

**Assessment of the Effectiveness of the Double Skin Facades
(DSFs) Configurations on Enhancing the Energy
Performance of Multi-Used Building in Hot-Arid Climate
The Case in Al-Ain City-UAE**

تقييم تأثير وفعالية انماط الواجهات المزدوجة على أداء الطاقة في المباني
المتعددة الاستخدام في المناخ الحار الجاف
الحالة الدراسية: في مدينة العين- الإمارات العربية المتحدة

by

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of the requirements for the degree of

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ABSTRACT

Implementation of **double-skin facades DSFs** is a sustainable technical solution for enhancing energy performance of building, but the climatic conditions could affect the DSF performance. Al-Ain city-UAE is a hot-arid climate zone and characterized by higher solar gains which play a key role in the DSF performance. In this work, the parametric study was carried out to assess the impact of *DSF geometry, cavity depth, glazing properties, openings vents, shading devices SDs and air flow mode* in enhancing energy performance and thermal comfort. A multi-used building (commercial and residential) in Al Ain city was selected as a reference base case model for this study. **Four -types of ventilated DSFs** were applied in the reference building under a wide range of strategies and scenarios based on modifying parametric study of (*Cavity width, glazing properties, solar shading devices SDs positions*), through replacing the conventional building wall of reference case with DSF system. Different strategies were adopted to analyze the energy performance (total annual cooling loads and total annual electricity consumption) of the building. This work is based on numerical simulation methodology, the **IES-VE** software tool was utilized to perform the simulation of total energy consumption. IES-VE tool is connected to different applications based on thermal analysis and energy consumption such as, *MacroFlo* and *MicroFlo-CFD* used to assess and predict the optimal type and parameter, based on measuring the efficient energy performance, air flow-rate, and air velocity of an integrated base building with DSF types. CFD application was used to simulate the airflow behavior with the air cavity and predicting the influence of DSF in promoting energy performance.

To identify the optimum configurations among the four types of natural ventilated DSFs system with External Air Curtin (EAC) mode; the 4 -types of DSFs based on partitioning cavity (*Box-*

Window, Shaft-Box, Corridor and Multi-Story facade) were investigated and compared in this work. The final findings found that the most effective parameter in reduction cooling loads is opening size area, glazing properties, cavity width, airflow within cavity, and shading devices SDs in sequence.

The most optimal case was Multi-Storey façade achieving about 10.30% reduction in cooling loads in comparison to the reference base. Overall, all types of DSFs achieved efficient performance in reduction the total annual cooling loads and total annual electricity consumption. In comparing with reference traditional building envelope. The target of this study is to investigate the thermal performance and the effectiveness of DSFs systems to improve the building energy efficiency, to afford a comparison and evaluation of the tested types of DSFs, and to determine the optimal design of the four DSF cases in dealing with thermal performance under hot-arid climate.

Keywords: *Double Skin Façades (DSFs), Air cavity, MacroFlo, CFD MicroFlo, Solar shading devices SDs, External air-curtain (EAC), energy performance, Dynamic thermal simulation, natural ventilated DSF.*

