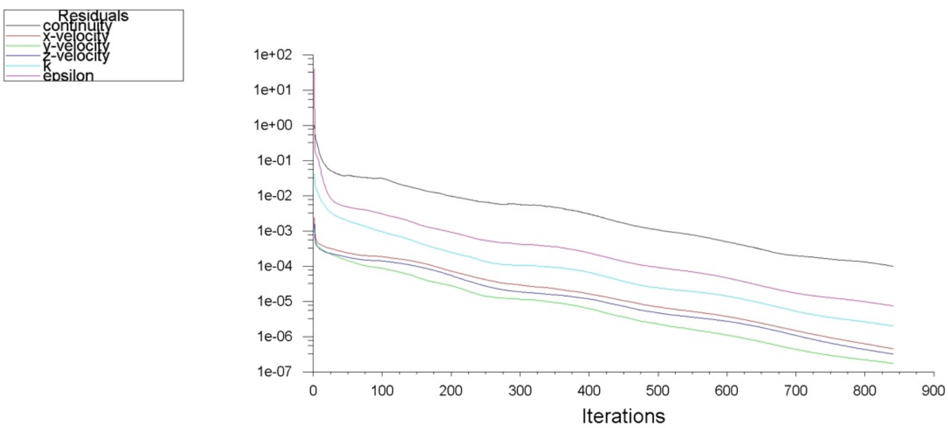


Figure 7-12 scenario 4 simulation convergence plot, source: the research

7.4.2.5 Scenario 5 (CFD) simulation setup

Scenario 5 quantifies the effects of roof additions on the inner court of the case study building using a mono pitch roof with inclination angle of 15^0, and in the case of this scenario placing the openings on the addition in the windward side. The openings area set was equal to the area of the floor openings 24 m^2 as demonstrated in chapter 5, analysing the case study building's features. The 3D model was modified with simplified geometry while attaining a high level of accuracy Figure 7-13. Solution domain was kept the same and meshed with the same values specified in Table 7-8. The simulation converged in 884 iterations approximately 7 hours.

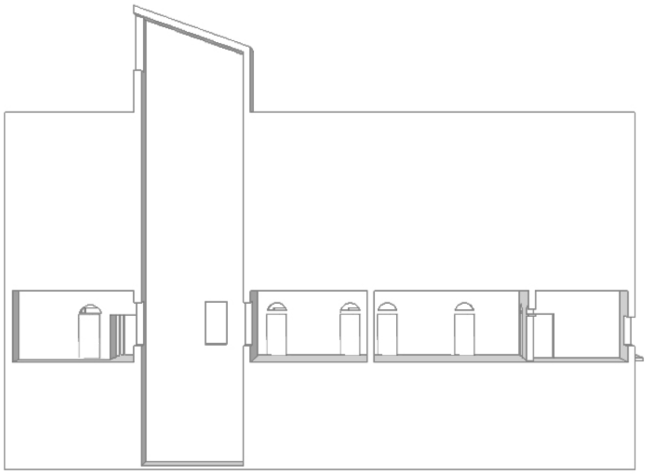


Figure 7-13 scenario 5 3D model for the mono pitch roof addition with openings on the windward side

Table 7-8 scenario 5 domain and mesh information

Domain zone	Domain extent (m)			Total volume (m^3)	Fluid volume (m^3)	Blockage %	Type of cells	No. of cells
	x	y	z					
Total	643	532	100	3.42E^{+7}	3.36E^{+7}	3.1	HEX	1,704,514

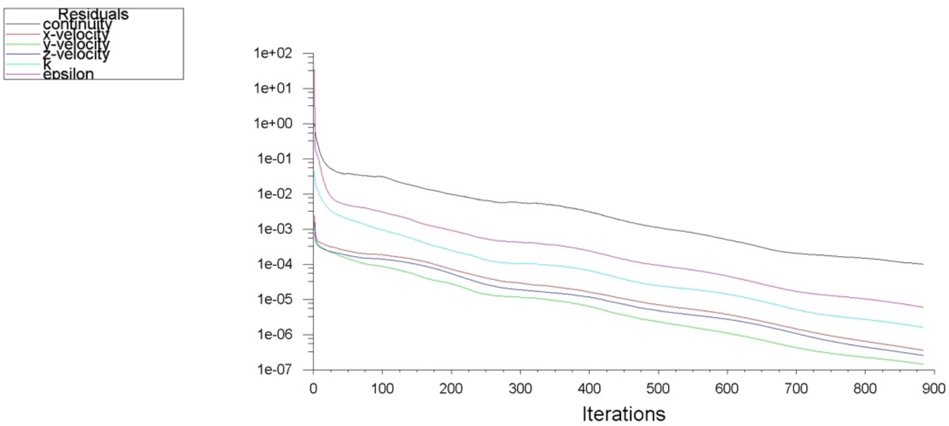


Figure 7-14 scenario 5 simulation convergence plot, source: the research

7.4.2.6 Scenario 6 (CFD) simulation setup

Scenario 6 quantifies the effects of roof additions on the inner court of the case study building using a mono pitch roof with inclination angle of 15^0, and in the case of this scenario placing the openings on the addition in the leeward and windward side. The openings area on each side was set with equal area of the floor openings 24 m^2 as demonstrated in chapter 5, analysing the case study building's features. The 3D model was modified according to Figure 7-15. Solution domain was kept the same and meshed with the same values specified, Table 7-9. The simulation converged in 864 iterations approximately 7 hours.

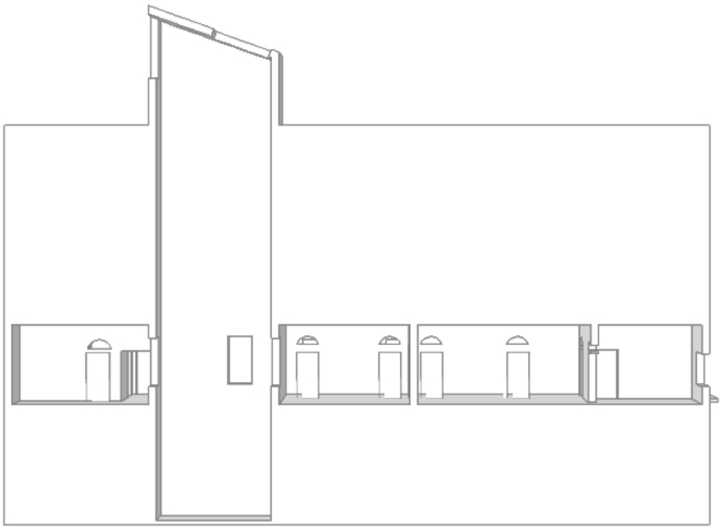


Figure 7-15 scenario 6 3D model for the mono pitch roof addition with openings on the windward and leeward side

Table 7-9 scenario 6 domain and mesh information

Domain zone	Domain extent (m)			Total volume (m^3)	Fluid volume (m^3)	Blockage %	Type of cells	No. of cells
	x	y	z					
Total	643	532	100	$3.42E^{+7}$	$3.36E^{+7}$	3.1	HEX	1,756,098

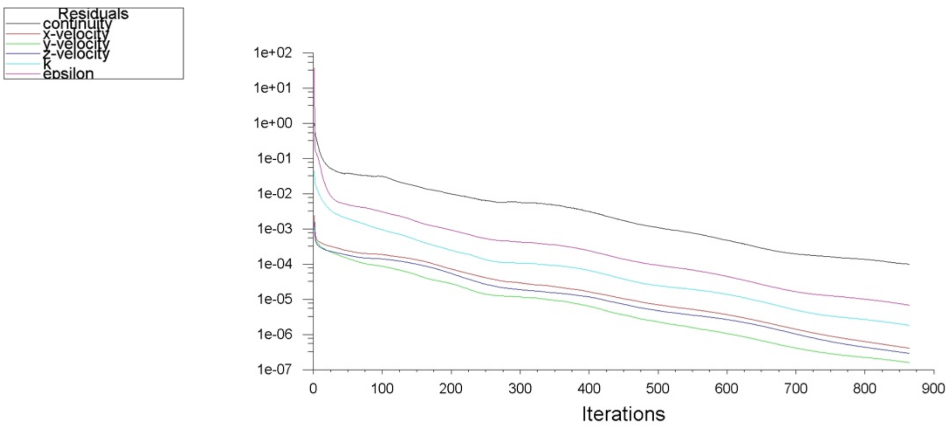


Figure 7-16 scenario 6 simulation convergence plot, source: the research

7.4.2.7 Scenario 7 (CFD) simulation model

Scenario 7 quantifies the effects of the roof addition to the inner court combined with the change in the opening type. The roof addition parameters would include a mono pitch roof with an inclination angle of 15^0 with openings on the leeward side, with an area equal to the floor openings 24 m^2. The opening type parameter would be using an operable single hung upper window, with a height of 0.7 m above the exiting operable windows increasing the area of the inlet. The 3D model was modified, Figure 7-17. Solution domain was kept the same and meshed with the same values specified in Table 7-10 showing the domain and mesh details. The simulation converged in 844 iterations approximately 7 hours.

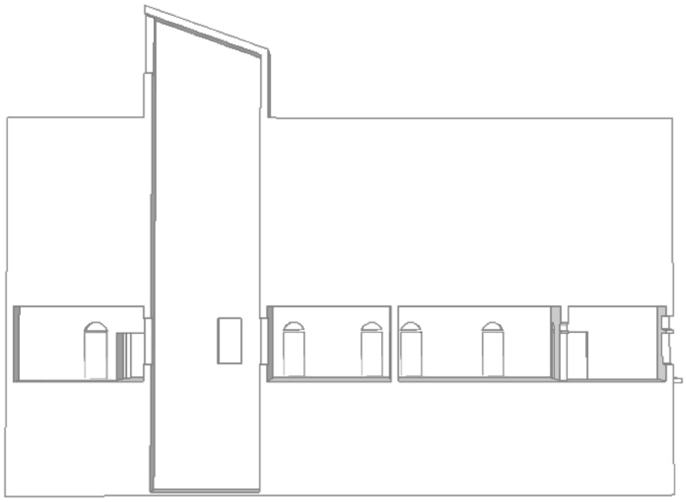


Figure 7-17 scenario 7 3D model for the mono pitch roof addition with openings on the leeward side and operable single hung upper window

Table 7-10 scenario 7 domain and mesh information

Domain zone	Domain extent (m)			Total volume (m^3)	Fluid volume (m^3)	Blockage %	Type of cells	No. of cells
	x	y	z					
Total	643	532	100	$3.42E^{+7}$	$3.36E^{+7}$	3.1	HEX	1,910,858

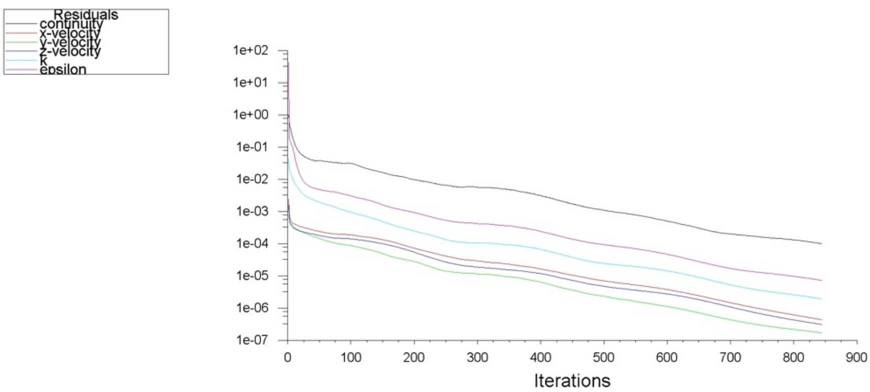


Figure 7-18 scenario 7 simulation convergence plot, source: the research

7.4.2.8 Scenario 8 (CFD) simulation model

Scenario 8 quantifies the effects of the roof addition to the inner court combined with the change in the opening type. The roof addition parameters would include a mono pitch roof with an inclination angle of 15^0 with openings on the windward side, with an area equal to the floor openings 24 m^2. The opening type parameter would be using an operable single hung upper window, with a height of 0.7 m above the exiting operable windows increasing the area of the inlet. The 3D model was modified according to the tested parameter, the solution geometry was simplified while attaining a high level of accuracy, Figure 7-19. Solution domain was kept the same and meshed with the same values specified, Table 7-11. The simulation converged in 884 iterations approximately 7 hours.

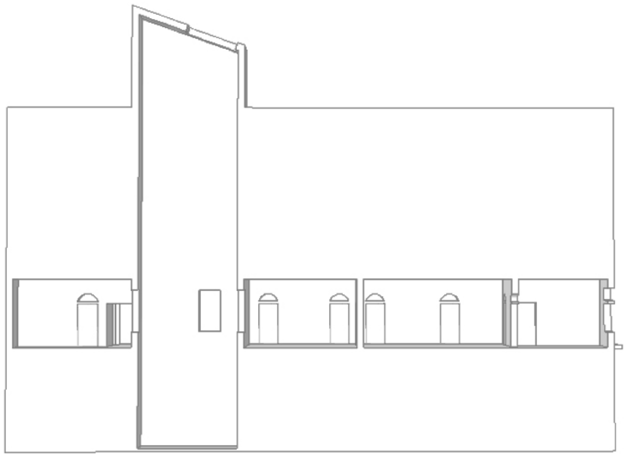


Figure 7-19 scenario 8 3D model for the mono pitch roof addition with openings on the windward side and operable single hung upper window

Table 7-11 scenario 8 domain and mesh information

Domain zone	Domain extent (m)			Total volume (m^3)	Fluid volume (m^3)	Blockage %	Type of cells	No. of cells
	x	y	z					
Total	643	532	100	$3.42E^{+7}$	$3.36E^{+7}$	3.1	HEX	1,914,823

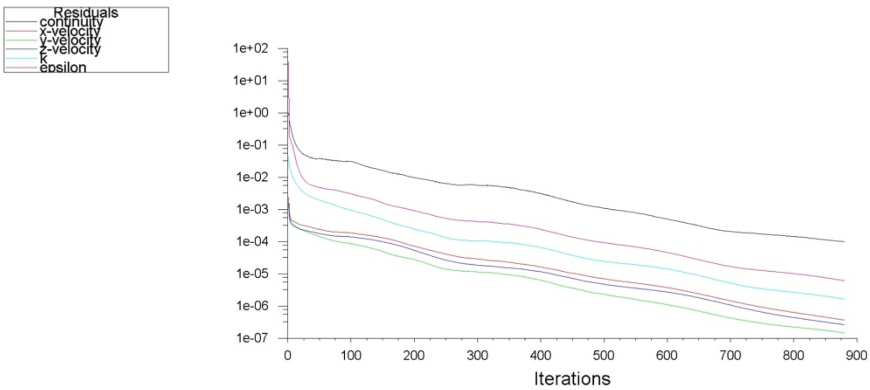


Figure 7-20 scenario 8 simulation convergence plot, source: the research

7.4.2.9 Scenario 9 (CFD) simulation model

Scenario 9 quantifies the effects of the roof addition to the inner court combined with the change in the opening type. The roof addition parameters would include a mono pitch roof with an inclination angle of 15^0 with openings on the leeward and windward side, with an area equal to the floor openings 24 m^2 set for both. The opening type parameter would be using an operable single hung upper window, with a height of 0.7 m above the exiting operable windows increasing the area of the inlet. The 3D model was modified, Figure 7-21. Solution domain was kept the same and meshed with the same values specified in Table 7-12. The simulation converged in 884 iterations approximately 7 hours.

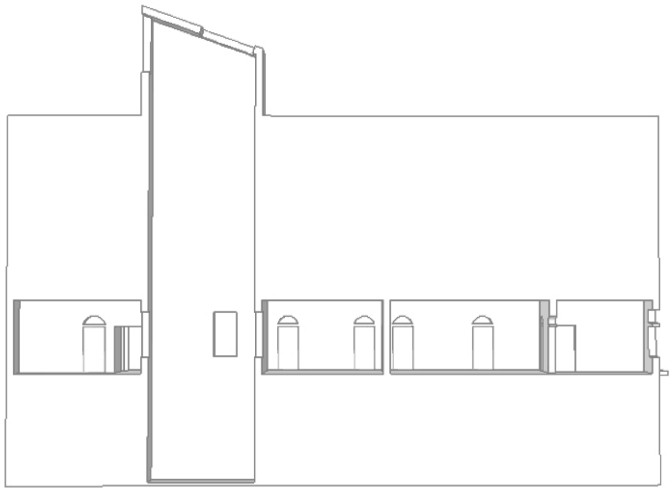


Figure 7-21 scenario 9 3D model for the mono pitch roof addition with openings on the windward and leeward side and operable single hung upper window.

Table 7-12 scenario 9 domain and mesh information

Domain zone	Domain extent (m)			Total volume (m^3)	Fluid volume (m^3)	Blockage %	Type of cells	No. of cells
	x	y	z					
Total	643	532	100	$3.42E^{+7}$	$3.36E^{+7}$	3.1	HEX	1,963,349

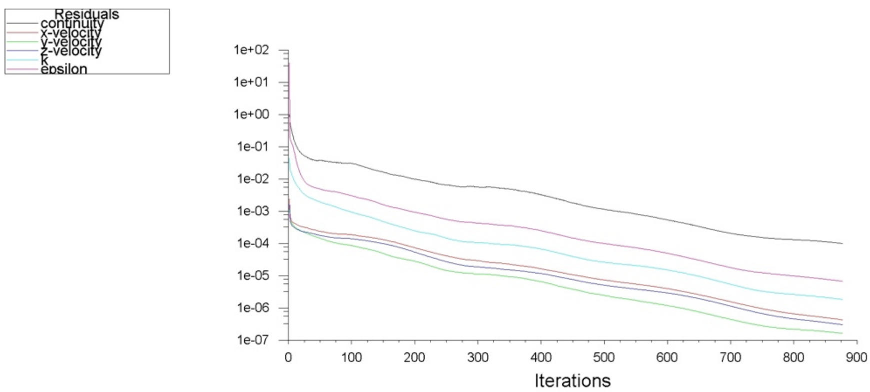


Figure 7-22 scenario 9 simulation convergence plot, source: the research

7.4.2.10 Scenario 10 (CFD) simulation model

Scenario 10 quantifies the effects of the roof addition to the inner court combined with the change in the opening type. The roof addition parameters would include a mono pitch roof with an inclination angle of 15^0 with openings on the leeward side, with an area equal to the floor openings 24 m^2. The opening type parameter would be using an operable top hung upper window, with a height of 0.7 m above the exiting operable windows with casement horizontal projection increasing the area of the inlet and directing the airflow. The 3D model was modified Figure 7-23. Solution domain values specified in Table 7-13. The simulation converged in 884 iterations approximately 7 hours.

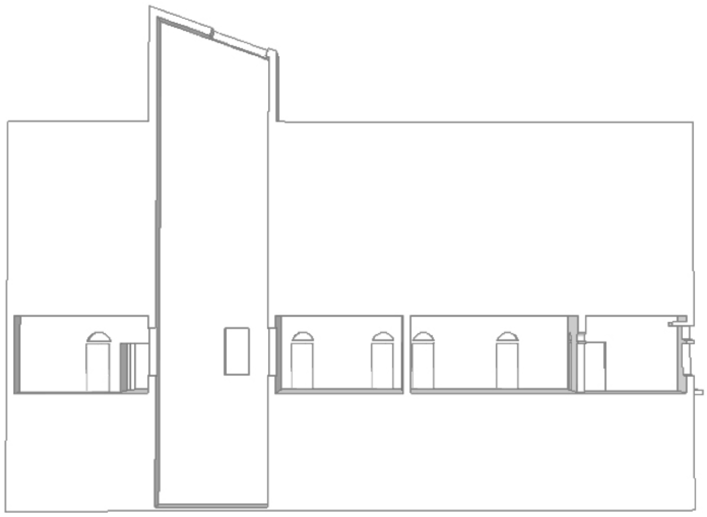


Figure 7-23 scenario 10 3D model for the mono pitch roof addition with openings on the leeward side and operable top hung upper window.

Table 7-13 scenario 3domain and mesh information

Domain zone	Domain extent (m)			Total volume (m^3)	Fluid volume (m^3)	Blockage %	Type of cells	No. of cells
	x	y	z					
Total	643	532	100	$3.42E^{+7}$	$3.36E^{+7}$	3.1	HEX	1,950,896

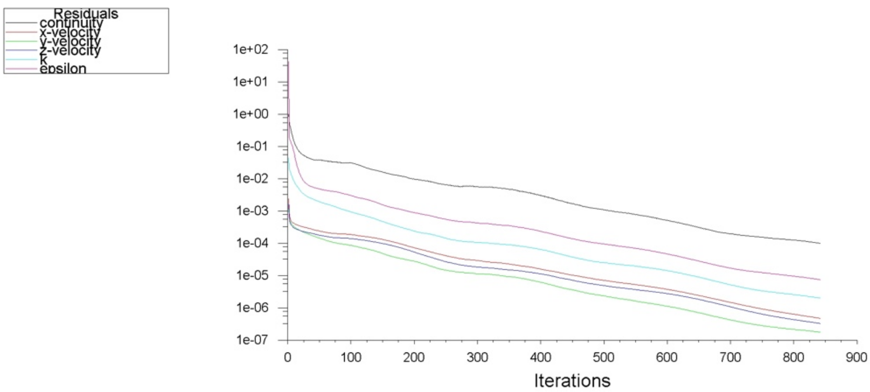


Figure 7-24 scenario 10 simulation convergence plot, source: the research

7.4.2.11 Scenario 11 (CFD) simulation model

Scenario 11 quantifies the effects of the roof addition to the inner court combined with the change in the opening type. The roof addition parameters would include a mono pitch roof with an inclination angle of 15^0 with openings on the windward side, with an area equal to the floor openings 24 m^2. The opening type parameter would be using an operable top hung upper window, with a height of 0.7 m above the exiting operable windows with casement horizontal projection increasing the area of the inlet and directing the airflow. The 3D model was modified Figure 7-25, solution domain was kept the same and meshed with the same values specified in Table 7-14. The simulation converged in 886 iterations approximately 7 hours.

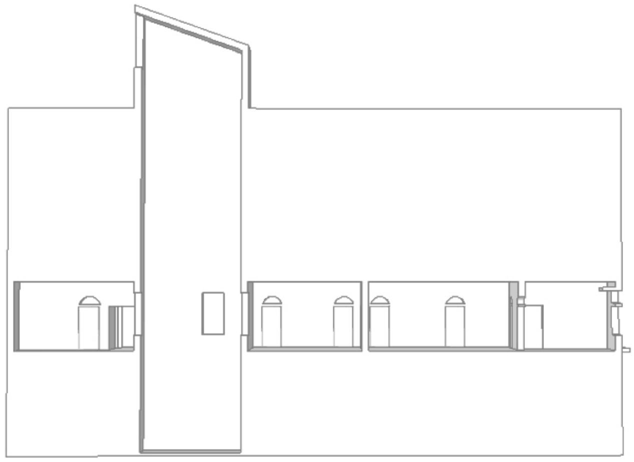


Figure 7-25 scenario 11 3D model for the mono pitch roof addition with openings on the windward side and operable top hung upper window.

Table 7-14 scenario 11 domain and mesh information

Domain zone	Domain extent (m)			Total volume (m^3)	Fluid volume (m^3)	Blockage %	Type of cells	No. of cells
	x	y	z					
Total	643	532	100	$3.42E^{+7}$	$3.36E^{+7}$	3.1	HEX	1,952,492

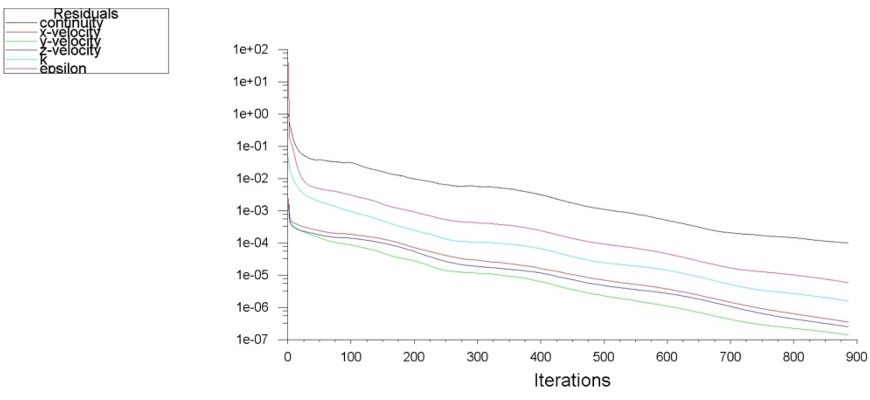


Figure 7-26 scenario 11 simulation convergence plot, source: the research

7.4.2.12 Scenario 12 (CFD) simulation model

Scenario 12 quantifies the effects of the roof addition to the inner court combined with the change in the opening type. The roof addition parameters would include a mono pitch roof with an inclination angle of 15^0 with openings on the windward and leeward side, with an area equal to the floor openings 24 m^2 set for both. The opening type parameter would be using an operable top hung upper window, with a height of 0.7 m above the exiting operable windows with casement horizontal projection increasing the area of the inlet and directing the airflow. The 3D model was modified Figure 7-27,solution domain was kept the same and meshed with the same values specified in Table 7-15. The simulation converged in 884 iterations approximately 7 hours.

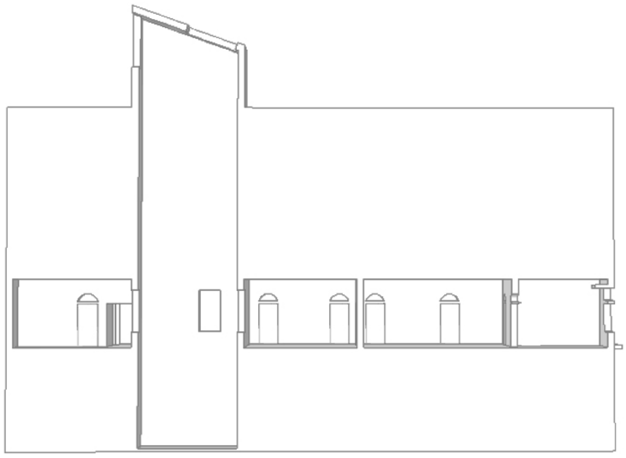


Figure 7-27 scenario 12 3D model for the mono pitch roof addition with openings on the windward and leeward side and operable top hung upper window.

Table 7-15 scenario 12 domain and mesh information

Domain zone	Domain extent (m)			Total volume (m^3)	Fluid volume (m^3)	Blockage %	Type of cells	No. of cells
	x	y	z					
Total	643	532	100	$3.42E^{+7}$	$3.36E^{+7}$	3.1	HEX	2,003,246

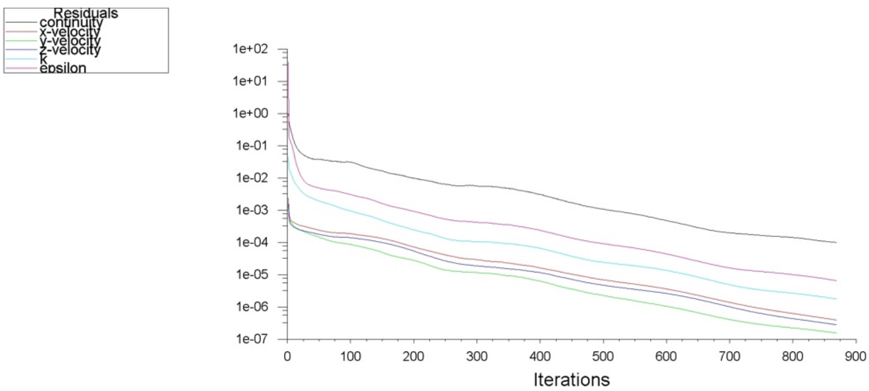


Figure 7-28 scenario 12 simulation convergence plot, source: the research

7.5 Conclusion

This chapter introduced the parametrical approach method for the case study building, the selection of the natural ventilation passive systems according to their effect on the building's performance and the heritage nature of the building. The selection criteria were based on the case study building's heritage listing which was found as grade c local level classification.

The proposed computational parametric study was based according to the selected measures; façade opening design; roof shape and connected internal spaces, compromised in 12 testing scenarios in three consecutive levels testing the performance of the selected measures separately and combined. For each of these scenarios CFD simulations were performed according to the established best practice to insure the validity of the simulations. The results of the computational parametric simulation are demonstrated in the following chapter.

Chapter 8 Results and analysis

8.1 Introduction

In this chapter, the results of the parametrical study of simulated scenarios of the selected retrofitting measures are presented in order to test their impact to enhance natural ventilation performance in the selected case study building. The results are analysed and discussed according to the airflow magnitude and patterns within the established internal spaces categorization of the detailed floor plan established in chapter 5 and contrasted with the actual building's performance as determined in chapter 6. The performance of each level of the parametrical analysis is discussed in order to deduce the overall impact of the proposed scenarios,Table 8-1.

Table 8-1 simulation scenarios sequence schedule

Level	Scenario	Description
Level 1	(1)	The restoration of the existing transom windows according to the separation of the apartments
Level 2	(2)	single hung casement upper window + Opening transom windows
	(3)	top hung casement upper window + Opening transom windows
	(4)	mono pitch roof with openings in leeward side + Opening transom windows
	(5)	mono pitch roof with openings in windward side + Opening transom windows
	(6)	mono pitch roof with openings in leeward and windward side + Opening transom windows
Level 3	(7)	single hung casement upper window + mono pitch roof with openings in leeward side + Opening transom windows
	(8)	single hung casement upper window + mono pitch roof with openings in windward side + Opening transom windows
	(9)	single hung casement upper window + mono pitch roof with openings in leeward and windward side + Opening transom windows
	(10)	top hung casement upper window + mono pitch roof with openings in leeward side + Opening transom windows
	(11)	top hung casement upper window + mono pitch roof with openings in windward side + Opening transom windows
	(12)	top hung casement upper window + mono pitch roof with openings in leeward and windward side + Opening transom windows

8.2 Level 1 results

The first level of the parametric analysis is composed of one scenario that comprises the effects of connecting the internal spaces through the restoration of internal transom windows within the detailed floor plan according to the apartments' separation. The model setup of this level scenario would be set as the base case of the further simulations to be undertaken.

8.2.1 Scenario 1 results

In general, the restoration of transom windows above the internal doors improved the average internal airflow patterns and magnitude throughout the different spaces. Figure 8-1 and Figure 8-2 illustrate the difference to airflow shown in the detailed floor plan. The S1, S2 and the inner court are more spatially connected allowing airflow to circulate within the internal spaces with a higher magnitude, as a result of the spaces connectivity.

The S1 spaces perform better than the actual performance case due to their direct relation with the external environment and the connection with the internal zones in the monitored typical floor resulting in the maximizing of the average internal speed due to the increase of the pressure difference. Meanwhile, the S2 spaces which are considered the main living spaces inside the building are more ventilated from the outer S1 spaces. The air flow patterns increased with a maximum internal airspeed reaching to 0.54 m/s against 0.08 m/s.

Different cross-ventilation patterns were created as a result of the transom windows opening S1 (8), S1(10) as an inlet connected with S1 (2), and S1 (3) as an outlet passing through the S2 (1) room with a connection to the inner shaft. This cross-ventilation pattern increased the internal airflow magnitude within all the spaces, with an increase of the inner S2 space from 0.16 m/s to 0.54 m/s when compared with the actual performance. Another cross-ventilation pattern was created between S1(9), S1(11), and S1(13) rooms acting as an inlet passing through the internal S2 rooms S2(2), S2(4), and S2(3) to the S1 rooms S1(6), S1(5) and S1(4) and inner shafts acting as an outlet, increasing the internal speeds of the inner spaces. The final cross-ventilation pattern was shown between the S1 (14), S1 (16) rooms overlooking Sizostris street and S1 (15) and S1(17) overlooking the small alley acting as an inlet passing through the inner space S2(6) and the inner shaft acts as the pressure outlet.

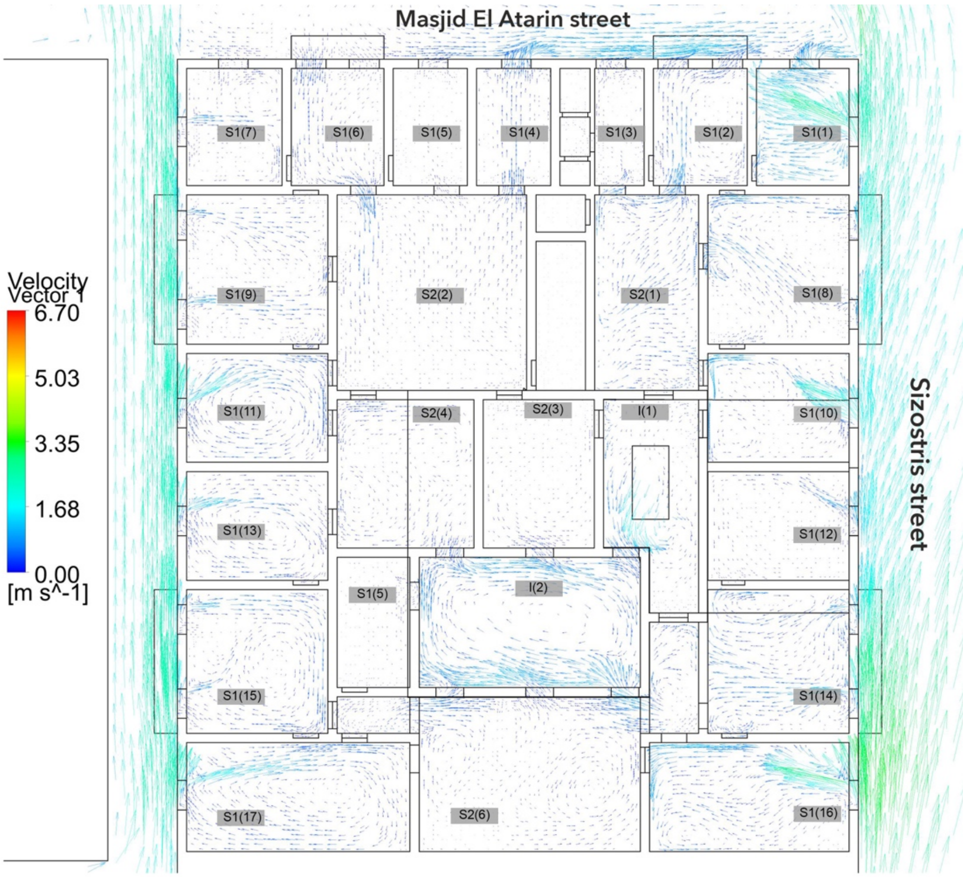


Figure 8-1 the airflow pattern inside the detailed floor scenario 1

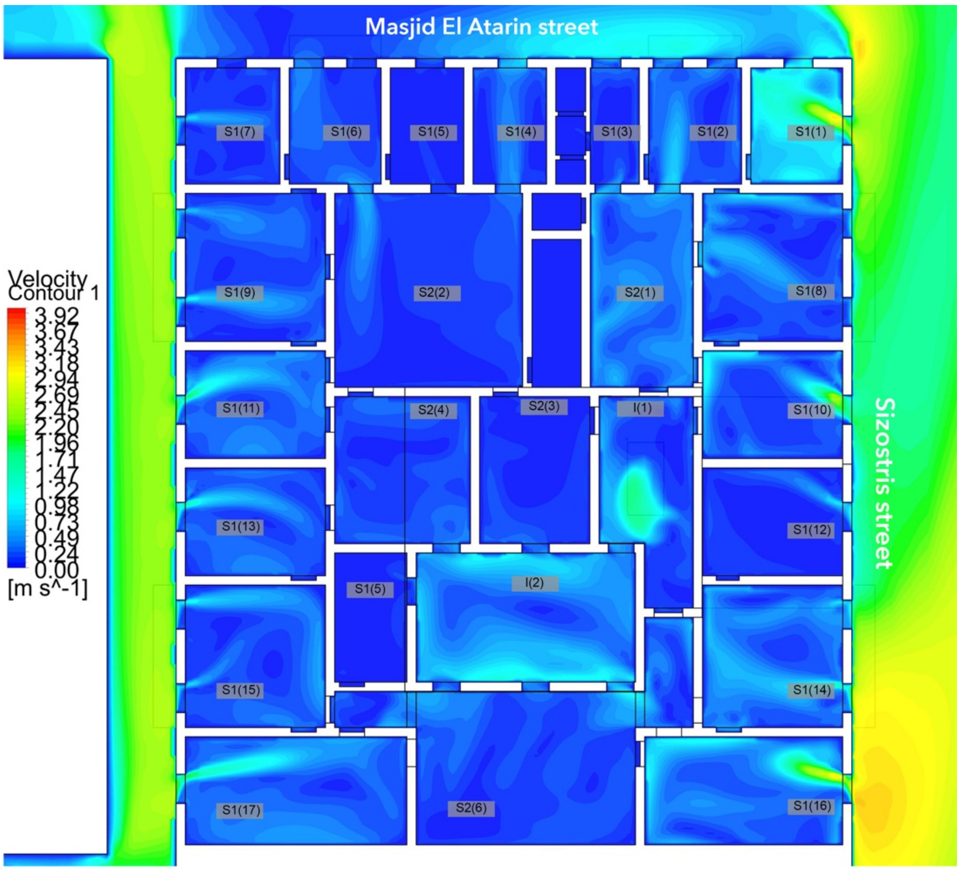


Figure 8-2 the airflow speed profile of the detailed floor scenario 1

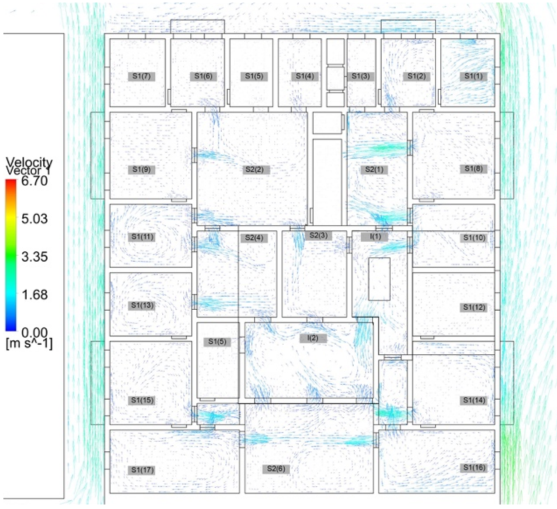


Figure 8-3 the airflow pattern inside the detailed floor scenario 1 at height 8.6 m

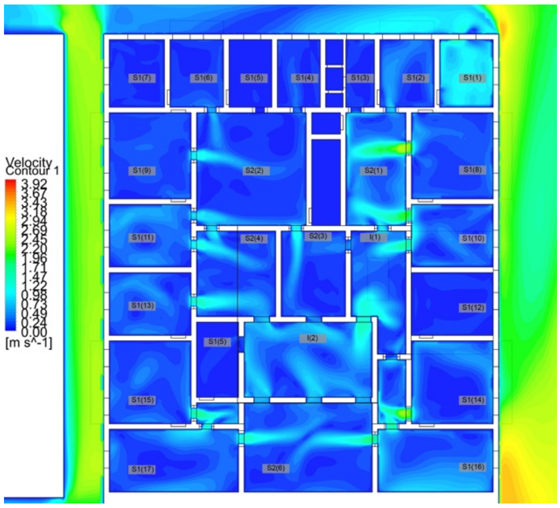


Figure 8-4 the airflow speed profile of the detailed floor scenario 1 at height 8.6 m

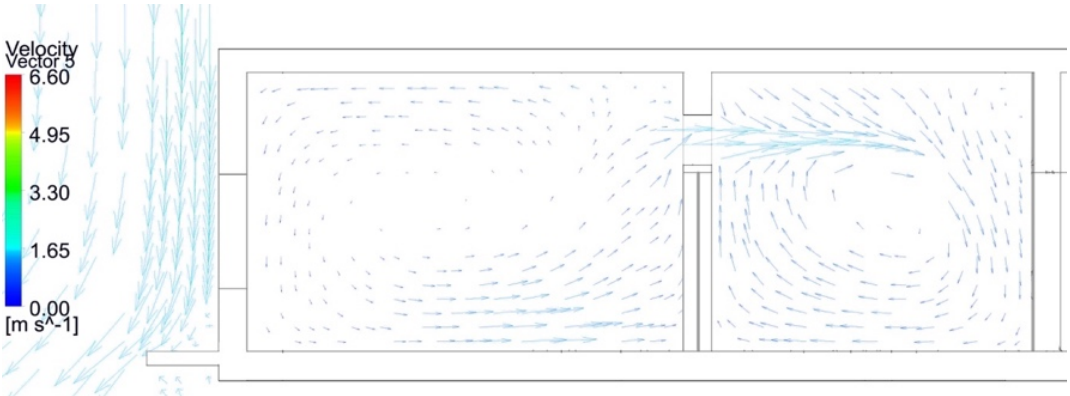


Figure 8-5 the airflow patterns as a result of connecting the S1 and S2 spaces

Table 8-2 internal airspeed inside the detailed floor plan spaces

Zone		Inlet airspeed (m/s)	Internal airspeed (m/s)		Average airspeed (m/s)
			max	min	
S1	1	2.1	1.2	0.94	1.42
	2	0.74	0.44	0.21	0.48
	3	0.42	0.35	0.30	0.36
	4	0.61	0.52	0.38	0.49
	5	0.48	0.23	0.12	0.29
	6	0.36	0.42	0.14	0.30
	7	0.51	0.43	0.16	0.36
	8	0.55	0.55	0.23	0.44
	9	0.66	0.26	0.20	0.38
	10	2.08	0.66	0.26	1.00
	11	0.42	0.34	0.31	0.36
	12	0.46	0.16	0.13	0.25
	13	0.31	0.25	0.23	0.26
	14	0.53	1.12	0.42	0.69
	15	0.81	0.47	0.30	0.51
	16	0.90	1.91	0.55	1.12
	17	0.34	0.38	0.26	0.33
S2	1	-	0.70	0.53	0.62
	2	-	0.59	0.26	0.43
	3	-	0.20	0.10	0.16
	4	-	0.33	0.26	0.33
	5	-	0.07	0.05	0.07
	6	-	0.51	0.36	0.44
I	1	-	1.09	0.59	0.85
	2	-	0.81	0.23	0.53

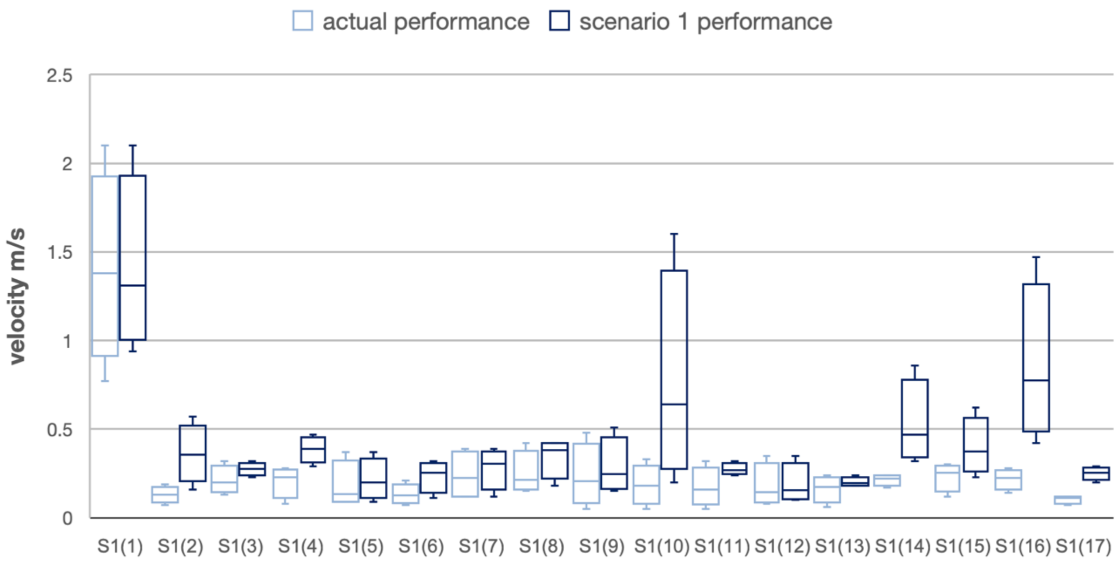


Figure 8-6 average velocity m/s for the S1 spaces

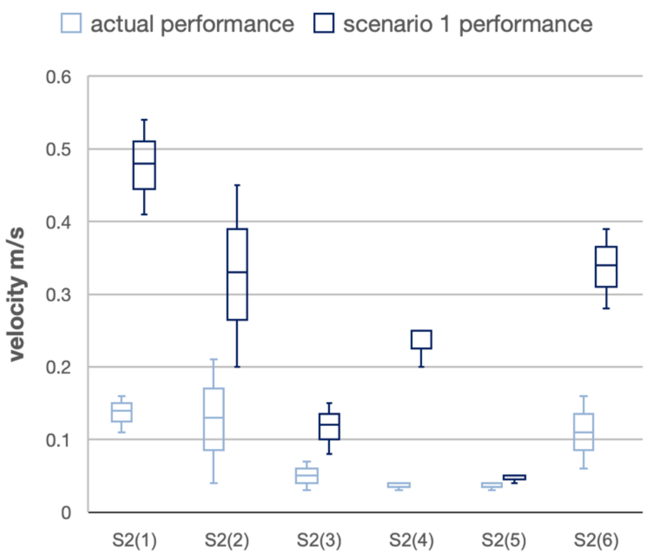


Figure 8-7 average velocity m/s for the S2 inner living spaces

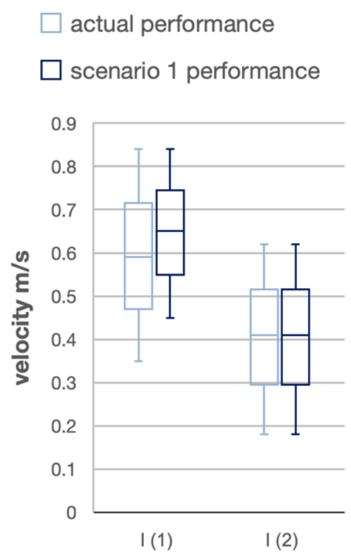


Figure 8-8 average velocity m/s for the Inner shafts' spaces

Table 8-2 illustrates the different internal airflow magnitude within the different space and compared to the actual current performance of the case study building in Figure 76 showing a general increase in magnitude in all the spaces specially in the S2 zones, and an average increase of the internal magnitude within the whole floor from 0.19 m/s to 0.54 m/s.

