IMPACT OF SHADING DEVICES ON THE THERMAL PERFORMANCE OF RESIDENTIAL BUILDING IN AMMAN, JORDAN

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by

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LIST OF SYMBOLS

A	Surface area
A	Opening area
A_{sol}	Solar absorptions fraction
C_p	Specific heat of air
D	Globe diameter
f_{cl}	Clothing area factor
G_o	Air exchange rate
H	Building's height
h	Heat transfer coefficient
h_c	Surface heat transfer coefficient
k	Thermal conductivity of the material
K_θ	Coefficient of heat removal efficiency
L	Layer thickness
L_b	Characteristic length
N	Inward flowing fraction
n	Total number of observations
M	Energy metabolic rate
V	Building's volume
v_a	Average air speed
V_b	Building's heated volume
R	Thermal resistance
RH	Relative humidity
S	Surface
ΣS_i	Total heat loss from all surfaces
T	Temperature difference

t_a	Air temperature
T_c	Temperature of the cold surface
t_{cl}	Clothing area temperature
T_f	Temperature of the fluid
t_g	Globe temperature
t_g	Temperature of the black sphere
T_h	Temperature of the hot surface
T_{mrt}	Mean radiant temperature
$t_{pma(out)}$	Prevailing mean outdoor air temperature
t_r	Mean radiation temperature
T_s	Temperature of the building's exposed surface
T_{sky}	Sky temperature
T_{sol}	Total solar transmittance
$T_{vis\text{-}glass}$	Glass visible transmittance
U	Thermal transmittance
UV	Ultraviolet
P	Plan
Δp	Volume flow rate
Pa	Partial pressure of water vapor
Q	Ventilation flow rate
$Q_{conduction}$	Quantity of heat flow
$Q_{convection}$	Quantity of heat transfer due to convection
$Q_{radiation}$	Quantity of heat transfer due to radiation
W	Width
W	Sum surplus heat released in a room
Y^{mean}	Mean observed data
Y_i^{obs}	ith observation for the constituent

Y_i^{sim}	*i*th simulated value for constituents
α	Exponential constant its value
θ_{uz}	Upper-zone air temperature
θ_{oz}	Occupied zone air temperature
λ_{eff}	Effective thermal conductivity
Φ	Relative humidity

LIST OF ABBREVIATIONS

ACS	Adaptive Comfort Standard
ANSI	American National Standards Institute
ASCE	American Society of Civil Engineers
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BESTEST	Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs
BFI	Bundesverband der Deutschen Industrie (Federation of German Industries)
CBE	Center for the Built Environment
CEN	European Committee for Standardization
CFD	Computational Fluid Dynamics
CONTAM	Multizone Airflow and Contaminant Transport Analysis Software
CZ	Climate Zone
DDY	Design Day Weather File
DOE-2	Department of Energy Version 2
eQUEST	Enhanced Energy and Environmental Sustainability Tool
HVAC	Heating, Refrigerating and Air-Conditioning
ISO	International Organization for Standardization
JUST	Jordan University for Science and Technology
MAE	Mean Absolute Error
MRT	Mean radiant temperature
NSE	Nash-Sutcliffe Efficiency
NREL	U.S. Department of Energy's National Renewable Energy Laboratory
PBIAS	Percentage Bias
PCM	Phase Change Materials

PMV	Predicted Mean Vote
PPD	Predicted Percentage of Dissatisfied
PV	Photovoltaic
RMSE	Root Mean Square Error
SC	Shading Coefficient
SHGC	Solar Heat Gain Coefficient
SSPCM	Shape-Stabilized Phase Change Materials
TRNSYS	Transient System Simulation Tool
WBGT	Wet-Bulb–Globe Temperature
WWR	Window-to-wall ratio

IMPAK PERANTI TEDUHAN TERHADAP PRESTASI TERMA BANGUNAN KEDIAMAN DI AMMAN, JORDAN

ABSTRAK

Strategi penyejukan semasa musim panas yang panas dan kering di Amman, Jordan, menghabiskan banyak tenaga elektrik setiap tahun. Menggunakan sumber semula jadi untuk mencapai keselesaan termal di dalam bangunan kediaman adalah amalan yang baik. Kajian ini menyiasat pengaruh konfigurasi peranti naungan tingkap luaran terhadap prestasi termal dan keselesaan termal tiga bentuk bangunan kediaman, iaitu segi empat, L, dan U, di Amman. Penyelidikan ini bermula dengan pengukuran tapak untuk mengesahkan data simulasi. Untuk kajian simulasi, model bangunan direka menggunakan plugin SketchUp OpenStudio dan kemudian dimasukkan ke dalam penyimulator EnergyPlus. Prestasi termal bangunan dikaji menggunakan suhu udara dalaman, suhu sinar purata, kelajuan udara, dan kelembapan relatif. Keselesaan termal dinilai berdasarkan model adaptif ASHRAE-55 dan model Fanger. Kajian ini menyiasat jenis naungan tingkap luaran secara menegak, mendatar, dan gabungan pada panjang yang berbeza. Didapati bahawa gabungan antara naungan menegak dan mendatar dengan panjang 1.25 m mempunyai prestasi terbaik dalam mengurangkan suhu udara dalaman, manakala naungan bilah menegak mempunyai impak yang minima. Jika tingkap dibuka dengan strategi seperti ini, suhu udara dalaman turun sebanyak 8.85 °C pada siang hari dan 12.04 °C pada waktu malam, yang meningkatkan prestasi termal semua bentuk bangunan. Gabungan naungan dan ventilasi semula jadi meningkatkan keselesaan termal dalam semua bentuk bangunan, di mana sensasi termal dalam berubah dari panas, sejuk, dan sedikit sejuk kepada sedikit sejuk, neutral, dan selesa, masing-masing. Kajian ini menyumbang kepada senibina mampan yang

bertujuan untuk merekabentuk bangunan yang mesra alam dengan prestasi termal yang dapat diterima dengan penggunaan tenaga penyejukan yang minima.