ملخص

يعتبر تطبيق واستخدام نظام واجهات الجلد المزدوجة حل تقني مستدام لتعزيز أداء الطاقة للبناء، ولكن الظروف المناخية يمكن أن تؤثر على أداء الواجهات المزدوجة في المباني. تعد مدينة العين في الإمارات العربية المتحدة منطقة مناخية حارة جافة وتتميز بارتفاع المكاسب الشمسية التي بدورها تلعب دورا أساسيا في أداء الواجهة المزدوجة. في هذا العمل، تم إجراء دراسة بارامترية لتقييم النظام الهندسي المتكامل للواجهة المزدوجة حيث تناولت تحليل ودراسة عمق التجويف، وضع تدفق الهواء، وخصائص الزجاج وفتحات التهوية وأجهزة التظليل في تعزيز أداء الطاقة والراحة الحرارية. تم اختيار مبنى متعدد الاستخدامات (تجاري وسكني) في مدينة العين كنموذج مرجعي لهذه الدراسة. تم تطبيق أربعة أنواع من الواجهات المزدوجة (ذات نظام التهوية الطبيعية) في المبنى المرجعي تحت مجموعة واسعة من الاستراتيجيات والسيناريوهات المبنية على أساس استبدال جدار المبنى التقليدي للحالة المرجعية وإنشاء الواجهة المزدوجة، ثم القيام بتعديل المعايير المؤثرة في أداء المنظومة كاملا وهي: عرض التجويف، خصائص الزجاج، مواقع أجهزة التظليل الشمسي. تم اعتماد استراتيجيات مختلفة لتحليل أداء الطاقة للمبنى (إجمالي حمولات التبريد السنوية وإجمالي الاستهلاك السنوي للكهرباء). وقد استخدم هذا العمل القائم على منهجية المحاكاة العددية، أداة البرمجيات (IES) وهي أداة متصلة بتطبيقات مختلفة مثل (تحليل دخول وخروج الهواء والانتقال الحراري من خلال الفراغ) تستند إلى التحليل الحراري واستهلاك الطاقة لأداء محاكاة والوصول للاستهلاك السنوي الكلي للطاقة المستخدمة بالتالي للتقييم والتنبؤ بالنوع الأمثل للنوع والمعيار والذي يقاس نسبة للأداء الفعال في استهلاك الطاقة، ومعدل تدفق الهواء، وسرعة الهواء للواجهة المقترحة المزدوجة للمبنى القائم. في هذه الدراسة أيضا تم استخدام تطبيق (MacrFlo-CFD، MicroFlo) لمحاكاة سلوك تدفق الهواء من خلال تجويف الهواء والتنبؤ بتأثير الواجهة المزدوجة في تعزيز أداء الطاقة. تم التحقيق في أربعة أنواع من نظام واجهة المزدوجة المصنفة بناء على أساس تقسيم التجويف وهي (مربع النافذة، صندوق شافت، الممر والواجهة متعددة الطوابق) ومقارنتها في هذا العمل لتحديد الأداء الأمثل بين هذه الأنواع الأربعة. وجدت النتائج النهائية أن المعالم الأكثر فعالية بالترتيب هي مساحة وحجم فتحات التدفق، وكمية تدفق الهواء داخل التجويف، يليه عرض التجويف، وخصائص الزجاج ثم أجهزة التظليل. بعد ذلك تم التحقيق في الأربعة أنواع وتوصلت النتائج النهائية ان الحالة الأكثر مثالية هي الواجهة متعددة الطوابق التي حققت انخفاضا بنسبة 10.30% تقريبا في أحمال التبريد مقارنة بالمبنى المرجع الحقيقي وبشكل عام، حققت جميع الأنواع أداء فعالا في خفض إجمالي أحمال التبريد السنوية وإجمالي الاستهلاك السنوي للكهرباء مقارنة مع مغلف البناء التقليدي. كان الهدف من هذه الدراسة هو التحقيق في الأداء الحراري وفعالية أنظمة الواجهة المزدوجة لتحسين كفاءة الطاقة في المبنى وكذلك لمقارنة وتقييم الأنواع المختارة من الواجهة المزدوجة والتوصل الى المنظومة المثالية التي تناسب المناخ الحار الجاف.

*To my compassionate and lovely family. I appreciate every and each support you provided me during this journey of hardships and ease. Thank you to my dear husband and children.
May God bless them and protect them*



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ABBREVIATIONS

DSF	Double Skin Façade
CFD	Computational Fluid Dynamics
IES-VE	Integrated Environmental Solutions -Virtual Environment
SDs	Solar Shading Devices
SSF	Single Skin Facades
EAC	External Air Curtain
SHGC	Solar Heat Gain Coefficient
CRFS	Climate Interactive Façade System
IEA	International Energy Agency
BPS	Building Performance Simulation
WWR	Window to Wall Ratio
IGU	Insulating Glass Unit

CHAPTER ONE

INTRODUCTION

1. CHAPTER 1 INTRODUCTION

1.1 BACKGROUND INFORMATION

Recent studies revealed that the buildings sector consumed a significant portion of energy specially in cooling and heating loads compared with other sectors (transportation, industrials...etc.). According to the UNEP's Global Status Report 2020, The total energy demand and CO₂ emissions of the global buildings and construction sector together account for 35% of global final energy use and about 40% of energy-related carbon dioxide (CO₂) emissions as adapted from the International Energy Agency (IEA) world energy statistics represents the greatest portion compared to other sectors as shown in fig. (1).