8.2.2 Parametric study Level 1 results

According to the depth map of the internal space's categorization and the monitoring points previously demonstrated in this chapter, the different spaces in the detailed floor plan were analysed according to their categorization and the different patterns of the airflow. In the detailed floor plan as mentioned, the S1 spaces are the main source of airflow inside the internal spaces.

The S1 spaces overlooking Sizostris street's airflow patterns and magnitude are as follows; the S1(1) and S1(7) room stayed with the same patterns and magnitude due to the unavailable transom window connection. The S1(8) has increased the average airflow to 0.34 m/s and the inlet airspeed increased from 0.25 m/s to 0.44 m/s. The S1(10) average internal airflow increased from 0.19 m/s to 1.0 m/s with air enters with a magnitude of 2.1 m/s. The same features are adapted by S1(12) room average internal airflow increased to 0.25 m/s with air enters with a magnitude of 0.45 m/s. The S1(14) room average internal airspeed increased from 0.21 m/s to 0.69 m/s with an inlet magnitude of 0.53 m/s. The S1(16) room with the deeper layout average internal airspeed increased from 0.22 m/s to 1.12 m/s with an inlet magnitude of 0.89 m/s.

The S1 spaces of the SW façade (overlooking Masjid El Atarin street) airflow patterns and magnitude are as follows; S1(2) space average internal airspeed increased from 0.09 m/s to 0.48 m/s with an inlet magnitude of 0.74 m/s. The S1(3) space average internal airspeed increased from 0.21 m/s to 0.36 m/s with an inlet magnitude of 0.41 m/s. S1(4) space average internal airspeed increased from 0.28 m/s to 0.49 m/s with an inlet magnitude of 0.61 m/s from the S2 (2) space with magnitude of 0.61 m/s. The S1(5) space average internal airspeed increased from 0.21 m/s to 0.39 m/s with an inlet magnitude of 0.48 m/s. The S1(6) space average internal airspeed increased from 0.11 m/s to 0.34m/s with an inlet magnitude of 0.36 m/s.

The S1 spaces on the SE façade (overlooking the small alley) airflow patterns and magnitude are as follows; The S1(9) room average internal airspeed increased from 0.23 m/s to 0.37 m/s with an inlet magnitude of 0.66 m/s. The S1(11) room average internal airspeed increased from 0.17 m/s to 0.37 m/s with an inlet magnitude of 0.41 m/s. The S1(13) room average internal airspeed increased from 0.16 m/s to 0.26 m/s with an inlet magnitude of 0.31 m/s. The S1(15) room average internal airspeed increased from 0.23 m/s to 0.51 m/s with an inlet magnitude of 0.81 m/s. The S1 (17) room average internal airspeed increased from 0.11 m/s to 0.33 m/s with an inlet magnitude of 0.34 m/s.

The internal spaces (S2) airflow patterns and magnitude are as follows; The S2(1) space is ventilated from the connection from the S1 (8), S1(10), S1(2) and S1(3) spaces having an average internal airflow magnitude increase from 0.14 m/s to 0.62 m/s. the S2(2) space is ventilated from the S1 (9), S1(11), S1(4) and S1(5) having an internal air speed increase from 0.13 m/s to 0.43 m/s. The S2(3) is connected to S2(2) and inner court with an average internal airflow magnitude increase from 0.05 m/s to 0.16 m/s. The S2(4) is connected to S1 (11), S1(13), S2(2) and inner court with an average internal airflow magnitude increase from 0.04 m/s to 0.32 m/s. The S2(5) is connected to the inner court with no transom windows available. Airflow magnitude almost stayed the same at 0.05 m/s. The S2(6) is connected to S2(16), S2(17) and the inner court with an average internal airflow magnitude increase from 0.11 m/s to 0.44 m/s.

The inner shafts are composed of the inner court and the staircase that are acting as a negative suction throughout the building with an average airflow magnitude increase from 0.59 to 0.84 m/s and the stair case stayed the same with a magnitude of 0.41m/s.

The overall performance of the inner spaces concerning the airflow magnitude and patterns through scenario 1 have increased specially in the S2 zones which had an almost still airflow magnitude, increasing the average airflow magnitude in the S1 zones from 0.26 m/s to 0.53 m/s, and in the S2 zones from 0.08 m/s to 0.39 m/s. The maximum airflow magnitude is seen in the S1 and S2 zones falling on Sizostris street as a result of the higher airflow magnitude coming from the street.

8.3 Parametric study level 2 results

The second level of the parametric analysis is composed of six test scenarios compromising the effects of the different retrofitting strategies as a stand-alone system, quantifying their impact on the case study building, simulating the effects of the different window types in scenario 2 and 3 and the effects of the different roof additions in scenario 4, 5, and 6. The different scenarios implemented in this level were set on the basis of the results of the first level scenario, allowing the connection of the internal spaces.

8.3.1 Scenario 2 results

The changing of the window type opening using a single hung casement upper window as illustrated in Figure 8-9, Figure 8-10, Figure 8-11, and Figure 8-12 shows the detailed floor plan airflow patterns and magnitudes on the different levels. The airflow pattern within the spaces is the same with the connected internal spaces. The main improvement noticed within the results of this scenario are in the general increase of the velocity magnitude of the naturally induced air which was allowed by the increase in the opening size of the external S1 spaces. This in return had an increasing effect of the velocity magnitude within the inner S2 living spaces within the detailed floor plan. The sections on Sizostris and Masjid el Atarin street, Figure 8-13 and Figure 8-14 show the effect of increasing the opening size on the S1 and the S2 spaces.

The S1 spaces perform better than the actual performance case due to their direct relation with the external environment with a larger area inlets and outlets in the monitored typical floor allowing the maximizing of the average internal speed due to the increase of the allowed airflow. The S2 spaces which are considered the main living spaces inside the building are more ventilated from the outer S1 spaces. The air flow patterns increased with a maximum internal airspeed reaching to 0.65 m/s against 0.21 m/s of the current building performance.

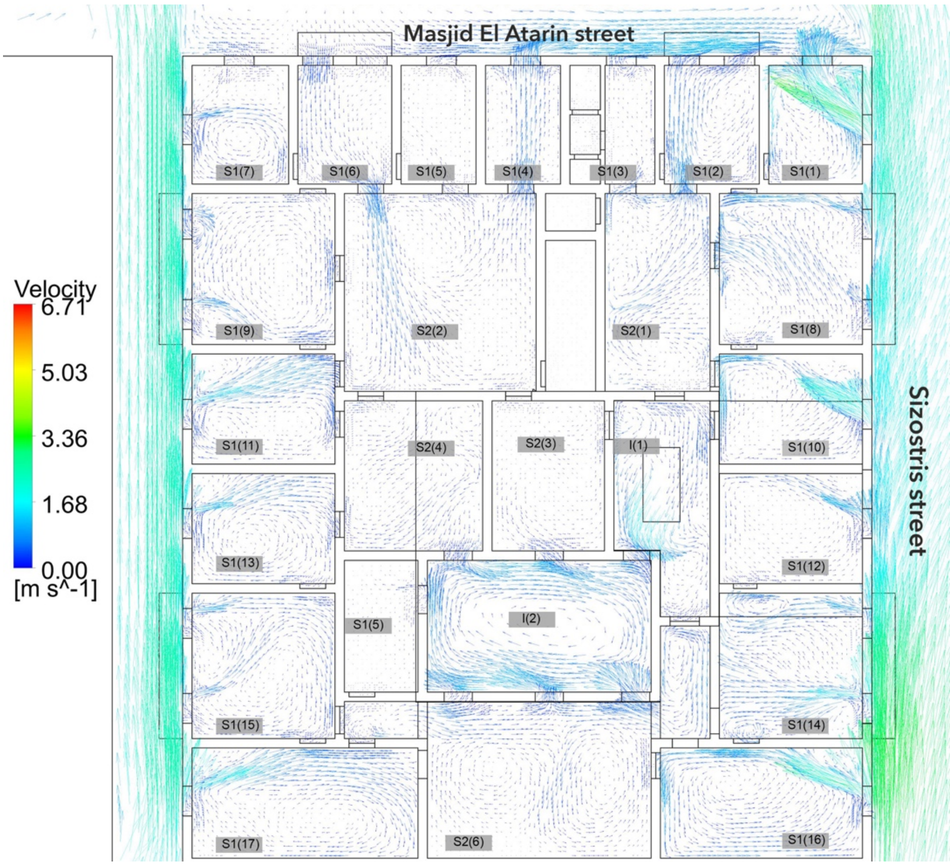


Figure 8-9 the airflow pattern inside the detailed floor scenario 2

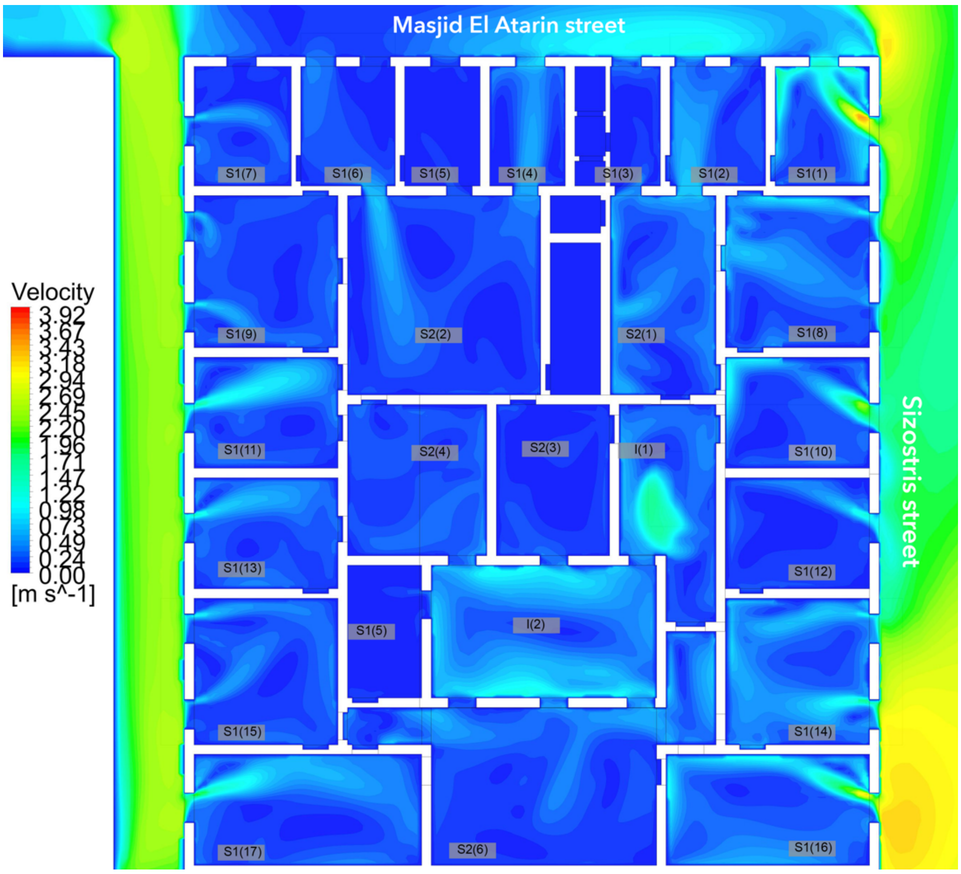


Figure 8-10 the airflow speed profile of the detailed floor scenario 2

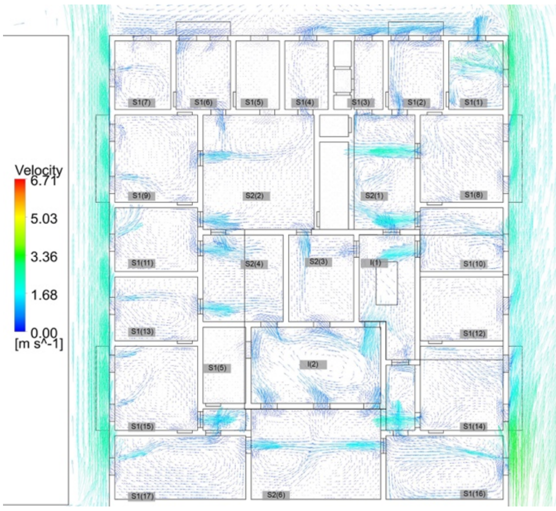


Figure 8-11 the airflow pattern inside the detailed floor scenario 2 at height 8.6 m

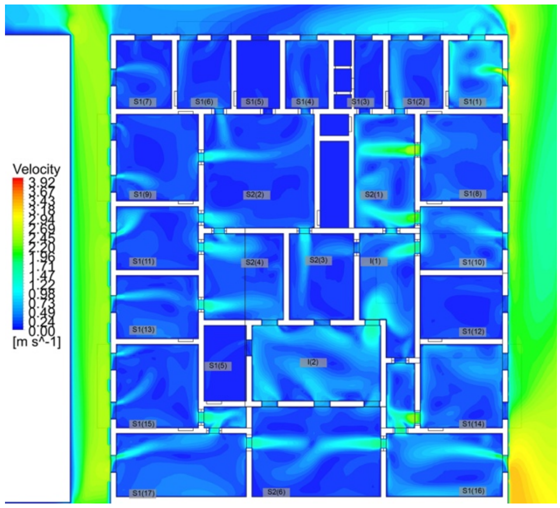


Figure 8-12 the airflow speed profile of the detailed floor scenario 2 at height 8.6 m

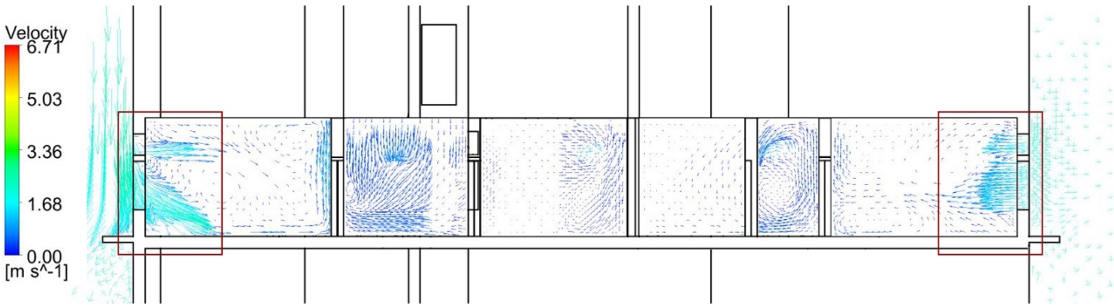


Figure 8-13 the airflow inlet from Sizostris street and the small alley showing the increase of the airflow magnitude

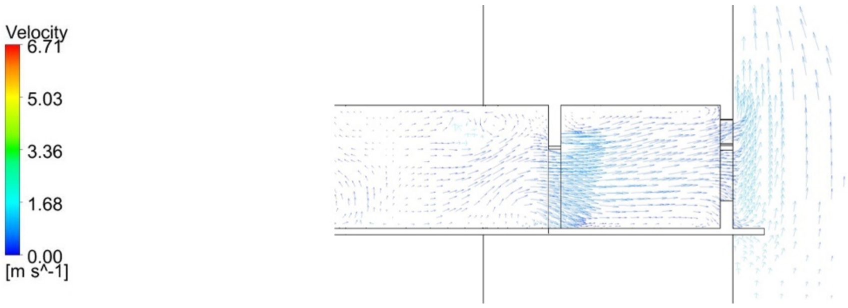


Figure 8-14 the airflow outlet on Msjid el Atarin street street the increase of the airflow magnitude

Table 8-3 internal airspeed inside the detailed floor plan spaces

Zone		Inlet airspeed (m/s)	Internal airspeed (m/s)		Average airspeed (m/s)
			max	min	
S1	1	2.6	1.16	0.82	1.52
	2	0.94	0.81	0.47	0.73
	3	0.49	0.39	0.27	0.39
	4	0.77	0.73	0.29	0.59
	5	0.23	0.20	0.12	0.18
	6	0.57	0.42	0.29	0.30
	7	0.92	0.57	0.26	0.59
	8	0.87	0.55	0.46	0.62
	9	1.01	0.81	0.29	0.56
	10	2.83	0.94	0.70	1.00
	11	1.39	0.73	0.55	0.88
	12	1.27	0.70	0.55	0.83
	13	1.44	0.83	0.55	0.26
	14	2.03	1.14	0.87	1.34
	15	0.94	0.83	0.55	0.77
	16	3.33	1.57	1.01	1.96
	17	2.56	1.20	0.83	1.52
S2	1	-	0.85	0.55	0.70
	2	-	0.85	0.43	0.64
	3	-	0.31	0.23	0.27
	4	-	0.35	0.29	0.33
	5	-	0.10	0.09	0.10
	6	-	0.57	0.44	0.51
I	1	-	1.09	0.59	0.85
	2	-	0.81	0.23	0.53

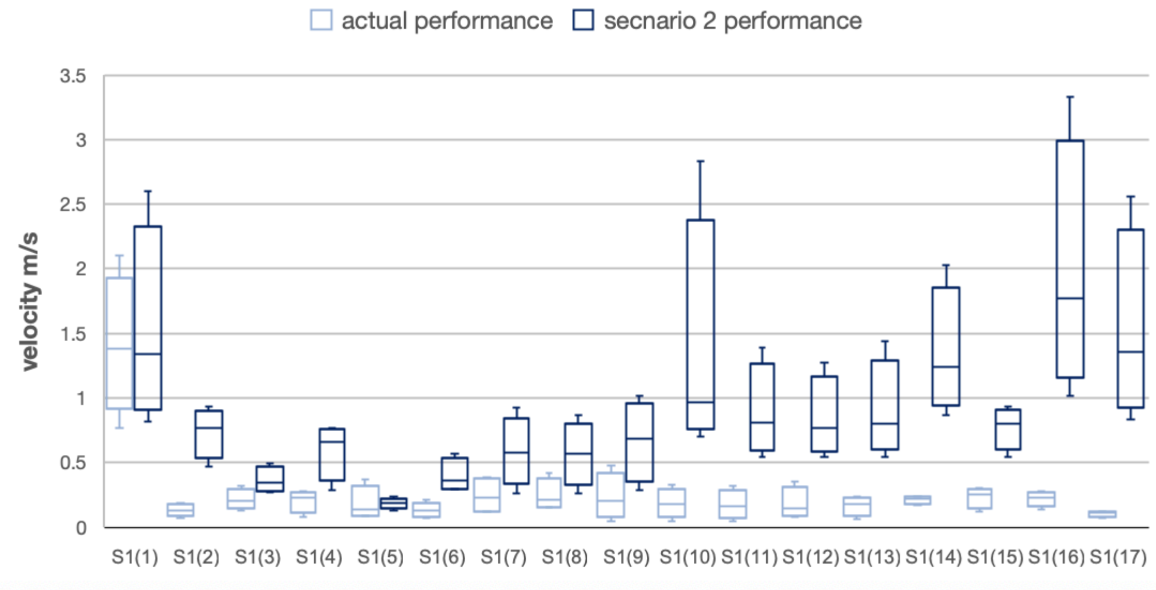


Figure 8-15 average velocity m/s for the S1 spaces

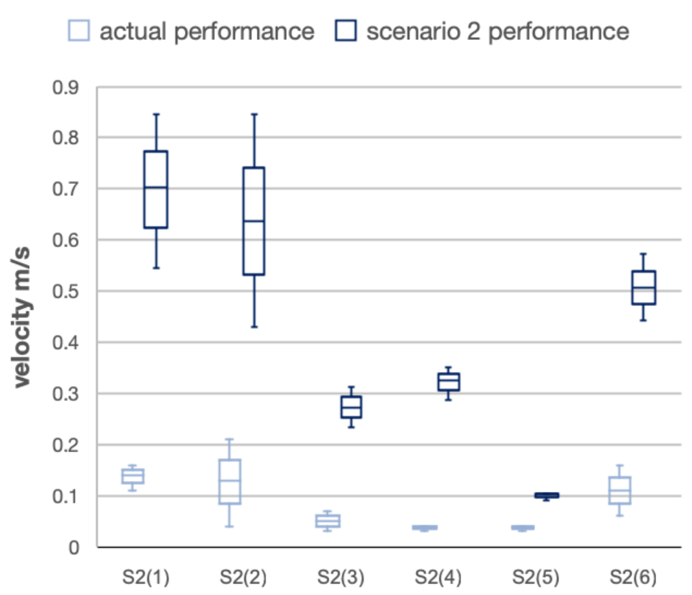


Figure 8-16 average velocity m/s for the S2 inner living spaces

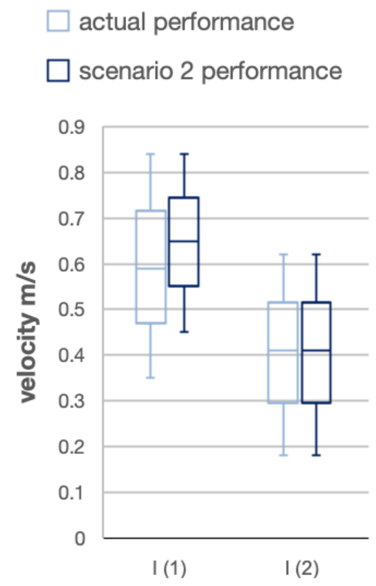


Figure 8-17 average velocity m/s for the Inner shafts' spaces

Table 8-3 illustrates the different internal airflow magnitudes within the different spaces, compared to the actual current performance of the case study building. In Figure 8-15, Figure 8-16, and Figure 8-17 a general increase in magnitude in all the spaces specially in the S2 zones, and an average increase of the internal magnitude within the S1 and S2 spaces from 0.26 m/s to 0.84 m/s and from 0.08 m/s to 0.49 m/s respectively are present.

According to the depth map of the internal space's categorization and the monitoring points previously demonstrated in this chapter the different spaces in the detailed floor plan where analyzed according to their categorization and the different patterns of airflows. In the detailed floor plan as mentioned, the S1 spaces are the main source of airflow inside the internal spaces. The S1 spaces overlooking Sizostris street and the small alley airflow magnitude have a general increase due to the increase in the surface are of the inlets, Figure 8-13. While the S1 spaces overlooking Masjid el Atarin outlet suction increased as a result of the outlet area increase, Figure 8-14.

8.3.2 Scenario 3 results

The changing of the window type opening using a single top hung casement upper window as illustrated in Figure 8-18, Figure 8-19, Figure 8-20, and Figure 8-21 of the detailed floor plan airflow patterns and magnitudes on the different levels. The airflow pattern within the spaces is the same with the connected internal spaces, the results from this scenario is quite similar to scenario 2 in terms of airflow magnitude, with the same increase in velocity magnitude against the actual performance of the case study building. However, the average increase in the velocity magnitude against the single hung upper window is slightly lower. The main difference against the single hung window is the change in the airflow pattern due to the horizontal projection of the upper window in directing the airflow within the S1 spaces. The sections on Sizostris and Masjid el Atarin street, Figure 8-22 and Figure 8-23 show the effect of airflow pattern within the S1 spaces.

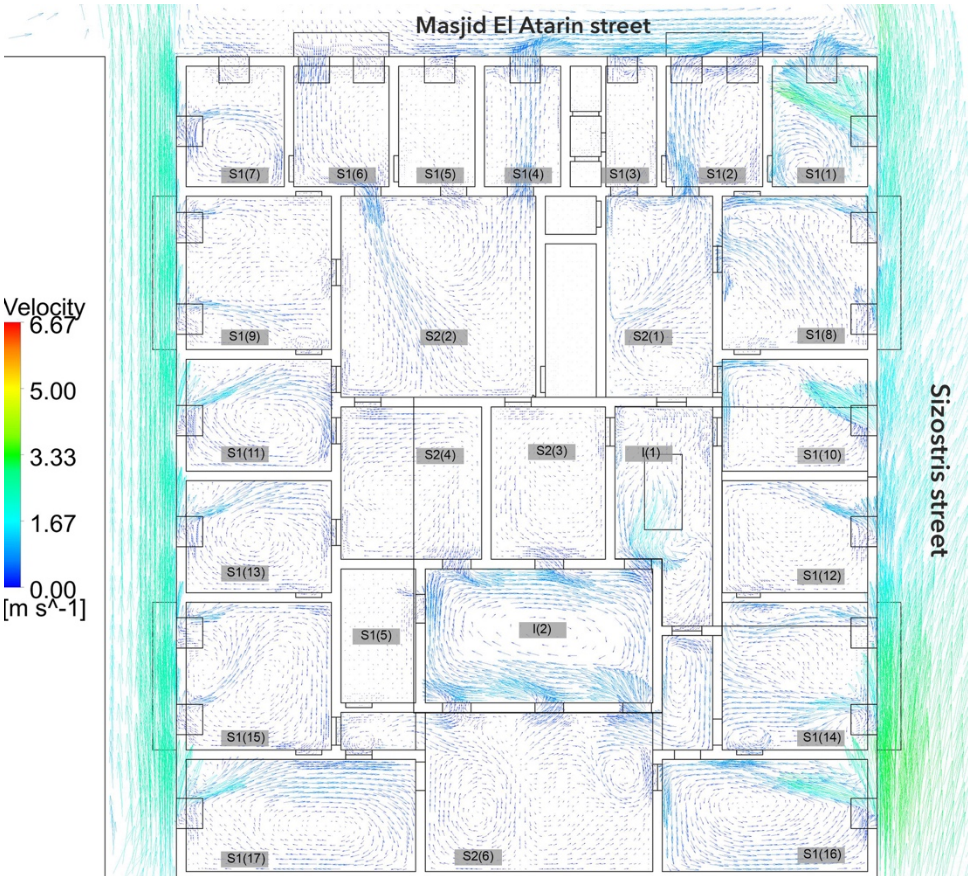


Figure 8-18 the airflow pattern inside the detailed floor scenario 3

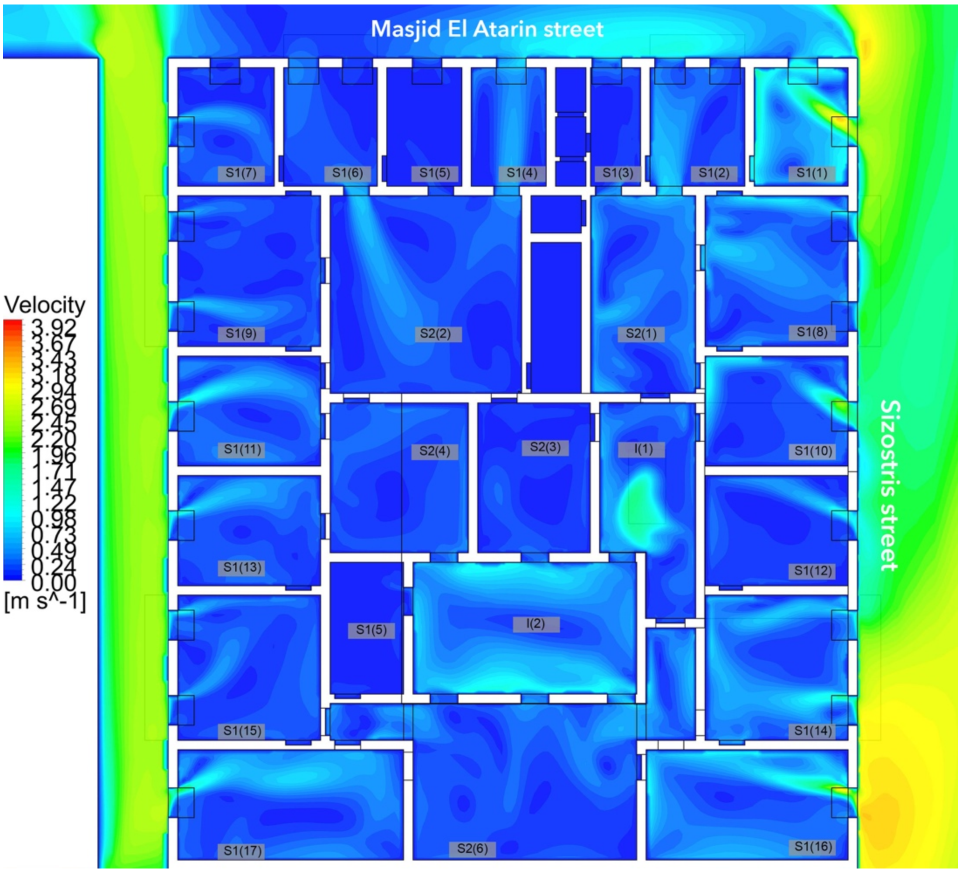


Figure 8-19 the airflow speed profile of the detailed floor scenario 3

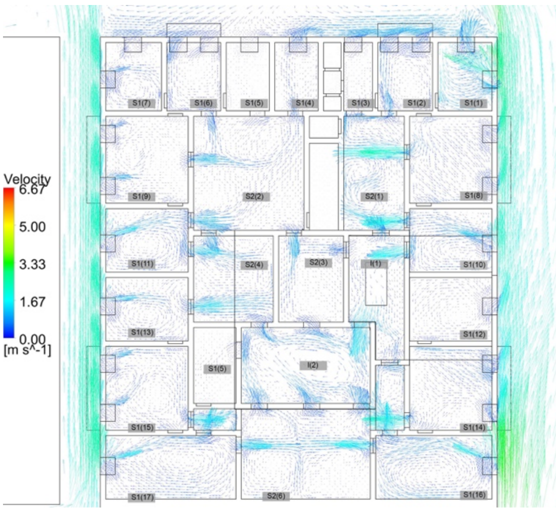


Figure 8-20 the airflow pattern inside the detailed floor scenario 3 at height 8.6 m

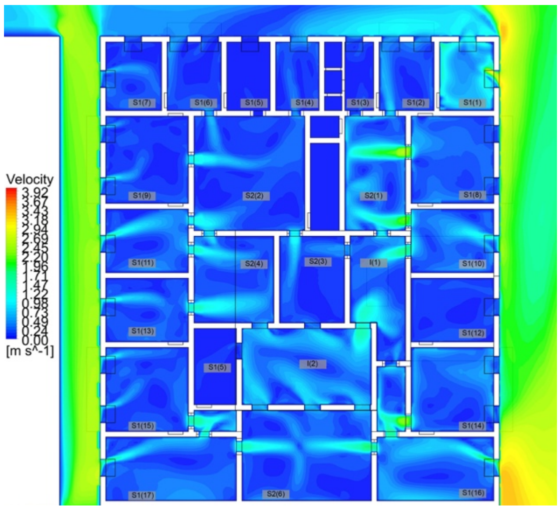


Figure 8-21 the airflow speed profile of the detailed floor scenario 3 at height 8.6 m

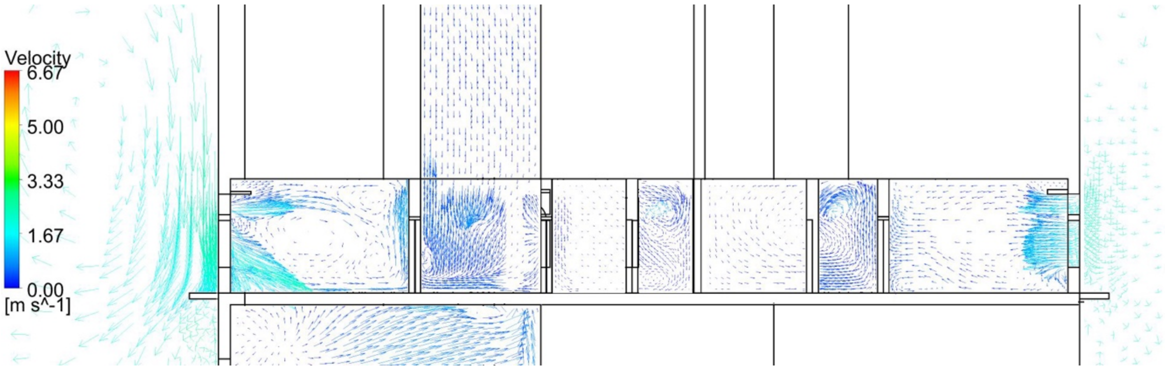


Figure 8-22 the airflow inlet from Sizostris street and the small alley showing the change of the airflow patterns

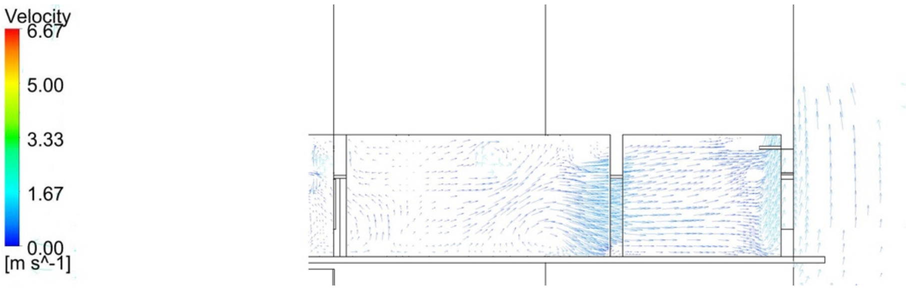


Figure 8-23 the airflow outletfrom Masjid el Atarin street and the small alley showing the change of the airflow patterns

Table 8-4 internal airspeed inside the detailed floor plan spaces

Zone		Inlet airspeed (m/s)	Internal airspeed (m/s)		Average airspeed (m/s)
			max	min	
S1	1	2.55	1.00	0.81	1.45
	2	0.96	0.46	0.35	0.59
	3	0.38	0.31	0.16	0.27
	4	0.77	0.74	0.17	0.56
	5	0.18	0.16	0.09	0.14
	6	0.59	0.42	0.21	0.40
	7	0.51	0.43	0.16	0.36
	8	0.90	0.46	0.27	0.53
	9	1.12	0.81	0.34	0.75
	10	2.81	2.05	1.07	1.98
	11	1.29	0.81	0.55	0.87
	12	1.33	0.55	0.36	0.74
	13	1.47	0.59	0.31	0.78
	14	0.78	0.62	0.51	0.64
	15	0.90	0.56	0.43	0.62
	16	2.9	1.81	1.14	2.34
	17	2.0	1.07	0.68	1.42
S2	1	-	0.65	0.44	0.55
	2	-	0.86	0.43	0.65
	3	-	0.30	0.14	0.29
	4	-	0.33	0.27	0.30
	5	-	0.09	0.07	0.08
	6	-	0.74	0.47	0.61
I	1	-	1.05	0.88	0.98
	2	-	0.64	0.48	0.56

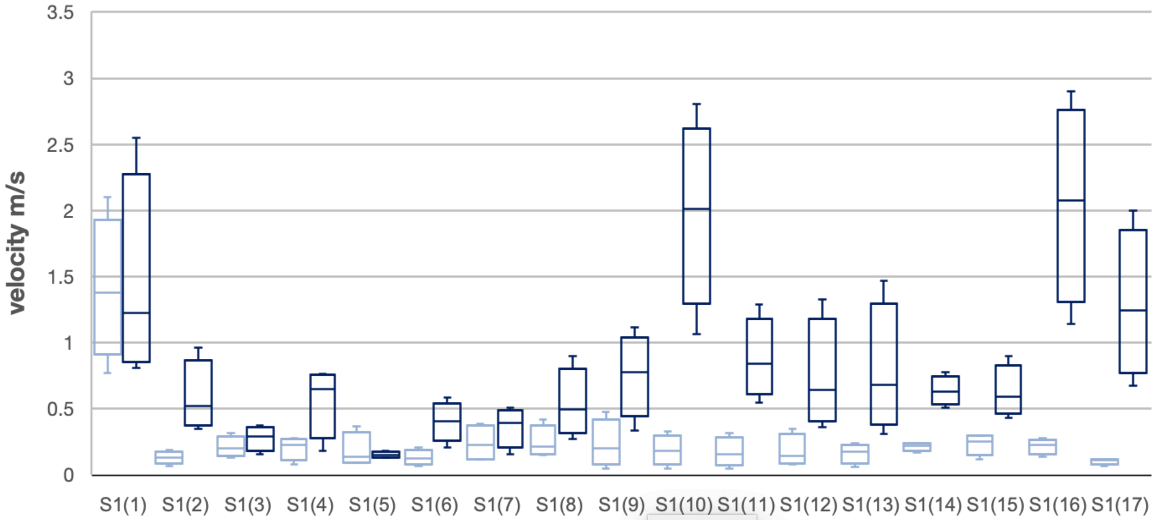


Figure 8-24 average velocity m/s for the S1 spaces scenario 3

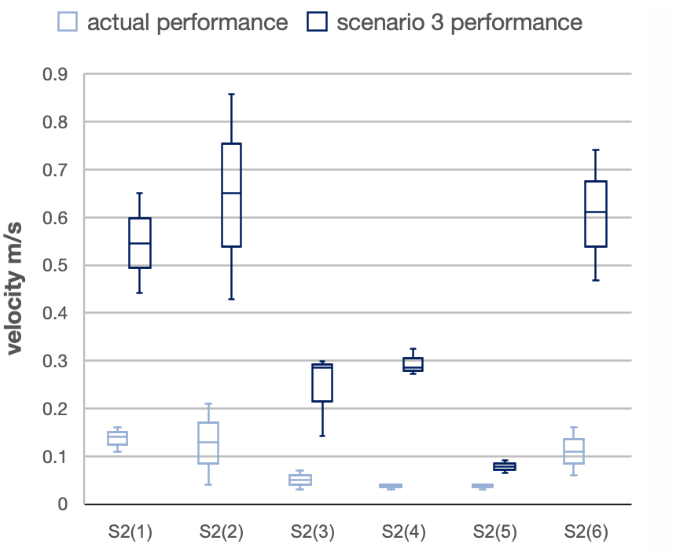


Figure 8-25 average velocity m/s for the S2 inner living spaces scenario 3

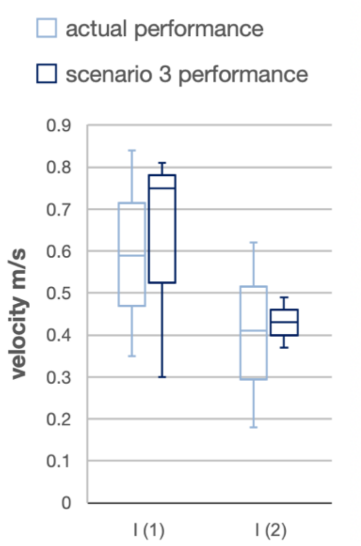


Figure 8-26 average velocity m/s for the Inner shafts' spaces

Table 8-4 illustrates the different internal airflow magnitude within the different space and comparing it to the actual current performance of the case study building in,, Figure 8-24, Figure 8-25 and Figure 8-26 showing a general increase in magnitude in all the spaces specially in the S2 zones, and an average increase of the internal magnitude within the S1 and S2 spaces from 0.26 m/s to 0.81 m/s and from 0.08 m/s to 0.46 m/s respectively.