IMPACT OF SHADING DEVICES ON THE THERMAL PERFORMANCE OF RESIDENTIAL BUILDING IN AMMAN, JORDAN

ABSTRACT

Cooling strategies during hot-dry summer in Amman, Jordan, consume a hefty amount of annual electrical energy. Exploiting natural sources to achieve a thermal comfort indoor environment in residential buildings would be a good practice. This work investigates the influence of external window shading devices configurations on the thermal performance and thermal comfort of three residential building forms, namely rectangular, L-shape, and U-shape, in Amman. The research starts with site measurements to validate the simulation data. For the simulation study the buildings' models are designed using the SketchUp plugin OpenStudio and then plugged into the EnergyPlus simulator. The thermal performance of buildings is studied using indoor air temperature, mean radiant temperature, air speed, and relative humidity. The thermal comfort is evaluated according to ASHRAE-55 adaptive model and Fanger's models. This study investigates the vertical, horizontal, and combined shading types of external window shadings at different lengths. It is found that the combination between vertical and horizontal shading of 1.25 m length has the best performance in minimizing indoor air temperature, and the vertical fins shading has minimal impact. In case of windows open with such strategies, the indoor air temperature is notably dropped up to 8.85 °C in the daytime and 12.04 °C at nighttime, which improves the thermal performance of all building forms. Combining shading and natural ventilation improves thermal comfort in all building forms, where the indoor thermal sensation shifts from hot, warm, and slightly warm to slightly warm, neutral, and comfortable, respectively. This work contributes to sustainable architecture that aims to design

buildings to be environmentally friendly with acceptable thermal performance at minimal cooling energy usage.

CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter introduces the importance of implementing passive design strategies to enhance the indoor environment of residential buildings in Amman, reducing the total energy consumption for building cooling during summer and heating during winter. It presents a literature review of the most relevant works that use building form, natural ventilation, and external window shading techniques to achieve sustainable houses in Amman and other cities with a similar climate to Amman. Next, in the problem statement section, the research gap has been highlighted based on the furnished literature survey to show the importance of performing this research. The research objectives and questions have been addressed based on the research gap. A brief description of the research framework, the scope of the experimental and simulation parts, and the limitation of this study have been described. The significance of this work to the residential building section in Amman and other regions with the same climatic conditions is also presented. Finally, an overview of the thesis chapters' content has been described.

1.2 Research Background

The increase in energy required for human life activities, especially for the building sector, consumes around 40% of the total energy worldwide. The high cost of energy production causes a big issue for communities' development (Yu et al., 2020). In Jordan, the residential building sector consumes about 24% of total energy, which is equal to the industrial sector consumption, which represents 45% of annual electric consumption (Almuhtady et al., 2019). The high usage of energy in residential buildings in Jordan refers to the great demand for cooling strategies for hot weather in summer and heating systems for cold weather in winter, where Jordan is characterized by various climatic conditions.

The location of Jordan at the latitude of 32.0° north and longitudinal 36° east has a hot-dry climate in summer and a cold climate in winter. According to the Köppen Climate Classification, Jordan exhibits a warm semi-arid climate characterized by a large range of temperatures. Specifically, Amman, the capital of Jordan, records an average air temperature of 17.2 °C throughout the year (Kapoor et al, 2006). The highest recorded temperature is 41.7 °C in August, and the lowest is -5 °C in February. The measured relative humidity in Amman is in the range of 36% in summer and 69% in winter, with an average of 50.5% during the year (Dar-Mousa & Makhamreh, 2019; Alkhalidi & Al Jolani, 2020). These temperature values in both seasons force the residents of buildings to use different mechanical systems to achieve thermal comfort, increasing energy needs and costs.

Applying passive design strategies in buildings enhances the interior environmental climate, which can be achieved through using environmental resources, i.e., sun lighting and natural ventilation, which in turn leads to minimizing the usage of cooling and heating loads and reduces energy consumption (Toe, 2013; Hui & Jiang, 2014; Gou et al., 2018; Yu et al., 2020; Uddin et al., 2019). The design concept is a fundamental stage to achieving thermal comfort; using passive building strategies such as building form, ventilation, shading devices, window-to-wall ratio, isolation, and orientation improves building efficiency (Lin et al., 2015; Altan et al., 2016). Among the passive design strategies, the building form directly impacts thermal performance and energy consumption by improving the indoor climate of buildings with the free sources available from nature (Raof, 2017; Lapisa, 2019). Indoor thermal comfort plays a crucial role in creating a healthy and pleasant environment for occupants. Natural ventilation and effective shading devices are two sustainable strategies that can significantly enhance indoor thermal performance while reducing energy consumption. By harnessing natural airflow and blocking excessive solar heat, these approaches promote better temperature regulation and air quality, resulting in a more comfortable and energy-efficient indoor space (Shahdan et al., 2018). Natural ventilation provides fresh air supply, removes indoor pollutants, and helps maintain comfortable indoor temperatures without relying heavily on mechanical systems. It promotes occupants' well-being and reduces the need for artificial cooling (Ma'bdeh et al., 2020). Shading devices minimize solar heat gain, reduce glare, and improve thermal comfort. By blocking excessive solar radiation, they contribute to energy savings by reducing the need for air conditioning (Minangi and Alibaba, 2018).