While the global electricity consumption of building operations is about 55% of global electricity consumption. (UNEP 2021) In 2021, global electrical demand is expected to increase by 4.5% due to rapidly growth and economic activity. (IEA 2020) This underlines the importance of sustainable strategy to reduce the energy demand in the buildings. The global direction on energy saving and building efficiency motivate both building engineers and researchers to create a technical solution to use building envelope for reduction the energy consumption. Many researches have improved the simulation tools and methodologies to process the problem of managing building energy performance with different attitudes.

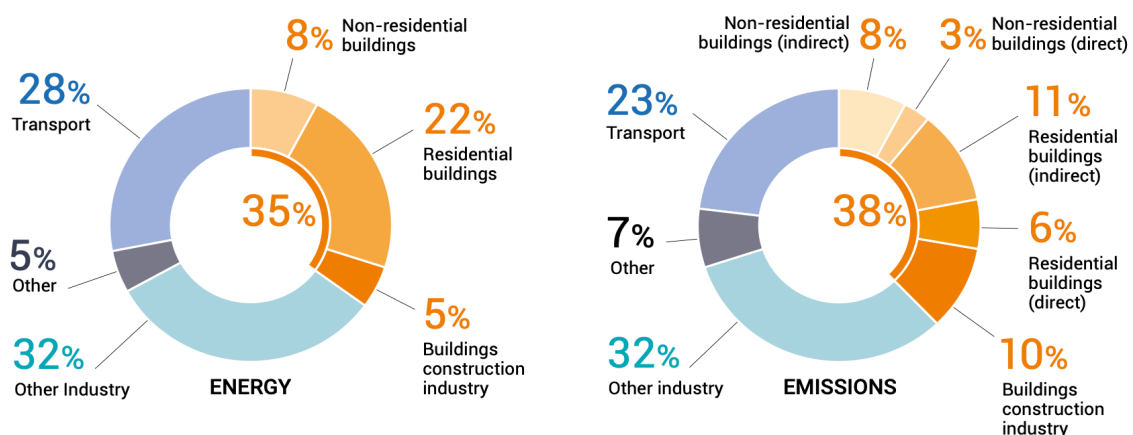


Fig. 1 Global share of buildings and construction final energy and emissions, 2019. Source: (IEA 2020d; IEA 2020b)

In the United Arab Emirates (UAE) significantly large proportion of electricity is consumed; more than 70% of the power generated is consumed by buildings sector and the cooling loads account about up to 80% of total building energy consumption.(Angeles, González & Ramírez 2018) resulting in the power shortage especially during summer months. Rapidly growing UAE cities led to great expansion in constructed high rise buildings which are typically built without load bearing external curtain walling with different ratios of glazing to opaque wall, these ratios influence the energy demands for cooling loads, recent trend in UAE shows significant increase ratio of glazing. (Aboulnaga 2006) (Radhi, Sharples & Fikiry 2013)

The challenge of sustainability, energy consumption in the UAE has grown an annual average of 4% over the past six years and projection expected to rise 5% through 2020.as shown in fig. (2) IEA The air-conditioning in typical commercial buildings accounts the largest electricity consumer for more than 40% of the total electricity consumption of a building. (Chan et al. 2009)