8.3.3 Scenario 4 results

The mono pitch roof addition to the inner court with openings in the leeward side with the combined effects of opening the internal transom windows, is illustrated in Figure 8-27, Figure 8-28, Figure 8-29, and Figure 8-30 showing the airflow patterns and magnitudes on different levels in the detailed floor plan.

As the inner court in the actual performance as discussed in chapter 6 was acting as an outlet for the detailed floor plan, extracting the airflow to the outer environment. The addition to the roof in this scenario included openings in the leeward side. The modification amplified the performance of the inner court as a shaft increasing the internal airflow magnitude within the detailed floor plan and preserving the actual airflow patterns with the floor plan. The external S1 spaces openings' on Sizostriss street and the small alley are still the main inlet for the detailed floor plan. The main air stream is coming from these spaces passing through the internal S2 spaces and the extraction is divided between the S1 external zones on Masjid el Atarin street and the internal shaft. The sections showing the connection of the inner court are illustrated in Figure 8-31 and Figure 8-32 showing the connection with the inner spaces and the stairwell respectively, demonstrating the amplified airflow magnitude increase against the actual performance of the open court.

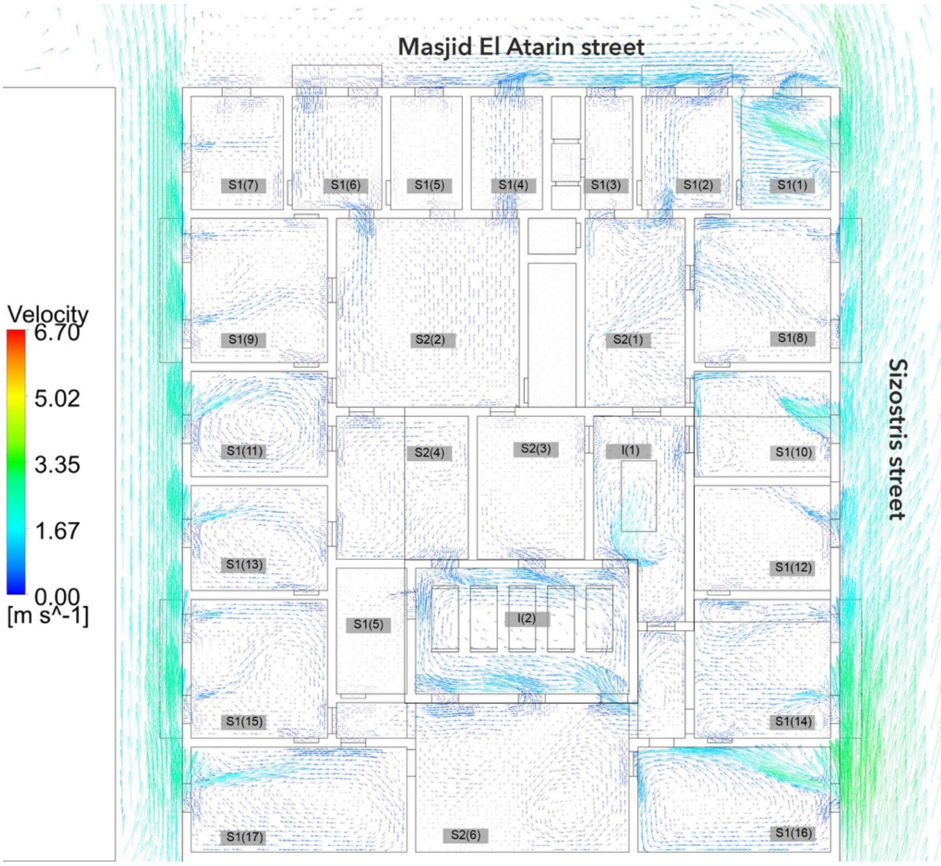


Figure 8-27 the airflow pattern inside the detailed floor scenario 4

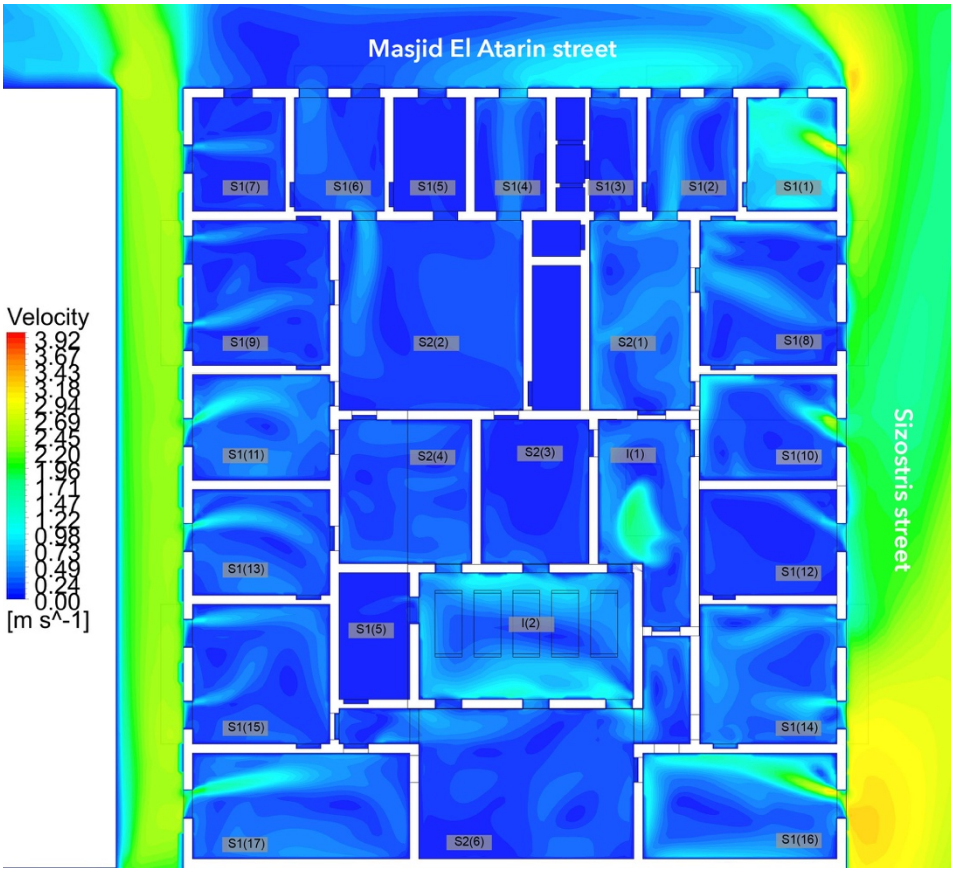


Figure 8-28 the airflow speed profile of the detailed floor scenario 4

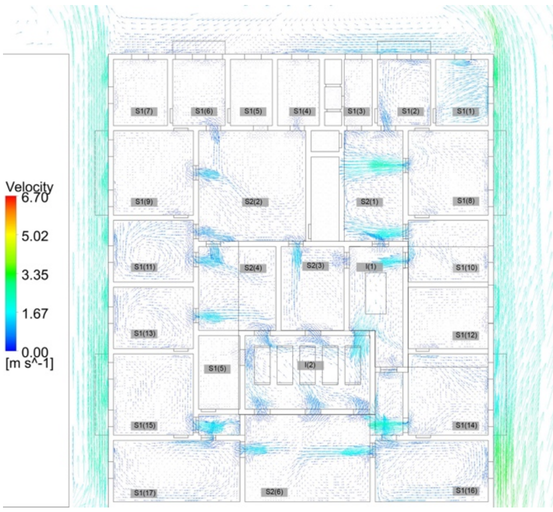


Figure 8-29 the airflow pattern inside the detailed floor scenario 4 at height 8.6 m

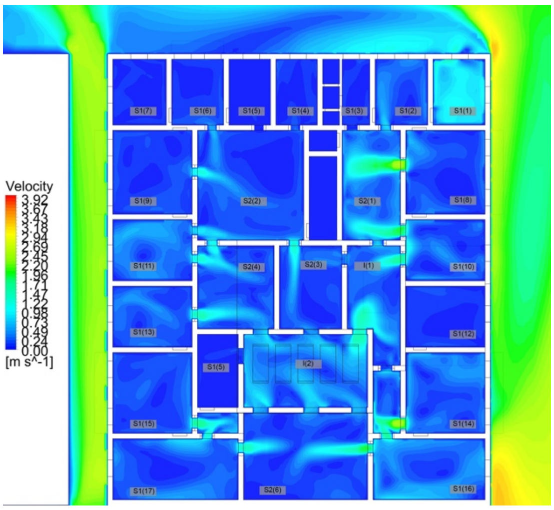


Figure 8-30 the airflow speed profile of the detailed floor scenario 4 at height 8.6 m

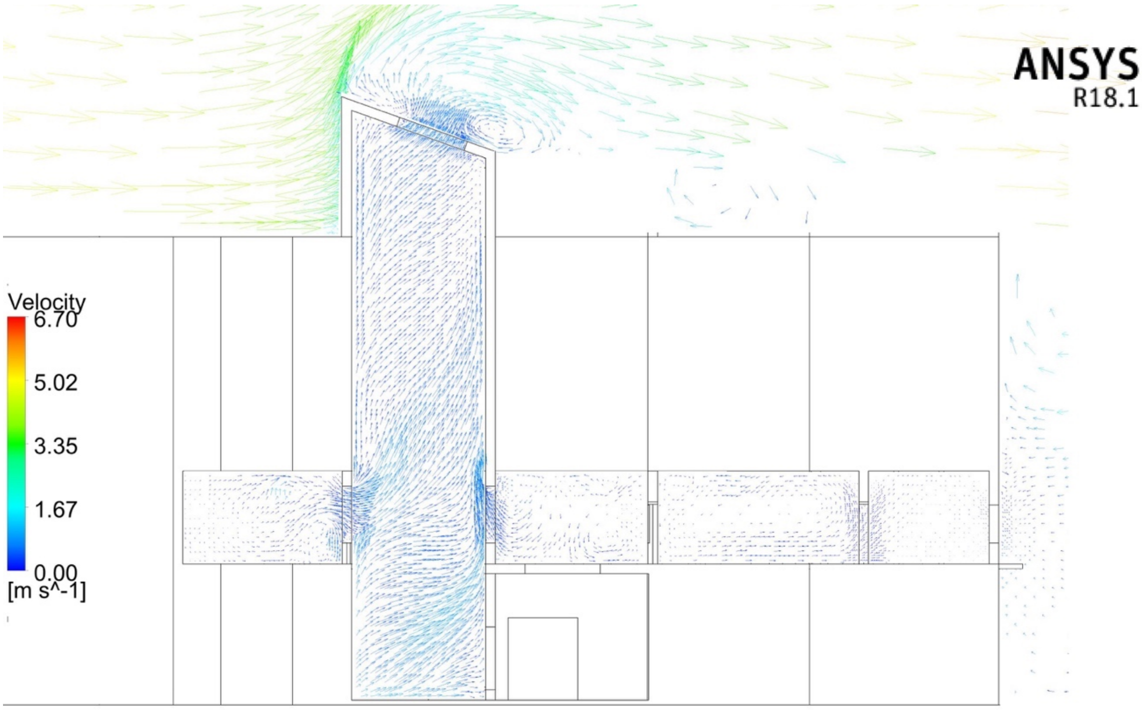


Figure 8-31 the inner court connection with the S2 spaces with the effect of scenario 4

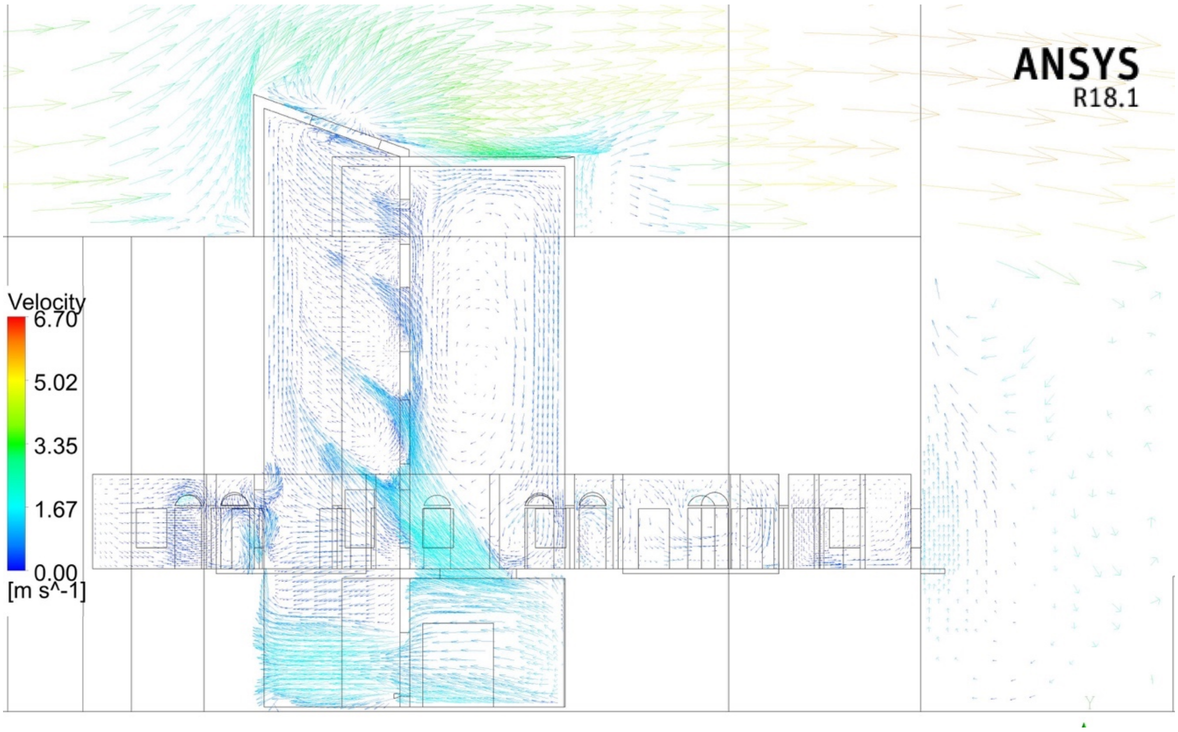


Figure 8-32 inner court connection with the inner stair well with the effect of scenario 4

Table 8-5 internal airspeed inside the detailed floor plan spaces

Zone		Inlet airspeed (m/s)	Internal airspeed (m/s)		Average airspeed (m/s)
			max	min	
S1	1	2.15	1.38	0.92	1.36
	2	0.65	0.68	0.55	0.62
	3	0.40	0.33	0.29	0.34
	4	0.70	0.52	0.42	0.55
	5	0.21	0.16	0.10	0.16
	6	0.55	0.46	0.17	0.39
	7	0.82	0.48	0.23	0.51
	8	0.60	0.47	0.40	0.49
	9	0.94	0.75	0.23	0.64
	10	2.58	1.46	0.85	1.78
	11	1.39	0.88	0.49	0.92
	12	0.92	0.59	0.33	0.61
	13	1.76	1.01	0.56	1.11
	14	1.81	1.07	0.60	1.16
	15	0.91	0.62	0.44	0.66
	16	2.87	2.41	1.16	2.15
	17	1.48	1.14	0.49	1.04
S2	1	-	0.60	0.49	0.55
	2	-	0.70	0.42	0.56
	3	-	0.44	0.35	0.40
	4	-	0.42	0.33	0.38
	5	-	0.10	0.07	0.09
	6	-	0.60	0.47	0.53
I	1	-	1.09	0.88	0.99
	2	-	0.44	0.39	0.42

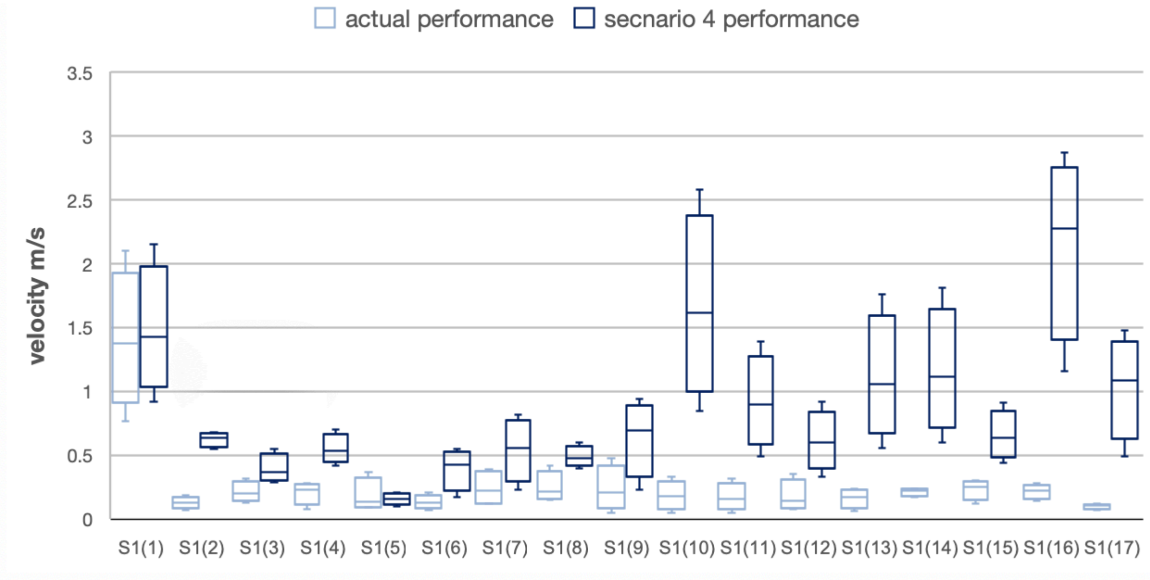


Figure 8-33 average velocity m/s for the S1 spaces

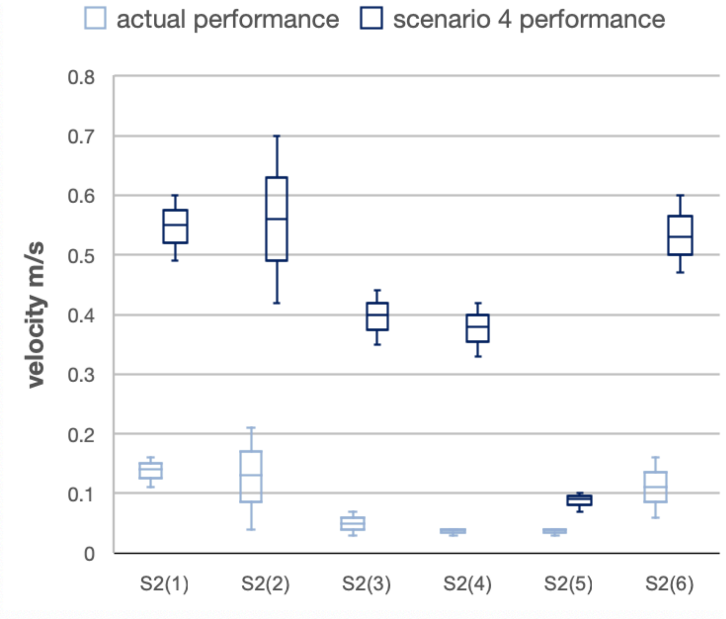


Figure 8-34 average velocity m/s for the S2 inner living spaces

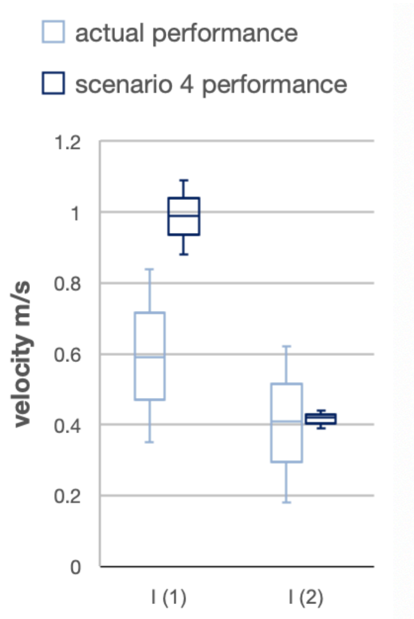


Figure 8-35 average velocity m/s for the Inner shafts' spaces

Table 8-5 illustrates the different internal airflow magnitude within the different space and comparing it to the actual current performance of the case study building in Figure 8-33, Figure 8-34, and Figure 8-35 showing a general increase in magnitude in all the spaces specially in the S2 zones, and an average increase of the internal magnitude within the S1 and S2 spaces from 0.26 m/s to 0.85 m/s and from 0.08 m/s to 0.48 m/s respectively.

8.3.4 Scenario 5 results

The mono pitch roof addition to the inner court with openings in the windward side with the combined effects of opening the internal transom windows, is illustrated in Figure 8-36, Figure 8-37, Figure 8-38, Figure 8-39 for the airflow patterns and magnitudes on different levels in the detailed floor plan.

The addition of roof on the inner court with openings on the windward side had a changing effect on the airflow behavior within the detailed floor plan. The inner atrium is now having the effect of the inlet to different spaces against its original performance as an outlet. This changing airflow patterns affected the inner spaces differently, as the original circulation was starting from the external openings on the S1 spaces on Sizostriss street and the alley passing through the S2 spaces and extracted through the outlet on the S1 spaces on Masjid el Atarin street openings and the inner court. However, this pattern changed as a result of the characteristic change of the court performance. The airflow patterns are now entering the floor plan from the inner court and the S1 spaces on Sizostriss street and the alley, passing through the S2 spaces and extracted from the S1 spaces openings outlet on Masjid el Atarin street. This change in pattern enhanced the airflow magnitude within the inner S2 spaces due to their direct interaction with the inlet spaces, and the S1 spaces on the Masjid el Atrarin street. The sections showing the connection of the inner court are illustrated in Figure 8-40, Figure 8-41 showing the connection with the inner spaces and the stairwell respectively demonstrating the amplified airflow magnitude as the air is induced from the inner court to the connected spaces.

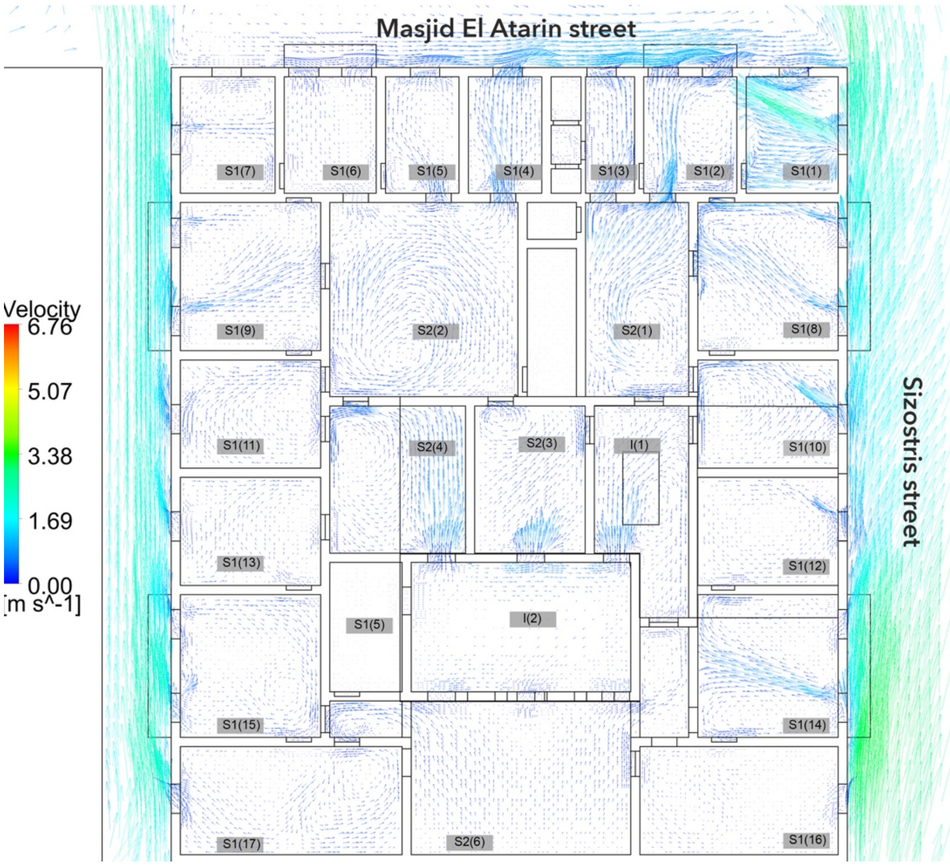


Figure 8-36 the airflow pattern inside the detailed floor scenario 5

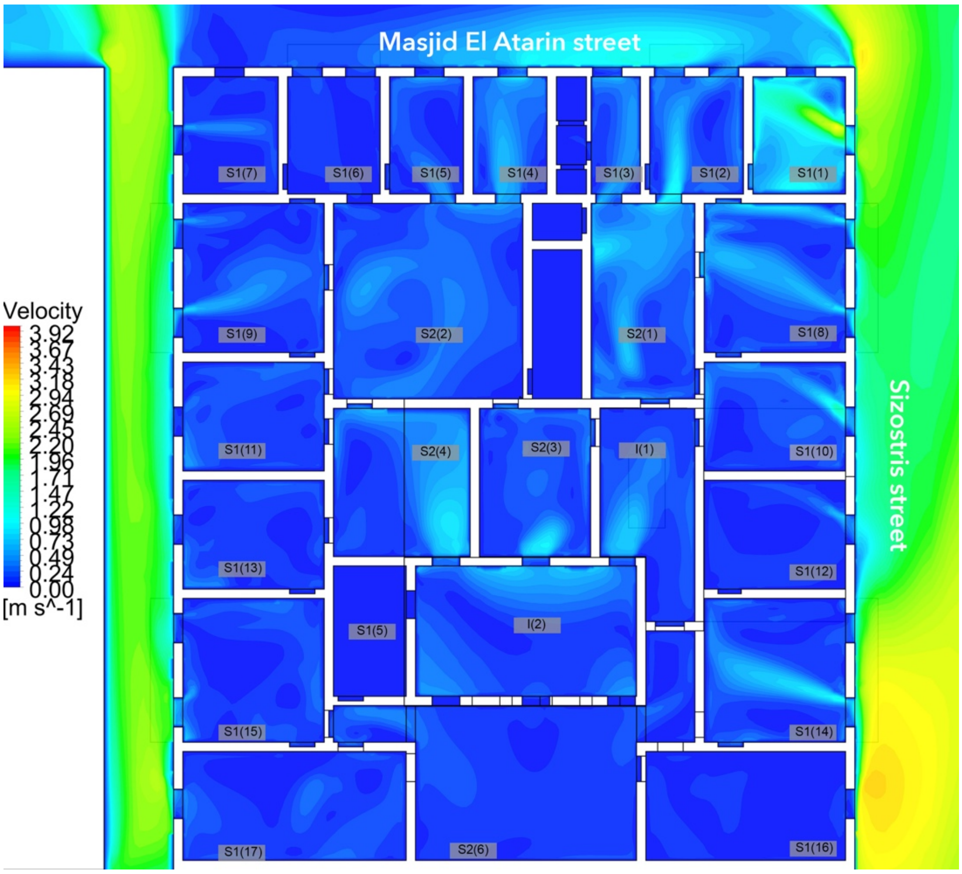


Figure 8-37 the airflow speed profile of the detailed floor scenario 5

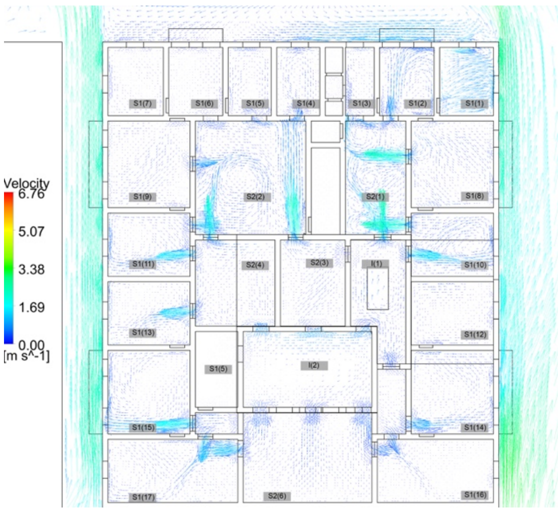


Figure 8-38 the airflow pattern inside the detailed floor scenario 5 at height 8.6 m

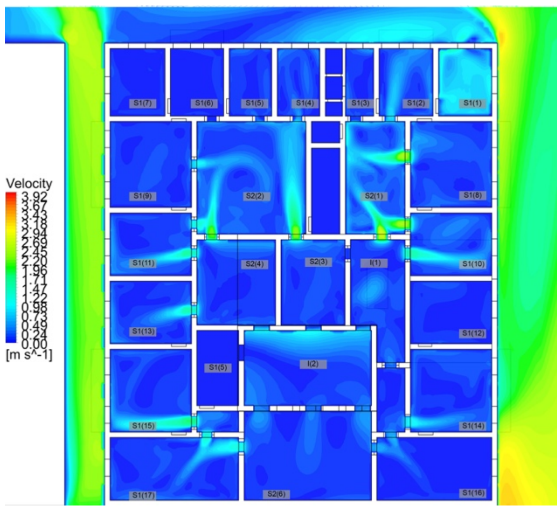


Figure 8-39 the airflow speed profile of the detailed floor scenario 5 at height 8.6 m

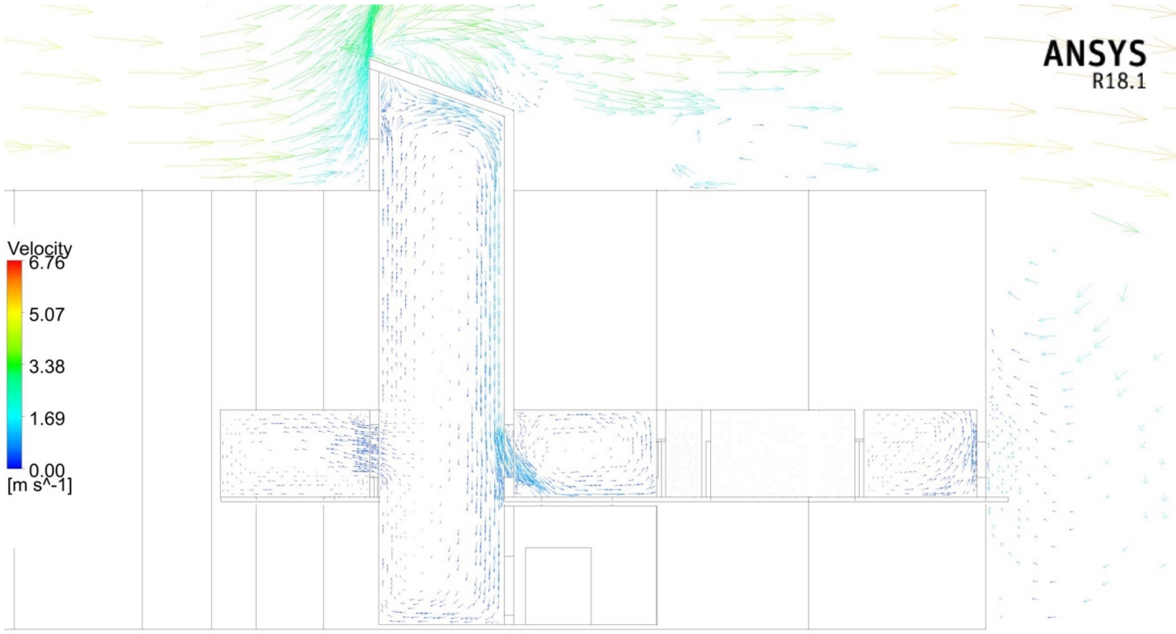


Figure 8-40 the inner court connection with the S2 spaces with the effect of scenario 5

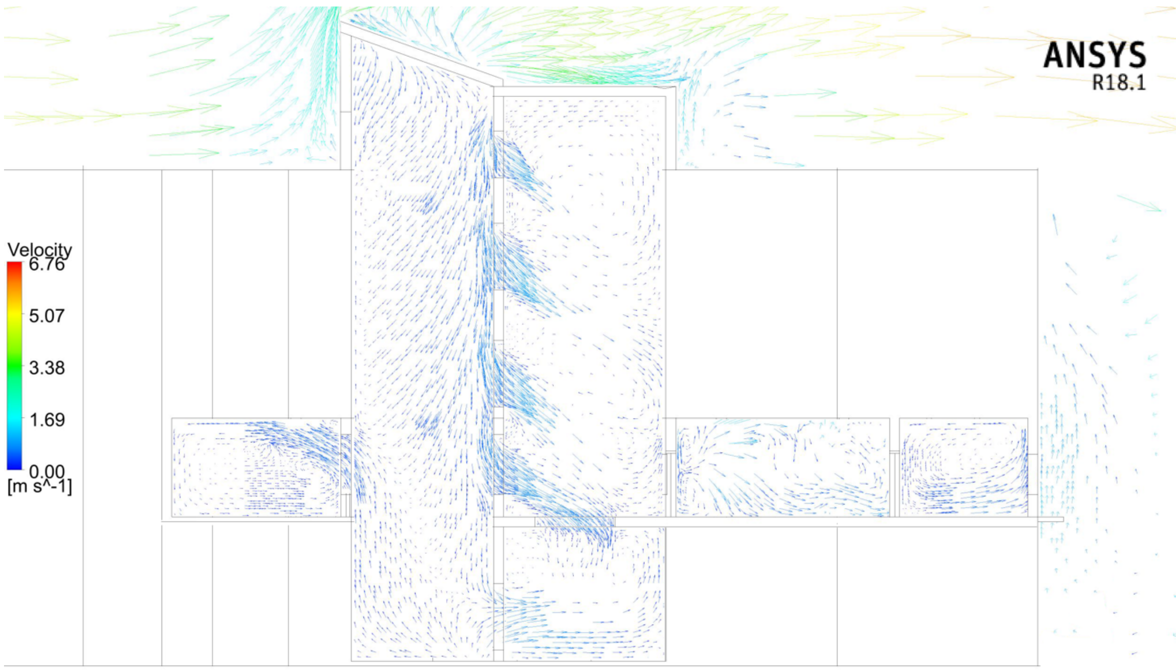


Figure 8-41 inner court connection with the inner stair well with the effect of scenario 5

Table 8-6 internal airspeed inside the detailed floor plan spaces

Zone		Inlet airspeed (m/s)	Internal airspeed (m/s)		Average airspeed (m/s)
			max	min	
S1	1	2.03	1.16	0.93	1.28
	2	0.73	1.17	0.59	0.83
	3	0.68	0.65	0.55	0.62
	4	1.03	0.69	0.53	0.75
	5	0.59	0.55	0.42	0.52
	6	0.29	0.20	0.16	0.21
	7	0.94	0.78	0.43	0.72
	8	0.66	0.61	0.42	0.56
	9	0.64	0.68	0.29	0.53
	10	1.13	0.66	0.55	0.78
	11	0.44	0.34	0.20	0.33
	12	0.64	0.42	0.16	0.40
	13	0.73	0.43	0.27	0.47
	14	1.08	0.56	0.34	0.66
	15	0.60	0.48	0.34	0.47
	16	0.43	0.29	0.17	0.30
	17	0.38	0.23	0.10	0.23
S2	1	-	0.81	0.68	0.74
	2	-	0.42	0.36	0.39
	3	-	1.08	0.68	0.88
	4	-	1.17	0.83	1.00
	5	-	0.09	0.08	0.09
	6	-	0.44	0.34	0.39
I	1	-	0.86	0.47	0.66
	2	-	0.64	0.31	0.48

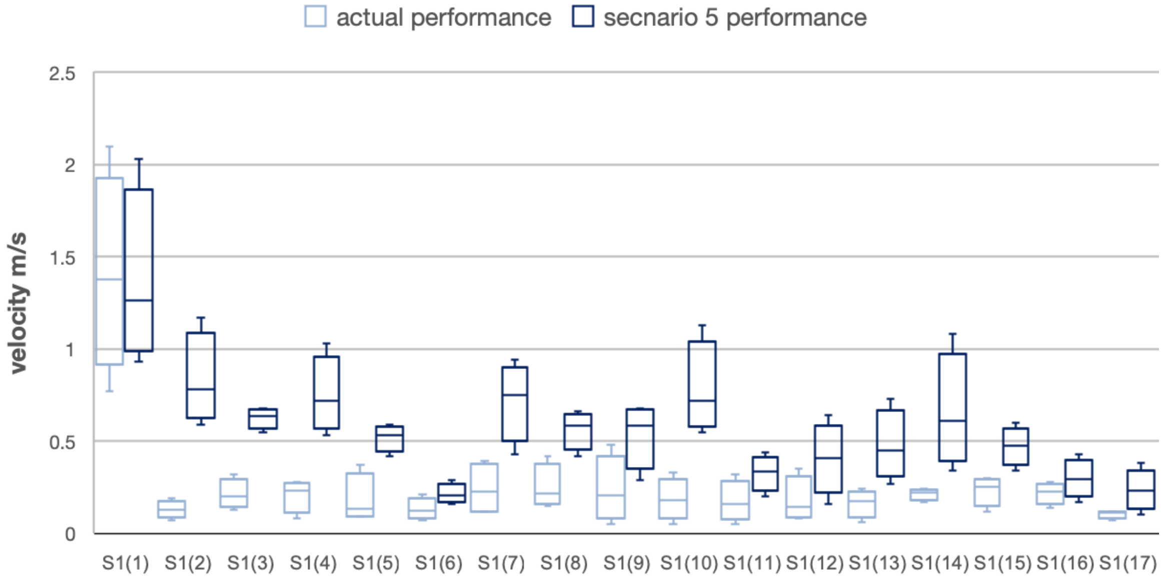


Figure 8-42 average velocity m/s for the S1 spaces

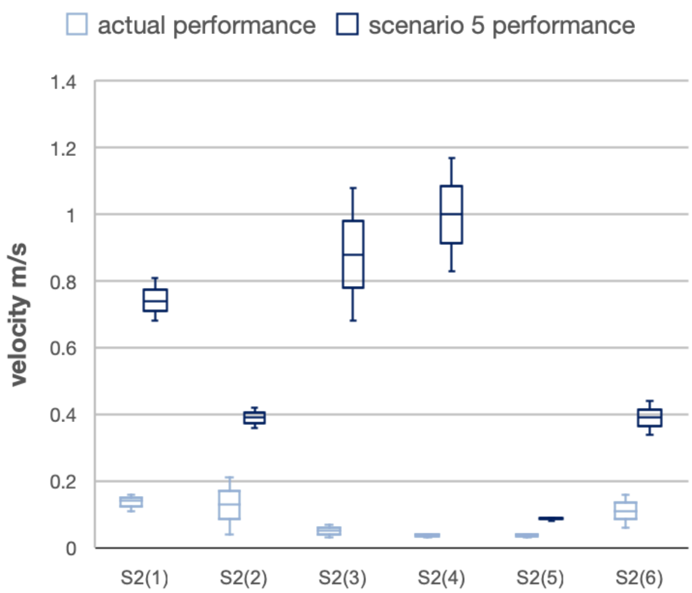


Figure 8-43 average velocity m/s for the S2 inner living spaces

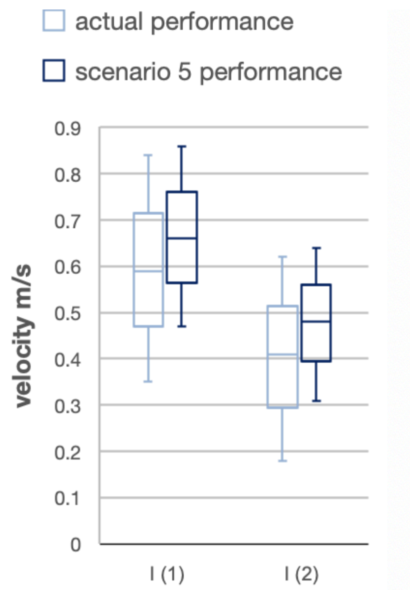


Figure 8-44 average velocity m/s for the Inner shafts' spaces

Table 8-6 illustrates the different internal airflow magnitude within the different space and comparing it to the actual current performance of the case study building in Figure 8-42, Figure 8-43, and Figure 8-44 showing a general increase in magnitude in all the spaces specially in the S2 zones, and an average increase of the internal magnitude within the S1 and S2 spaces from 0.26 m/s to 0.57 m/s and from 0.08 m/s to 0.67 m/s respectively.