Residential building forms have the potential to serve as effective passive methods for energy efficiency. By considering orientation, window placement, insulation, natural ventilation, shading devices, and thermal mass, building designs can optimize energy performance and occupant comfort. The integration of these passive design strategies allows residential buildings to harness natural resources and environmental conditions, reducing reliance on mechanical systems and promoting sustainability. Passive building forms contribute to energy savings, improved indoor comfort, and a greener built environment (Mokrzecka, 2018; Yang et al., 2018).

Lapisa (2019) presented a study of two building forms in different climates to find that a square building reduces energy consumption compared to a rectangular building for all climates. AlAnzi, Seo, and Krarti (2009) studied the influence of building form on different wall-to-window ratios in office buildings in Kuwait; they selected rectangle, L-shape, U-shape, and H-shape forms at different dimensions using the DOE-2 simulation program through the annual energy consumption. The results show that in the case of a low window-to-wall ratio, the annual energy demands increase whenever the building is more compact, regardless of building form. Raof (2017) compared the energy demand for rectangle, vertical curve, and horizontal curve forms with or without glazing area using the EnergyPlus simulator in the desert climate in Abu Dhabi. He found that the rectangle building has minimum demands for energy without glazing; however, in the case of a glazing area, the horizontal curve and rectangle forms give very close results. Ali et al. (2010) presented a general study of some buildings which are built between (1900-2000) in Irbid (Mountainous climate) and Karak (Desert climate), where both cities are in Jordan. The study is carried out based on a survey and simulation to investigate the effect of some parameters, such as forms, orientation, and materials, on energy consumption. They found that the rectangular form is suitable for desert area buildings in winter, while the compact form is useful in summer. In addition, the concrete slab roof gives high efficiency to minimize the cooling demands in the desert. Mokrzecka (2018) studied the influence of building orientation and building form (square, rectangle, L-shape, U-shape, and C-shaped) in temperate climates on energy heating demands for residential buildings using Sefaira software. He found that the square building shows minimal heating energy consumption, and the orientation does not influence heating consumption for the well-insulated building. A study based on simulation using EnergyPlus in various climates at different regions in China investigated the effect of window-to-wall ratio and different building forms, i.e., rectangular, pyramid, dome, and cylindrical shape on thermal load, and the results showed that the dome shape gives the best thermal behavior. The pyramid shape was the worst form compared with other forms in all climates; in addition, the thermal behavior of cylindrical shape in the mild climate is better than dome shape when the window-to-wall ratio is more than 10% where the cylindrical shape is lower thermal loads than dome shape in other climates (Yang et al., 2018).

Natural ventilation improves the thermal comfort of buildings by enhancing the air quality of the internal environment in the summer, especially at night, where the ventilation level in the winter season must be controlled since it might reduce indoor thermal comfort (Rodrigues et al., 2019). There are several types of ventilation, such as cross-ventilation, stack-driven ventilation, tower ventilation, and single-side ventilation. Moreover, it is found that the window's position has a higher impact on the ventilation level than the building orientation (Kubota et al., 2009; Rodrigues et al., 2019).

Ma'bdeh et al. (2020) investigated the effect of introducing a wind tower, once at the north facade and another to be at the south facade, on interior thermal performance for a classroom in a building located at Jordan University for Science and Technology (JUST) in Irbid in the summer and winter. The results show that the wind tower improves indoor air efficiency for both cases, whereas the highest number of comfort hours is obtained when the tower is built on the southern side of the building. Al-Hemiddi and Al-Saud (2001) studied the impact of the natural ventilation in a courtyard house on internal thermal performance in a hot-aired climate in Riyadh, Saudi Arabia; they found that the cross ventilation through the courtyard contains a water pool can reduce the indoor air temperature by 5℃. Mastouri et al. (2019) examined the influence of night ventilation in a double-storey house in a hot semi-arid climate in Marrakech, Morocco. They concluded that night ventilation gives high-efficiency results by reducing the ground floor temperature by 2℃ and the first floor by 3 ℃. In addition, it can reduce the annual cooling loads by 27%. Omrani et al. (2017) investigated two types of ventilation, i.e., cross ventilation and one-sided ventilation, for high-rise buildings in Brisbane, Australia, which has a subtropical climate; she found that cross ventilation achieves thermal comfort around 70% of all-times and one-side ventilation gives comparably hot indoor climate with predict mean value (PMV) > 0.5.

Shading devices have a clear significance in enhancing thermal performance by reducing heat gain by blocking direct sun rays in the summertime and decreasing heat loss during wintertime, which minimizes the cooling and heating loads, respectively (Samanta et al., 2014). There are several shading methods are frequently used, such as overhangs, external window shading, and interior window shading, as well as shading can be achieved by architectural elements like 'Iwan'. Most of these methods can be introduced for existing buildings to improve their efficiency (Samanta et al., 2014; Eskandar, Saedvandi, and Mahdavinejad, 2018). Adjacent shading results from adjacent buildings or tall trees able to improve the thermal performance of the buildings, including both residential and commercial, in a hot climate (Minangi and Alibaba, 2018).

Freewan (2014) investigated the influence of three window shading types (egg crate shape, vertical fins, and diagonal fins) on air temperature for the southwest facade of an office building in Irbid, Jordan. He found that the shading devices improve the indoor air temperature to be within an acceptable range compared to the office without shading devices. Moreover, the egg crate and diagonal fins types show an advantage performance to enhance the air temperature compared to the vertical fins. Atzeri et al. (2013) studied the effect of Venetian blinds and roller window shading devices on energy consumption and thermal comfort for semi-open offices in Roma, Italy, in the summer and winter seasons. The results show that the shading devices less the energy needed for cooling in the summer season, whereas they increase the energy demand for lighting in winter. Seok-Hyun et al. (2017) analyzed the effect of horizontal window shading for an office building in South Korea on energy consumption. The results show that shading devices increase the heating energy demand but decrease the needed cooling loads, reducing the overall energy consumption. A simulation study using EnergyPlus for a residential building in Casablanca, Morocco, which has a Mediterranean climate explored the impact of overhangs on energy consumption; the result shows that the overhangs reduce 4.1% of cooling energy (Sghiouri et al., 2018). Shahdan et al. (2018) compared the energy efficiency of buildings with different external shading types, namely, vertical, horizontal, and egg crate shading through solar radiation and glare parameters for a school in Shah Alam, Malaysia, that considered hot-humid climate using Autodesk Revit software, they found that the egg crate shading device presents best behavior. A study based on the EnergyPlus simulator for residential buildings in hot-humid Hong Kong, China, examined the effect of vertical and horizontal shading panels on energy saving; the result shows that vertical panels reduce energy consumption by 2.5% while horizontal panels by 5.6% (Liu et al., 2019).