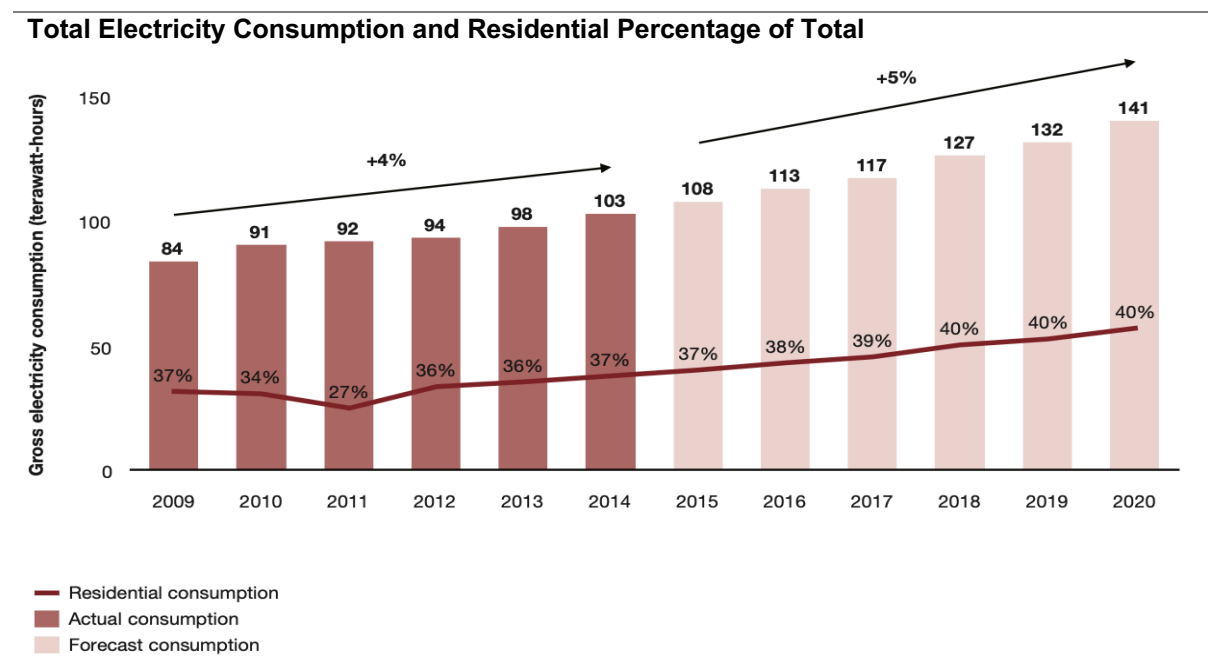


Fig. 2 Electricity consumption of UAE and forecast. Source: The Economist Intelligence Unit, 2015; International Energy Agency (IEA)

The urgent demand for sustainable cooling solutions by reducing energy and cooling consumption required advanced technology in retrofitting and design building façade for adaptation, resilience and sustain cooling thermal environment building. These facts forced the engineers, governments and scientific platforms over the world for enhancing the energy efficiency, reduce energy consumption in buildings and improving the indoor environment quality.

Nowadays, the sustainable building development witnessed escalating concern around the world, the energy conservation of building is one of the main issues. A new trend of modern architecture has been noticed in the cities for buildings construction and design style of modern architecture by creating an extensive glazing facade that facing solar radiation leading to increasing heat gains, resulting in maximizing cooling loads.

The glazing facade system has grown rapidly especially in commercial building due to their multi-functional light weight structure, daylighting performance and aesthetical purposes. These large glazed area facades facing the sun have appeared in cities such as Dubai, Abu Dhabi and Sharjah and turn as the icon of Dubai building. (Radhi, Sharples & Fikiry 2013) This large area of glazing system in building façade increasing the heat exchange between the façade and the outdoor environment resulting in escalating the energy demands, so these facades typology need avoiding overheating and sun glare in summer time. (Abounaga 2006) In general, the buildings account about 40% of using global final energy and this obviously indicates the needs to implement effective sustainable technique for enhancing the green buildings performance. During the early design stage, efficient energy saving plan should be considered for building facades, and considered as one of the most critical issues of designing energy efficiency for green buildings.

1.1.1 DEVELOPMENT OF THE BUILDING FAÇADE

“Façades are seen as a zone with some depth; the Façade Tectonics research group at the University of Southern California calls the façade “the outside six feet” of a building. (Mary Ben Bonham 2020)

The concept of architecture of the buildings was connected with a classical idiom deriving from the ancient Greek art of the building where the main values are aesthetical aspects focusing on the shape, proportion of the building, elements, and material. In the middle of the 20th century, the climatic change with depleting resources resulted in modifying the perspective of building envelope design. The architectural concept is not relied only on the building’s appearance and technology of materials, it also based on the users’ comfort and environmental issues.

The development of the building façade (solid wall construction) can be described as follows; the first design based on the openings of the building façade were constructed to escape smoke, then improved to let light in. Next, using horizontal beams to avoid the weakening of building fabric of solid wall through creating openings in it. In Gothic architecture, a large area of openings is expanded and reduced an amount of solid masonry area to permit more light in the building space. Later, it is possible to create large openings in unstressed parts of the wall (Ulrich Knaack et al. 2007) fig. (3). shows Merchants houses, 16th century using large area of glazing in building facades.