8.3.5 Scenario 6 results

The mono pitch roof addition to the inner court with openings in the leeward and windward side with the combined effects of opening the internal transom windows, is illustrated Figure 8-45, Figure 8-46, Figure 8-47, and Figure 8-48 for the airflow patterns and magnitudes on different levels in the detailed floor plan.

The addition of roof on the inner court with openings on the leeward and windward side have significantly increased the airflow magnitude within the inner court, and added a general increase within the detailed floor plan. As a result of the atrium having inlet and outlets, the airflow that enters through the inlet openings on the windward side part of the induced air is directly extracted through the openings on the leeward side and the rest circulates within the atrium. The changes of pattern and magnitude within the inner court have affected the airflow behavior while interacting within the inner direct contact spaces S2, resulting in a mixed behavior of inducing or extracting the air from theses spaces. The S2 spaces openings on the windward side of the atrium are acting as an inlet for these spaces, while the S2 spaces openings on the leeward side of the atrium are acting as an outlet for these spaces. This change in behavior of the airflow magnitude and patterns within the S2 spaces has affected the direct related external S1 spaces in direct contact. The S1 spaces in contact with the S2 spaces that have openings outlet behavior have increased in the airflow magnitudes, while the S1 spaces in contact with the S2 spaces openings inlet behavior magnitude increase is not with the same effect of the others.

The sections showing the connection of the inner court are illustrated in Figure 8-49 and Figure 8-50 showing the connection with the inner spaces and the stairwell respectively demonstrating the different interaction of the S2 inner spaces with the inner atrium.

Figure 8-45 the airflow pattern inside the detailed floor scenario 6

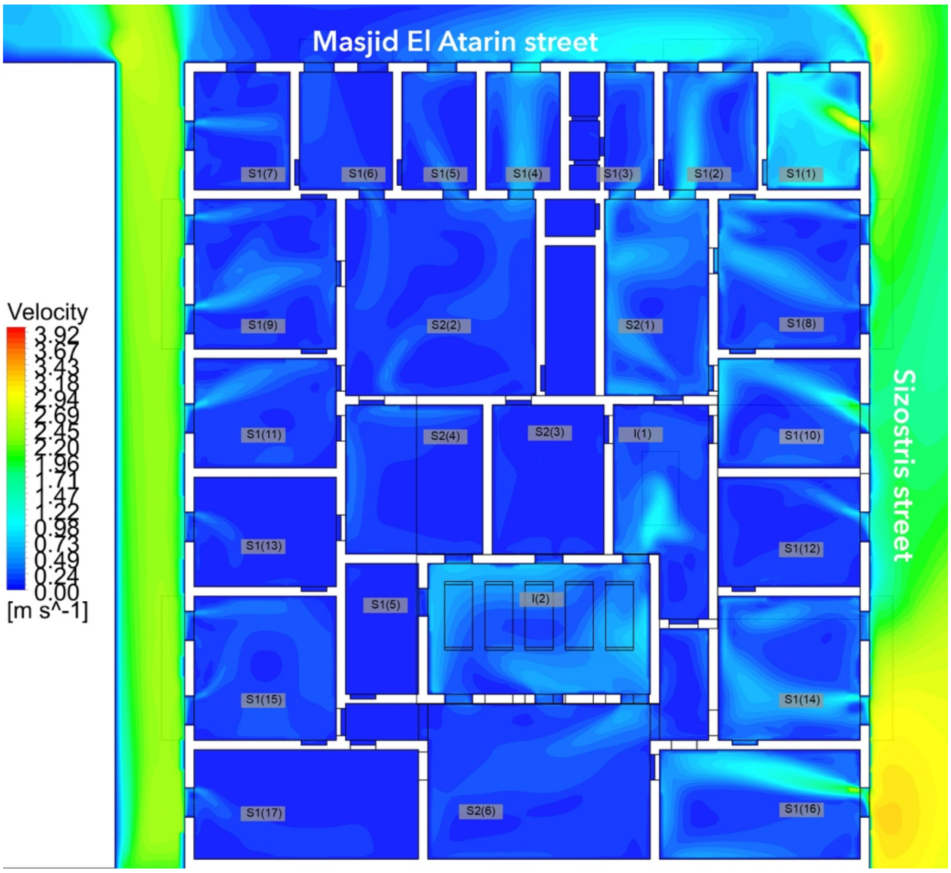


Figure 8-46 the airflow speed profile of the detailed floor scenario 6

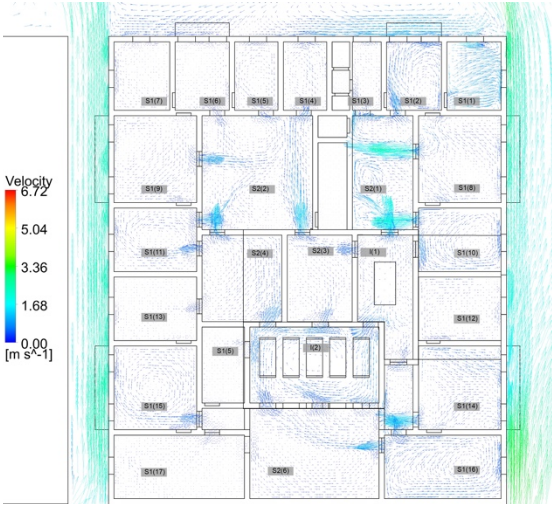


Figure 8-47 the airflow pattern inside the detailed floor scenario 6 at height 8.6 m

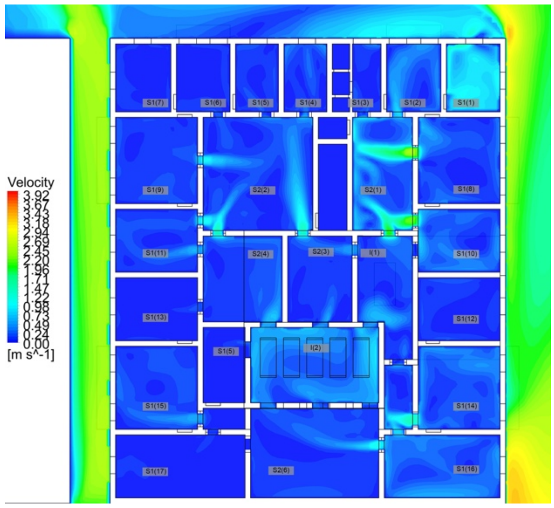


Figure 8-48 the airflow speed profile of the detailed floor scenario 6 at height 8.6 m

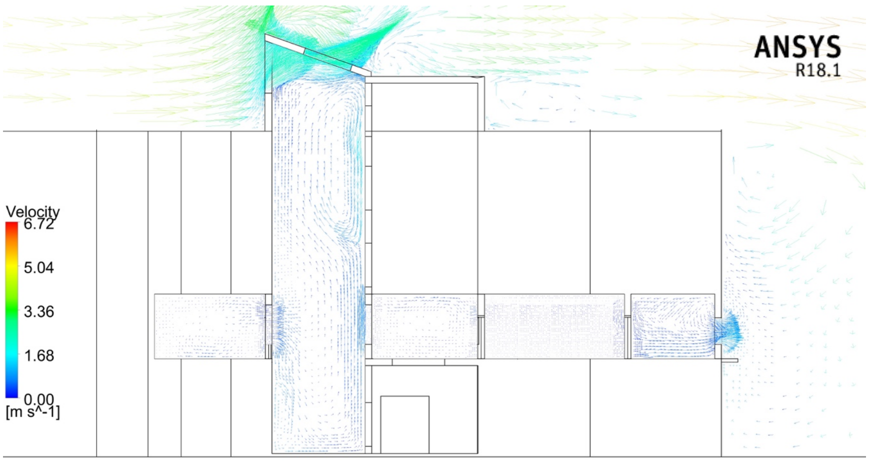


Figure 8-49 the inner court connection with the S2 spaces with the effect of scenario 6

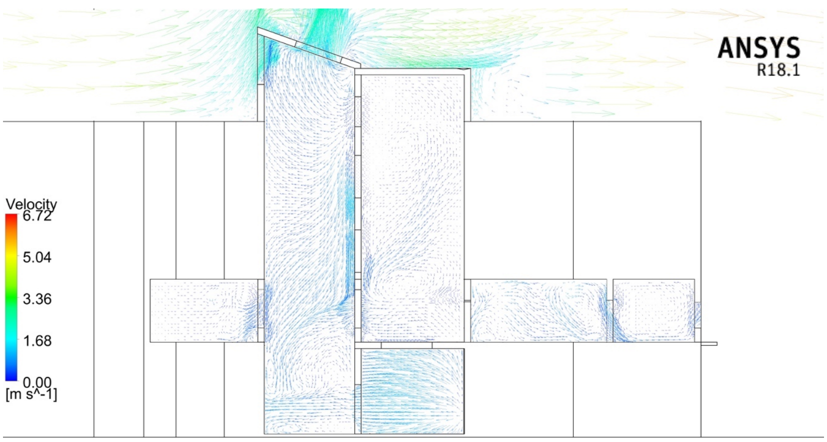


Figure 8-50 inner court connection with the inner stair well with the effect of scenario 6

Table 8-7 internal airspeed inside the detailed floor plan spaces

Zone		Inlet airspeed (m/s)	Internal airspeed (m/s)		Average airspeed (m/s)
			max	min	
S1	1	2.1	1.21	0.94	1.31
	2	0.79	1.00	0.55	0.78
	3	0.59	0.55	0.36	0.49
	4	1.04	0.81	0.53	0.79
	5	0.47	0.44	0.21	0.38
	6	0.42	0.36	0.20	0.33
	7	0.72	0.60	0.42	0.57
	8	0.61	0.48	0.42	0.51
	9	0.75	0.69	0.53	0.66
	10	2.37	1.48	0.91	1.59
	11	0.73	0.60	0.42	0.59
	12	0.75	0.68	0.46	0.62
	13	0.42	0.27	0.14	0.27
	14	1.53	1.26	0.73	1.17
	15	0.53	0.42	0.27	0.40
	16	3.29	1.24	1.18	1.90
	17	0.82	0.56	0.42	0.60
S2	1	-	0.95	0.68	0.82
	2	-	0.52	0.39	0.46
	3	-	0.29	0.10	0.20
	4	-	0.42	0.34	0.38
	5	-	0.05	0.04	0.05
	6	-	0.69	0.43	0.56
I	1	-	0.82	0.64	0.73
	2	-	0.43	0.34	0.39

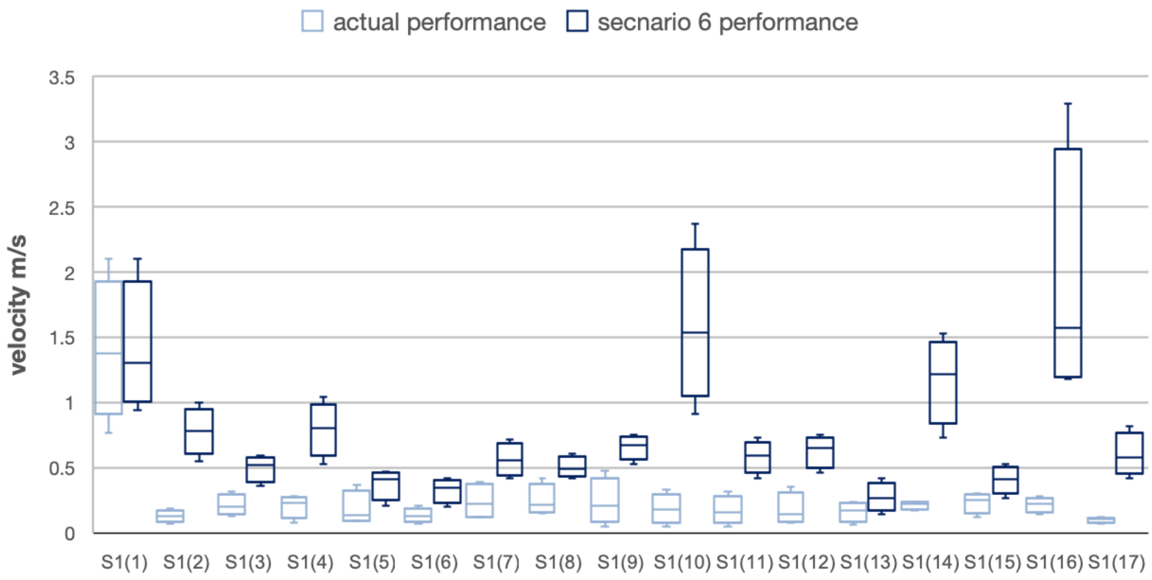


Figure 8-51 average velocity m/s for the S1 spaces

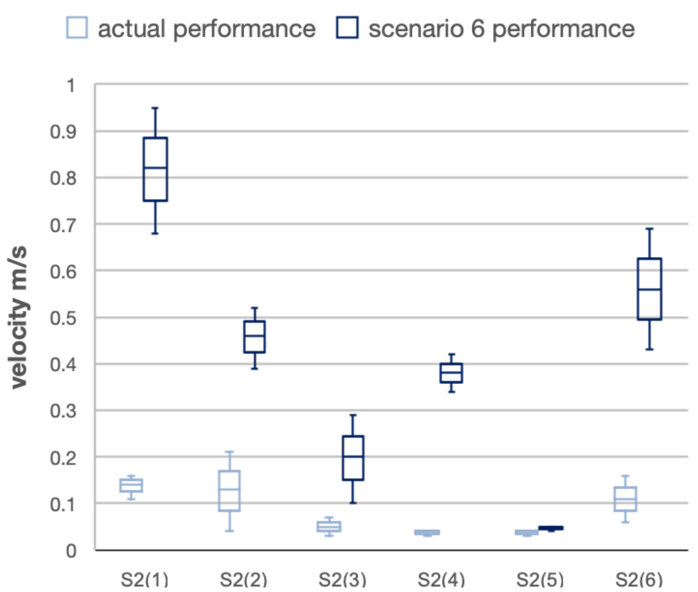


Figure 8-52 average velocity m/s for the S2 inner living spaces

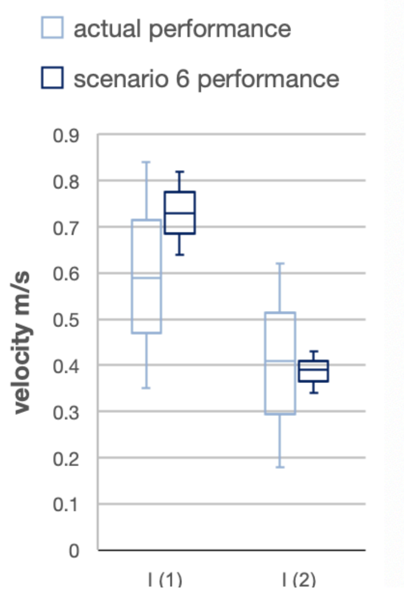


Figure 8-53 average velocity m/s for the Inner shafts' spaces

Table 8-3 illustrates the different internal airflow magnitude within the different space and comparing it to the actual current performance of the case study building in Figure 8-51, Figure 8-52, and Figure 8-53 showing a general increase in magnitude in all the spaces specially in the S2 zones, and an average increase of the internal magnitude within the S1 and S2 spaces from 0.26 m/s to 0.76 m/s and from 0.08 m/s to 0.48 m/s respectively.

8.3.6 Parametric study Level 2 results

The level 2 of the parametric study quantifies the effect of the different retrofit effect of the measures separately combined with the effects of the first level of connected internal spaces. This level tested the effects of increasing the opening size through changing the opening type to a single hung operable upper window and to an operable top hung upper window in scenarios 2 and 3 respectively. In addition, this level tested the effects of roof additions to the court using a mono pitch roof with openings on the leeward side, openings on the windward side, and openings on the windward and leeward side in scenarios 4, 5, and 6 respectively.

The results of the different scenarios were discussed in the previous sections. These different scenarios had an improved effect against the actual performance of the case study building internal detailed floor plan and the scenario 1 performance of connected internal spaces. However, in order to compare the different outcomes of the retrofit effect according to their relevance, the effect of changing the opening types of scenario 2 and 3 contrasted with each other, while the effects of the mono pitch roof addition in scenario 4, 5, and 6 were contrasted with each other.

The different chosen parameters of changing the opening type are represented in scenarios 2 and 3 according to the depth map of the internal space's categorization and the monitoring points. The S1 spaces in both scenarios' airflow magnitude are relatively equal in most of the spaces with a slightly higher magnitude in scenario 2 against scenario 3. This is seen mostly in S1(7), S1(14), S1(16), and S1(17). This result demonstrates the result of directing the airflow as a result of applying the top hung operable window have reduced the induced internal airflow within the connected internal spaces. The directed airflow induced, redirected the airflow inside the S1 spaces to a lower pattern reducing the flow at the upper connected transom windows Figure 8-54.

The S2 spaces airflow magnitude due to the reduction in the induced airflow from the connected airflow is proportionally lower in scenario 3 when compared to scenario 2, especially in the S2(1) space. However, the airflow magnitude increased in S2(6) due to the deep layout of the external spaces S1(16) and (17) connected to it, Figure 755. When comparing the inner shafts represented in the inner court and the stair well, the average airflow magnitude of scenario 2 is higher than scenario 3 Figure 8-56

The overall performance of the inner spaces concerning the airflow magnitude and patterns through scenario 2 and 3 have increased specially in the S2 zones which had an almost still airflow magnitude, increasing the average airflow magnitude in the S1 zones from 0.26 m/s in the actual performance to 0.84 m/s and 0.81 m/s in scenarios 2 and 3 respectively, and in the S2 zones from 0.08 m/s in the actual performance to 0.49 m/s and 0.46 m/s in scenarios 2 and 3 respectively.

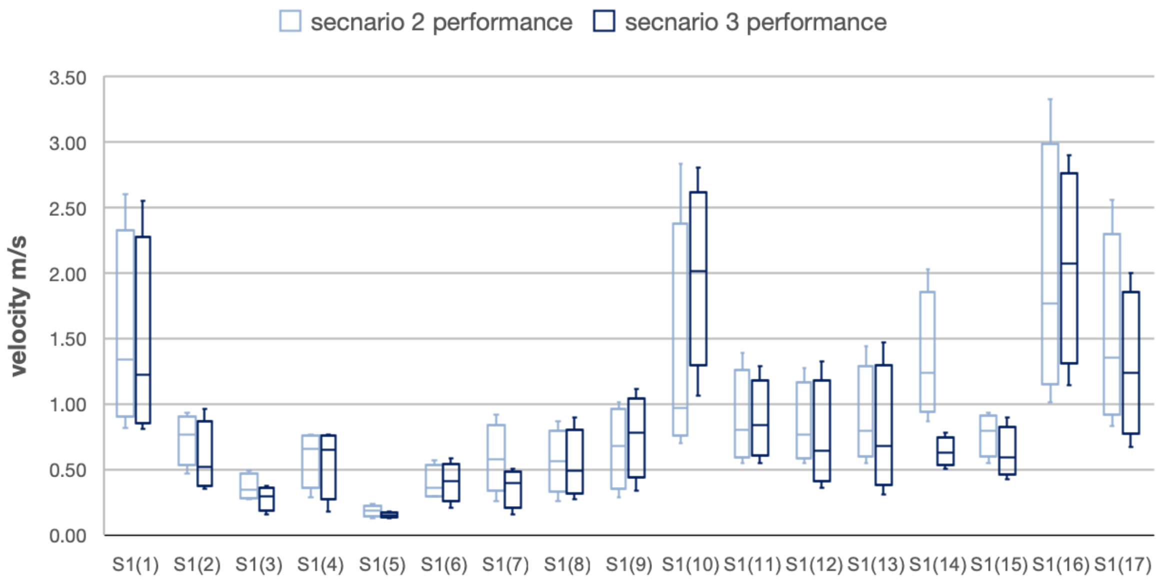
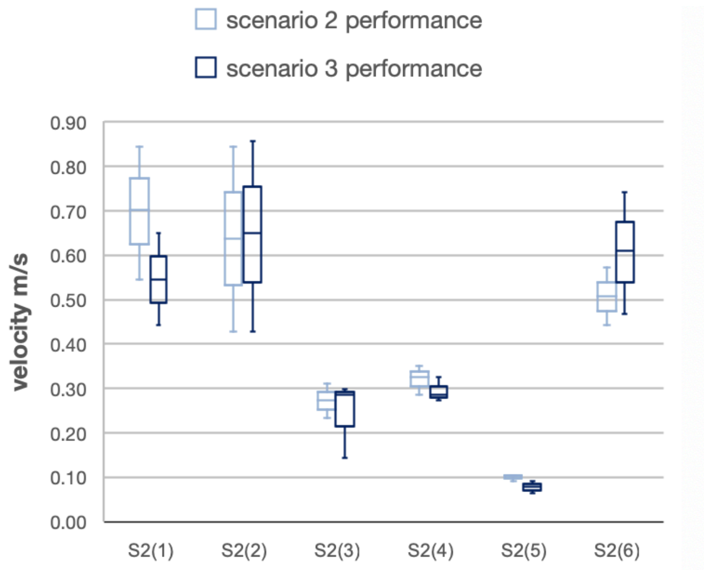


Figure 8-54 average velocity m/s for the S1 spaces in scenario 2 and 3



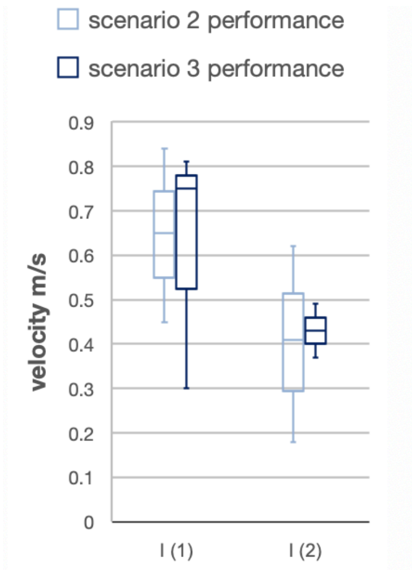


Figure 8-55 average velocity m/s for the S2 inner living spaces in scenario 2 and 3

Figure 8-56 average velocity m/s for the Inner shafts' spaces in scenario 2 and 3

The different chosen parameters of mono pitch roof addition to the inner court with different opening locations are represented in scenarios 4, 5, and 6 according to the depth map of the internal space's categorization and the monitoring points. As a result, change occurred in the airflow patterns as discussed in the previous results of the different scenarios. The performance of the spaces was different in terms of magnitude in each scenario. The S1 spaces in scenarios 4 and 6 openings performed as an inlet on Sizostriss street and the alley better than the similar spaces in scenario 5, as a result of their behaviour as the main airflow inlet to the detailed floor plan against the inlet behaviour that is demonstrated in scenario 5 of the opening of the roof addition on the windward side, reducing the pressure difference between the inlet in the S1 spaces against scenario 5. However, the S1 spaces on Masjid el Atarin openings performing as the outlet, these spaces airflow magnitude in scenario 5 performed better due to the combined induced airflow effect from S1 spaces and the inner atrium Figure 8-57.

The S2 spaces as a rational effect of their direct contact with the inner court in scenario 5 (where the inner atrium performs as an inlet with opening in the windward side) perform higher than the S2 spaces in the other scenarios, especially in the spaces with the direct contact S2(3) and (4). However, in the case of S2 spaces in the windward side of the atrium, the airflow is induced only from the S1 spaces, resulting in a better performance in S2(6) space in scenarios 4 and 6 against 5, Figure 8-57.

When comparing the inner shafts represented in the inner court and the stair well, the average airflow of the inner atrium in scenario 4 has a higher magnitude against scenarios 5 and 6. While the inner stair well as a result of the induced airflow pattern in scenario 5 has a significant airflow magnitude against scenarios 4 and 6, Figure 8-56.

The overall performance of the inner spaces concerning the airflow magnitude and patterns through scenarios 4, 5 and 6 have increased in all the scenarios while scenario 4 has a significant effect on the S1 spaces. Scenario 5 has a significant increase on the S2 spaces and scenario 6 has a balance effect between both scenarios, indicating that a closed atrium performance in that case has a better performance against the open court, increasing the average airflow magnitude in the S1 zones from 0.26 m/s in the actual performance to 0.85 m/s, 0.57 m/s and 0.76 m/s in scenarios 4, 5, and 6 respectively, and in the S2 zones from 0.08 m/s in the actual performance to 0.48 m/s, 0.67 m/s and 0.48 m/s in scenario 4, 5, and 6 respectively.

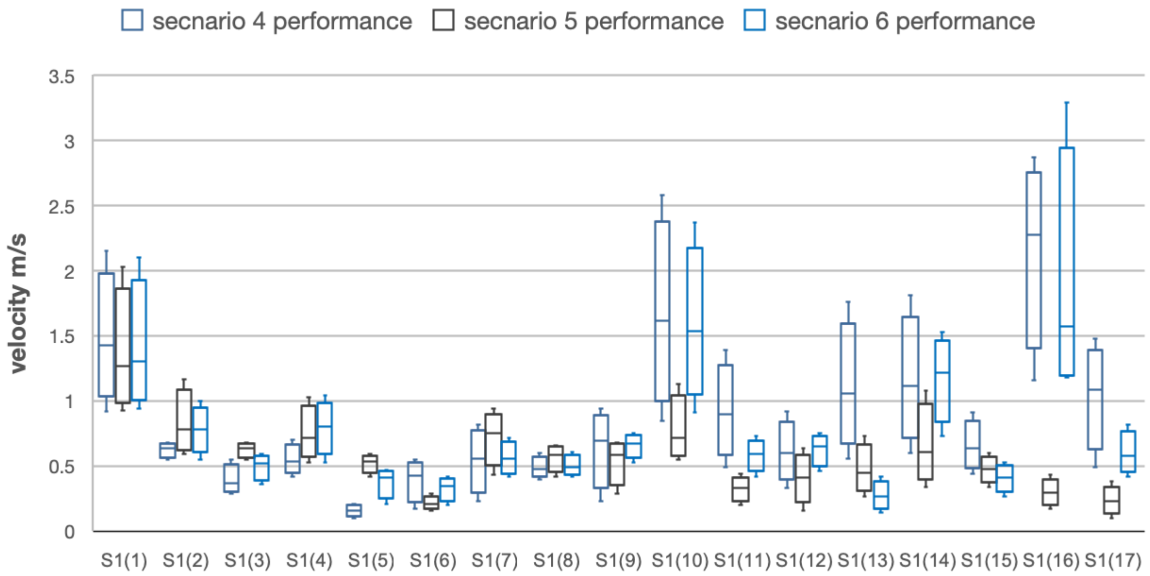


Figure 8-57 average velocity m/s for the S1 spaces in scenario 4, 5, and 6

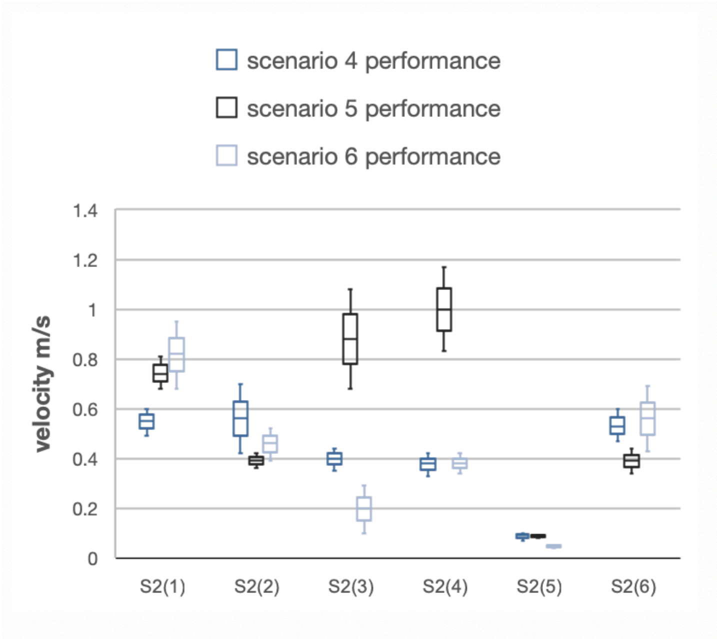


Figure 8-58 average velocity m/s for the S2 inner living spaces in scenario 4, 5, and 6

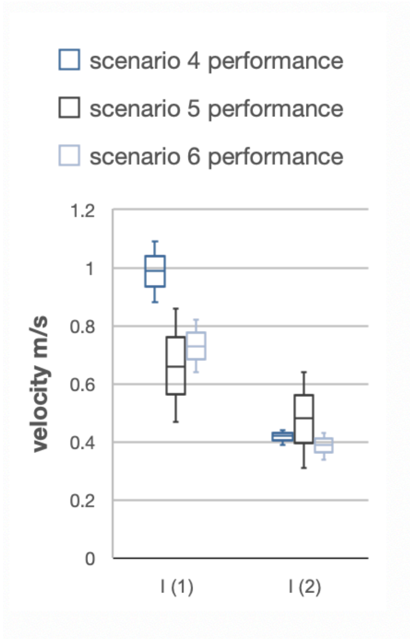


Figure 8-59 average velocity m/s for the Inner shafts' spaces in scenario 4, 5, and 6

8.4 Parametric study level 3 results

The third level of the parametric design analysis is composed of six scenarios comprises of the different retrofitting strategies comprehensively applied together quantifying their impact on the case study building. The effect of the different opening type and the mono pitch roof additions to the inner court would be combined together with different setup according to the established parameters of the different scenarios, which were previously simulated as a stand-alone system in the second level of the parametric analysis. The different scenarios implemented in this level was set on the basis of the results of the first level scenario, allowing the connection of the internal spaces. The results of each scenario would be compared to the actual base case performance.

8.4.1 Scenario 7 results

The scenario combines the effect of changing the opening type to an operable single hung upper window with the effect of mono pitch roof addition to the inner court with openings in the leeward side with the combined effects of opening the internal transom windows, previously tested in scenario 2 and 4 as a stand-alone strategy. The results are illustrated in Figure 8-60, Figure 8-61, Figure 8-62, and Figure 8-63 for the airflow patterns and magnitudes on different levels in the detailed floor plan.

The results of this scenario demonstrate the effects of the increase of the velocity magnitude of the naturally induced air which was allowed by the increase in the opening size of the external S1 spaces combined with the effect of the roof addition with opening on the leeward side that amplified the performance of the inner court as a shaft.

Having the same air flow patterns as the base case, where the external S1 spaces openings' on Sizostriss street and the small alley are still the main inlet for the detailed floor plan, the main air stream in coming from these spaces passing through the internal S2 spaces and the extraction is divided between the S1 external zones on Masjid el Atarin street and the internal shaft. The main noticeable difference is the amplified magnitude of the airflow with the inner spaces of the detailed floor plan against the actual base case performance. The sections showing the connection of the inner court shaft enhancement combined with the change of the opening type are illustrated in Figure 8-64 and Figure 8-65 showing the connection with the inner spaces and the stairwell respectively demonstrates the amplified airflow magnitude increase against the actual performance of the open court.

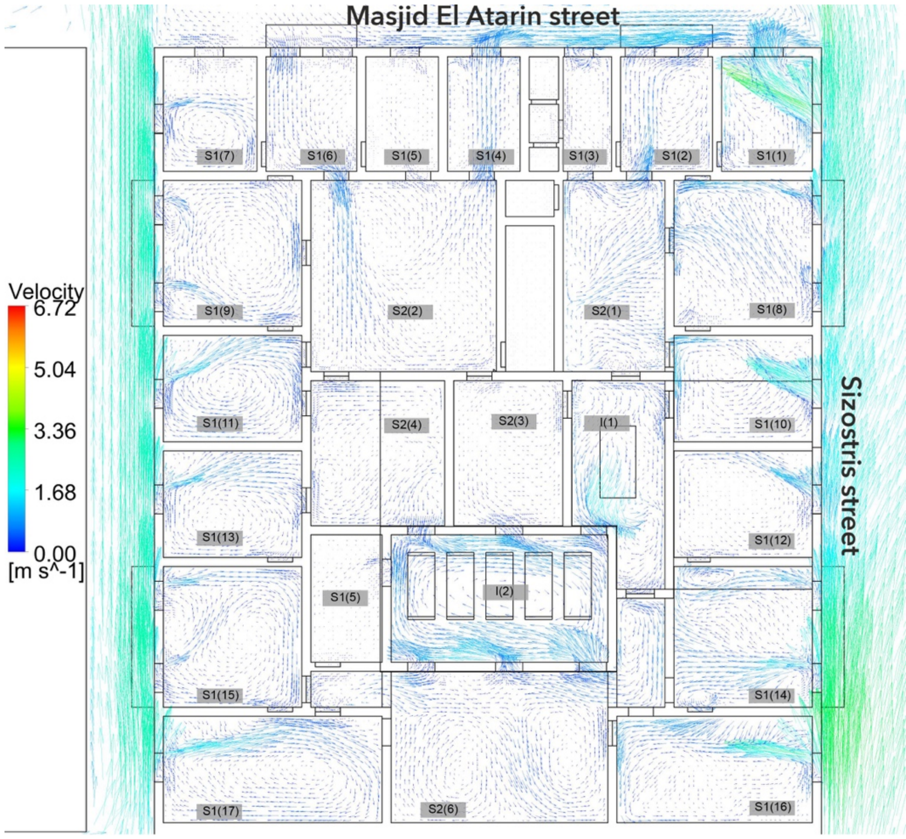


Figure 8-60 the airflow pattern inside the detailed floor scenario 7

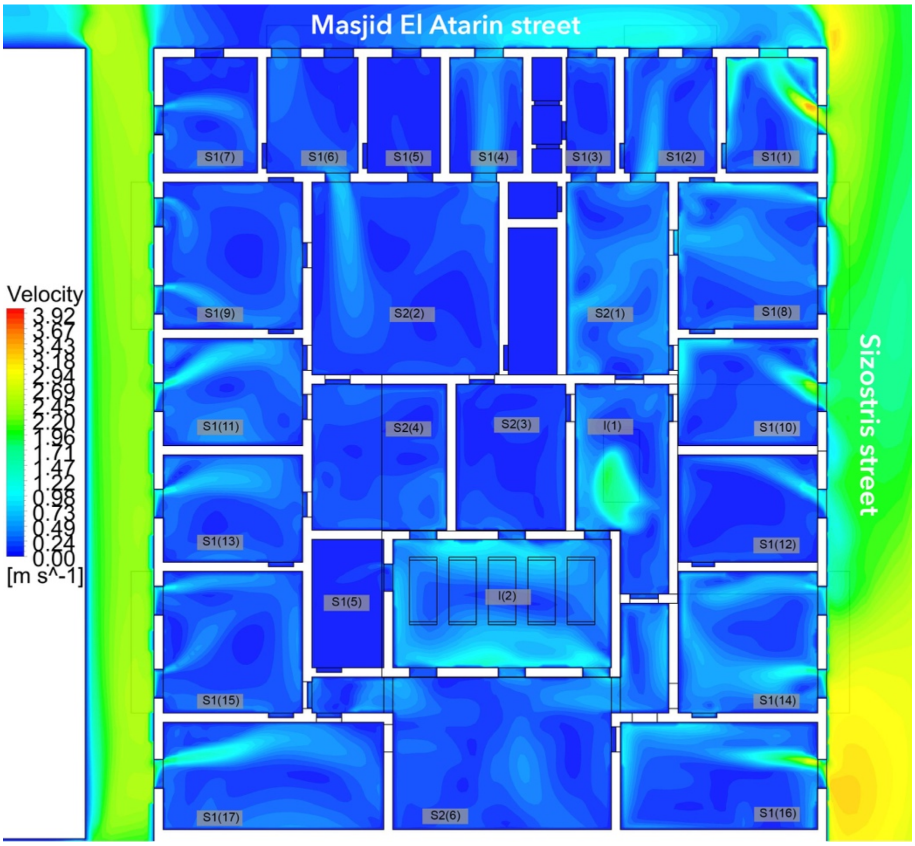


Figure 8-61 the airflow speed profile of the detailed floor scenario 7

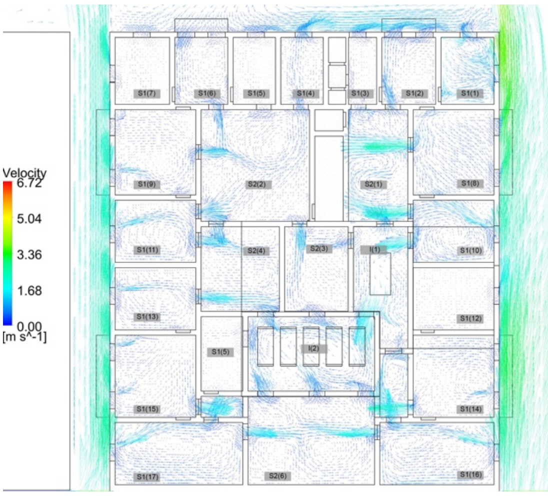


Figure 8-62 the airflow pattern inside the detailed floor scenario 7 at height 8.6 m

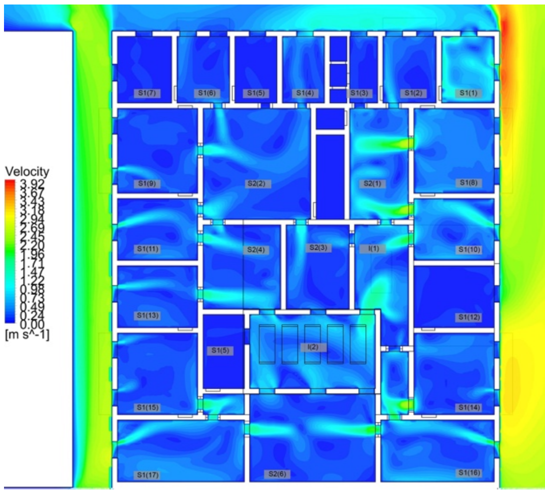


Figure 8-63 the airflow speed profile of the detailed floor scenario 7 at height 8.6 m

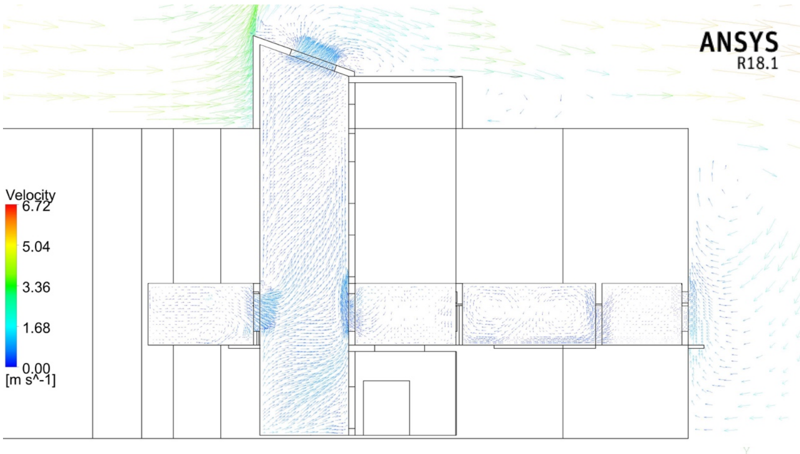


Figure 8-64 the inner court shaft performance connection with the S2 spaces, and the effect of opening type in the S1 spaces of scenario 7

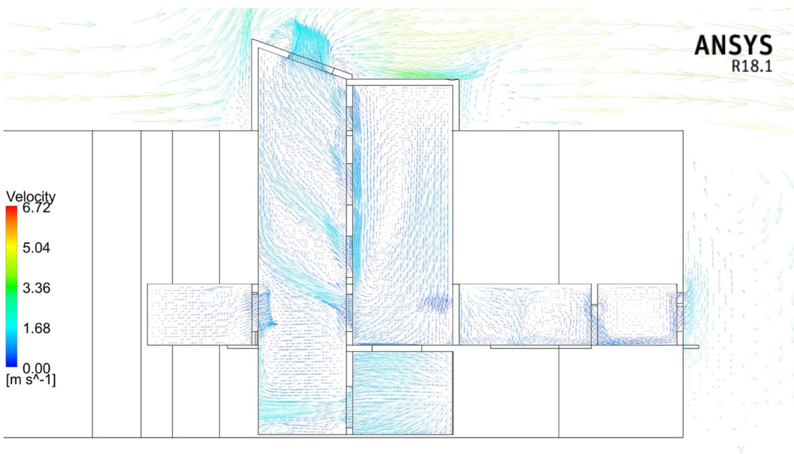


Figure 8-65 the inner court shaft performance connection with the stair well, and the effect of opening type in the S1 spaces of scenario 7

Table 8-8 internal airspeed inside the detailed floor plan spaces scenario 7

Zone		Inlet airspeed (m/s)	Internal airspeed (m/s)		Average airspeed (m/s)
			max	min	
S1	1	2.57	1.19	1.19	1.65
	2	0.61	1.03	0.66	0.76
	3	0.75	0.70	0.61	0.68
	4	1.14	1.09	0.67	0.97
	5	0.46	0.32	0.24	0.34
	6	1.03	0.87	0.52	0.80
	7	0.99	0.74	0.66	0.79
	8	1.16	1.08	0.75	0.99
	9	0.94	0.77	0.36	0.68
	10	3.23	2.72	2.01	2.65
	11	1.56	1.18	0.96	1.23
	12	1.57	1.24	0.97	1.26
	13	1.73	1.18	0.81	1.24
	14	2.22	1.57	1.23	1.67
	15	1.03	0.89	0.61	0.84
	16	3.43	3.23	1.82	2.83
	17	3.29	2.75	2.09	2.71
S2	1	-	1.00	0.61	0.80
	2	-	1.33	0.94	1.13
	3	-	0.76	0.43	0.59
	4	-	0.61	0.46	0.53
	5	-	0.10	0.11	0.11
	6	-	0.85	0.81	0.83
I	1	-	1.24	0.91	1.08
	2	-	0.70	0.52	0.61

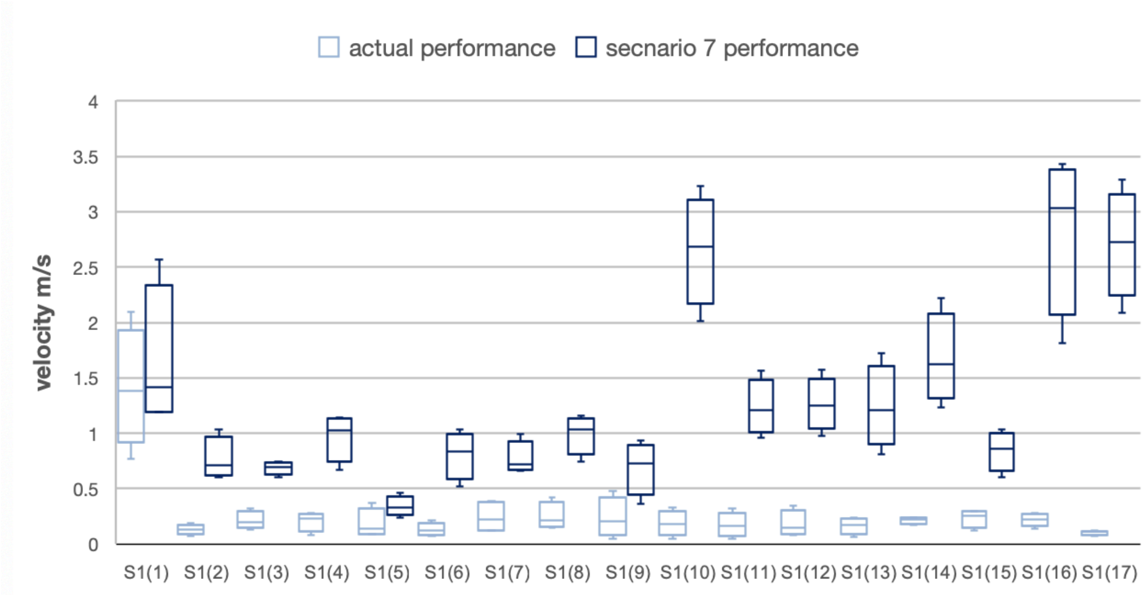


Figure 8-66 average velocity m/s for the S1 spaces

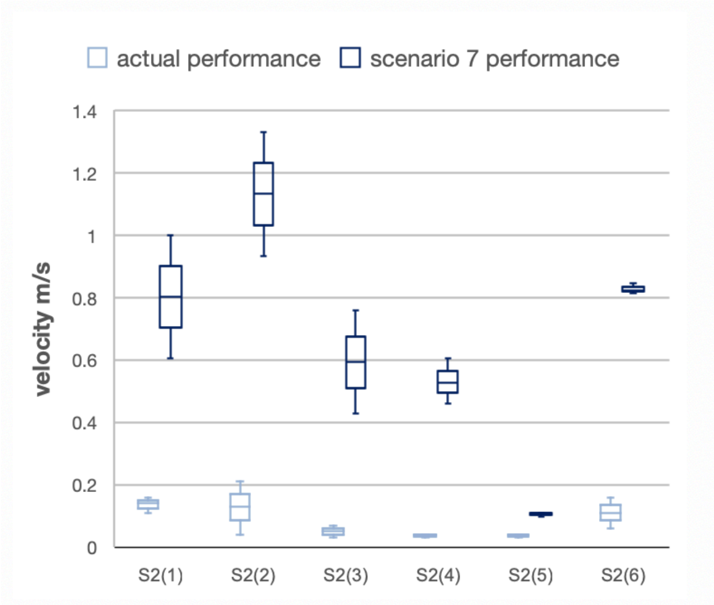


Figure 8-67 average velocity m/s for the S2 inner living spaces

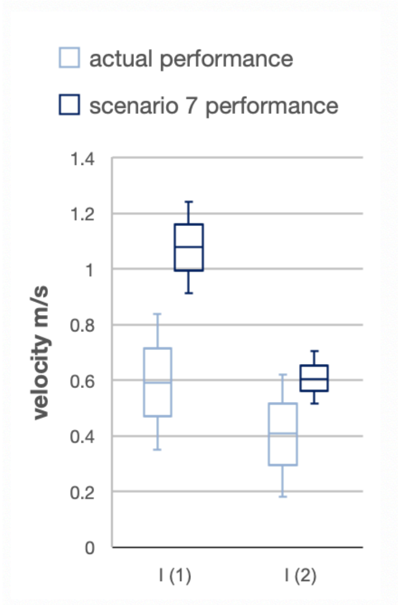


Figure 8-68 average velocity m/s for the Inner shafts' spaces

Table 8-8 illustrates the different internal airflow magnitude within the different space and compares it to the actual current performance of the case study building in Figure 8-66, Figure 8-67, and Figure 8-68 showing a general increase in magnitude in all the spaces specially in the S2 zones, and an average increase of the internal magnitude within the S1 and S2 spaces from 0.26 m/s to 1.23 m/s and from 0.08 m/s to 0.76 m/s respectively.