1.3 Problem Statement

Residential buildings considered the largest constructed building sector worldwide, face a big issue in offering sufficient thermal comfort for residents in various climates. Specifically, Jordan is characterized by having a hot-dry climate summer that makes the issue greater. Thus, high electric energy is required for cooling devices to achieve thermal comfort for houses. For an instance, the residential building sector alone consumes about 24% of annual electric consumption in Jordan (Almuhtady et al., 2019). This problem could be generated due to the lack of passive design building strategies used during house construction.

It is very important to implement passive designs during the house designing and construction stages of collaborating different strategies, not just focusing on a single strategy. Literature survey shows that most studies regarding this issue in Jordan and other countries with hot-dry climatic summer investigated only a single passive strategy to enhance the thermal performance of different types of buildings (Freewan, 2014; Graiz & Al Azhari, 2019; Ma'bdeh et al., 2020; Eskandari et al., 2017; Raof, 2017; Sghiouri et al., 2018; Mastouri et al., 2019). It is also noted that most of the conducted studies in Jordan are carried out for existing office and educational buildings; none of them applied to existing residential buildings, which could be due to the difficulty of getting data during daytime due to occupant privacy (Zhang et al., 2017; Minangi & Alibaba, 2018; Lapisa, 2019; Ma'bdeh et al., 2020).

An extensive inspection of the effect of building form in different countries and climates in several sectors, such as offices, commercial, and schools, shows that selecting an optimal form can improve the thermal comfort of such buildings (Raof, 2017; Soufiane et al., 2019). Meanwhile, only a general study in Jordan is found that reported the influence of building form on the thermal performance of residential buildings, which carried out based on resident survey responses for old existing residential buildings without considering site measurement and improvement, discusses the form of building in two different cities in Jordan namely Irbid and Al-Karak (Ali et al., 2010).

Natural ventilation plays an important role in achieving thermal comfort for all types of buildings since it offers airflow through the interior area, reducing the interior temperature and humidity. Despite the importance of natural ventilation in improving indoor thermal performance, unfortunately, few studies explored its impact on thermal performance in different countries with a climate the same as Jordan's in summer (Mastouri et al., 2019). A study examined the effect of introducing a wind tower on indoor thermal performance quality for a classroom building at Jordan university for science and technology (JUST) in Irbid in summer and winter (Ma'bdeh et al., 2020).

Shading devices significantly enhance thermal performance by offering shade that, in turn, blocks direct sun radiation and reduces heat gain in summer. Very limited works focus on investigating the effect of window shading on thermal performance and thermal comfort in Jordan, where most of them deal with window shading as a passive design to enhance energy performance (Bataineh & Alrabee, 2018; Bataineh & Al Rabee, 2022; Abu Qadourah et al., 2022). Freewan (2014) reported a study investigating the influence of three window shading devices (egg crate shape, vertical fins, and diagonal fins) on indoor air temperature for an office building in Jordan. It is found that none of these studies considers examining the influence of using different shading types at various lengths in hot-dry climates.

From the literature, one can notice a lack of deep understanding of the influence of building form in collaboration with the natural ventilation and window shading for residential buildings, particularly in Jordan and the hot-dry climate, which makes it difficult to construct suitable houses that can offer acceptable thermal performance for this kind of climate (Ali et al., 2010; Alibaba, 2018; Ma'bdeh et al., 2020).

1.4 Research Objective

This study aims to investigate the effect of passive design strategies (natural ventilation and different window shading types at various lengths) in collaboration with building form on thermal performance for the residential buildings in Amman, Jordan, in a hot-dry climate in summer. The objectives of this research can be summarized as follow:

i) To investigate the impact of natural ventilation on the thermal performance of residential buildings in the hot-dry climate of Amman, Jordan.

ii) To study the effect of external window shading devices on indoor air temperature, relative humidity, air velocity and mean radiant temperature of residential buildings in Amman, Jordan.

iii) To evaluate the impact of shading device configurations on the thermal performance and thermal comfort of residential buildings in Amman, Jordan.

1.5 Research Questions

Based on the problem statement and research gap, realizing the impact of natural ventilation and window shading in collaboration with building form for residential buildings on their thermal performance and thermal comfort in Jordan drives to the following questions:

i) How the natural ventilation influences the thermal performance of rectangular, L-shape, and U-shape residential buildings in hot-dry climates?

ii) How do external window shading devices affect indoor air temperature, relative humidity, air velocity and mean radiant temperature of residential buildings in Amman, Jordan?

iii) What is the impact of shading device configurations on the thermal performance and thermal comfort of residential buildings in Amman, Jordan?

1.6 Research Framework

Figure 1.1 summarize the research structural methodology framework.