Fig. 3 Merchants' houses in Antwerp, 16th century using large area of glazing in building facades. Source:(Photos 2021)

During the recent two decades, the glass material developed into a high-innovative technology, resulted in full transparency and complexity construction of building facades. (Heimrath 2005)

In the beginning of the 20th century, the exterior design of the building envelope (skin) transferred to a high window- to- wall ratio WWR and free form building structure interests. Though, improved the glazing materials in the building envelope introduced a fully glazed facades resulting with acceptable daylighting and higher visual connection to the outdoor environment. (Lee, Alshayeb & Chang 2015)

The building envelope is a physical barrier between the indoor and outdoor environments of the building, also it should provide comfort (satisfactory) of the indoor spaces and adapting to the climate changes. Recently, the most commercial buildings are installed fully transparency glazing façade resulting in increasing energy consumption. Although a sever hot-arid climate is featured the desert in Al-Ain city, the fully glazing facades have been expanded (growing) investigated in the UEA. (Aldawoud, Salameh & Ki Kim 2020)

The following fig. (4) illustrates the local structure buildings in in Al-Ain city central district (*Wast-Al-Madinah*), the physical development of Al-Ain city exposed a special combination of tradition and modernity. (Yildirim & El-Masri 2010).The most recent building typologies (features) of the commercial, the commercial building facades are constructed with fully glazing façade as noticed.



Al Ain city down town, public street view of characteristic/typical buildings prototype façades style

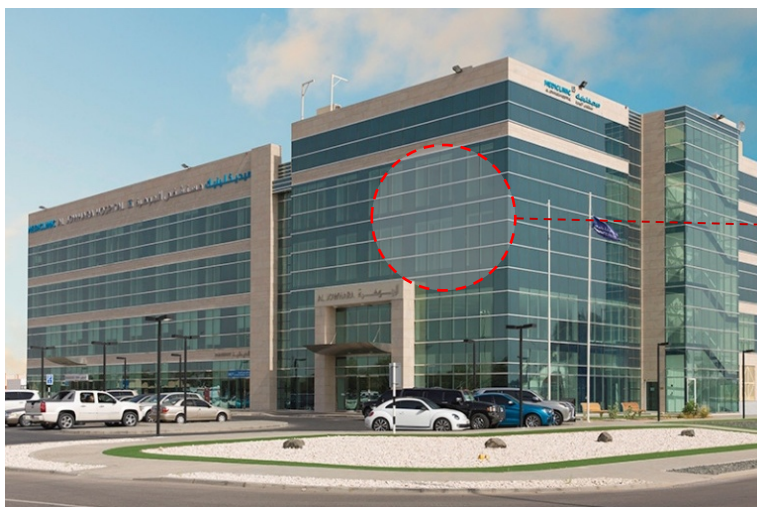


Al Ain multi-used buildings prototype

**a. Common building façade
Tradition Punched window**



**b. Common prototype of commercial building
Large glazing window to wall ratio**



**c. Current building façade prototype
Fully glazing facade**

Fig. 4 Development of glazed building façade in the Al-Ain city- UAE for commercial buildings. Fully glazing façade identify the most commercial building in the UAE. Source:(author)

Recently, Increasing the complexity development trend of the building façade technology is the prevailing trend, range of technical solutions is expanding constantly indicates for the (state-of-the-art) such as, more intelligent facades, facades and technical components interact to each other, more insulation, higher efficient, lower need cooling units and so on.(Ulrich Knaack et al. 2007) Moreover, the building envelope had a great influence in the sustainability effects of building spaces. (Hindman & Hindman 2020) Avoiding heat is one of the primary concerns in hot climates in order to reduce energy consumption and achieve comforts for occupants. Different passive strategies have been designed to cut down the solar gain such as shading system and improving thermal insulation wall.

Over the last decades, a new development trend in the building envelope design was observed, mainly belonging to the office buildings have totally changed by using the large double-glazing envelopes. However, the double-glazed envelope is a part of the building technology which transfers the outer-shell visually, concerning in energy saving and depends on a complex assessment of the whole building. From different perspectives, the multiple-skin facades do not necessarily improve the efficient energy of the building designs, possibility to enhance some components of the whole building's energy demand. Unfortunately, the most typologies unable to reduce the heating and cooling demand simultaneously. (Saelens 2002)

1.1.2 CONTEXT OF DSF IDENTIFICATION

The Double Skin Façade (DSF) is derived from architectural movement where aesthetic considerations play an important role. (Pérez-Grande, Meseguer & Alonso 2005). The DSF system could be an optimal solution in managing the interaction between the internal spaces and external conditions. It works as a screen for heat gains from radiation and conduction under hot climates and enhancing thermal internal comfort. In hot arid climates the amount of solar radiation is increasing over the building envelope surface, this overheating could be the major

problem. The building envelope of DSF system construction consists 3 main components; two transparent surfaces (external skin and internal skin) separated by air cavity which used as air channel, the skin layers can be single or double glass, and the depth cavity depends on the environment conditions. (Harris Poirazis 2006) The efficient system of DSFs design is required, understanding the airflow mechanism, the main factors and parameters impact in ventilation mode, thermal, and energy performance.