As discussed, scenario 7 is the combination of the retrofit parameters of scenarios 2 and 4 combined. The outcomes considering the airflow magnitude were contrasted together in Figure 8-69, Figure 8-70, and Figure 8-71. The comparison shows an average increase in all the spaces within scenario 7 against 2 and 4. However, the average increase in the magnitude differs according to the internal spaces' categorization. In the S1 external spaces, the magnitude increase differs according to their openings' performance, as the S1 spaces where the openings perform as an inlet. The average increase is relatively higher than the S1 spaces where the openings perform as an outlet. While considering the S2 internal spaces the average increase is relatively equal.

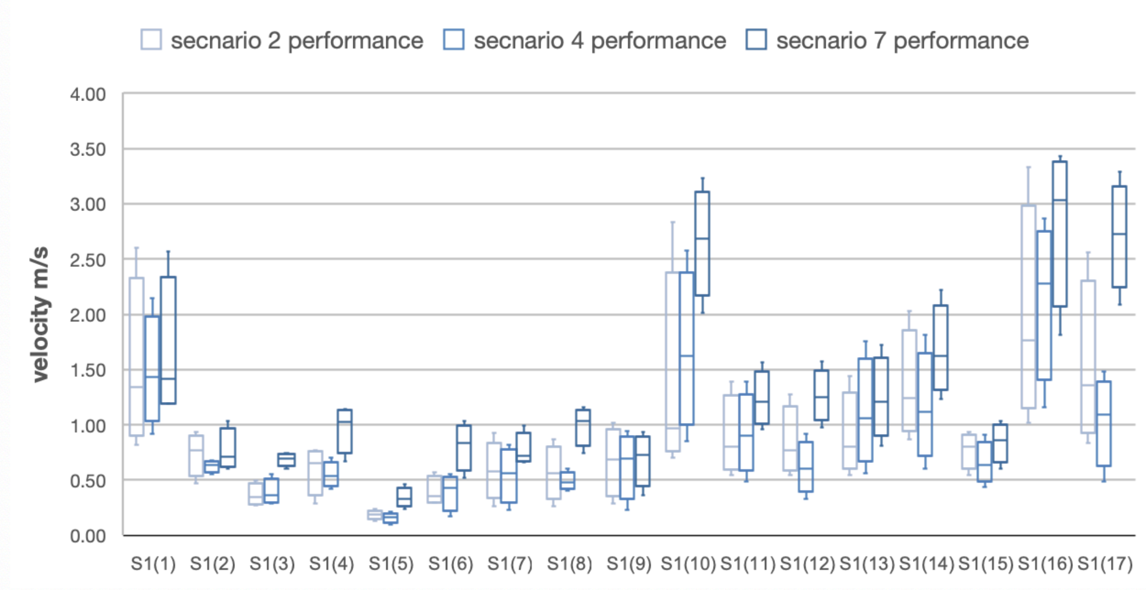


Figure 8-69 average velocity m/s for the S1 spaces in scenario 2, 4, and 7

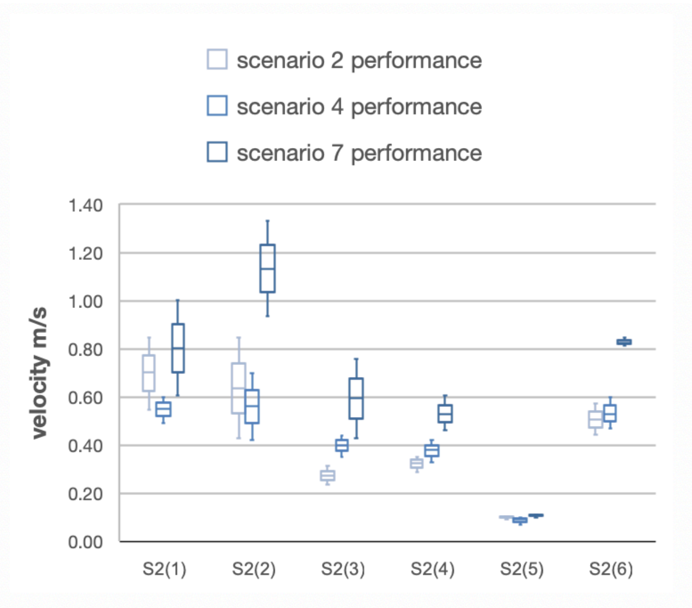


Figure 8-70 average velocity m/s for the S2 inner living spaces in scenario 2, 4, and 7

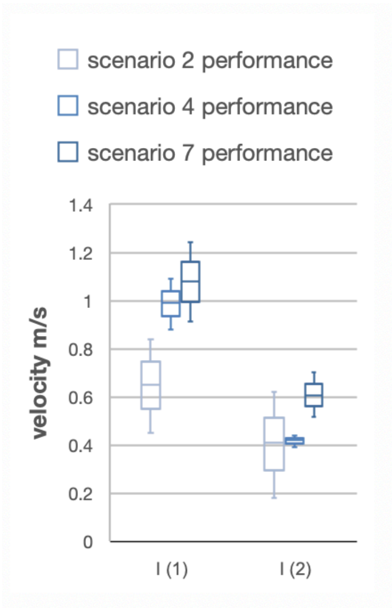


Figure 8-71 average velocity m/s for the Inner shafts' spaces in scenario 2, 4, and 7

8.4.2 Scenario 8 results

The scenario combines the effect of changing the opening type to an operable single hung upper window with the effect of mono pitch roof addition to the inner court with openings in the windward side with the combined effects of opening the internal transom windows, previously tested in scenarios 2 and 5 as a stand-alone strategy. The results are illustrated in Figure 8-72, Figure 8-73, Figure 8-74, Figure 8-75 for the airflow patterns and magnitudes on different levels in the detailed floor plan.

The results of this scenario demonstrate the effects of the increase in the velocity magnitude of the naturally induced air which was allowed by the increase in the opening size of the external S1 spaces combined with the effect of the roof addition with opening on the windward side that has a changing effect on the airflow behavior within the detailed floor plan, due to its performance as an inlet to the inner spaces. The airflow patterns are now entering the floor plan from the inner court and the S1 spaces on Sizostriss street and the alley, passing through the S2 spaces and extracted from the S1 spaces openings outlet on Masjid el Atarin street.

Having a different air flow patterns from the base case, where the external S1 spaces openings' on Sizostriss street and the small alley are still the main inlet for the detailed floor plan. The main air stream in coming from these spaces passing through the internal S2 spaces and the extraction is divided between the S1 external zones on Masjid el Atarin street and the internal shaft. The main noticeable difference is the amplified magnitude of the airflow with the S2 inner spaces of the detailed floor plan against the actual base case performance. The sections showing the connection of the inner court inlet performance are illustrated in Figure 8-76 and Figure 8-77 showing the connection with the inner spaces and the stairwell respectively demonstrating the amplified airflow magnitude as the air is induced from the inner court to the connected spaces.

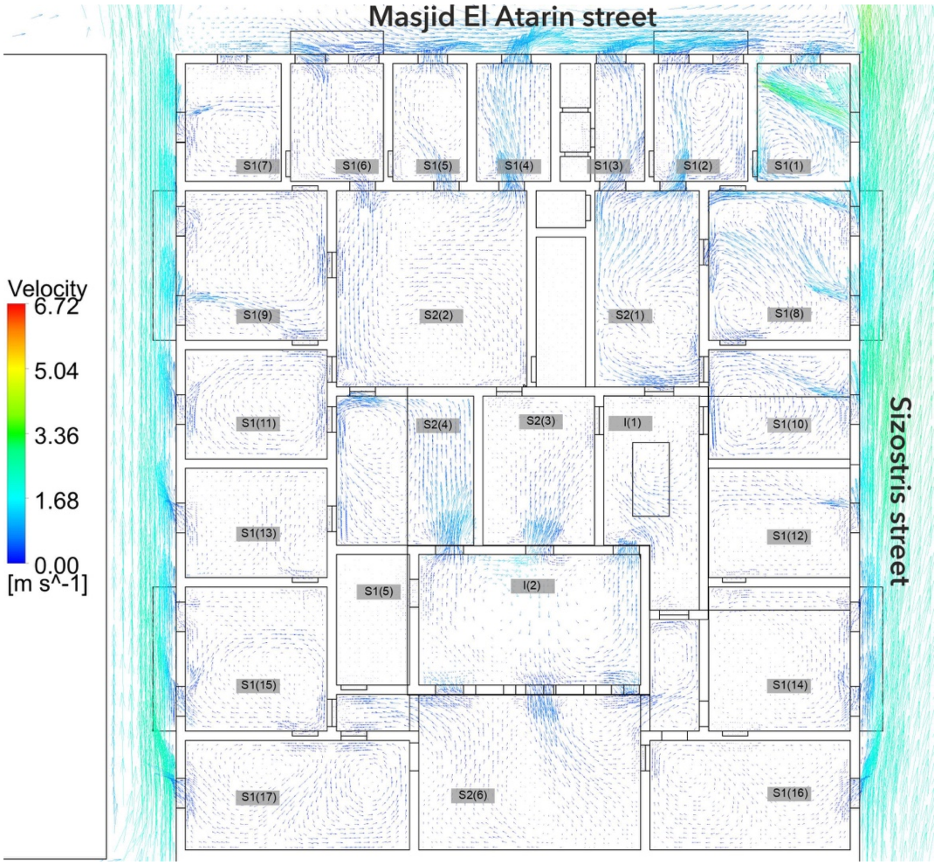


Figure 8-72 the airflow pattern inside the detailed floor scenario 8

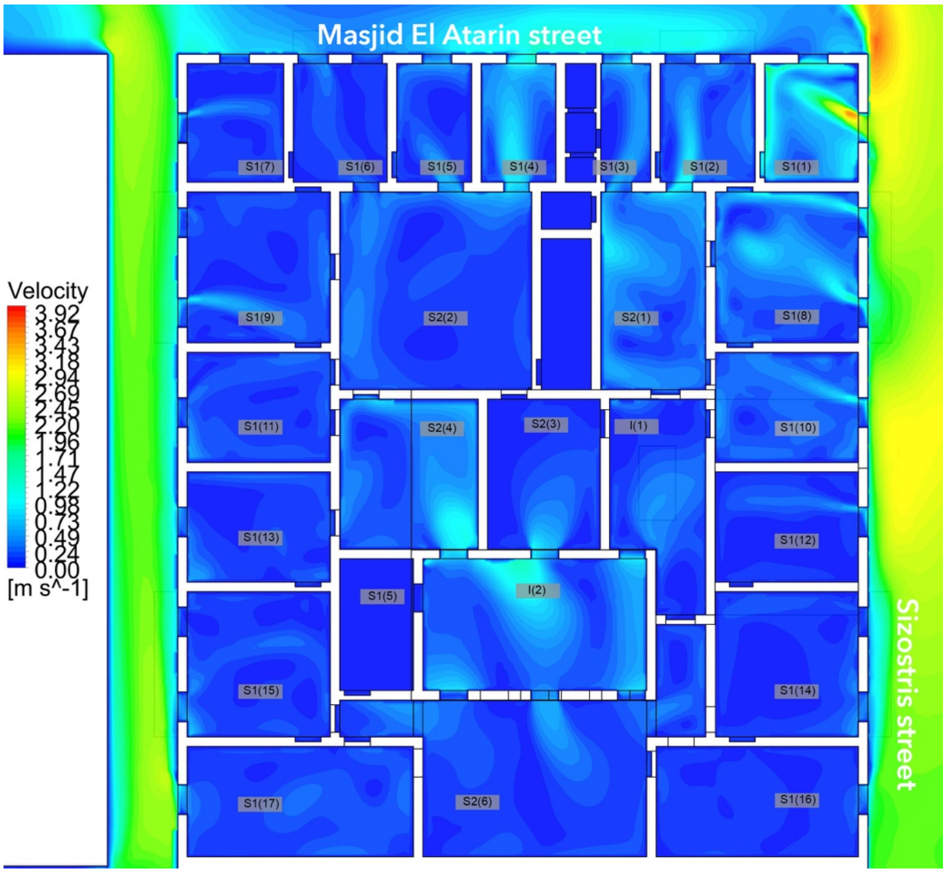


Figure 8-73 the airflow speed profile of the detailed floor scenario 8

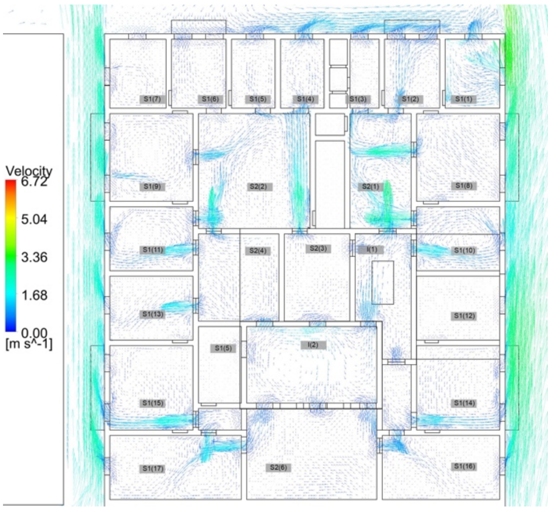


Figure 8-74 the airflow pattern inside the detailed floor scenario 8 at height 8.6 m

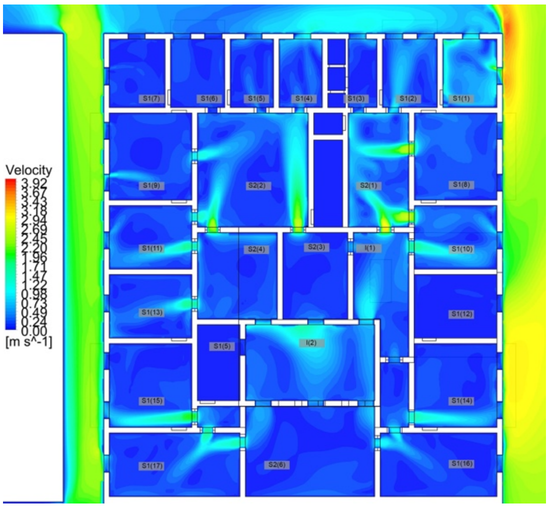


Figure 8-75 the airflow speed profile of the detailed floor scenario 8 at height 8.6 m

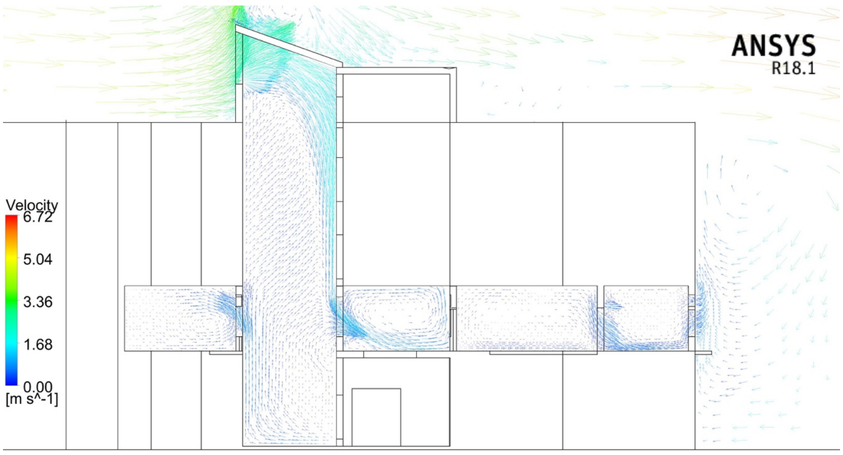


Figure 8-76 the airflow inlet from Sizostris street and the small alley showing the increase of the airflow magnitude

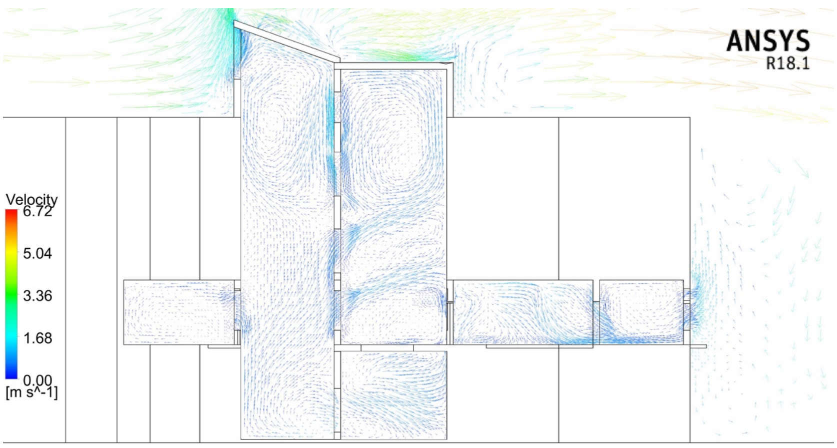


Figure 8-77 the airflow outlet on Msjid el Atarin street street the increase of the airflow magnitude

Table 8-9 internal airspeed inside the detailed floor plan spaces scenario 8

Zone		Inlet airspeed (m/s)	Internal airspeed (m/s)		Average airspeed (m/s)
			max	min	
S1	1	2.59	1.15	1.14	1.63
	2	0.79	1.16	0.54	0.83
	3	0.86	0.79	0.52	0.72
	4	1.30	1.16	0.95	1.13
	5	0.80	0.70	0.40	0.63
	6	0.56	0.46	0.40	0.47
	7	0.90	0.70	0.56	0.72
	8	1.96	1.30	1.11	1.46
	9	1.03	0.68	0.47	0.73
	10	1.59	0.96	0.77	1.10
	11	0.67	0.46	0.29	0.47
	12	1.23	0.84	0.70	0.92
	13	0.51	0.39	0.24	0.37
	14	1.43	1.03	0.67	1.04
	15	0.97	0.73	0.37	0.68
	16	0.79	0.53	0.36	0.56
	17	0.53	0.39	0.25	0.39
S2	1	-	1.25	0.90	1.09
	2	-	0.83	0.70	0.77
	3	-	1.13	0.79	0.96
	4	-	1.16	0.74	0.96
	5	-	0.08	0.06	0.08
	6	-	1.01	0.83	0.94
I	1	-	1.16	0.83	1.00
	2	-	0.66	0.31	0.49

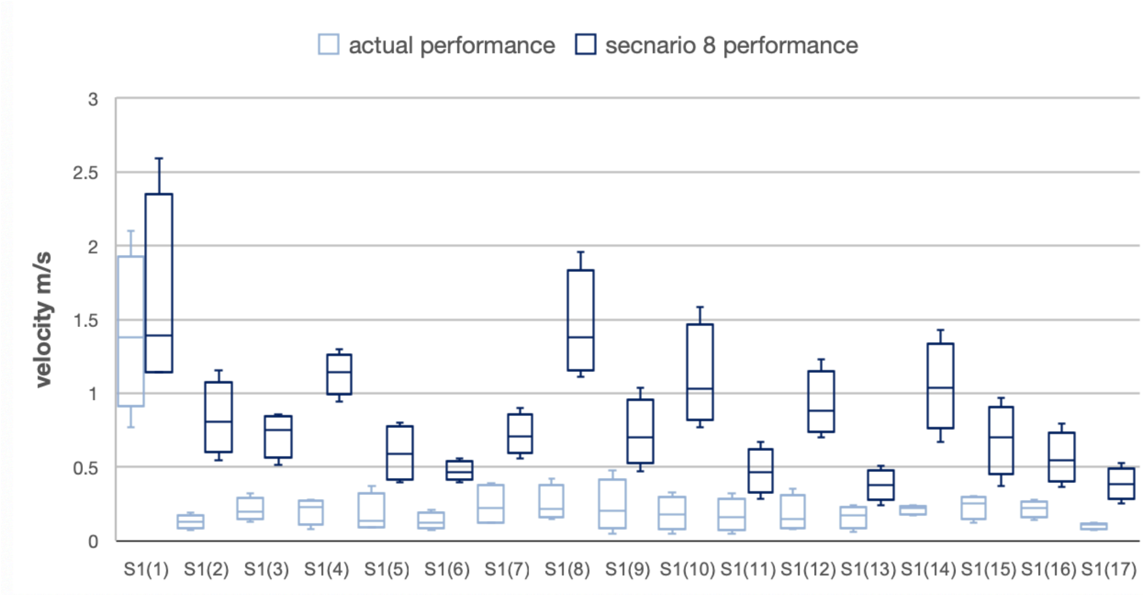
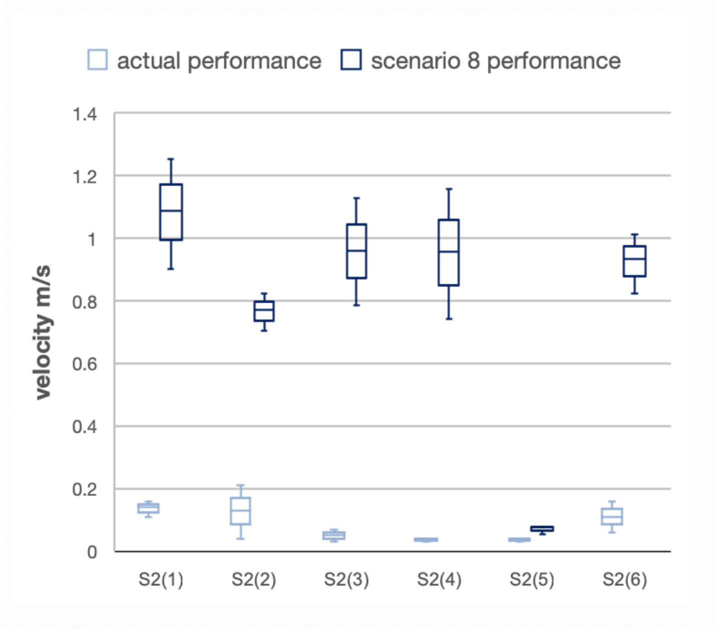


Figure 8-78 average velocity m/s for the S1 spaces



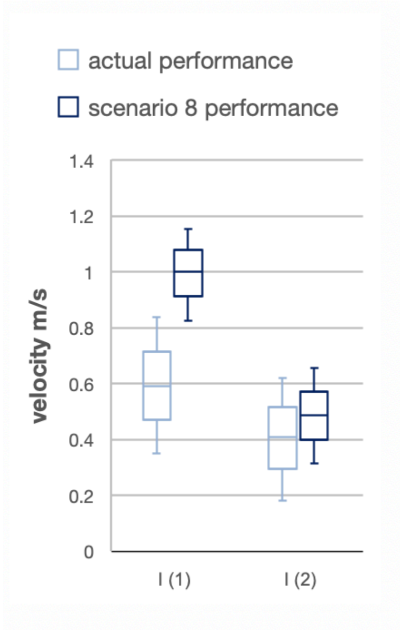


Figure 8-79 average velocity m/s for the S2 inner living spaces

Figure 8-80 average velocity m/s for the Inner shafts' spaces

Table 8-9 illustrates the different internal airflow magnitude within the different space and compares it to the actual current performance of the case study building in Figure 8-78, Figure 8-79, Figure 8-80 showing a general increase in magnitude in all the spaces specially in the S2 zones, and an average increase of the internal magnitude within the S1 and S2 spaces from 0.26 m/s to 0.77 m/s and from 0.08 m/s to 0.92 m/s respectively.

As demonstrated, scenario 8 is the combination of the retrofit parameters of scenarios 2 and 6 combined, the outcomes considering the airflow magnitude were contrasted together in Figure 8-81, Figure 8-82, Figure 8-83. The comparison shows an average increase in all the spaces within scenario 8 against 6, but when the results were compared to scenario 2 in the S1 external spaces the average internal airflow magnitude is lower in most of the spaces as a result of the lower pressure difference between the S1 openings and the outlets. The S1 external spaces magnitude where the openings perform as an outlet, there is a slight increase in magnitude against scenario 2, while the S1 spaces where the openings perform as an inlet, the magnitude is lower than scenario 2. However, when considering the S2 internal spaces there is a noticeable average increase in the magnitude to the internal spaces, as a result of their direct interaction with the inner atrium.

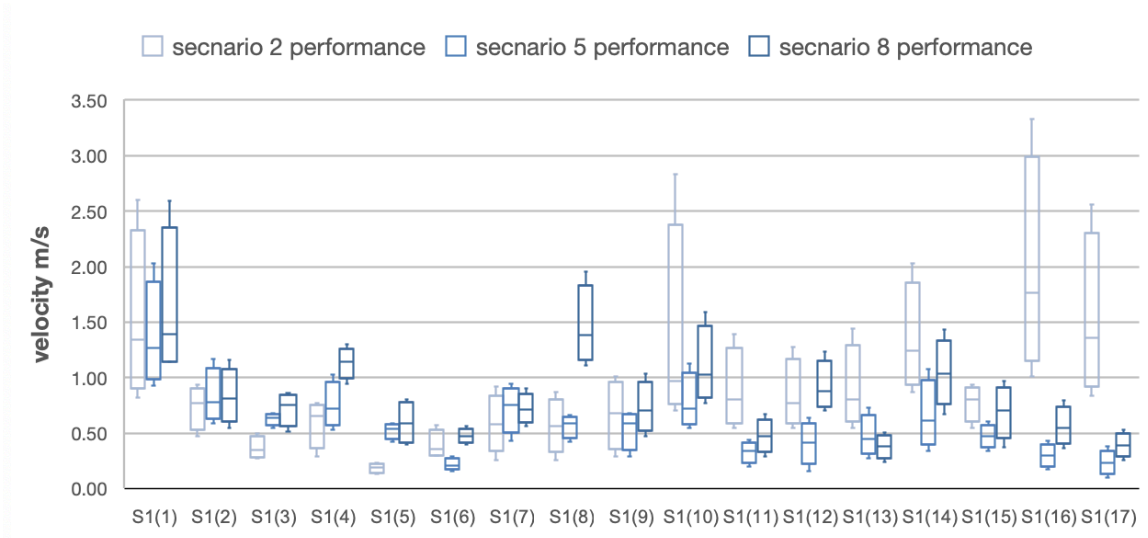


Figure 8-81 average velocity m/s for the S1 spaces in scenario 2, 5, and 8

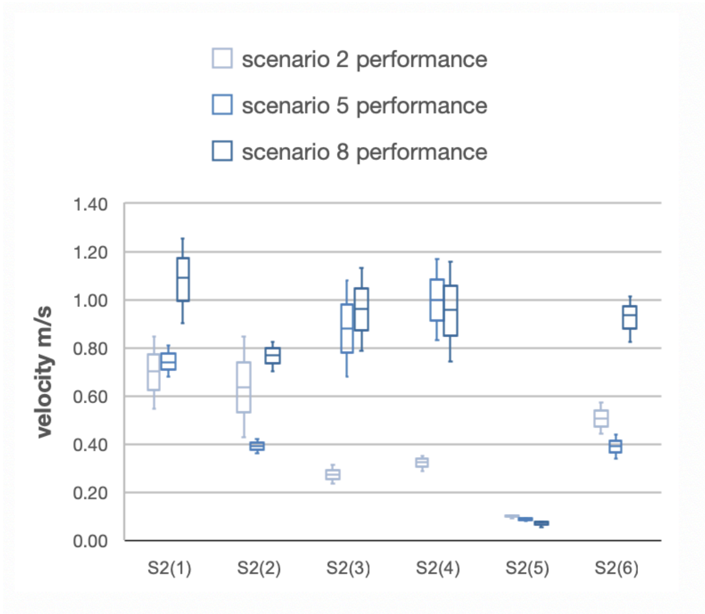


Figure 8-82 average velocity m/s for the S2 inner living spaces in scenario 2, 5, and 8

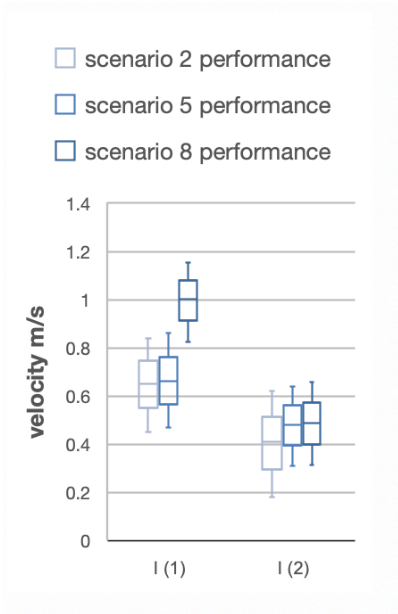


Figure 8-83 average velocity m/s for the Inner shafts' spaces in scenario 2, 5, and 8

8.4.3 Scenario 9 results

The scenario combines the effect of changing the opening type to an operable single hung upper window with the effect of mono pitch roof addition to the inner court with openings in the windward and leeward side with the combined effects of opening the internal transom windows, previously tested in scenarios 2 and 5 as a stand-alone strategy. The results are illustrated in Figure 8-84, Figure 8-85, Figure 8-86, and Figure 8-87 for the airflow patterns and magnitudes on different levels in the detailed floor plan.

The results of this scenario demonstrate the effects of the increase in the velocity magnitude of the naturally induced air which was allowed by the increase in the opening size of the external S1 spaces. This, combined with the effect of the roof addition with opening on the windward and leeward side that has a changing effect on the airflow behavior within the detailed floor plan while interacting within the inner direct contact inner spaces S2 resulting in a mixed behavior of inducing or extracting the air from these spaces according to their position regarding the windward and the leeward side of the atrium. Which all in return affected the S1 external spaces according to their relation with the different behavior of the S1 spaces, as discussed earlier in scenario 6 results.

The sections showing the connection of the inner court inlet and outlet performance with the change of the opening type are illustrated in Figure 8-88and Figure 8-89 showing the connection with the inner spaces and the stairwell respectively demonstrates the amplified airflow magnitude as the air is induced from the inner court to the connected spaces.

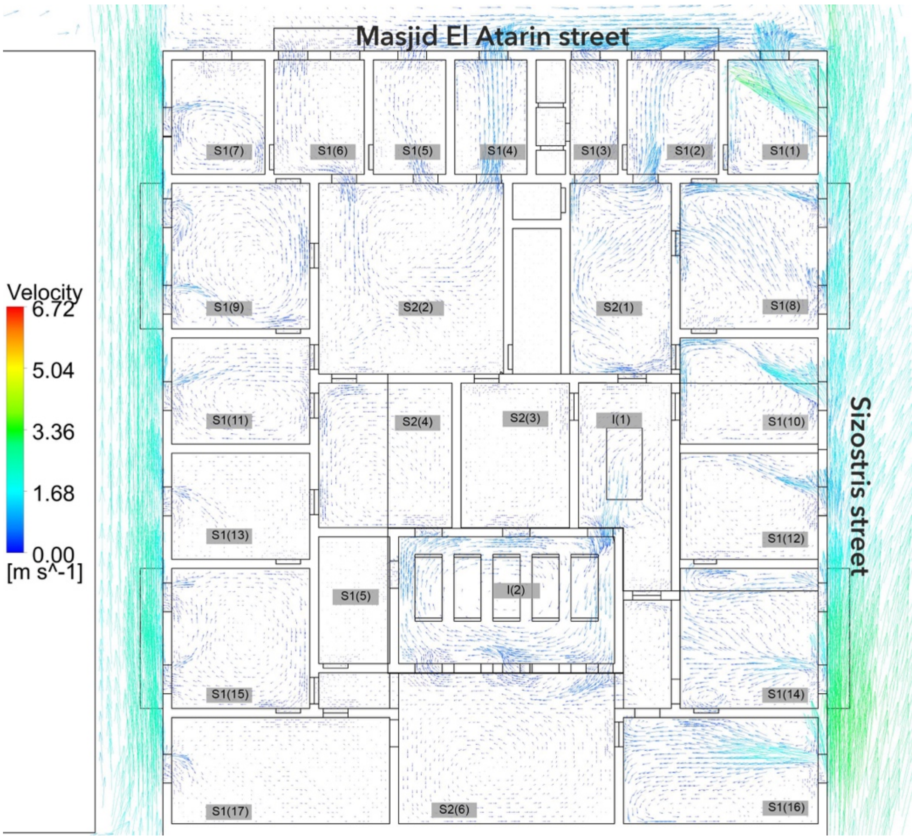


Figure 8-84 the airflow pattern inside the detailed floor scenario 9

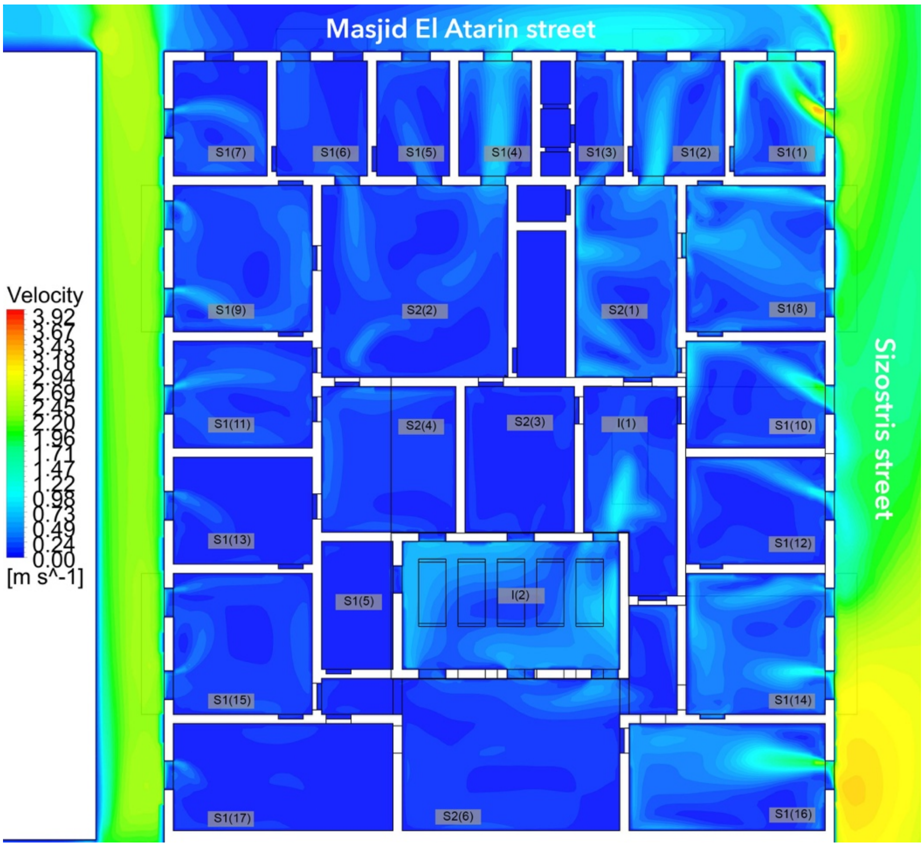


Figure 8-85 the airflow speed profile of the detailed floor scenario 9

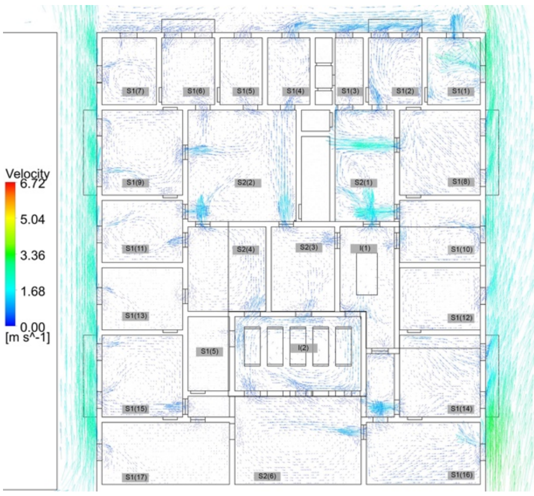


Figure 8-86 the airflow pattern inside the detailed floor scenario 9 at height 8.6 m

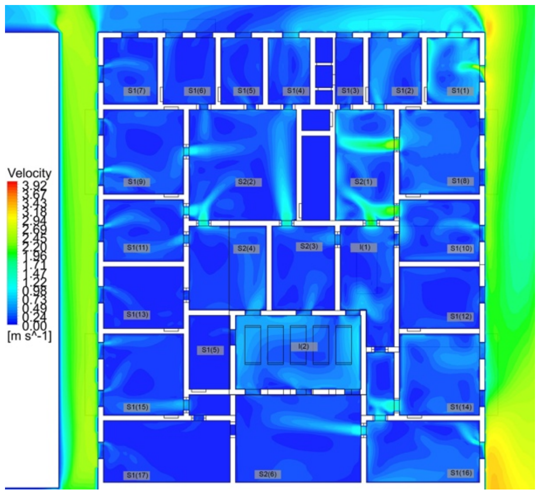


Figure 8-87 the airflow speed profile of the detailed floor scenario 9 at height 8.6 m