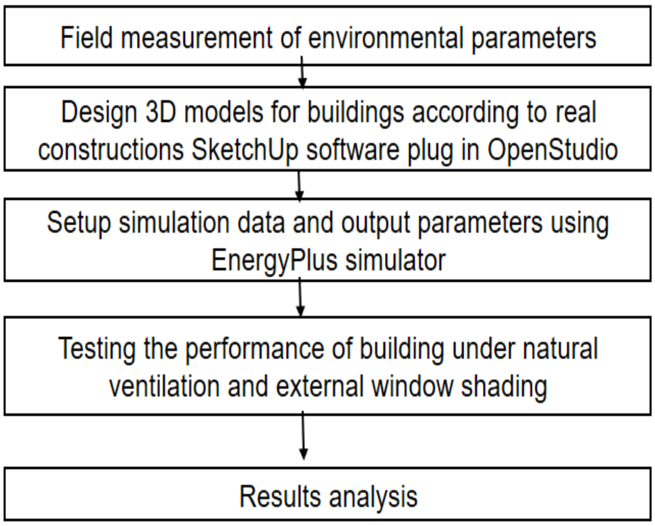


Figure 1.1 Research Structural Methodology Framework

1.7 Scope and Limitations of Research

This research will mainly focus on the residential building sector in Amman, Jordan, which has a hot-dry climate in the summer season. Three existing residential buildings with different forms (rectangular-shape, L-shape, and U-shape) that are facing to west direction are picked up as case studies to investigate the influence of building forms, in collaboration with natural ventilation and window shading, on thermal performance and thermal comfort using SketchUp plugin OpenStudio software and EnergyPlus simulator. Site measurement for the indoor environmental parameters including air temperature, mean radiant temperature, and relative humidity has been carried out to validate the simulation results under basic conditions of the rectangular building. The thermal performance (air temperature and relative humidity, air velocity, and mean radiant temperature parameters) of all buildings under ventilation and external window shading conditions has been investigated based on simulation approach using EnergyPlus simulator. The thermal comfort is evaluated based on the ASHRAE-55 adaptive model and predicted mean vote (PMV) and predicted percentage of dissatisfied (PPD) according to Fanger's model using the environmental parameters obtained from simulation.

The influence of natural ventilation is studied by designing two models for each building form: (i) All external windows are closed (no ventilation). (ii) Second, all external windows are opened.

The effect of external window shading on each building form's thermal performance and thermal comfort is investigated by installing different exterior window shading types, namely vertical, horizontal, and combined at different lengths i.e. 0.75m, 1m and 1.25m.

Lastly, to study the influence of building form in collaboration with natural ventilation and shading devices on thermal performance and thermal comfort, naturally ventilated models for the buildings with the presence of optimal shading devices are examined.

This study is limited to the residential building sector and might apply to buildings in use for 24 hours in Amman, Jordan, to enable investigating the effect of night ventilation during night-time and studying the impact of combining natural ventilation and shading devices during daytime. Moreover, the study can be applied to other regions with the same climate, which is the hot-dry climate.

1.8 Significance of Research

This research is important to improve the efficiency of indoor thermal performance and reduce the cooling loads in residential buildings in the hot-dry climatic season in Jordan and other countries with similar climates. Moreover, this study will suggest the optimum form for residential buildings in collaboration with the optimal parameters for natural ventilation and window shading devices that enhance indoor thermal performance and thermal comfort. In addition, this research can be taken as guidance for people planning to construct new residential buildings that offer acceptable thermal comfort in similar climatic conditions, subsequently reducing the energy demands for cooling loads, thus, reducing the monthly electric bill cost. As well as it may provide a passive cooling design solution to improve the thermal performance of existing residential buildings.

1.9 Thesis Overview

Chapter 1 describes a research background for some passive design strategies, i.e., building form, natural ventilation, and shading devices, and the advantages of using them to enhance thermal comfort in buildings. The research gap for correlating the impact of using ventilation and external shading as passive cooling methods with different building forms in the hot-dry climate in Jordan. The research work's objectives, methodology, scope, and limitations are also presented.

Chapter 2 presents a literature review of passive design methods. It also discusses reports that applied passive building strategies in residential buildings in different climatic regions. The climate profile for Jordan and the residential building development in Jordan are also presented. Moreover, concepts such as thermal performance and thermal comfort evaluation methods are detailed. Besides, a table displays a summary of the previous studies that are discussed applying various passive strategies related to the current work to focus on the lack of literature regarding the residential building sector in Jordan and to have a good understanding of the research gap of this study.

Chapter 3 describes the three case studies that represent residential buildings in Amman, the modelling procedures, and the buildings' simulation steps in detail. The parameters used and the conditions of each experiment are also included.

Chapter 4 discusses the data validation that is obtained for the rectangular building under basic conditions. Then it presents the results of the impact of natural ventilation and different types of external window shading devices at various lengths for different building forms on thermal performance through thermal environmental parameters, i.e., indoor air temperature, mean radiant temperature, relative humidity, and air velocity. It also evaluates the indoor thermal comfort for the buildings under investigation at various ventilation and shading conditions using ASHRAE-55 adaptive model and PMV and PPD indicators according to Fanger’s model on 21st July as a design day in a hot-dry climate.

Chapter 5 summarizes the investigation of the effect of natural ventilation and window shading devices on thermal performance and thermal comfort for the three different building forms. Suggestions for future work that may be considered by researchers interested in this field are presented.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter presents a literature review of various passive building strategies that will be the subject of study in this research, including building form, nature ventilation, and shading devices. The significant impact of passive strategies on residential buildings' thermal performances has been discussed in different climates. In order to have comprehensive knowledge about Jordan as the case study country, the development of residential buildings and Jordan's climate profile have also been discussed. Concepts such as thermal performance and thermal comfort are elaborated in detail to understand the effect of passive strategies thermally better.