The high glazing to wall ratios demonstrates the current and ongoing trend of many high-rise buildings in the UAE. (Aboulnaga 2006) The concept of DSF introduce a passive solution method to decrease cooling demand in different buildings. The DSFs provide ability of reduction the outdoor temperature of air surrounding the external surfaces of conditioned indoor rooms below of the ambient air temperature, through flushing undesirable heat away from conditioned inner skins by natural ventilation and decreasing solar heat gain, since that enhancing the external skins DSF thermal performance would decrease the air cavity temperature and hence reduce the heat gain conductivity, and affording shading from solar. (Johny 2018) The reasoning behind employing fully glazed facades in commercial buildings in order to enhancing the natural daylighting, but these façade configurations lead to increase the total solar energy significantly to the indoor environment and hence maximizing temperature of inner glazing layer in summertime leading to increase total energy power consumption used for cooling load of the building. (Tascon 2008) However, installing multilayered skins could enhance the building insulation against thermal and external environment conditions.

The concept of the **Double Skin Façades (DSF)** was created in Germany in early 1900's. The DSF has significant characters for enhancing the ventilated system and indoor air quality by creating a thermal buoyancy within the cavity (air gab) due to different pressure and wind

movement. In addition, it maximizes a thermal comfort, daylighting performance with reduction electricity power loads.

Last decades, the DSF is considered as advanced sustainable technology that help architect to motivate the combination of transparent façade for creating a significant solutions of building envelope performance for adapting and response to surrounding environment conditions.

However, the development of DSF performance still in early stage in hot and humid climate. Furthermore, studies on DSF in the last decade have been notably extended to a wider range of climate from cool continental to Mediterranean, hot and arid regions. (Sabrina Barbosa n 2014) The first published topic of DSF was done by Eberhard Oesterle in 2001, named “*Double-Skin Façades: Integrated Planning*” then followed by hundreds of research projects and papers which either agree or disagree this system. (Boake et al. 2014)

The research looks for different elements and components that could be influenced on the building performance; might be the building form, orientation, window to wall ratio, glazing properties, transparent and opaque system, passive systems and others. However, the building envelope act as physical barrier that separates between the indoor and outdoor environments also it is considered a key factor that impacts on the indoor quality environment, energy saving and control the comfort conditions. Adopting advanced technology such as DSF requires a critical considerations of its functional system under extreme hot climate conditions, this study investigated in design different types of DSF based on cavity partitioning and analyzing their performance which influenced by several parameters like (optical glazing properties, cavity depth, solar control shading devices SDs and vents opening) in order to reduce the solar gain reaching inner space conditioned. The concept of DSF system introduce an envelope of air (cavity air ventilation either natural or mechanical) combined/merged conditioned spaces in order to create lower temperature than ambient outdoor environment resulting to reduce SHGs by evacuating the radiative heat absorbed by the building envelope elements then achieving

saving whole building annual cooling demands. In the recent, DSF as architectural element is adopted in the modern office buildings as a solution for highly glazed building façade to mitigate the annual cooling loads. (Sabrina Barbosa 2015)

However, design an optimal DSFs system under hot climate required different criteria should be taken in account regarding with energy consumption and enhancing the indoor environment thermal performance, since the reduction cooling loads of the building related to the heat gains and energy consumption become the main issue, thus constructing ventilated façade minimize temperatures in the building. (Tascon 2008).

The study assessed the impacts of employing DSF systems on the annual energy demands of the commercial buildings in the UAE in hot climate, also to make comparison between the base case (existing building) and four types of DSF in terms of energy efficiency for enhancing thermal building performance also suggesting the optimal design of DSF configurations.

1.2 RESEARCH INSPIRATION AND MOTIVATION

If we think of clothing as a 'second skin,' a building enclosure is a 'third skin' that invites or repels these environmental forces in degrees necessary for our physiological and psychological comfort In the book Climate and Architecture, Torben Dahl and Eva Tind Kristensen, (Mary Ben Bonham 2020)

The commercial buildings usually have large glazing façade resulting in trapped solar heat gain inside the room, which can dissipate by natural, mechanical ventilation. These building prototype dominated by cooling loads due to the large floor area to the glass facade area. So, DSF has been widely considered. This study selected natural ventilated DSF system as advanced sustainable building skin design solution to retrofit the typical building envelope in Al-Ain city under extreme hot weather. To prove its potentially in reduction the energy consumption and enhancing thermal performance for the buildings.