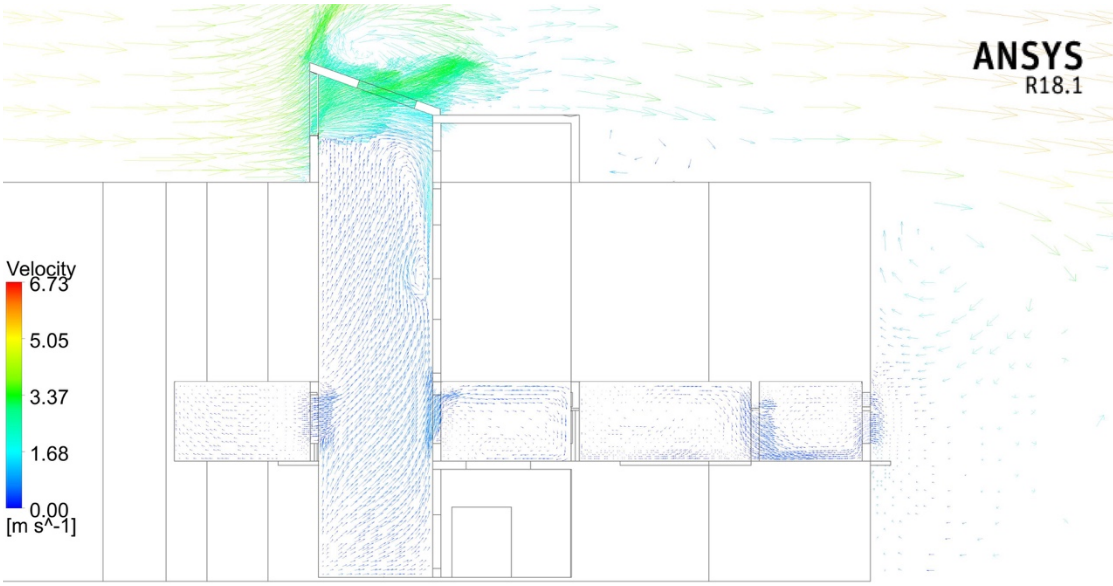


Figure 8-88 the combined effect of changing opening type and roof addition with opening on the windward and leeward side with the inner spaces, scenario 9

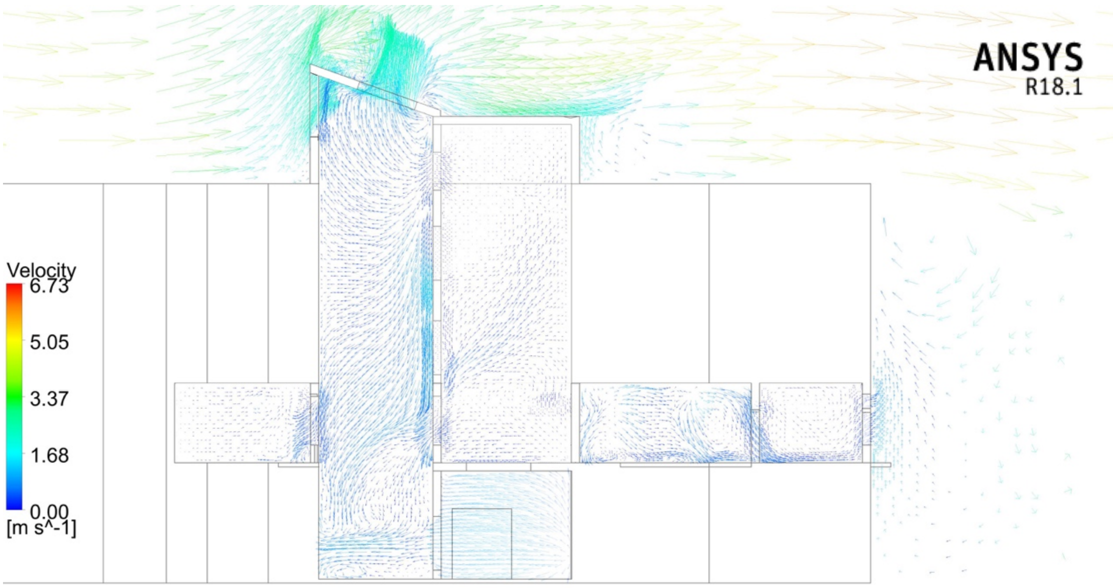


Figure 8-89 the combined effect of changing opening type and roof addition with opening on the windward and leeward side with the stair well, scenario 9

Table 8-10 internal airspeed inside the detailed floor plan spaces scenario 9

Zone		Inlet airspeed (m/s)	Internal airspeed (m/s)		Average airspeed (m/s)
			max	min	
S1	1	2.51	1.25	0.93	1.56
	2	1.06	0.77	0.44	0.76
	3	0.76	0.74	0.60	0.70
	4	1.37	1.34	1.24	1.32
	5	0.64	0.59	0.53	0.59
	6	0.67	0.64	0.46	0.59
	7	0.86	0.64	0.46	0.64
	8	1.56	1.14	0.82	1.17
	9	0.92	0.84	0.53	0.76
	10	2.62	1.59	0.73	1.64
	11	0.96	0.67	0.54	0.73
	12	1.42	1.10	0.77	1.09
	13	0.74	0.63	0.43	0.60
	14	1.96	1.56	1.14	1.54
	15	0.66	0.51	0.41	0.53
	16	3.4	2.75	1.72	2.63
	17	1.02	0.90	0.73	0.87
S2	1	-	1.16	0.82	0.99
	2	-	0.97	0.82	0.90
	3	-	0.60	0.57	0.59
	4	-	0.64	0.53	0.59
	5	-	0.10	0.07	0.09
	6	-	0.77	0.53	0.66
I	1	-	1.03	0.77	0.90
	2	-	0.59	0.37	0.49

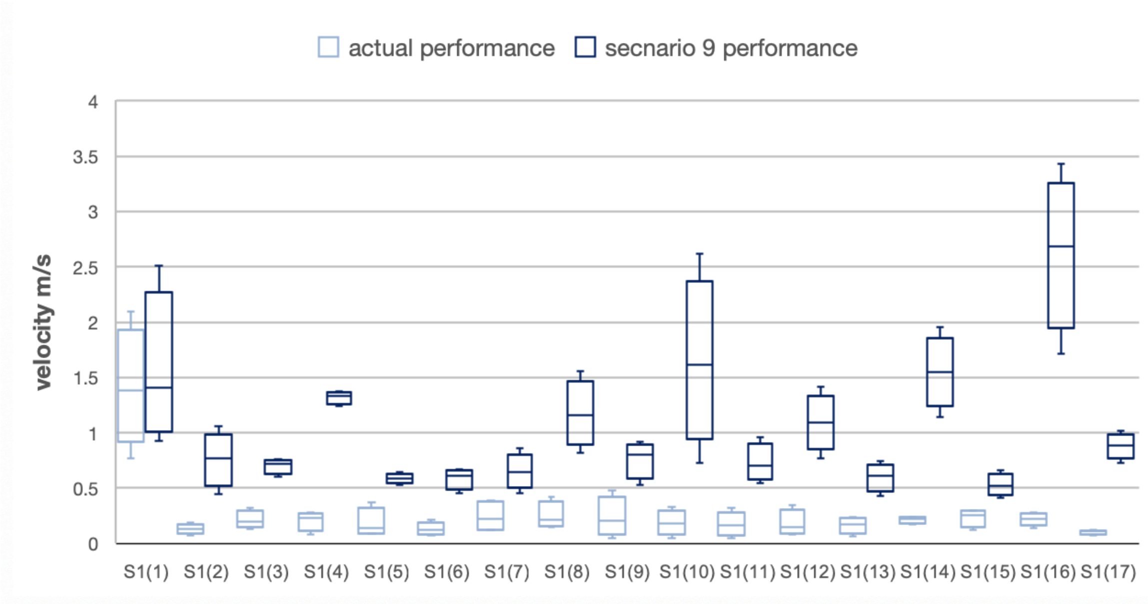


Figure 8-90 average velocity m/s for the S1 spaces

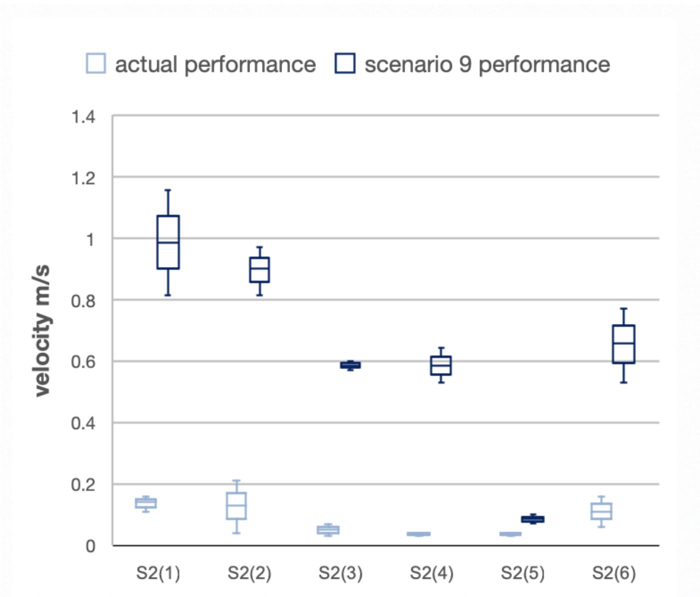


Figure 8-91 average velocity m/s for the S2 inner living spaces

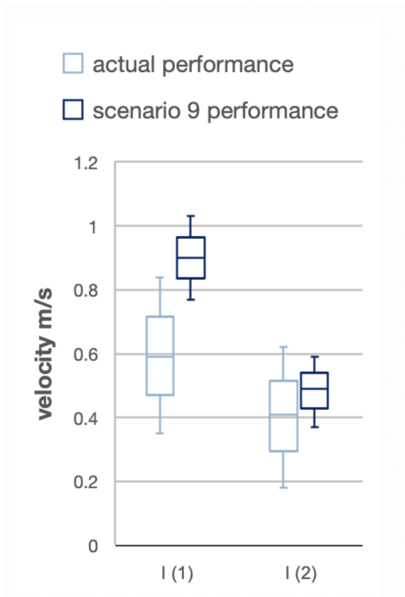


Figure 8-92 average velocity m/s for the Inner shafts' spaces

Table 8-3 illustrates the different internal airflow magnitudes within the different space and compares it to the actual current performance of the case study building in Figure 8-15, Figure 8-16, and Figure 8-17 showing a general increase in magnitude in all the spaces specially in the S2 zones, and an average increase of the internal magnitude within the S1 and S2 spaces from 0.26 m/s to 0.98 m/s and from 0.08 m/s to 0.75 m/s respectively.

As discussed, scenario 9 is the combination of the retrofit parameters of scenarios 2 and 6 combined. The outcomes considering the airflow magnitude were contrasted together in Figure 8-93, Figure 8-94, and Figure 8-95. The comparison shows an average increase of airflow magnitude mainly in the inner S2 spaces within scenarios 9 against 2 and 5. However, within the external S1 spaces scenario 9 with the combined effect of the retrofit strategies performs slightly better regarding the magnitude when compared to the scenario 6 results, but when the results are compared to the S1 spaces of scenario 2, the average airflow magnitude is higher than the S1 spaces where the openings perform as an outlet and lower than the S1 spaces where the openings perform as an inlet, this is due to the change in the airflow pattern as a result of the mixed behaviour of the inner atrium.

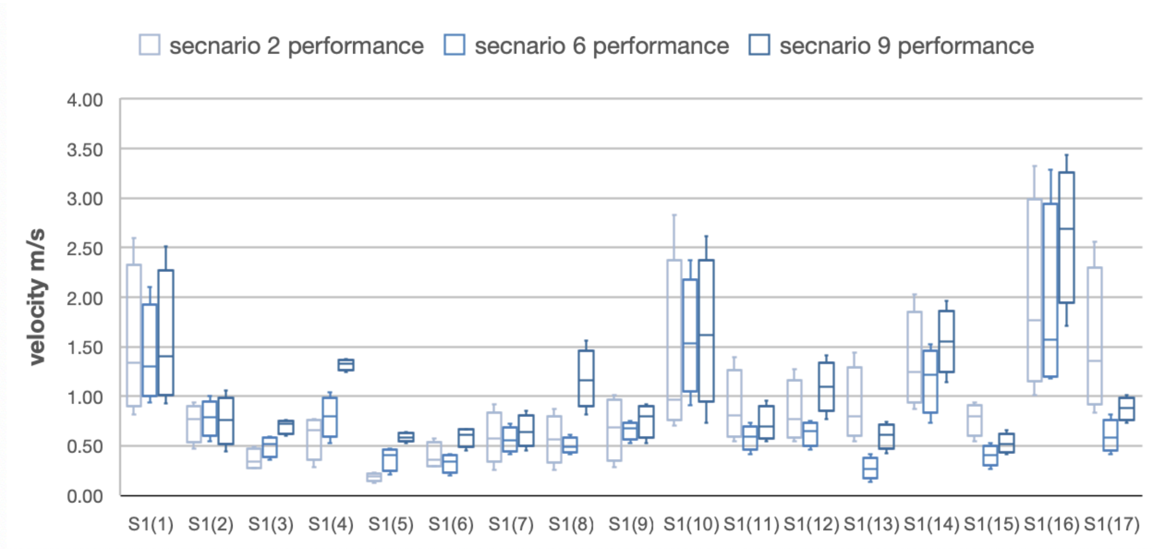


Figure 8-93 average velocity m/s for the S1 spaces in scenario 2, 6, and 9

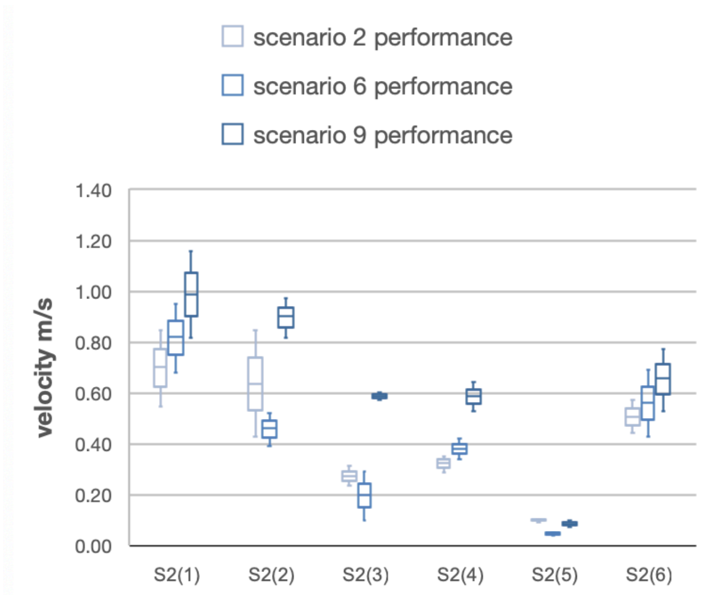


Figure 8-94 average velocity m/s for the S2 inner living spaces in scenario 2, 6, and 9

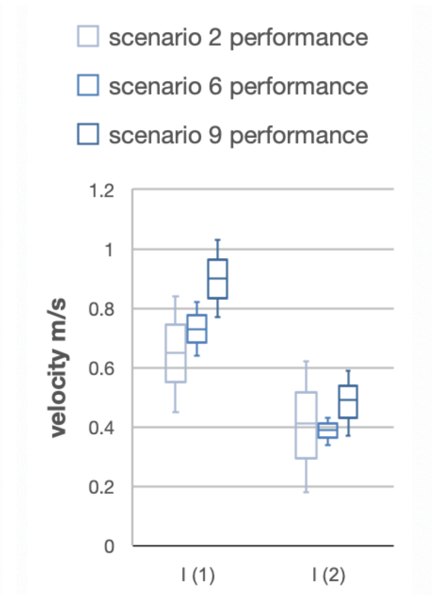


Figure 8-95 average velocity m/s for the Inner shafts' spaces in scenario 2, 6, and 9

8.4.4 Scenario 10 results

The scenario combines the effect of changing the opening type to an operable top hung upper window with the effect of mono pitch roof addition to the inner court with openings in the leeward side with the combined effects of opening the internal transom windows, previously tested in scenarios 3 and 4 as a stand-alone strategy. The results are illustrated in Figure 8-96, Figure 8-97, Figure 8-98, Figure 8-99 for the airflow patterns and magnitudes on different levels in the detailed floor plan.

The results of this scenario demonstrate the effects of the increase in the velocity magnitude of the naturally induced air which was allowed by the increase in the opening size of the external S1 spaces and the horizontal projection of the casement effect on directing the airflow, combined with the effect of the roof addition with an opening on the leeward side that amplified the performance of the inner court as a shaft.

The airflow patterns had a directed airflow pattern as a result of the opening horizontal projection, and the amplified magnitude of the airflow with the inner spaces of the detailed floor plan against the actual base case performance due to the enhanced shaft performance of the inner atrium. However, the behavior of inlets and outlets is kept the same with the same air flow patterns as the base case, where the external S1 spaces openings' on Sizostriss street and the small alley are still the main inlet for the detailed floor plan, the main air stream in coming from these spaces passing through the internal S2 spaces and the extraction is divided between the S1 external zones on Masjid el Atarin street and the internal shaft

The sections showing the connection of the inner court shaft enhancement combined with the change of the opening type are illustrated Figure 8-100 and Figure 8-101 showing the connection with the inner spaces and the stairwell respectively demonstrating the amplified airflow magnitude increase against the actual performance of the open court ,and the redirecting of the patterns from the top opening horizontal projection .

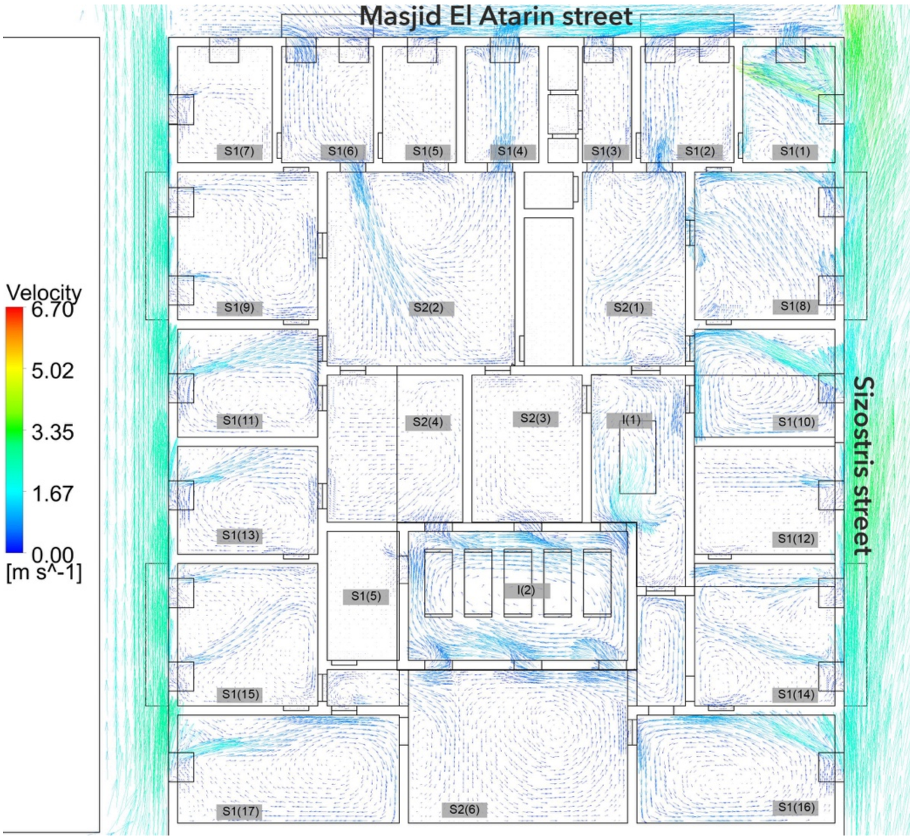


Figure 8-96 the airflow pattern inside the detailed floor scenario 10

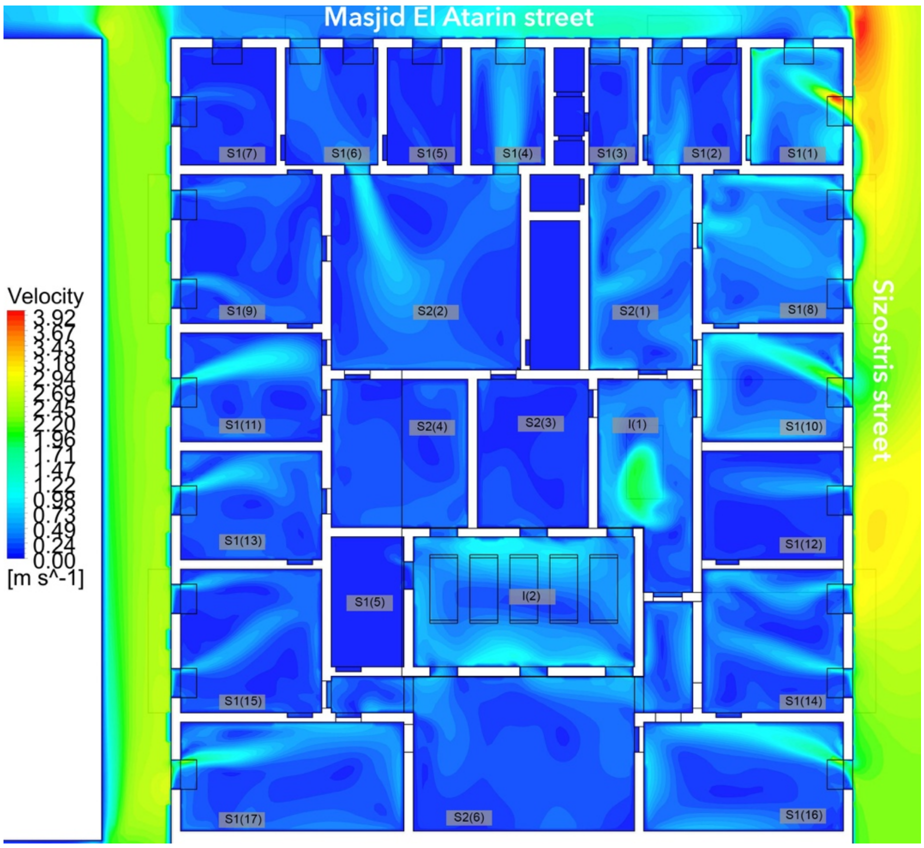


Figure 8-97 the airflow speed profile of the detailed floor scenario 10

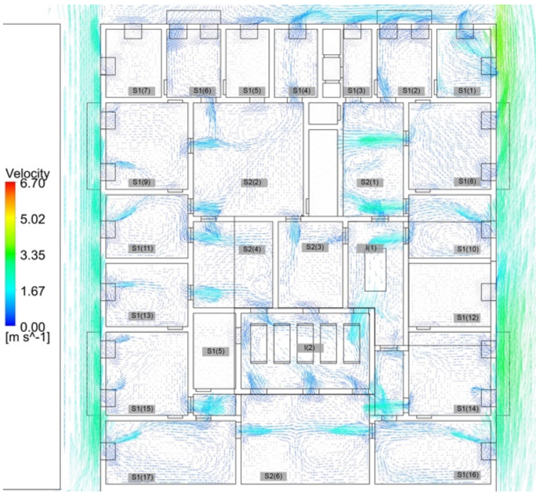


Figure 8-98 the airflow pattern inside the detailed floor scenario 10 at height 8.6 m

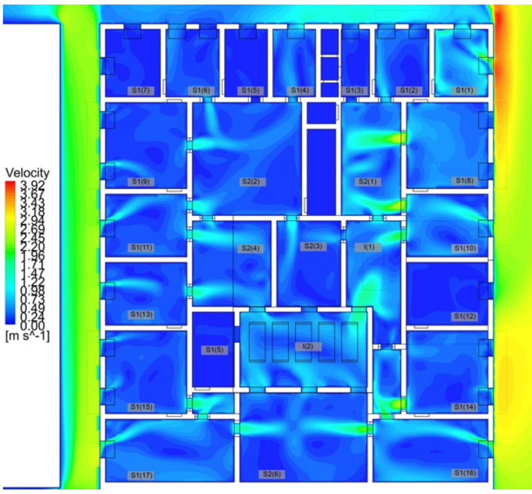


Figure 8-99 the airflow speed profile of the detailed floor scenario 10 at height 8.6 m

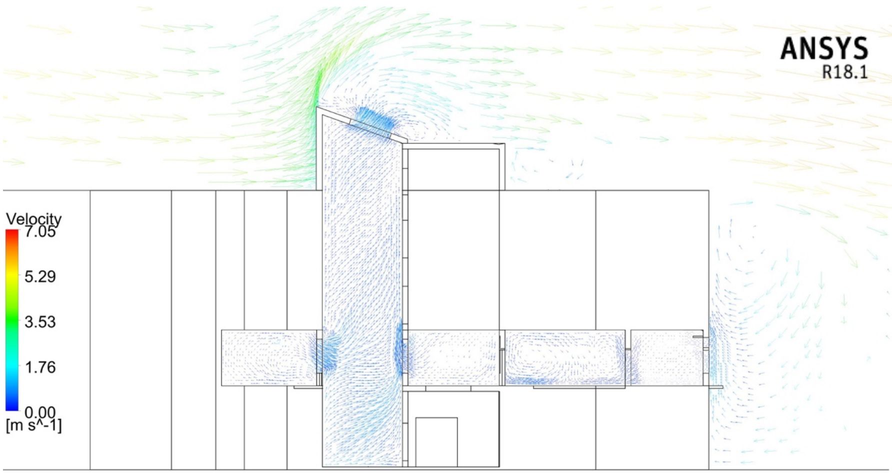


Figure 8-100 the inner court shaft performance connection with the S2 spaces, and the effect of opening type projection in the S1 spaces of scenario 10

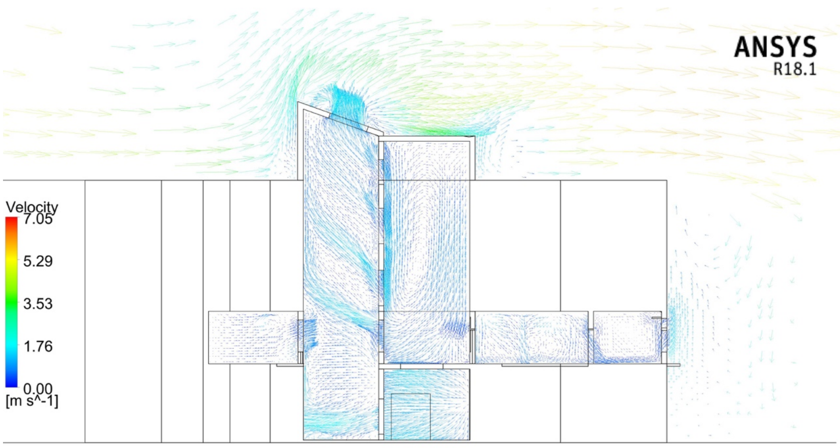


Figure 8-101 the inner court shaft performance connection with the stair well, and the effect of opening type projection in the S1 spaces of scenario 10

Table 8-11 internal airspeed inside the detailed floor plan spaces scenario 10

Zone		Inlet airspeed (m/s)	Internal airspeed (m/s)		Average airspeed (m/s)
			max	min	
S1	1	2.55	0.89	0.79	1.41
	2	1.10	0.97	0.64	0.90
	3	0.77	0.77	0.63	0.73
	4	1.26	1.22	0.84	1.10
	5	0.69	0.64	0.60	0.64
	6	1.10	0.84	0.57	0.84
	7	0.90	0.84	0.61	0.79
	8	1.36	1.24	0.93	1.17
	9	1.00	0.89	0.79	0.89
	10	3.26	2.80	2.29	2.79
	11	1.70	1.39	1.09	1.39
	12	1.63	1.04	0.82	1.16
	13	1.72	1.19	1.02	1.30
	14	2.20	1.34	1.13	1.55
	15	1.06	0.83	0.61	0.83
	16	3.46	3.03	2.23	2.90
	17	3.33	2.79	1.67	2.60
S2	1	-	1.02	0.70	0.86
	2	-	1.33	1.02	1.17
	3	-	0.73	0.59	0.66
	4	-	0.80	0.77	0.79
	5	-	0.11	0.10	0.11
	6	-	0.94	0.84	0.90
I	1	-	1.27	0.93	1.10
	2	-	0.53	0.25	0.39

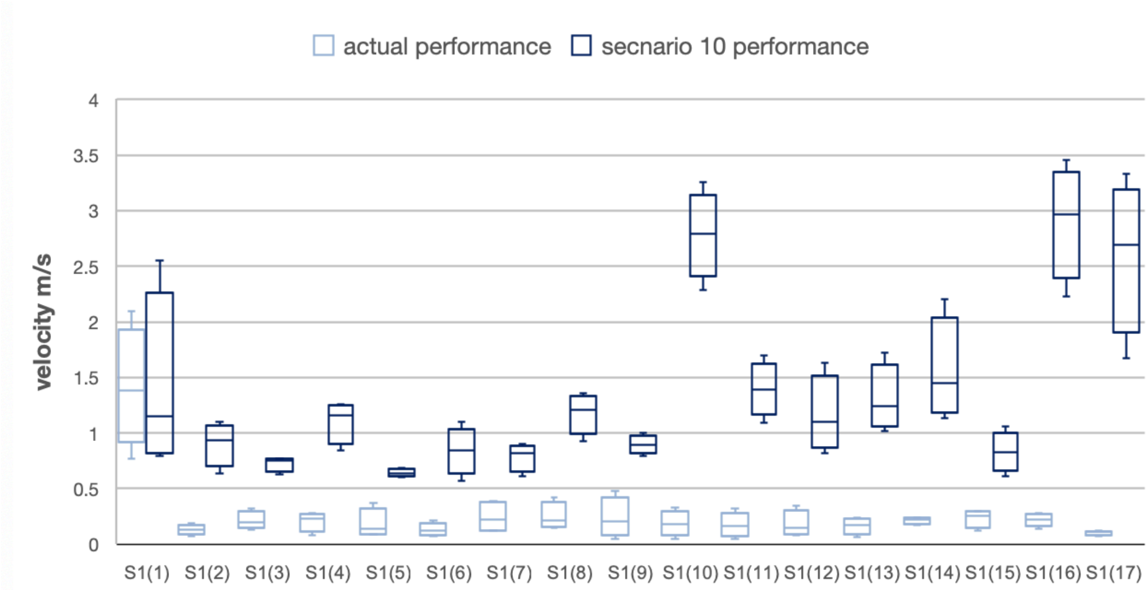


Figure 8-102 average velocity m/s for the S1 spaces

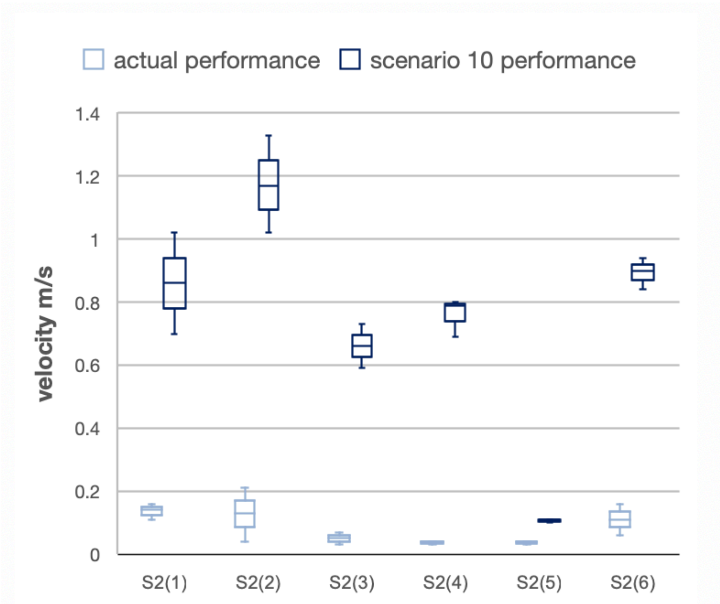


Figure 8-103 average velocity m/s for the S2 inner living spaces

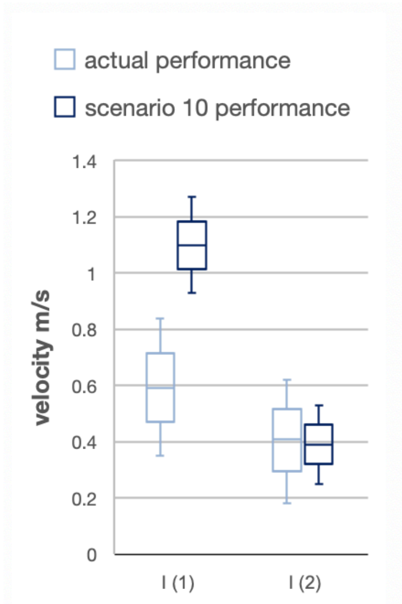


Figure 8-104 average velocity m/s for the Inner shafts' spaces

Table 8-11 illustrates the different internal airflow magnitude within the different space and compares it to the actual current performance of the case study building in Figure 8-102, Figure 8-103, Figure 8-104 showing a general increase in magnitude in all the spaces specially in the S2 zones, and an average increase of the internal magnitude within the S1 and S2 spaces from 0.26 m/s to 1.28 m/s and from 0.08 m/s to 0.88 m/s respectively.

As mentioned, scenario 8 is the combination of the retrofit parameters of scenarios 3 and 4. The outcomes considering the airflow magnitude were contrasted together in Figure 8-105, Figure 8-106, and Figure 8-107. The comparison shows an average increase in all the spaces within scenario 8 against 3 and 4. However, the average increase in the magnitude differs according to the internal spaces' categorization. In the S1 external spaces most of the zones improvements are better than the results of both scenarios testing the retrofit action as a stand-alone system as just one zone performed better in scenario 3 S1(9), and another performed better in scenario 4 S1 (13). While considering the S2 internal spaces, the average increase is at a higher rate against scenario 3 and 4 in all the zones.

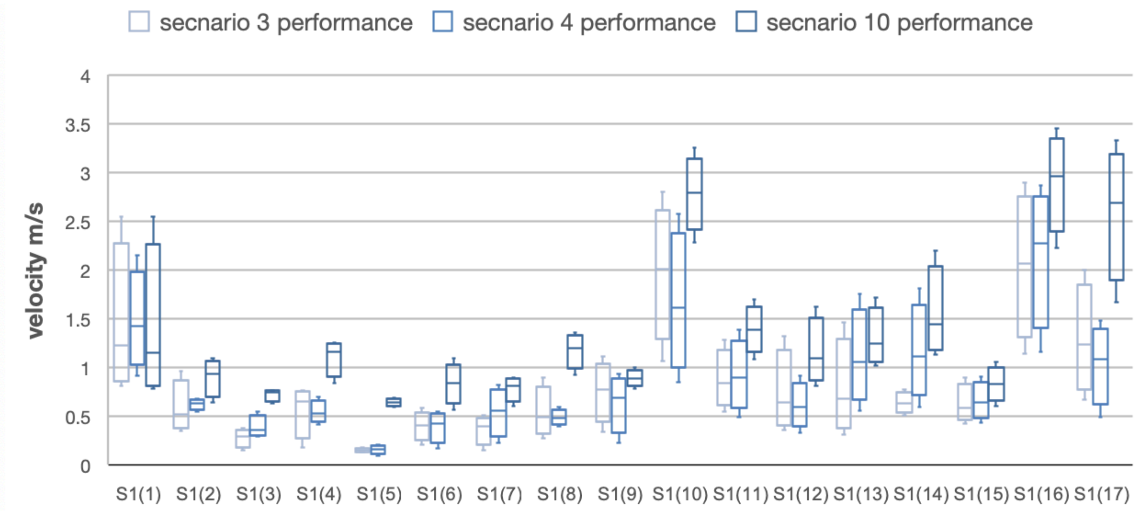


Figure 8-105 average velocity m/s for the S1 spaces in scenario 3, 4, and 10

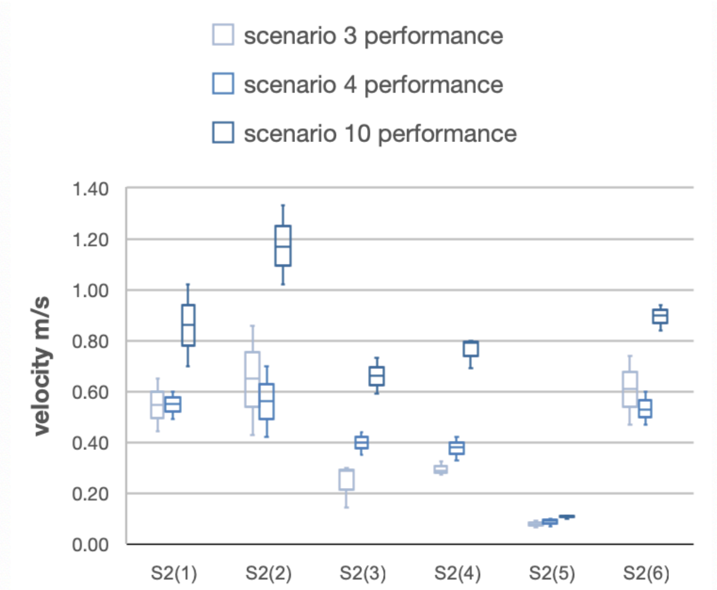


Figure 8-106 average velocity m/s for the S2 inner living spaces in scenario 3, 4, and 10

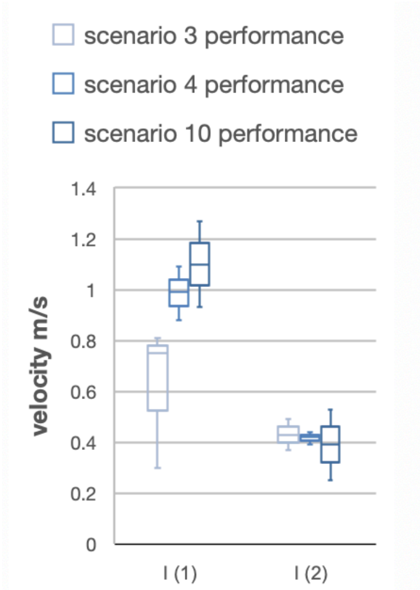


Figure 8-107 average velocity m/s for the Inner shafts' spaces in scenario 3, 4, and 10

8.4.5 Scenario 11 results

The scenario combines the effect of changing the opening type to an operable top hung upper window with the effect of mono pitch roof addition to the inner court with openings in the windward side with the combined effects of opening the internal transom windows, previously tested in scenarios 3 and 5 as a stand-alone strategy. The results are illustrated in Figure 8-108, Figure 8-109, Figure 8-110, and Figure 8-111 for the airflow patterns and magnitudes on different levels in the detailed floor plan.

The results of this scenario demonstrate the effects of the increase of the velocity magnitude of the naturally induced air which was allowed by the increase in the opening size of the external S1 spaces and the horizontal projection of the casement effect on directing the airflow, combined with the effect of the roof addition with an opening on the windward side changing the properties of the inner court from air extraction to an inlet to the inner spaces.

The airflow patterns had a directed airflow pattern as a result of the opening horizontal projection. Moreover, the characteristic change of the inner atrium changed the airflow pattern with the detailed floor plan. The airflow is now entering the floor plan from the inner court and the S1 spaces on Sizostriss street and the alley, passing through the S2 spaces and extracted from the S1 spaces openings outlet on Masjid el Atarin street. This change in pattern enhanced the airflow magnitude within the inner S2 spaces due to their direct interaction with the inlet spaces, and the S1 spaces on the Masjid el Atrarin street.

The sections showing the connection of the inner court inlet performance combined with the change of the opening type are illustrated in Figure 8-112and Figure 8-113 showing the connection with the inner spaces and the stairwell respectively demonstrating the amplified airflow magnitude increase within the inner S1 spaces, and the redirection of the patterns from the top opening horizontal projection in the external S2 spaces.