2.2 Passive Building Strategies

Passive designs for buildings maintain the comfort of the interior environment and can make the air temperature within the building suitable for residents using natural resources and climate. Using passive strategies enhances indoor air quality and reduces the usage of mechanical systems for cooling, heating, and lighting, which minimizes energy costs. Thus, thermal comfort and interior climate parameters are considered significant indicators that must be considered to consider that passive building is valuable and efficient (Altan et al., 2016).

Passive architecture designs are not new approaches; they have been applied in several traditional buildings in different countries for decades. For example, low thermal mass is used for the building's envelope in hot-humid climate areas, and a hipped roof is introduced to allow ventilation circulation. In middle east countries, which have a hot-dry climate, the courtyard is employed in traditional houses to create a local climate and increase cross ventilation (Zaki et al., 2008; Omrani et al., 2017; Moey et al., 2021).

Designed buildings considering passive strategies have many benefits, such as saving energy consumption and reducing the hefty cost of electric bills, enhancing the quality of the indoor environment, and minimizing the Greenhouse gas emission related to mechanical system usage. Besides, it directly affects human health and activities (House, 2009; Altan et al., 2016; Guzowski, 2021; Elaouzy & El Fadar, 2022).

Several passive building strategies are usually applied for architectural design, such as building form, orientation, window size, shading devices, building color, glazing, daylighting, natural ventilation, isolations, thermal mass, and interior layout (Stevanović, 2013; Lakhdari et al., 2021).

2.2.1 Building Form

Building form and its geometrical composition are considered one of the most critical aspects that impact the internal thermal performance of buildings (Lapisa, 2019). This can be explained according to the building's envelope area exposed to the outdoor environment. The building envelope includes the building surfaces and roof. The buildings' surfaces are the exposed element of the building to the outside and determine the amount of received solar gain, where a larger exposed area leads to higher thermal exchange. The roof shape affects the convection heat transfer range, where the flat roof has less heat transfer compared to a curve shape, like a dome, and the cylindrical due to comparable low contact area; besides, the 'plan (P) to surface (S) or (P/S) ratio has essential effects on the thermal behavior of the building. A high

P/S ratio means that a building has a relatively large plan area compared to its surface area, while a low P/S ratio means that a building has a relatively small plan area compared to its surface area.

High-rise buildings typically have a high P/S ratio because they are tall and have a small footprint (i.e., a small plan area). Low-rise buildings, on the other hand, tend to have a lower P/S ratio because they have a larger footprint (i.e., a larger plan area) compared to their height., as depicted in Figure 2.1 (Rosenlund, 2000; Abed, 2012). Therefore, the earlier stage of building design is a crucial step since it helps to propose a minimum contact area with the external environment, subsequently, improve the thermal comfort level (Mushtaha & Helmy, 2017). Consequently, ignoring the building form and envelope design during building design increases the heat gain and energy needs (Al-Sallal et al., 2013). Generally, several factors impact building form: building usage, planning, feasibility, and construction cost.

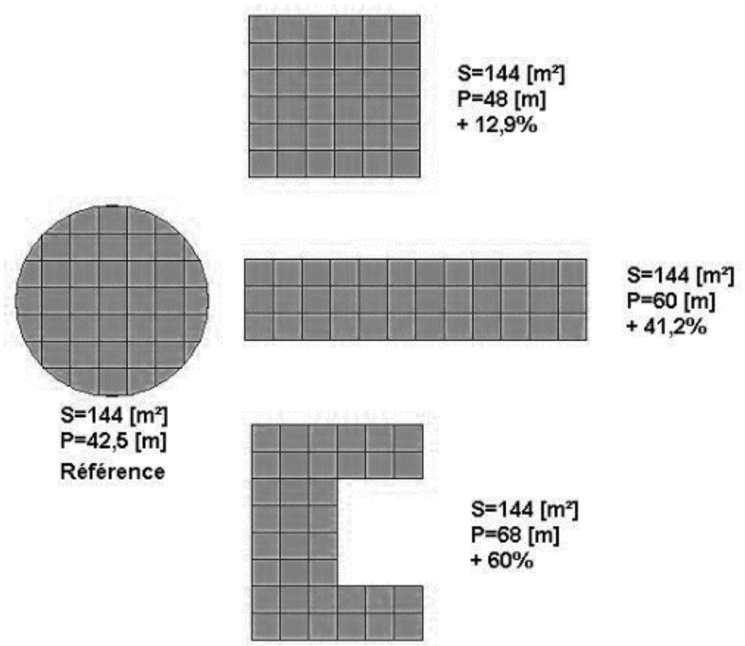
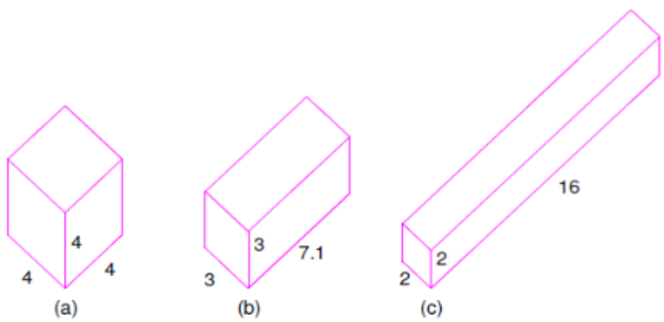


Figure 2.1 Plans for surface area (P/S) ratios for various building forms (Rosenlund, 2000; Abed, 2012).