The concept of creating different types of DSFs to provide suggestions and guidelines which assist architects and engineers in early design decisions for understanding another alternative building façade that be efficient, improving the energy performance and thermal comfort of building occupants. In terms of architectural view, the study offers different perspective concept for alternative typical building façade. The DSF is an appealing architectural façade in modern buildings due to transparent appearance to the building envelope, also it can be able to manage the indoor thermal conditions and reduce energy demands.

Despite its great effect, there is limited utilization of DSF system in UAE due to different limitations such as construction costs issue with little of understanding DSF mechanism and techniques. Additional, studies of naturally ventilated DSFs are limited number of cases to date especially in hot climate. Currently, several types of DSFs system have been used in many architectural projects. These sustainable building facades attempted to enhance thermal indoor environment and saving energy consumption. According to growing environment sustainability consciousness, designing the building envelope (façade) is considered one of most significant way of saving energy. Sustainable development and needing energy conservation in buildings create a new vision towards passive solar system. DSFs is considered as one of the optimal options through the recent intelligent buildings for energy conservation. DSF achieves potential flexibility in architectural design, it is also one of the best optimal system selections in managing between the internal and the external interaction spaces of the building facade. The DSF was selected as a technical strategy to optimize the efficient energy of building envelope, esthetic purposes and thermal comfort are the main design criteria.

1.2.1 OBJECTIVES

The main targets of this study are:

- To provide sufficient comparison between four the DSF types (*Box-Window, Shaft-Box, Corridor façade and Multi-Storey façade*) based on cavity partitioning which are constructed on an existing building (reference base case).
- Evaluation of the optimized DSF types regarding with energy saving, thermal and ventilation performance to improve the building efficiency level.
- To assess the effect of different DSF types in enhancing energy performance of the building.
- To model and simulate the airflow and heat transfer in the DSF system by using CFD technique. For focusing on the influence of variable parameters in improving the energy performance of the building envelope, study the influence of, air inlet and outlet configurations, the cavity depth either thin or wide, changing glazing properties, and the location of the blinds on the temperature and air distribution in the air cavity
- Establishment of guidelines for efficient and ideal DSF design in hot-arid climate. Furthermore, draw frameworks for architects and engineers to select the optimal performance of DSFs under the same conditions considering the building function, orientation and climate conditions.
- To analyze the importance of modifying main components of DSF system in minimizing cooling energy consumption in building.
- Highlighting the strategies that play significant role in enhancing building performance.
- Investigate the effects of using different parameters on lowering energy consumption such as *glazing properties, cavity depth, vent openings and solar shading devices SDs* to avoid undesired solar heat gain and decrease cooling loads during cooling seasons.

- Using IES-VE simulation software to assess which type can be proven its ability in reduction energy consumption and achieving highly thermal comfort in the building.
- Fill the gap in scarcity of research by testing the potentials of DSFs technology in achieving saving energy in hot-arid climate.

1.2.2 HYPOTHESIS

The potential of DSF which is typically defined as “*a pair of glass layers separated by air cavity*” more energy efficient than conventional single skin facades SSFs in hot-arid climate. also changing the geometry design, cavity depth, glazing properties, and shading devices SDs can achieve better thermal performance and reduction energy consumption. Determining an optimal DSF type of the four design types; **Box-window, Corridor, Shaft-Box and Multi-Story** in hot-arid climates based on modifying the design parameter and combinations required adequate design to predict the final observations.

DSF design in multi-used building could be efficient design regarding with energy efficiency, passive strategies design with DSF increase capability of this design and afford alternative concepts of glazing building façade. The weakest points of building construction are windows because of their high U-value conductivity. The risk of overheating inside the environment space have increased caused by highly glazed facades, electric lighting and other equipment such as computers which release extra internal heat gains. That’s why recently the high-tech image of DSF has been witnessed a great deal of interest in employing it in building envelope. In addition, increasing in cavity temperature of the DSF system could be not adequate in extreme hot regions where surrounding ambient temperature are relatively high. that’s why limitation in applications such like this system remains controversial and still needs more investigation.