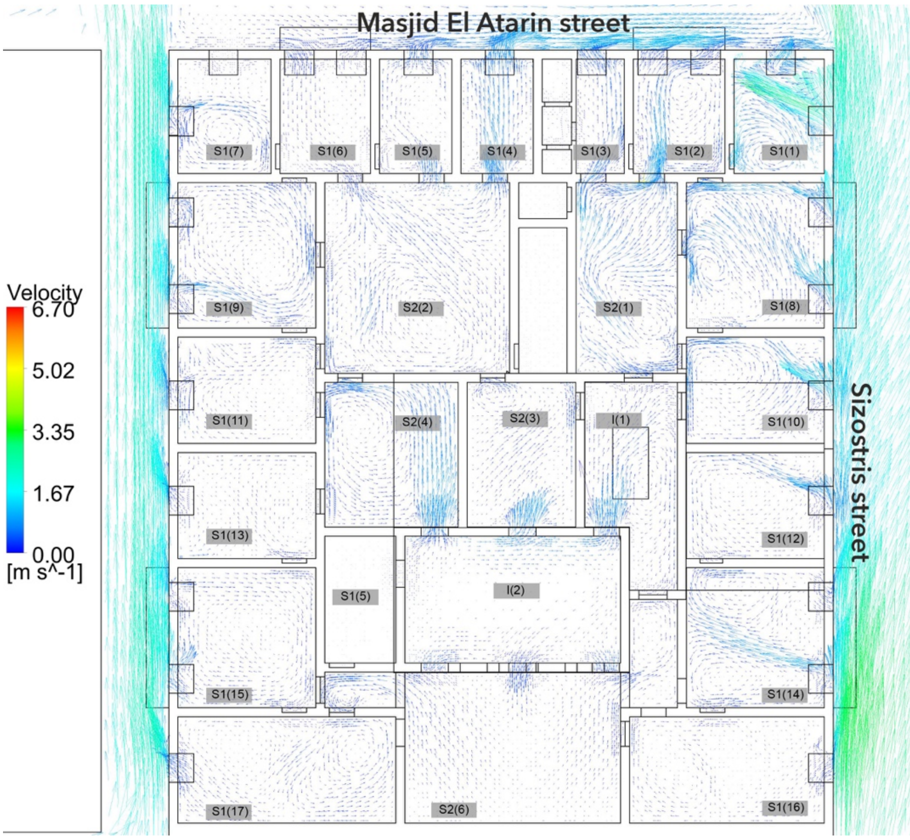


Figure 8-108 the airflow pattern inside the detailed floor scenario 11

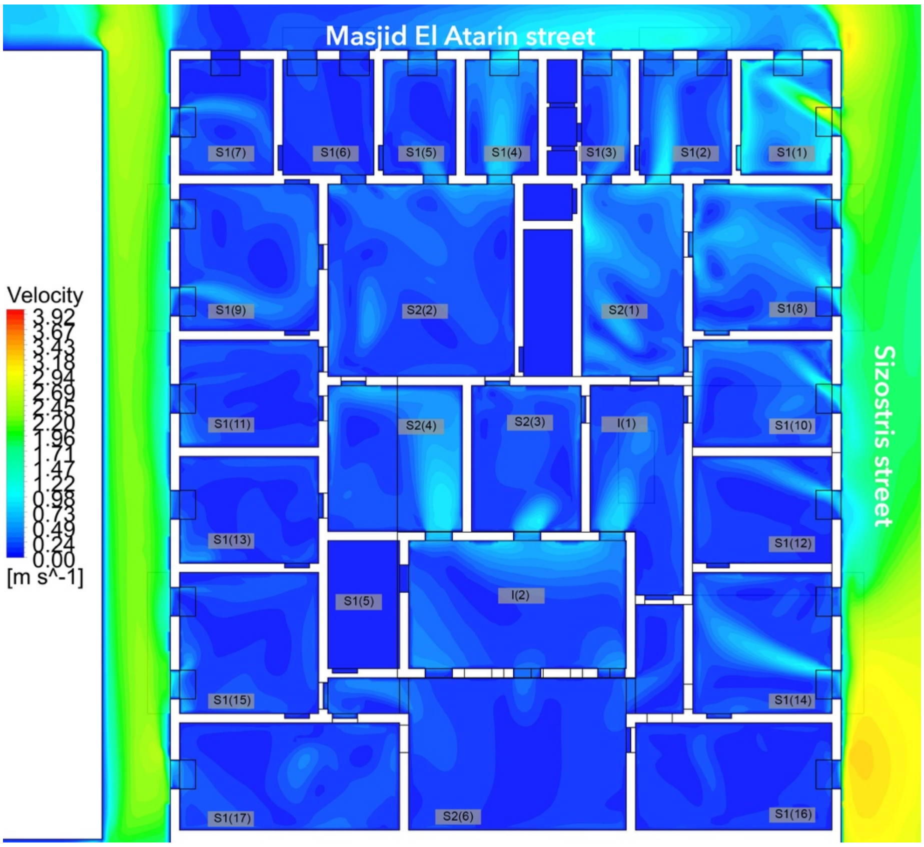


Figure 8-109 the airflow speed profile of the detailed floor scenario 11

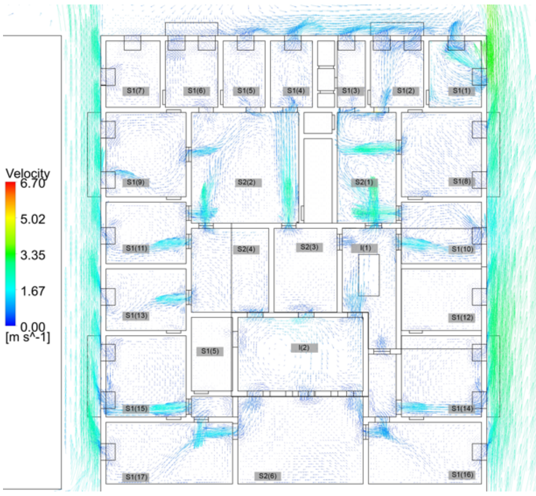


Figure 8-110 the airflow pattern inside the detailed floor scenario 11 at height 8.6 m

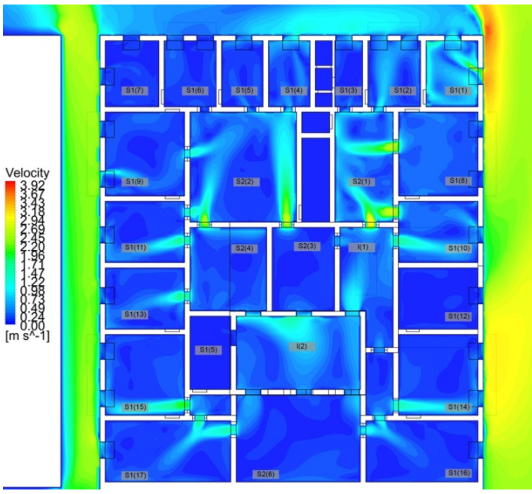


Figure 8-111 the airflow speed profile of the detailed floor scenario 11 at height 8.6 m

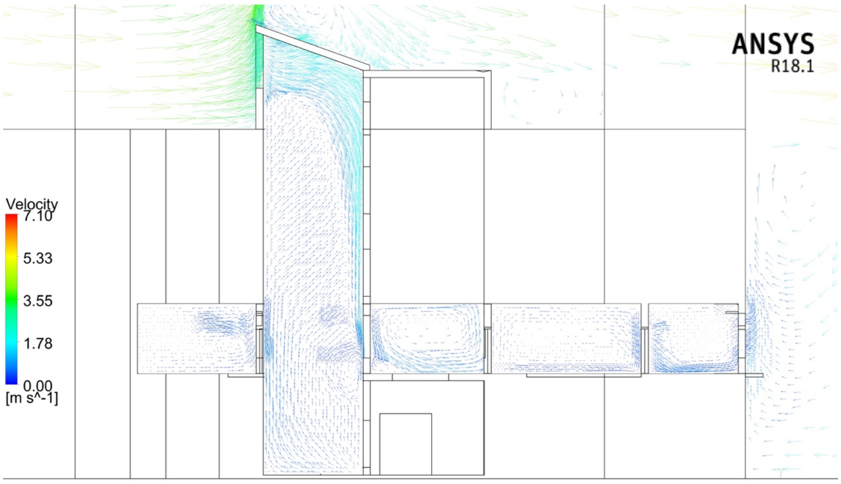


Figure 8-112 the inner court inlet performance connection with the S2 spaces, and the effect of opening type projection in the S1 spaces of scenario 11

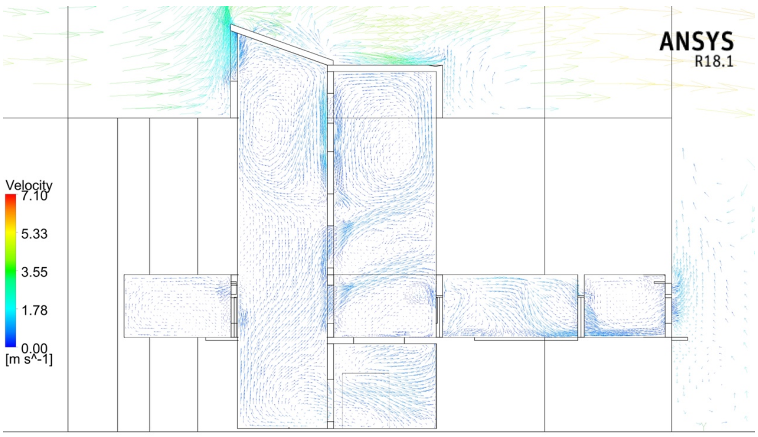


Figure 8-113 the inner court inletperformance connection with the stair well, and the effect of opening type projection in the S1 spaces of scenario 11

Table 8-12 internal airspeed inside the detailed floor plan spaces scenario 11

Zone		Inlet airspeed (m/s)	Internal airspeed (m/s)		Average airspeed (m/s)
			max	min	
S1	1	2.42	1.02	0.87	1.43
	2	1.26	0.83	0.54	0.87
	3	0.97	0.83	0.80	0.87
	4	1.29	1.16	0.99	1.14
	5	0.87	0.82	0.63	0.77
	6	0.56	0.50	0.41	0.49
	7	1.03	0.86	0.60	0.83
	8	1.44	1.12	0.76	1.10
	9	0.90	0.83	0.60	0.77
	10	1.62	1.23	0.92	1.26
	11	0.64	0.59	0.40	0.54
	12	1.20	1.04	0.80	1.02
	13	0.64	0.50	0.41	0.51
	14	1.46	1.00	0.77	1.07
	15	1.00	0.77	0.51	0.76
	16	0.67	0.54	0.46	0.56
	17	0.59	0.47	0.41	0.49
S2	1	-	1.39	0.90	1.14
	2	-	0.79	0.73	0.76
	3	-	0.89	0.51	0.70
	4	-	1.50	0.96	1.23
	5	-	0.10	0.07	0.09
	6	-	0.87	0.76	0.82
I	1	-	0.92	0.83	0.87
	2	-	0.37	0.17	0.27

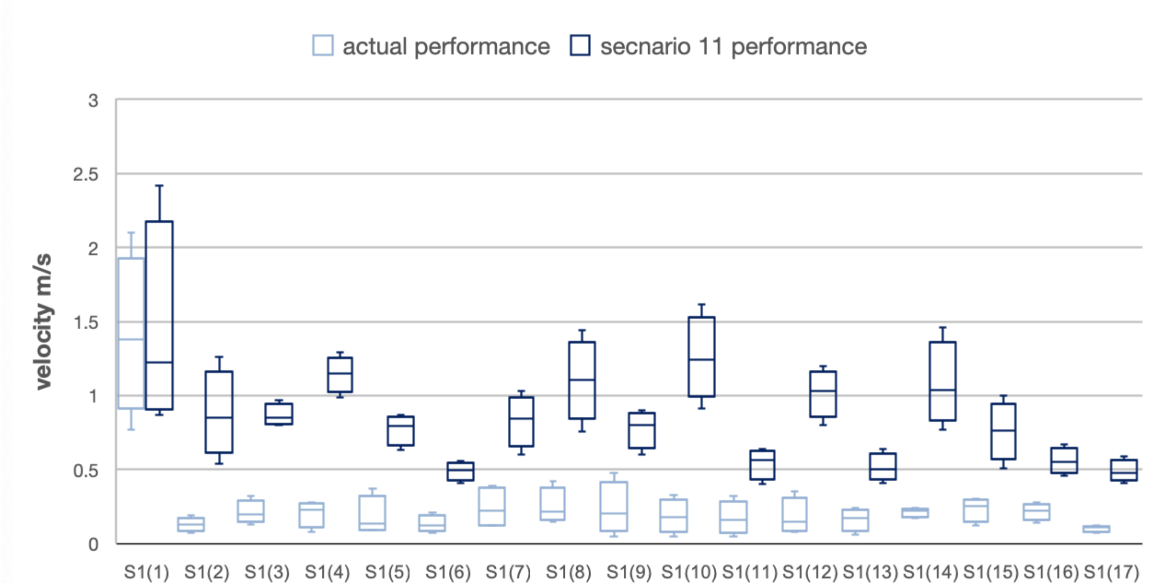


Figure 8-114 average velocity m/s for the S1 spaces

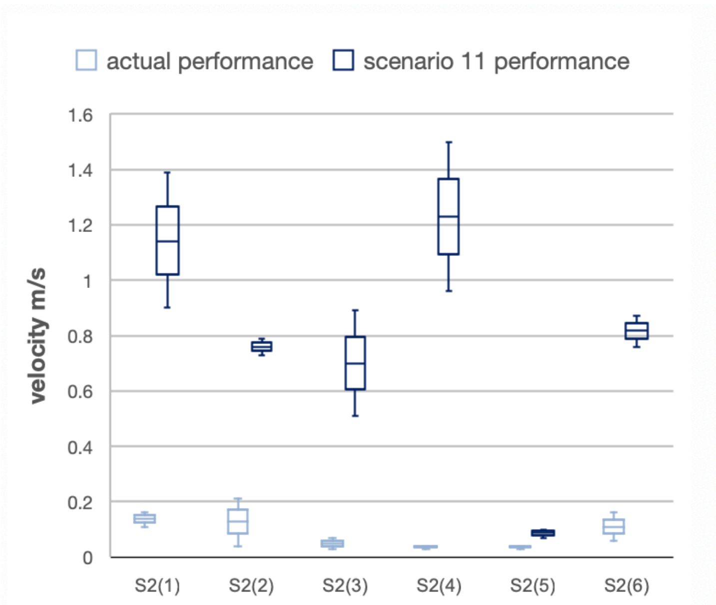


Figure 8-115 average velocity m/s for the S2 inner living spaces

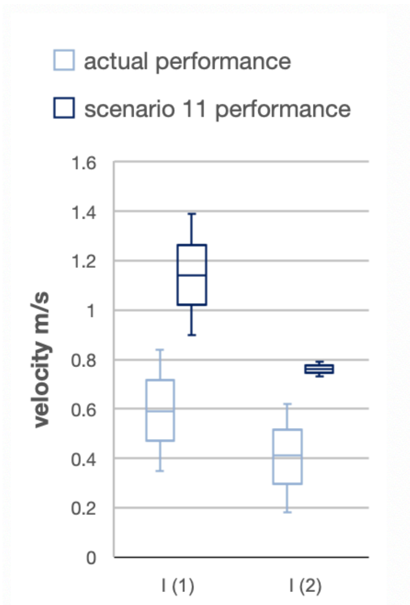


Figure 8-116 average velocity m/s for the Inner shafts' spaces

Table 8-12 illustrates the different internal airflow magnitude within the different space and compares it to the actual current performance of the case study building in Figure 8-114, Figure 8-115, and Figure 8-116 showing a general increase in magnitude in all the spaces specially in the S2 zones, and an average increase of the internal magnitude within the S1 and S2 spaces from 0.26 m/s to 0.8 m/s and from 0.08 m/s to 0.93 m/s respectively.

As demonstrated scenario 11 is the combination of the retrofit parameters of scenarios 3 and 5 combined. The outcomes considering the airflow magnitude were contrasted together in Figure 8-117, Figure 8-118, and Figure 8-119. The comparison shows an average increase in all the spaces within scenario 11 against 5, but when the results were compared to scenario 2 in the S1 external spaces, the average internal airflow magnitude is lower in most of the spaces as a result of the lower pressure difference between the S1 openings and the outlets. The S1 external spaces magnitude where the openings perform as an outlet, there is a slight increase in magnitude against scenario 3, while the S1 spaces where the openings perform as an inlet the magnitude is lower than scenario 3. However, when considering the S2 internal spaces there is a noticeable average increase in the magnitude to the internal spaces, as a result of their direct interaction with the inner atrium.

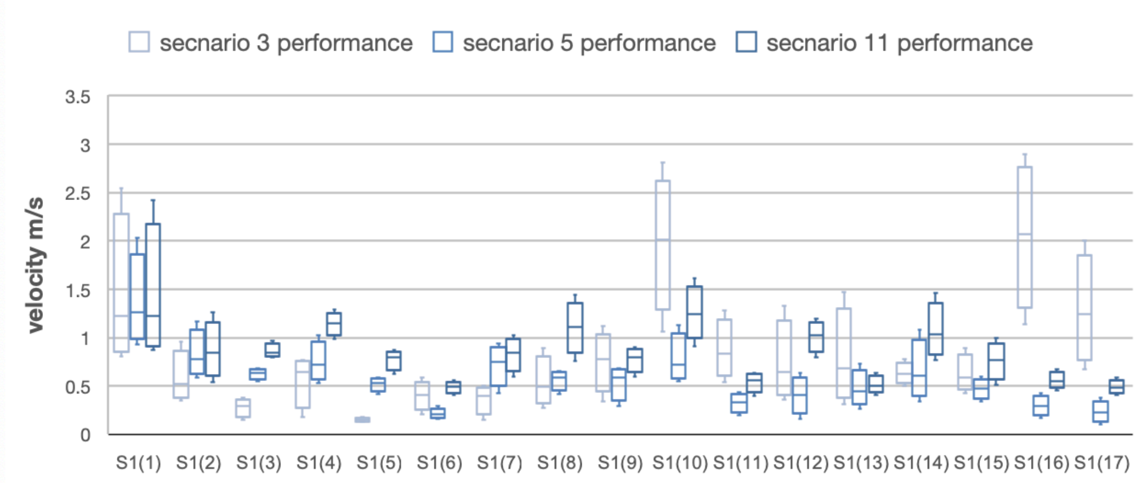


Figure 8-117 average velocity m/s for the S1 spaces in scenario 3, 5, and 11

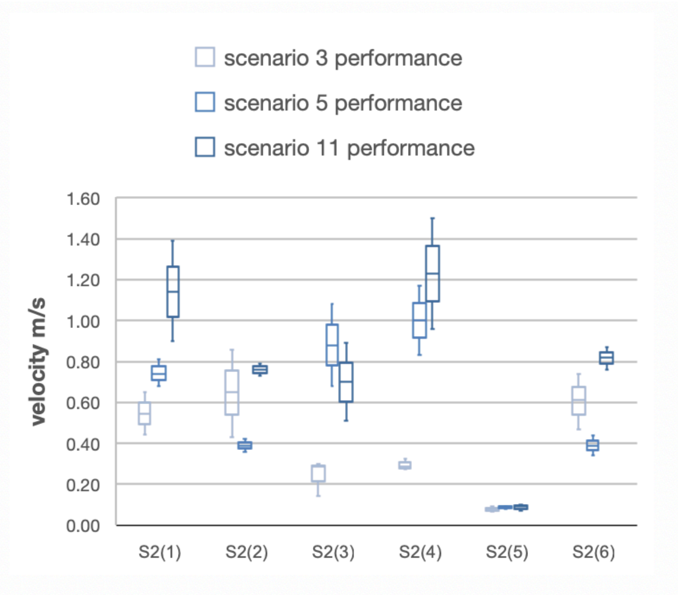


Figure 8-118 average velocity m/s for the S2 inner living spaces in scenario 3, 5, and 11

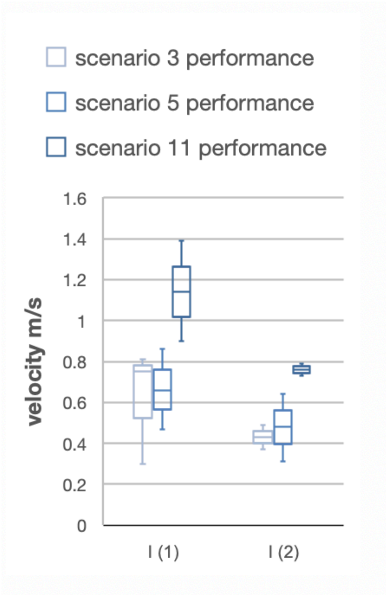


Figure 8-119 average velocity m/s for the Inner shafts' spaces in scenario 3, 5, and 11

8.4.6 Scenario 12 results

The scenario combines the effect of changing the opening type to an operable top hung upper window with the effect of mono pitch roof addition to the inner court with openings in the windward and leeward side with the combined effects of opening the internal transom windows, previously tested in scenario 3 and 6 as a stand-alone strategy. The results are illustrated in Figure 8-120, Figure 8-121, Figure 8-122, and Figure 8-123 for the airflow patterns and magnitudes on different levels in the detailed floor plan.

The results of this scenario demonstrate the effects of the increase in the velocity magnitude and direction of the naturally induced air which was allowed by the increase in the opening size of the external S1 spaces and the horizontal projection of the casement, combined with the effect of the roof addition with an opening on the windward and leeward side that has a changing effect on the airflow behavior within the detailed floor plan, interacting within the inner direct contact inner spaces S2 resulting in a mixed behavior of inducing or extracting the air from theses spaces according to their position regarding the windward and the leeward side of the atrium, which in return affected the S1 external spaces according to their relation with the different behavior of the S1 spaces, as discussed earlier in scenario 6 results.

The sections showing the connection of the inner court inlet and outlet performance combined with the change of the opening type top hung projection are illustrated in Figure 8-124 and Figure 8-125 showing the connection with the inner spaces and the stairwell respectively demonstrating the amplified airflow magnitude as the air is induced from the inner court to the connected spaces.

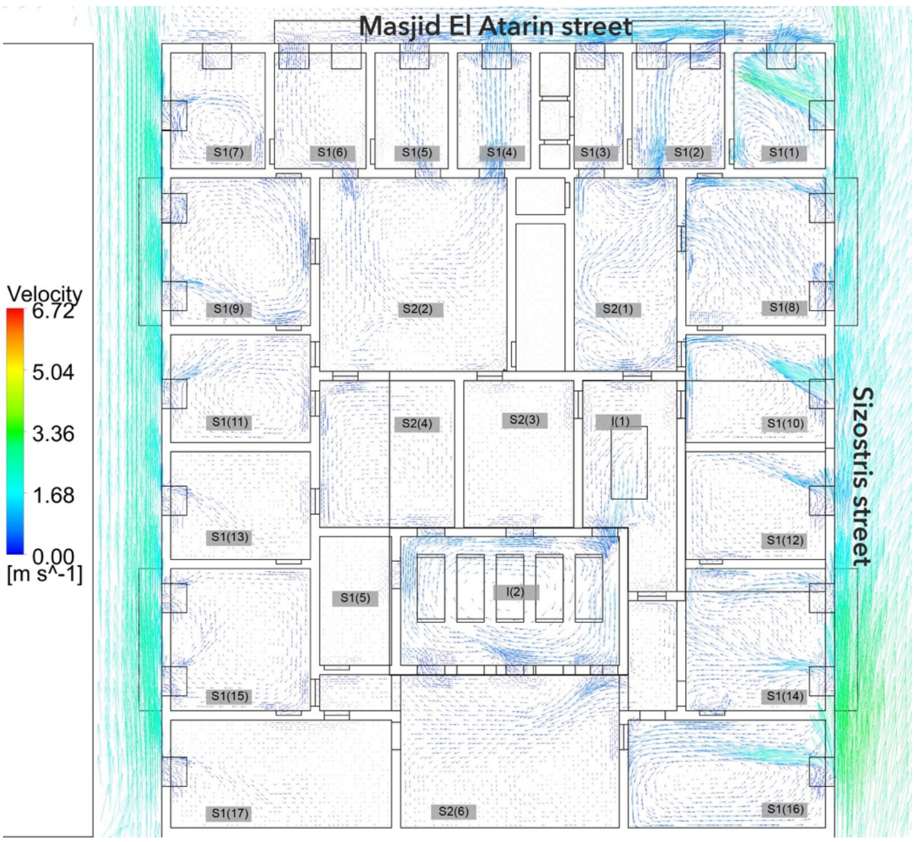


Figure 8-120 the airflow pattern inside the detailed floor scenario 12

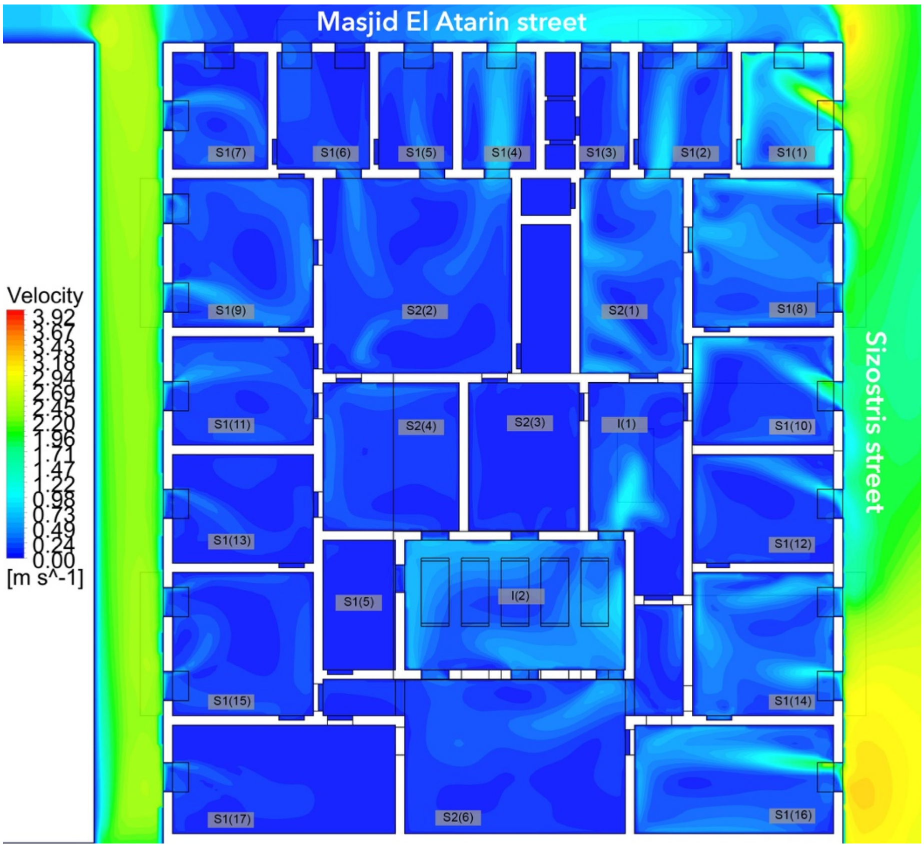


Figure 8-121 the airflow speed profile of the detailed floor scenario 12

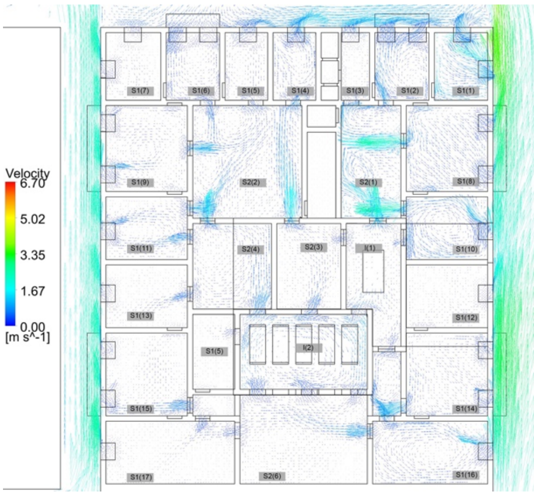


Figure 8-122 the airflow pattern inside the detailed floor scenario 12 at height 8.6 m

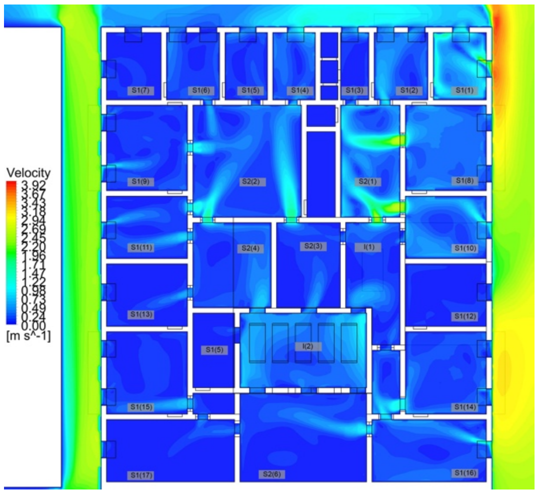


Figure 8-123 the airflow speed profile of the detailed floor scenario 12 at height 8.6 m

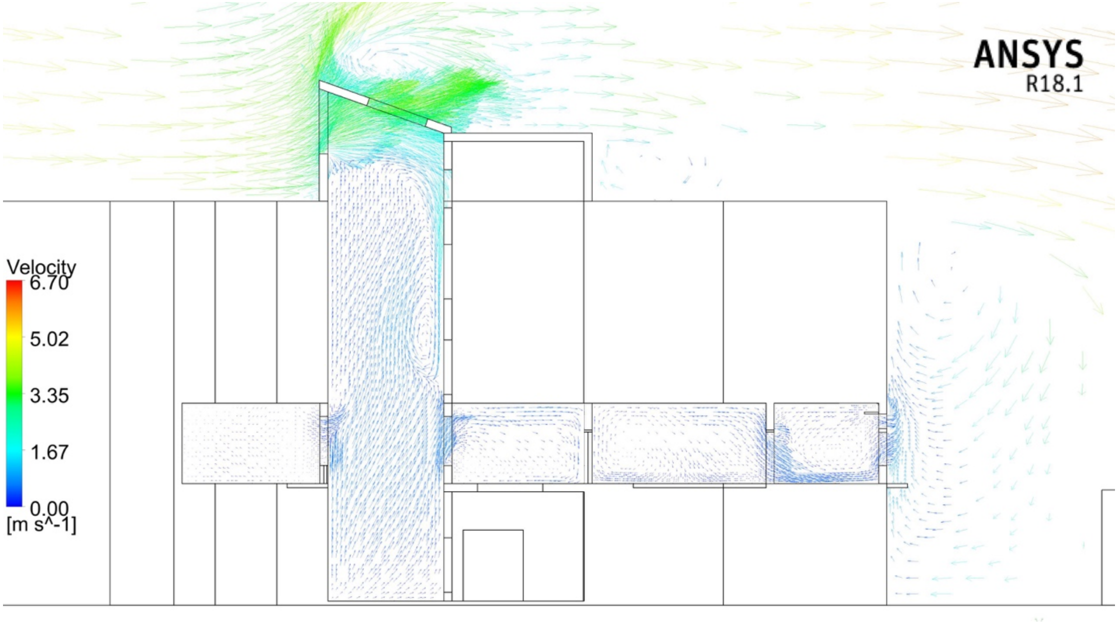


Figure 8-124 the inner court inlet and outlet performance connection with the S2 spaces, and the effect of opening type projection in the S1 spaces of scenario 12

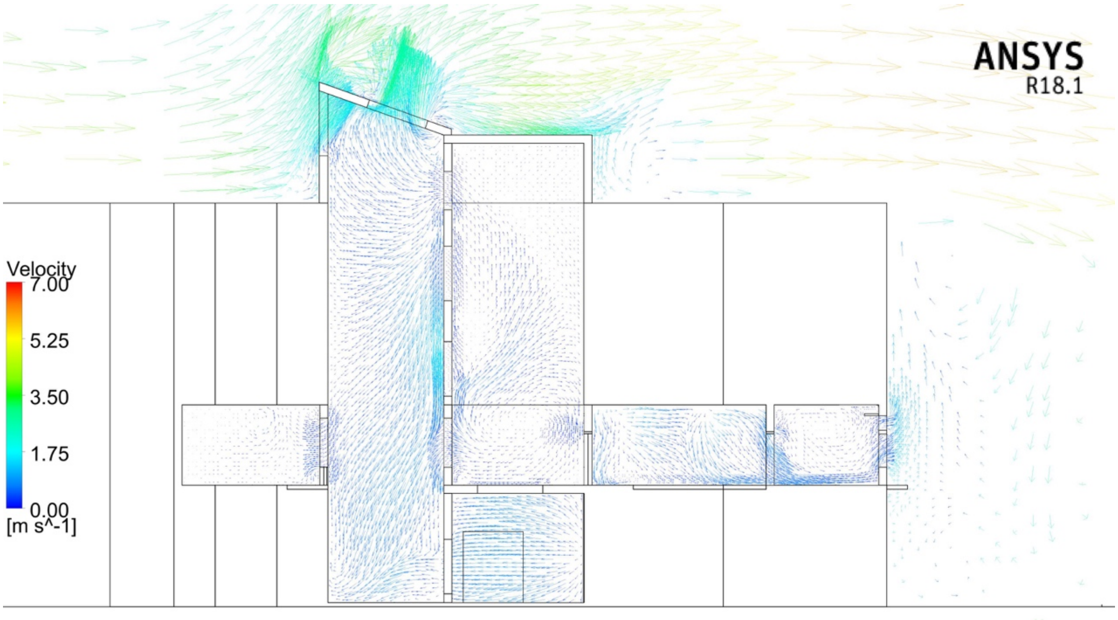


Figure 8-125 the inner court inlet and outlet performance connection with the stair well, and the effect of opening type projection in the S1 spaces of scenario 12

Table 8-13 internal airspeed inside the detailed floor plan spaces scenario 12

Zone		Inlet airspeed (m/s)	Internal airspeed (m/s)		Average airspeed (m/s)
			max	min	
S1	1	2.55	0.89	0.79	1.41
	2	1.17	0.93	0.66	0.92
	3	0.94	0.90	0.77	0.87
	4	1.34	1.33	1.09	1.26
	5	0.83	0.76	0.54	0.72
	6	0.80	0.64	0.56	0.67
	7	0.87	0.74	0.67	0.76
	8	1.72	1.30	0.99	1.33
	9	1.02	0.89	0.60	0.83
	10	2.23	1.73	1.23	1.73
	11	0.80	0.60	0.53	0.64
	12	1.42	1.20	0.89	1.17
	13	0.83	0.60	0.56	0.66
	14	1.92	1.40	0.67	1.33
	15	0.69	0.53	0.41	0.54
	16	3.35	2.79	1.89	2.67
	17	0.84	0.63	0.54	0.67
S2	1	-	0.99	0.72	0.86
	2	-	0.94	0.76	0.86
	3	-	0.60	0.46	0.53
	4	-	0.72	0.59	0.66
	5	-	0.11	0.10	0.11
	6	-	0.77	0.53	0.66
I	1	-	0.84	0.60	0.73
	2	-	0.63	0.39	0.51

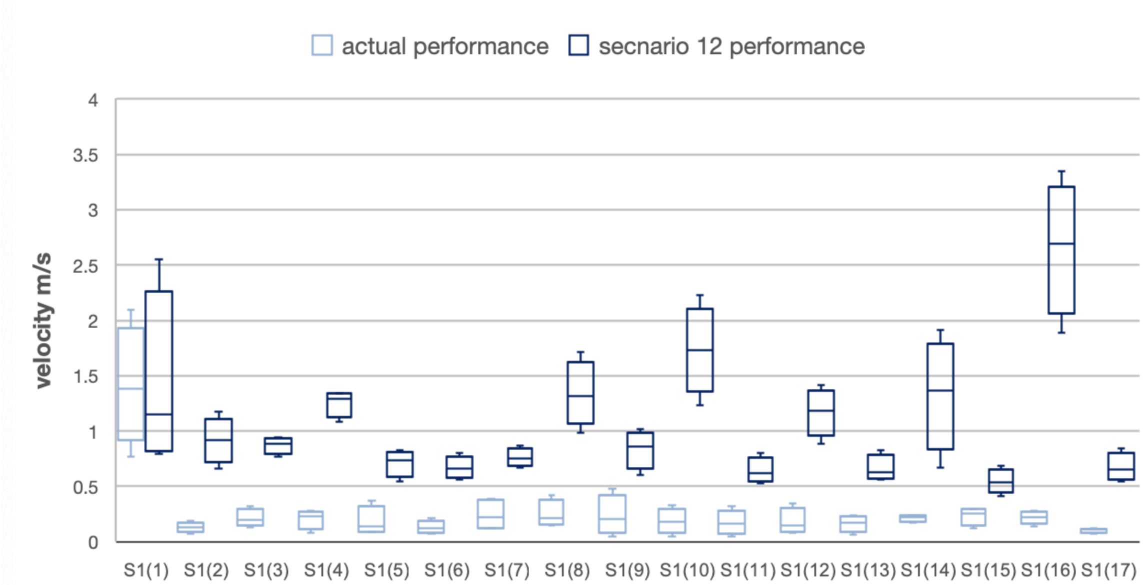


Figure 8-126 average velocity m/s for the S1 spaces

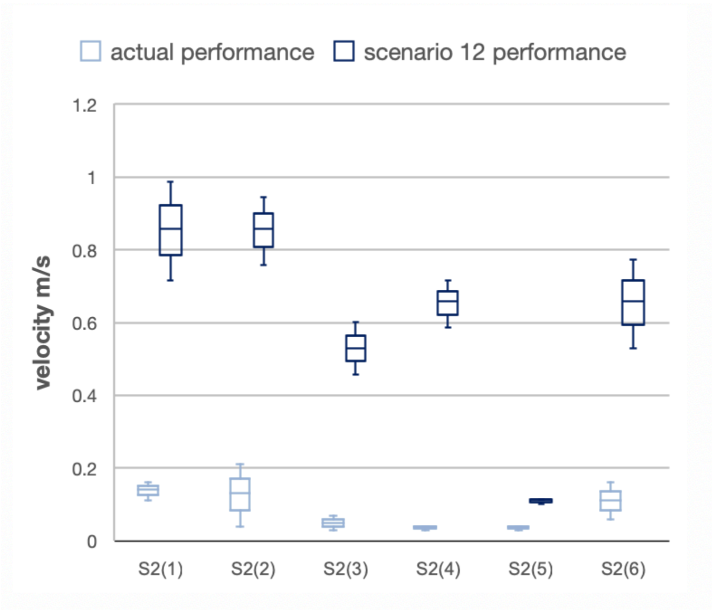


Figure 8-127 average velocity m/s for the S2 inner living spaces

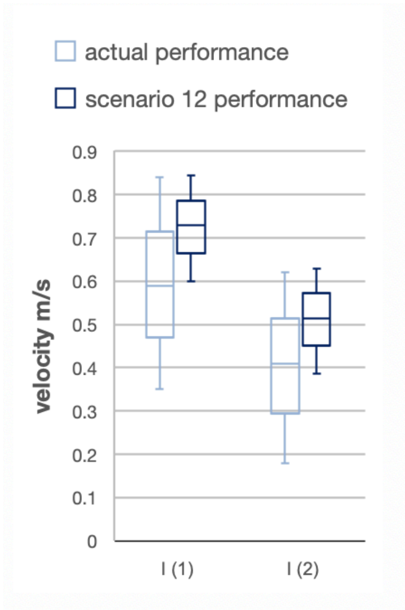


Figure 8-128 average velocity m/s for the Inner shafts' spaces

Table 8-13 illustrates the different internal airflow magnitude within the different space and compares it to the actual current performance of the case study building in Figure 8-126, Figure 8-127, Figure 8-128 showing a general increase in magnitude in all the spaces specially in the S2 zones, and an average increase of the internal magnitude within the S1 and S2 spaces from 0.26 m/s to 1.01 m/s and from 0.08 m/s to 0.72 m/s respectively.

As discussed, scenario 12 is the combination of the retrofit parameters of scenarios 3 and 6 combined. The outcomes considering the airflow magnitude were contrasted together in Figure 8-93, Figure 8-94, and Figure 8-95. The comparison shows an average increase of airflow magnitude mainly in the inner S2 spaces within scenario 12 against 3 and 6. However, within the external S1 spaces, scenario 12 with the combined effect of the retrofit strategies performs slightly better regarding the magnitude when compared to the scenario 6 results, but when the results are compared to the S1 spaces of scenario 3 the average airflow magnitude is higher than the S1 spaces where the openings perform as an outlet and lower than the S1 spaces where the openings perform as an inlet. This is due to the change in the airflow pattern as a result of the mixed behaviour of the inner atrium.