A study of different forms of traditional residential buildings in a hot-dry climate in Diyarbakır, Turkey, shows that the building shape greatly influences indoor thermal comfort and energy demands. The presence of the inner courtyard of a U-shape with the building can reduce 63% of heating loads and 79% of cooling loads. (Kocagil & Oral, 2015). AlAnzi et al. (2009) investigated the effect of compactness on an office building in a hot-arid climate in Kuwait. They found that the compact shape enhances the thermal performance and less the cooling loads independently of its shape as long as the windows are small. Numerical research shows that the compact shape greatly influences the energy needs for cooling in a desert area (Bekkouche et al., 2013). In addition, it is found that the form plays an important impact in enhancing indoor air quality, where it can reduce 10% of energy consumption in mosques in Sharjah, United Arab Emirates (Mushtaha & Helmy, 2017). Another study, introduced by Pathirana et al., demonstrates that the L-shape gives the best result for natural lighting compared to cubic and rectangle forms (Pathirana et al., 2019). The H-Shape building gives the best result in the cold climate in China compared to the other seven building shapes for schools, according to Zhang et al. (2017). It reduces the heating load by 13.6% and improves internal thermal comfort by 3.8%. A building's shape, spacing, and position concerning neighborhood directly impact the natural factors such as wind and solar radiation, subsequently, influence the airflow and ventilation circulation and the amount of heat gain received by surfaces of the buildings (Nayak & Prajapati, 2006; Hachem-Vermette, 2020). Choosing an optimum form in collaboration with envelope configuration and building orientation can reduce 40% of total energy demands (Wang et al., 2006). The major parameters that affect the designing of an optimal form are:

2.2.1(a) Compactness

The ratio between the building's surface area (S) to the volume (V) is called compactness (S/V). The compactness factor determines the nature of the interchange heat process between the outdoor environment and the interior of the building, which depends on the building's exterior surfaces (Climate Responsive Building: Appropriate Building Construction in Tropical and Subtropical Regions, 1993). Thus S/V ratio determines the size of the exposed building's skin to the outdoor environment, whereas a high S/V ratio allows for heat loss in winter and increased heat gain in summer, as shown in Figure 2.2. The geometric form is defined as the width-to-length ratio (W/L), which is inverse to the S/V ratio. The W/L ratio and orientation are considered significant factors in defining the solar radiation situation for buildings (Ling et al., 2007; Muhaisen and Abed, 2015; Oh and Kim, 2019). Figure 2.3 shows the influence of the W/L ratio on cooling load demand applied in a hot-dry climate in Turkey.



SOLID SHAPE	SURFACE AREA 'S'	VOLUME 'V'	SURFACE AREA/ VOLUME RATIO 'S/V'
a	96	64	1.5
b	103.2	64	1.61
c	136	64	2.13

Figure 2.2 Surface area (S) to the volume (V) ratio (S/V) for different building forms (Ling et al., 2007 Abed, 2012).

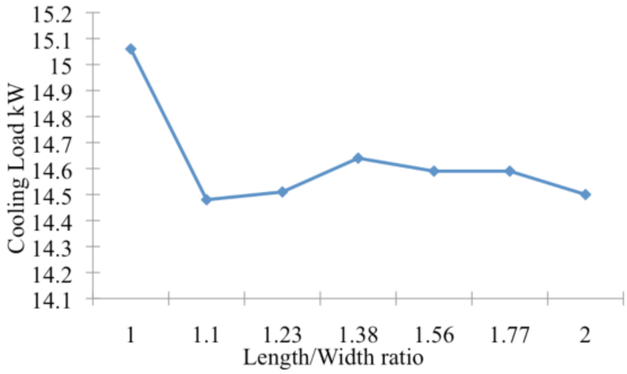


Figure 2.3 Impact of (W/L) ratio on cooling loads demand (Abed, 2012).

2.2.1(b) Perimeter-to-area ratio

The perimeter (P) to floor area (A) ratio or (P/A) is a measure of the degree to which the perimeter of the floor is exposed to the outside. The floor area is determined from the internal surfaces of the heated external walls. The exposed perimeter includes the external perimeter and perimeters that are in contact with the unheated outside spaces of the insulated body of the building, which points to the losses or radiative heat gain and the ventilation performance. The lower (P/A) ratio, the better thermal performance, thus low (P/A) ratio is more appropriate for a hot-arid climate (Teri, 2009; Oh and Kim, 2019).

2.2.1(c) Building characteristic length (L_b):

Characteristic length (L_b) is defined as the relation between the building's heated volume and total heat loss from all surfaces (ΣS_i), including surfaces that are in contact with the ground, surfaces that are in contact with the exterior side, and the surfaces near to the non-heated areas. The building's characteristic length is given by the following equation (Catalina et al., 2011):

$$L_b = V_b / \sum_{i=1}^{n} S_i \qquad (2.1)$$

where L_b is the building's characteristic length, V_b is the building's heated volume, and ΣS_i is the sum of total heat loss from all surfaces.

2.2.1(d) Building's form and self-shading

Some forms make self-shading, such as H-Shape, U-Shape, L-Shape, and courtyard. Such building forms influence thermal performance by playing an essential role in reducing the direct solar radiation amount received by the building. However, the layout of the building's envelope controls the self-shading, improving the thermal comfort efficiency (Chan, 2012; Youssef, 2022). Figure 2.4 shows the relation between the building's shape and heat wastage.