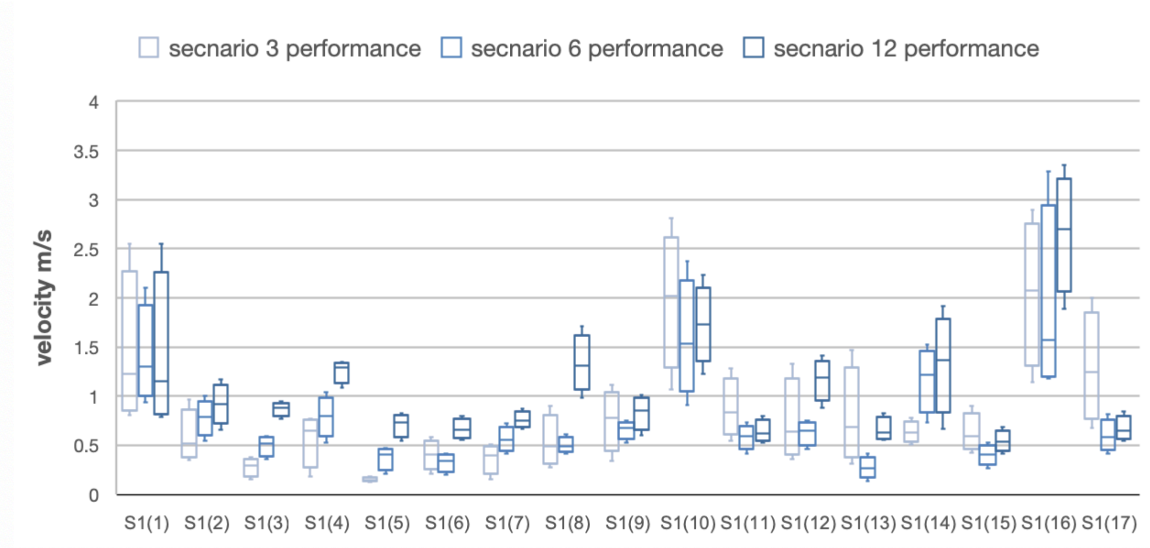


Figure 8-129 average velocity m/s for the S1 spaces in scenario 3, 6, and 12

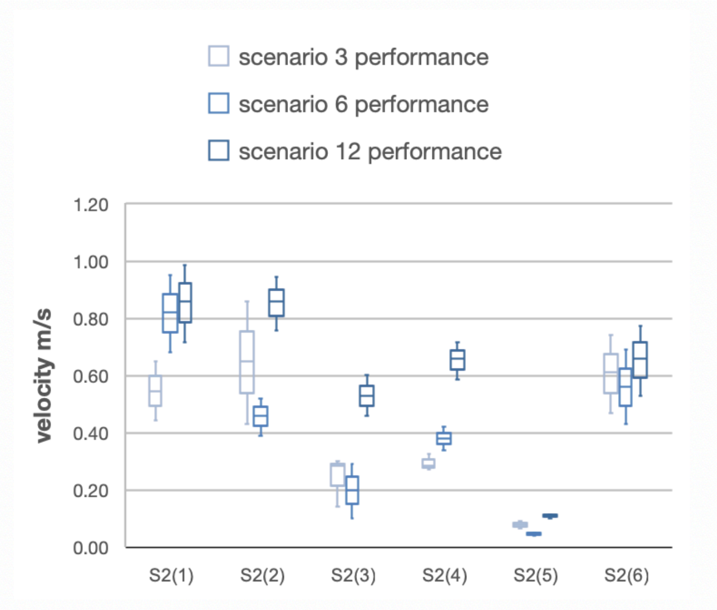


Figure 8-130 average velocity m/s for the S2 inner living spaces in scenario 3, 6, and 12

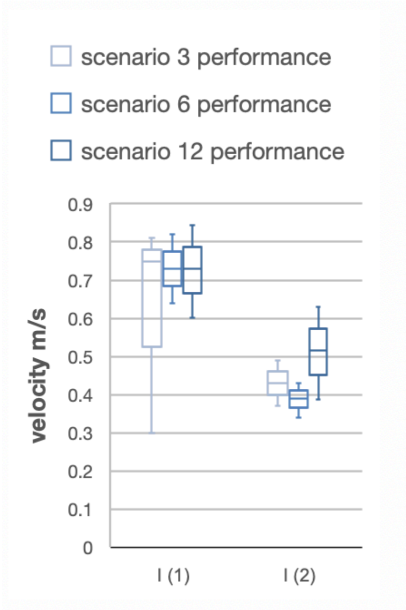


Figure 8-131 average velocity m/s for the Inner shafts' spaces in scenario 3, 6, and 12

8.4.7 Parametric study Level 3 results

Level 3 of the parametric study quantifies the effect of the different retrofitting strategies comprehensively applied together including the connected internal spaces as a base case, changing opening types and roof additions to the inner court applied in scenarios 7, 8, 9, 10, 11 and 12. The results of the different scenarios were discussed in the previous sections. These different scenarios had an improved effect against the actual performance of the case study building internal detailed floor plan. These results regardless the combined retrofitting parameters of each scenario indicate that the performance of the interior spaces is modified against the standalone retrofitting parameters when the results are compared with the actual performance of the building. According to the depth map of the internal space's categorization and the monitoring points within the different scenarios, results obtained were plotted in Figure 8-132, Figure 8-133, and Figure 8-134.

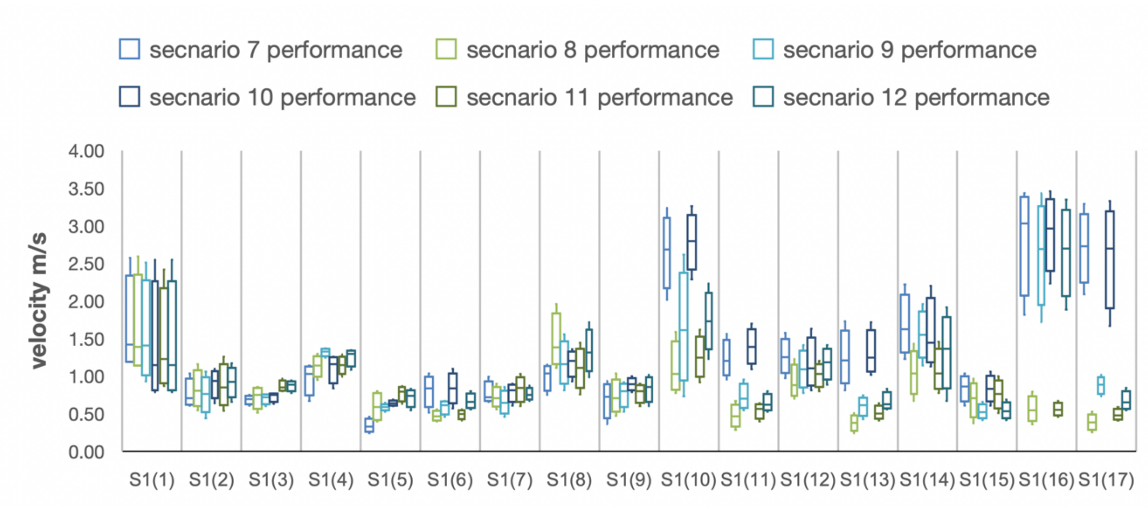
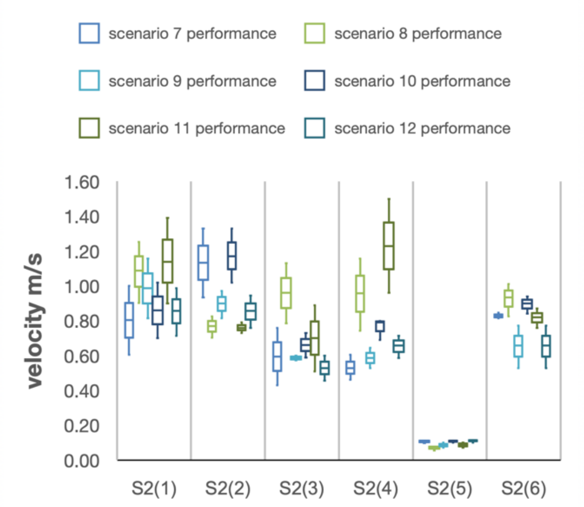


Figure 8-132 average velocity m/s for the S1 spaces



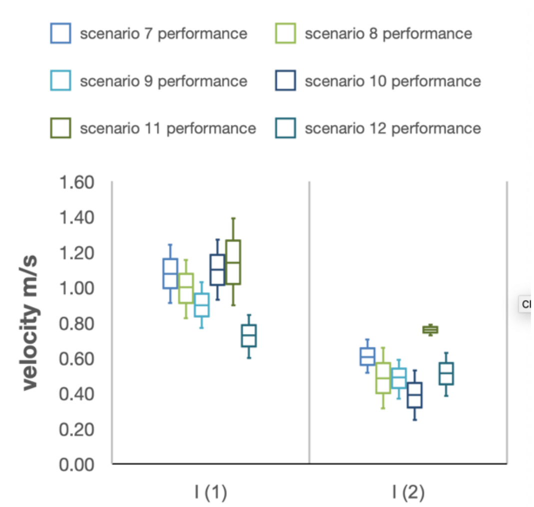


Figure 8-133 average velocity m/s for the S2 inner living spaces

Figure 8-134 average velocity m/s for the Inner shafts' spaces

The different scenarios' setup has different effects on the detailed floor plan with regards to the different spaces' categorization (S1 external spaces and S2 internal spaces). The performance of the spaces was different in terms of magnitude and patterns in each scenario according to the applied retrofitting strategy. The S1 external spaces performance changes in each scenario when compared as a result to many factors compromised in its location with the detailed floor plan and its opening performance regarding its location whether it performs as an inlet or an outlet. The S1 spaces can be categorized as;

- S1 spaces on Sizostriss street where the openings perform as an airflow inlet
- S1 spaces on the alley where the openings perform as an inlet
- S1 spaces on Msjid el Atarin street where the openings perform as an outlet
- S1 spaces on the corners where the openings perform as an inlet and outlet

According to this classification, Table 8-14 shows the S1 spaces according to their spatial performance categorization average airflow magnitude combined with the total S1 average in each scenario.

Table 8-14 average airflow magnitude m/s for the different S1 spaces according to their location and opening behaviour

S1 spaces location	Opening performance	Space labels	Average airflow magnitude m/s					
			S7	S8	S9	S10	S11	S12
Sizostriss street	Inlet	S1(8)	0.99	1.46	1.17	1.17	1.10	1.33
		S1(10)	2.65	1.10	1.64	2.79	1.26	1.73
		S1(12)	1.26	0.92	1.09	1.16	1.02	1.17
		S1(14)	1.67	1.04	1.54	1.55	1.07	1.33
		S1(16)	2.83	0.56	2.63	2.90	0.56	2.67
		S1 average	1.88	1.02	1.61	1.91	1.00	1.65
Alley	Inlet	S1(9)	0.68	0.73	0.76	0.89	0.77	0.83
		S1(11)	1.23	0.47	0.73	1.39	0.54	0.64
		S1(13)	1.24	0.37	0.60	1.30	0.51	0.66
		S1(15)	0.84	0.68	0.53	0.83	0.76	0.54
		S1(17)	2.71	0.39	0.87	2.60	0.49	0.67
		S1 average	1.34	0.53	0.70	1.40	0.61	0.67
Msjid el Atarin	Outlet	S1(2)	0.76	0.83	0.76	0.90	0.87	0.92
		S1(3)	0.68	0.72	0.70	0.73	0.87	0.87
		S1(4)	0.97	1.13	1.32	1.10	1.14	1.26
		S1(5)	0.34	0.63	0.59	0.64	0.77	0.72
		S1(6)	0.80	0.47	0.59	0.84	0.49	0.67
		S1 average	0.71	0.76	0.79	0.84	0.83	0.89
S1 corner spaces	Inlet and outlet	S1(1)	1.65	1.63	1.56	1.41	1.43	1.41
		S1(7)	0.79	0.83	0.64	0.79	0.83	0.76
		S1 average	1.22	1.23	1.10	1.10	1.13	1.09

When comparing the S1 spaces on Sizostriss street and the alley where the openings perform as an inlet, results from comparing the different outcomes show that the average airflow of the within scenarios (7 and 10) have the highest magnitude followed by scenarios (12 and 9) with the lowest magnitude that was achieved in scenarios (11 and 8). These results indicate that the scenarios where the mono pitch roof additions with openings on the leeward side performed significantly better than the other scenarios, with a higher average magnitude obtained where the opening type parameter is changed to top hung operable upper window expressed in scenarios (10, 11, and 12).

The S1 spaces where the openings are performing as an outlet located on Masjid el Atarin street, comparing the results from the different scenarios, the average airflow of scenarios (12 and 9) has the highest magnitude followed by scenarios (11 and 8) with the lowest magnitude that was achieved in scenarios (10 and 7). Results show that the impact on the outlet opening spaces has a better performance with mono pitch roof addition with openings on the windward and leeward side against one sided opening. Results also implicate a higher average magnitude obtained where the opening type parameter is changed to top hung operable upper window expressed in scenarios (10, 11, and 12).

The corner spaces S1 results indicate that the scenarios where the mono pitch roof additions with openings on the leeward side exist, performed better than the other scenarios. Same results exist as the S1 spaces with inlet openings. However, scenarios with operable single hung upper windows performed better than the top hung upper window shown in scenarios (7, 8, and 9).

According to the different results considering the S1 external spaces the average airflow magnitude difference in Scenario (7 and 10) have a better performance in the spaces where the openings operated as an inlet reaching a 54 % higher when compared with the other scenarios. While in the other case in scenario (12 and 10) performed better in the S1 spaces with outlet openings, the average increase difference is not significant but around 11 %. This concludes that scenario 10 has the better performance in the external S1 spaces. The S2 internal spaces performance in the different scenarios is affected throughout the manipulation of the different retrofitting strategies. The results of their average airflow magnitude are shown in Table 8-15 combined with the total average in each scenario.

Comparing the S2 internal spaces that results from comparing the different scenarios outcomes shows that the average airflow of the within scenarios (8 and 11), where the inner court room addition included openings on the leeward side. This is a result of the direct induction of the airflow from the inner court on the S2 spaces. However, the directed airflow from the top hung upper window reduced the airflow magnitude suction from the S2 spaces, having a higher airflow average magnitude in scenario 8 against scenario 11.

Table 8-15 average airflow magnitude m/s for the different S2 spaces

S2 spaces	Space label	Average airflow magnitude m/s					
		S7	S8	S9	S10	S11	S12
Inner living spaces	S2 (1)	0.80	1.09	0.99	0.86	1.14	0.86
	S2 (2)	1.13	0.77	0.90	1.17	0.76	0.86
	S2 (3)	0.59	0.96	0.59	0.66	0.70	0.53
	S2 (4)	0.53	0.96	0.59	0.79	1.23	0.66
	S2 (5)	0.11	0.08	0.09	0.11	0.09	0.11
	S2 (6)	0.83	0.94	0.66	0.90	0.82	0.66
	S2 average	0.67	0.8	0.64	0.75	0.79	0.61

In the cases of scenarios with roof additions where the openings are on the leeward side, the average of the internal magnitudes came lower represented in scenarios (10 and 7). The effect of the top hung opening projection amplified the magnitude of the internal airflow coming from the S1 spaces, having a higher airflow average magnitude in scenario 10 against scenario 7.

The lowest average airflow magnitude was the results of the scenarios where the roof addition openings on the leeward and windward side took place in scenarios (9 and 12), where the effect of the mono pitch roof addition to the inner court with openings on the leeward and windward side were applied. When considering the effect when combined with the changing of the opening type in the cases of the inner atrium performed as a just an extraction shafts, the top hung operable window in scenario 10 performed better than the single hung window of scenario 7. This is not the case when the atrium performed as an inlet or a mixed behaviour, both the scenarios where the opening type have a single hung with no horizontal opening projection of scenario 8 and 9 performed better than scenario 11 and 12.

From the discussion above, it can be clearly seen that each space has different circumstances according to the different scenarios results. However, when combining all the effects to the different spaces regarding the different scenarios, it was indicated that the highest obtained airflow magnitude average increase is the result of scenario 10, where the opening type was changed to operable top hung window, roof mono pitch addition opening on the leeward side, and combined with the internal spaces connection of transom windows. The scenario obtained the highest airflow magnitude within the S1 external spaces compared with the other scenarios with an average airflow of 1.28 m/s. In the results of the S2 internal spaces, the highest obtained average was in scenario 8 with an average airflow of 0.8 m/s against the average airflow of scenario 10 which was 0.75 m/s. When considering the average difference between both scenarios, it is not that significant, not affecting scenario 10 from optioning the highest total average of the airflow magnitude within the internal spaces of the case study building.

8.5 Conclusion

In the parametrical enhancement process, the effectiveness of several passive retrofitting measures in terms of airflow for natural ventilation purposes were quantified. The quantification emphasized the importance of these retrofitting measures even when considering the impact on the heritage value of such type of buildings for improving natural ventilation performance. These enhancements that were applied to the case study considered the heritage value and level of the building, the effect on the heritage context, the building's structure, and the privacy requirements of the occupants mixed ownership of the apartments.

The research considered the use of multi-space case within its full context, rather than using a simplified model (spaces without surroundings) which is used in most of the previous researches, hence, attaining more reliable results based on the contextual effect on natural ventilation. Using ANSYS fluent 18.1 CFD software, the enhancement was conducted in a parametrical manner testing the different effects of the strategies separately and combined together, showing the different strategies integrated together effects.

The different applied retrofitting strategy had a different effect according to their application. The internal spaces connection through reverting existing transom windows considering the different ownerships have allowed the presence of cross ventilation airflow patterns. Therefore, connecting many zones together including the external (S1) and internal (s2) spaces and the inner court rather than the short circuit of cross ventilation that was obvious in the actual performance of the case study building.

Changing the opening type in general have increased the opening size in both cases single or top hung operable casement windows. However, these results when comparing both the opening types varied according to the combined effects of the other strategies.

The roof mono pitch addition indicated that the results obtained from a closed atrium compared to the exiting open court had much-improved results no matter the position of the added opening orientation. In the case of the openings on the leeward side enhancing the shafting effect of the existing court have a better result in general and specifically on the S1 external spaces. When openings were placed on the windward side, the improvements were obvious on the S2 internal spaces due to their direct connection with the inner atrium. Having openings on the leeward and windward side resulted in an average result between both cases.

The combined effect of the connected internal spaces, changing the opening type, and the mono pitch roof addition to the inner court showed improvements that can reach 6 times average airflow increase, when comparing the highest attained airflow average of scenario 10 (1.94 m/s) against the actual base case average performance (0.22 m/s). This case treatment can be claimed to maximize the potential of using comfort ventilation, by improving the airspeed and the airflow quality inside the internal spaces Figure 8-135.

However, not all the spaces as a result of the applied strategies reached the preferred air speed (1-2 m/s) inside a naturally ventilated residential building identified by (Givoni, 1994) for effective comfort ventilation. In general, results show the difficulty to optimize the air speed for comfort ventilation within all the spaces in a very dense multi-space design like the case study with the heritage value limitations. However, there is a clear enhancement in all the spaces even if they didn't reach the required minimum.

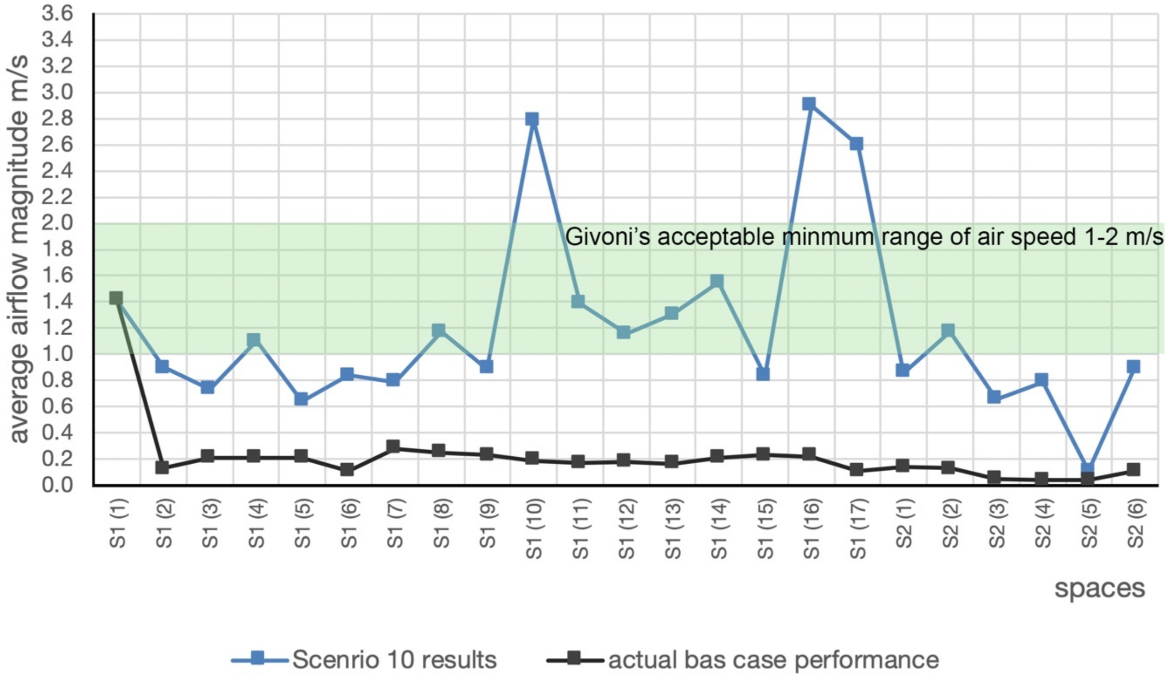


Figure 8-135 the highest average magnitude scenario 10 with the actual building's performance in contrast to Givoni's acceptable minimum range of air speed (m/s) needed for thermal comfort.

Chapter 9 Conclusion and further work

9.1 Introduction

There were two main drivers behind the rationale of the thesis; Firstly, formulating a natural ventilation retrofit for heritage buildings, preserving their cultural significance and upgrading embedded environmental performance. Provides a prospect bridging the gap between the conservation practices and environmental concerns. Secondly, to apply the framework to the cosmopolitan heritage fabric of Alexandria, responding to the opportunity of the fabric's preservation and upgrading their environmental performance.

The findings determine that the sustainable heritage retrofit process requires a sensitive approach and a complex process described as a balancing act between the conservation principles and environmental performance requiring the protection of the building's heritage fabric distinguished character, merged with the principles understood from natural ventilation principles. However, a lack of research relevant produce a systematic approach retrofit to either the context or the climatic context of this study was found, underlining the need for this work.

This chapter represents the final conclusions of the thesis, an overall view of the main thesis aims. The main findings of this investigation of a proposed natural ventilation retrofit framework. The findings on the applied framework on the heritage context of Alexandria discussed setting out their contribution to existing knowledge. In addition, the limitations of the study are addressed. Finally, recommendations for future research are presented.

9.2 Heritage building natural ventilation retrofit – Framework

As discussed in Chapter 1, the main aim of this research is to develop a natural ventilation retrofitting Framework, and the relative criteria that govern the process. The frame work is developed in response to the challenges imbedded during the course of research for the cosmopolitan heritage of Alexandria built between (1882-1930). Through the mixed methods adopted including the historical analysis, literature review and the case study application, the research has indicated the complexity of the balancing process between the cultural significance of the heritage buildings and their passive cooling performance. Figure 9-1 illustrates a systematic approach to identify, determining and implementing the most suitable natural ventilation retrofit measures for existing heritage buildings.

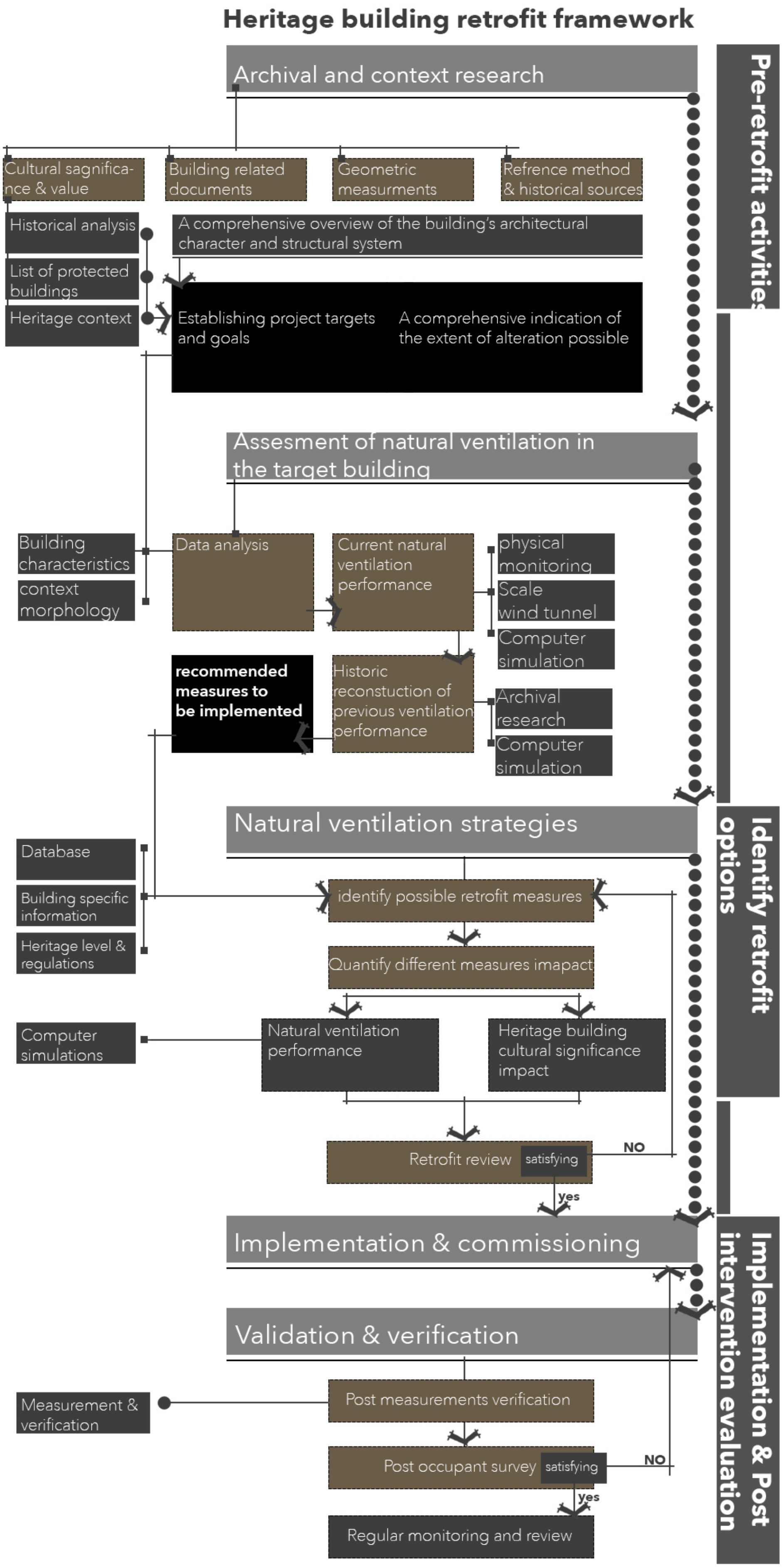


Figure 9-1 concluded natural ventilation retrofitting Framework

The framework can be used for any type of buildings requiring a balanced modification between the conservation principles and ventilation strategies. The framework process consists of three phases: (a) pre-retrofit activities, (b) identifying retrofit options, and (c) implementation and post intervention evaluation. The frame work has with a clear vision towards optimizing the process providing indoor thermal comfort in coherence with existing heritage buildings' characteristics, subsystems and climatic considerations of the context.

(a) Pre-retrofit activities

Initially the pre-retrofit activities phase is required in order to have a better understanding involving a synthesis association, bringing together the cultural understanding of the heritage values and the engineering science of natural ventilation as a passive cooling means. Based on mutual understanding of the heritage nature and natural ventilation requirements, where the scope of historical research and physical investigation are considered on the conservation context and the building scale. Setting the retrofitting targets and the appropriate levels and limitations of the different strategies.

In accordance to the association between these different aspects the phase involves the archival and context research. During this part a complete archival research is performed, underlining the cultural significance and value of the context and understanding its evolution phases, morphology of protected buildings' list, infrastructure, and current state. On the targeted heritage building scale a complete geometrical measurement is performed backed up by archival resources and building related archival documents.

Throughout the research this process has proven to be vital underling the building as a record, understanding the historic aspects, heritage level classification, building layout, the implemented building technologies, construction methods, and acquiring a current precise knowledge of the building's fabric. The archival resources are essential to understand how it used to perform when it was built. This phase includes establishing the project targets and goals and sets an indication of the extent and limits of the proposed retrofit.

During the pre-retrofit activities, the archival and context research is followed by the assessment of natural ventilation in the target building and the surrounding context. Initially, data analysis of the context's climatic compatibility for natural ventilation for improving thermal comfort including wind direction and airflow magnitude, temperature, relative humidity, the built-up environment layout and building's typology, and context constrains (pollution, noise and cultural barriers).

In addition to complete analysis of the heritage building functioning in accordance to natural ventilation including on field monitoring and computational fluid dynamics CFD simulations. However, during the course of the research CFD simulations have proven to be efficient with accurate presentation of the airflow patterns and magnitude for detailed analysis, giving that the simulation is calibrated and validated through field monitoring insuring the reliability of the results. Performance assessment is employed to benchmark airflow patterns and magnitude for insuring adequate thermal comfort. Diagnostics is used to identify improper schemes and any malfunction in the building operation.

While dealing with heritage building during this phase it was important to gain a critical understanding of the building intended performance when it was built using historic reconstruction CFD simulations. Understanding its environmental historic principles and how it was intended to function in terms of natural ventilation, giving a useful insight for these principles referenced for providing a more sustainable retrofit application. Historic reconstruction can bridge the gap between the conservation principles and the sustainable retrofit.

Throughout this phase a complete image is projected regarding the heritage significance and a complete understanding of the heritage building's fabric and historical context. Defining the current performance of the building and identifying the possible recovery, improvement and solution for natural ventilation performance. This phase includes establishing the project targets and goals and sets an indication of the extent and limits of the proposed retrofit.

(b) Identifying retrofit options

The second phase in the framework identifying the retrofit options in terms of natural ventilation strategies. Through the literature review, it is found that, the performance for natural ventilation efficiency for achieving thermal comfort is affected by several design measures incorporated and can be complemented to the building. The design measures are: façade opening design, roof shape, connected internal spaces, double skin façade, ventilation shafts and building envelope projection. These measures manipulation and integration can have a significant effect on improving the indoor thermal comfort.

Applying with these systems may require physical changes to the existing physical form of the building intended for retrofitting. Some of these changes require modifications on the external façade with different extents, while other systems require interior changes. However, implementing these strategies within the retrofitting plan of heritage buildings can only succeed if they are based on the association between their sustainable and physical impact, and the conservation principles and the heritage nature of the building intended for retrofit.

The selective criteria of the different strategies were based on two primary objectives. The first is to explore the different strategies applicability, according to their environmental impact and the conservation principles. Setting the degree of alteration according to the building heritage listing level, either externally or internally. During this objective the critical understanding of the building's history, design and technical performance will provide a useful insight on the already imbedded principles, that can be reused and integrated into a modern system. Employing its capabilities into the modern system. The reuse of the existing strategies can offer a balanced approach integrating the conservation principles and sustainability. Providing a more sustainable approach for ventilation. The heritage stock of Alexandria has shown natural ventilation sustainable characteristics imbedded, with the availability of connected internal spaces, large openings, and internal open court.

The second is testing the different strategies and their impact on natural ventilation using computational fluid dynamics (CFD). However, the literature review has shown that the physical features of airflow can differ according to the manipulation of the different strategies. Which lead to the construction of a parametrical study structure, cross comparing the effect of the different strategies as a stand-alone system and the different strategies integrated together, observe the changes in natural ventilation performance retrofit in different testing scenarios. Therefore, identifying the effectiveness of each measure and the best proposed parameter within each measure. This method has proven its success through identifying the effect of the different strategies can be prioritised according to the outcomes depending on their integration and manipulation. corresponding to the different results if the retrofit selected criteria was satisfying the framework can move to the third and final phase which is implementation.

(c) Implementation and post intervention evaluation

The phase summarizes the decision-making process of the retrofit option. With the different natural ventilation retrofit strategies proposed, several outcomes have been generated. Outcomes can be prioritised according to the occupants needs, concerning achieving the highest achievable thermal comfort with respect to airflow magnitude and distribution through the different spaces. The parametrical study method has shown different successful alternatives, selected according to the occupants needs concerning thermal comfort, different spaces use, and cultural context.

The implementation is a result of the framework methodology adopted illustrating the particular retrofit intervention adopted with respect to the heritage values of the building and environmental benefit. During this phase tests are recommended insuring the optimal operation of the proposed retrofit and the effect on occupants.

According to the literature review, the post intervention evaluation is an essential phase verifying the endurance operation of the retrofit, thermal comfort and the occupant’s satisfaction with the results.

The framework is the product of the thesis attempt for cultural bridging between the conservation and environmental benefits. The framework emphasized on the understanding of the history, design and natural ventilation of the building. And ways in which these embedded historic principles and modern strategies could be reused and implemented in the current use. Bringing together technology and culture, recognizing and integrating the cultural heritage values and energy retrofit application.

The framework in this work is addressed towards the cosmopolitan context of Alexandria. However, following the mixed methods adopted in historical research and environmental benefits adopted can have the potential to be widely applicable to different contexts and can regulate towards sustainable development in countries where heritage protection is not regulated.

9.3 Summary of conclusions addressing framework application on the cosmopolitan heritage buildings of Alexandria

The outcomes of this part are a result of the developed retrofitting framework conducted and applied on the heritage fabric of Alexandria. Through mixed methods adopted, archival research, field surveys, and computational simulation support, to gain a critical understanding of the heritage fabric, the investigation of the current and historic natural ventilation performance and the effectiveness of proposed amendments to enable rational selection of appropriate retrofit strategies.

9.3.1 Findings regarding the heritage context of Alexandria

Through the literature analysis and review, the existing cosmopolitan heritage fabric in the city centre of Alexandria today can be considered as a general reflection of its evolution. This work contributes to establishing evidence of a historical continuity between the contemporary centre and the city's background. The current morphology and heritage listing indicated 1135 heritage buildings divided across the city's districts focused within the central districts and within the downtown area which consequently represented the Heritage node of the city, emphasizing its urban significance. According to the classification of the heritage buildings, the majority were the local level classification (around 75% of the listed buildings) represented in the eclectic neo-revival styles. These were found to be mostly residential buildings.

As a consequence of the political, social changes and lack of awareness starting from the social and economic changes of the city starting from the 1952 revolution to the present day as outlined in Chapter 2, these historic buildings within the urban and architectural context are no suffering many threats to their continued existence and can be seen to share common problems.

- Intended demolition of heritage buildings for economic reasons
- Deformed fabric from inappropriate additions and new concrete expansions,
- Deteriorated conditions from the lack of maintenance,
- Unsympathetic façade treatments and additions

The study and analysis of the heritage context of Alexandria performed has demonstrated the consistency of the heritage typology of the city influenced by the establishment of the Municipality of Alexandria as the first council of its kind in Egypt. The heritage context sharing similarities through; the buildings' mass, their building surfaces and materials as well as their ordering principles. As a result of this study, the consistency of the heritage urban context, the heritage building typology within the context shared common features, demonstrated in the architectural style, built with traditional building materials and technologies, height and number of floors, internal layout and spatial organization including inner courts could be determined. At the urban scale, the study also demonstrates that the heritage context of Alexandria provides a good opportunity for determining the potential success of natural ventilation applications. As a consequence of the climatic properties of the city; its airflow, air velocity and the wind direction combined with the heritage fabric and courtyarded building typology, its suitability as a case-study to explore ventilation retrofit options in a heritage context was confirmed;

- **Built up environment:** the initial planning of Alexandria adopted a chess-board layout, its orthogonal planning with a street network running parallel to the Mediterranean Sea. Subsequently the city's planning commission was concerned with the public health and the adaptation of natural lighting and ventilation within the built fabric. The physical form of the urban fabric was historically characterized by the arrangement of regular streets and squares. Main streets ran parallel to the coast, while secondary streets perpendicularly intersect with them.
- **Heritage buildings typology:** The eclectic neo-revival styles within the context commonly share the same building characteristics including; building materials, deep central compact masses, opening proportions, court linking the inner spaces to the roof, in addition to the similar internal spatial organization of the internal spaces. this typical layout offers good potential for healthy indoor air replacement.
- **Wind direction:** The city's heritage fabric extends along the Mediterranean Sea, with prevailing cold damp wind coming from the north-west direction.
- **Air velocity and airflow:** The heritage context is extended parallel to the Mediterranean Sea, allowing a large volume of the sea's air mass to be received. With typical wind speeds vary from 3.4 m/s (light air to moderate breeze), and rarely exceed 5 m/s gentle breeze).
- **Temperature and relative humidity:** Mean air temperature in the city ranges from 28.5^{o}C in September to 32^{o}C in August. Relative humidity typically ranges from 65% to 92% over the course of the summer months. According to the ranges of external temperatures within Alexandria's context comfort ventilation is an applicable requirement.

9.3.2 Evaluating natural ventilation performance in the selected representative case study heritage building

The representative case study was monitored and the airflow in and around the building was investigated using the CFD simulation tool (ANSYS Fluent), the following conclusions were drawn from the evaluation:

- In general, the airflow inside the typical floor is very poor as there is a great separation noticed between the external spaces, internal spaces, and the inner courtyards. The main sources of air are the external spaces on the outer boundary of the building having external openings. The airflow circulates inside these spaces, however, there isn't any cross ventilation throughout the whole building floor between the external openings and the inner courtyard, due to the unavailability of connections between the different zones according to their classification. The average internal airflow magnitude within the internal spaces is 0.19 m/s
- The external spaces perform better due to their direct relation with the external environment in the monitored typical floor. Their performance may vary according to the number of openings in each space, as some spaces have two openings creating a cross ventilation and other spaces have one opening which results in single-sided ventilation. The average internal airflow magnitude within the external spaces is 0.26 m/s
- While the internal living spaces inside the building are very poorly ventilated as a result of its complete separation between these spaces, the outer environment and the inner courtyard. The resulting airflow within these spaces where almost still air is found, indicates the poor potential of using comfort ventilation. The maximum obtained air speed inside these spaces is found to be 0.08 m/s

The results obtained demonstrate unacceptable conditions for indoor comfort. This failure is evidently due to a combination of factors including occupants' behaviour and modifications to the functional environmental principles of the building's original design. Alterations include the blockage of upper openings which have negatively affected the induction of cross ventilation and the stack effect throughout the building.

9.3.3 Enhancing natural ventilation performance in the case study building Outcomes of the parametrical approach

The effectiveness of the selected design measures was quantified and qualified in order to reach the balanced enhanced performance for the case study under investigation. The enhancement process was conducted using a parametrical approach with the Ansys Fluent CFD software. The approach emphasized the importance of using such measures within the sustainable heritage retrofit process, conducted at three consecutive levels testing the performance of the selected measures separately and combined as one system. The analysis process showed that the following measures introduced the best potentials to facilitate natural ventilation use as a passive cooling strategy for the case study;

- Restoring the existing internal transom windows while considering the apartment's separation and occupant's privacy, provided an increase in the internal porosity and facilitated cross ventilation.
- Increasing the opening size through changing the opening type using an operable upper window, increased the airflow magnitude in the internal spaces. However, when comparing the two tested parameters using a single hung casement upper window as a stand-alone system had a slight better performance than the top hung window
- Testing the addition to the roof to the internal inner court, the overall performance through the different tested parameters have shown an improved airflow magnitude. The results indicate that roof projections combined with openings in the leeward side amplified the effect of the of the inner court as a shaft mechanism increasing the airflow magnitude in all the internal spaces. While placing the opening as a windward side just emphasized internal airflow magnitude in the internal spaces.
- The combined effects of the adjustments had an improved effect on the results, regardless of the combined retrofitting parameters of each scenario indicating that the performance of the interior spaces is modified against the standalone retrofitting parameters.
- The combined effect of the connected alterations in tested scenario 10, where restoring existing transom windows, changing the opening type to a top hung operable window, and the mono pitch roof addition with openings acting as an inlet, are seen to have the highest airflow magnitude improvement against the other tested scenarios.
- The combined effect of the different measures doesn't have an accumulative improvement to the results, it depends on how the measures interact with each other.
- The use of the tested measures showed improvements that can reach 6 times the average airflow increase, when comparing the highest attained airflow average of (1.94 m/s) against the actual base case average performance (0.22 m/s). The methodology used can be claimed to maximize the potential of using comfort ventilation, by improving the airspeed and the airflow quality inside the internal spaces.

- In general, the results show the difficulty of seeking to optimize the air speed for comfort ventilation within all the spaces in a very dense multi-space design like the case study with the heritage value limitations. However, there is a clear enhancement achieved in all the spaces

Some general conclusions also could be drawn from the enhancement parametrical study such as:

- The design measures applied to the case study presented the maximum intervention that can be applied to the case study heritage building, regarding its heritage listing and the maximum intervention allowed without out changing its heritage significance and the consistency of the preserved fabric.
- The case study listed heritage building adopted in the research can be recognized as a representative of the residential building of the local level classification, 75% the cosmopolitan listed heritage of Alexandria (1882-1952). Demonstrating the applicability of the adopted method for improvement of the majority of heritage buildings within the area.
- The treatments adopted in the parametrical study can be claimed to maximize the potential of using ventilation passive strategies for comfort ventilation, when the external climatic conditions allow, indicating their suitability as a passive cooling heritage building retrofit strategy

9.4 Limitations of the research

Although this research aimed to investigate heritage building sustainable retrofit processes and the different means of integrating the established criteria of natural ventilation strategies, there were subjects outside the scope or recognized as potential shortcomings of this research. The boundaries and scope of this research have been limited in response to the available time and resources. It must be acknowledged that this research has certain limitations, as set below:

- The research is more concerned with the cosmopolitan residential heritage buildings as a result of their high percentage in forming the city's context, however, there is scope to address other heritage typologies including other styles, dates or types of use including public buildings.
- The outcomes of the retrofitted methods adopted were based on the simulation results without field implementation of the different design measures. It was impossible to implement any measured tests as these would require the approval of the building owner and its multiple occupants.

- This research was limited to comfort ventilation based on driven forces for achieving thermal comfort in internal environments. Other impacts of night cooling and the effect of the building's thermal mass were not explored.

9.5 Recommendation for future studies

The findings of this research have suggested a number of potential parts for future research.

- The effect of the retrofitting measures used on the spaces and the indoor air quality should be investigated and considered regarding the potential effect of external noise and air pollution.
- The need to evaluate the retrofitting strategy in the means of cultural barriers, regarding the occupant's acceptance and constrains.
- Further research is needed to investigate and enhance the thermal properties of the case study building's fabric in order to identify the means to decrease the heat absorbance of its thermal mass and, hence maximize the effectiveness of using the treated airflow in night ventilation
- The need to re-iterate the methodology on a wider scale including different aged buildings and buildings with different functions.
- Further research is needed to investigate other retrofitting approaches other than natural ventilation, their implementation methods and criteria insuring these buildings' computability in order to support their continuity with the global demands and changes.
- At the moment, there are no specific environmental or natural ventilation standards for heritage buildings in Egypt. Hence developing a version of such standards is essential for the future.
- Although a measured validation of this research would require a significant budget and the availability of monitoring equipment, and the means to assimilate the complexity of data collection afterwards, the findings here indicate that such further research would be justified in an attempt to fully validate the hypothesis that heritage buildings in Alexandria could indeed provide acceptable thermal comfort through passive means.

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