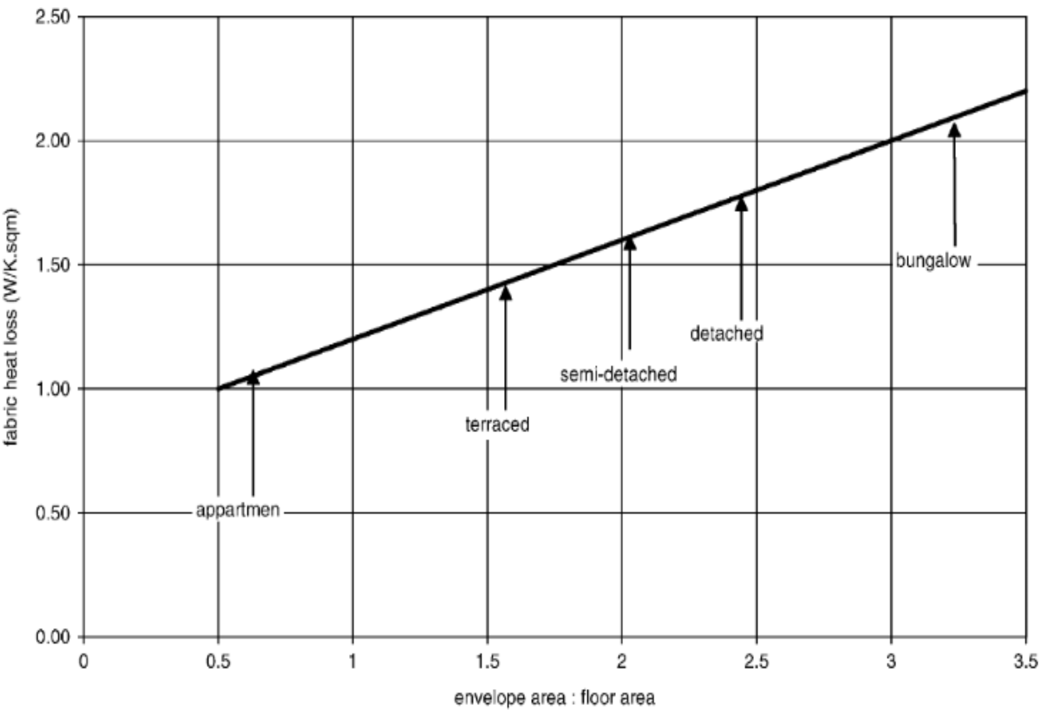


Figure 2.4 Relationship between the building's shape and heat wastage (Chan, 2012.

The geometry of the building influences the local climate of the urban canopy layer, where the open areas, courtyards, and planning streets pattern affect the overall climate in the district. The ratio between building height (H) and width of the street (W) or (H/W) is called the aspect ratio. The aspect ratio impacts the street's shading and affects night ventilation, limiting and controlling wind circulation (Krüger et al., 2010; Chen et al., 2020). Figure 2.5 shows the effect of aspect ratio and building depth on the air temperature that impacts thermal performance. One effect of the aspect ratio is on street shading. Buildings with higher aspect ratios (taller buildings and narrower streets) tend to cast longer shadows, resulting in increased shading of the streets below. This shading can have implications for the local microclimate, affecting factors such as the distribution of solar radiation, heat absorption, and overall thermal comfort (Chen et al., 2020). It illustrates the relationship between aspect ratio, building depth (another geometric parameter related to building design), and air temperature. It demonstrates how different aspect ratios and building depths can affect the air temperature within the urban environment, which has implications for the thermal performance of buildings and the surrounding spaces (Krüger et al., 2010).

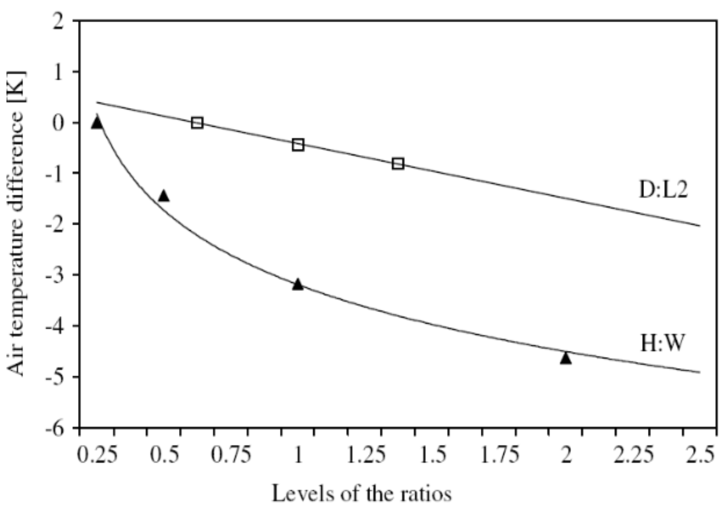


Figure 2.5 Impact of aspect ratio and building's depth on the air temperature (Krüger et al., 2010).

2.2.2 Natural Ventilation

Natural ventilation is the process of dragging fresh air into the building, forcing the hot-dirty air to move out of the building through the windows without using any mechanical systems. Thus, natural ventilation improves indoor air quality, enhances the thermal comfort level, and decreases energy consumption (Hughes et al., 2012; Ahmed, 2021; Kapoor et al., 2021). Natural ventilation occurs due to two mechanisms: wind moves outdoors around the building, and the buoyancy air is created by the difference in air temperature inside and outside the building. Thus, the designer should consider these mechanisms during the earlier stage of designing the building to achieve maximum ventilation (Krarti, 2018). Besides, natural ventilation offers a healthy environment for occupants. It gives a satisfactory feeling leading to an increase in their productivity, whereas natural ventilation gives excellent results compared to mechanical systems. At the same time, it is found that Sick Building Syndrome (SBS) symptoms infected the residents due to using the mechanical cooling system by 30% -200% higher than natural ventilation (El Zeina & Hijazi, 2021; Wang et al., 2022). The literature shows that using purely natural ventilation can help to achieve a thermal comfort level in a temperate climate, but in a hot-humid climate reaching to acceptable comfort level via natural ventilation is not possible (Lion et al., 2012).

The natural ventilation that occurs from one side for opening (single-side ventilation) can be calculated by the following equation (Krarti, 2018)

$$Q = C\,A\sqrt{\frac{2\,\Delta p}{\rho}} \tag{2.2}$$

where Q is the ventilation flow rate, C is the airflow coefficient, A is the opening area, Δp is driving pressure differences, and ρ is the volume flow rate.