The most investigation studies of DSFs and their performance is mostly studied in cold climate and there are a lot of literature considering DSF in European and North American countries. But there is lack of papers have been done for DSF applications in hot-arid climate, and also is not studied enough yet. This paper would aim to evaluate the efficiency of DSF in lowering solar heat gains in UAE. To observe thermal performance of installing DSF, study the behavior applications of DSF in hot climates and address their configuration in terms of natural ventilation, achieving better thermal comfort and saving energy demands for buildings. Additionally, focusing on heat/solar avoidance is considered essential concern in hot climate scenario translated into reduction cooling loads and achieving comfort for occupants. It is possible to provide efficient shading protection for building façade by applying DSF systems. This study depends on **Inductive** approach to answer the study hypothesis, it might be different and still uncertain form the concept, so the **Quantitative method** has been adopted by using IES-VE software tool.

1.3 RESEARCH FOCUS AND LIMITATION

The study focused on improving the DSF system through modifying the conventional existing building envelope, depending on merging the optimum solution results of the best DSF scenarios and configuration derived from proposed design of DSF types simulation results by integration with a real case studies and previous theoretical studies. Due to the complexity of DSF design with various parameters, the study attempts to enhancing the main parameters mainly supporting thermal performance and determining the optimal options of; air cavity depth, glazing properties and shading devices control which play a significant role in hot climate in reduction overheating indoor space. **The focusing** of this study mainly is in reduction cooling loads passively, through applying natural ventilated DSF cavity, as

sustainable building envelope scenario on multi-used building in the hot-arid climate of Al-Ain city.

This work spent long time to model the whole reference building in details by using Sketch-Up software then export to IES-VE simulation tool for analysis energy performance of the tested building. However, during stage of energy modeling analysis. During run simulation phase many obstacles have met researcher; accuracy of simulation could be related to the complexity details of the base building envelope projection and structural elements, the lack of numerical data analyzed the DSFs structure and construction materials in hot climate in Gulf region, the innovative technology of DSF is still limited not popular in the region.

1.4 DISSERTATION CONTENTS AND STRUCTURE

The first chapter provides the main introduction associated with study targets. Identifying the problem statement, hypothesis, briefly description of DSF system, research inspiration and motivation and limitation of research study.

The second chapter is literature review LR describes in details the various aspects, configurations, definitions and analysis of DSF. It addresses the history of DSF concept, functionality and typologies as well as illustrates different case studies global and local have applied DSFs on building envelopes. This chapter reviews in-depth several previous studies focusing on the main parameters associated with DSF design and how could impact on the energy performance of buildings.

The third chapter provides the methodological in details followed the previous studies of LR. It includes the main parametric methods, collecting data have adopted to assess the energy

performance of DSF building. Draw flow chart for identifying the bulk study area including proposal design alternatives, design guidelines, this chapter also described the proposed methodology, and frame work structure.

The fourth chapter presents overview of case study, analysis precisely for the actual collecting data, analysis the current state of the base case building (reference building), site analysis, weather climate profile in hot-arid climate in Al-Ain city in the UAE and the concept description of the proposal four types of DSFs (geometry modelling), verified between simulation model and actual measurement of the reference base case validity the simulation software IES-VE for proposed design simulation analysis, addressed the design concept and development process of energy modeling, identifying the main parametric study of proposed DSF system, describe in details the 4 DSF cases with model-set up and analysis dynamic thermal simulation, evaluating parametric design of DSF system of four DSF types.

The fifth chapter demonstrates the simulation analysis by using IES-VE for the base case and proposed strategies of 4 DSFs types that rendering individually based on different parameters and criteria associated with final graph results show the annual energy consumption, air-flow analysis by adopting MacroFlo and MicroFlo-CFD applications to predict the energy and thermal performance of DSF

The last chapter of paper based on conclusions reflect from all simulation analysis connected with a set of suggestions and design guidelines. Set-up summary guidelines indicated capability applying natural ventilated DSF system for enhancing energy performance of in building façade under hot climate. Draw future plan and predicting final results.

CHAPTER TWO

LITERATURE REVIEW

2. CHAPTER 2 LITERATURE REVIEW LR

2.1 BACKGROUND OF THE DOUBLE SKIN FACADES DSFs

Building facades have a significant influence on the building thermal behavior and improving energy performance. Nowadays, fully glazed facades (large glazing areas) are widely used mainly in the high-rise buildings (modern tall buildings) all over the world for aesthetics purposes. However, widely glass cladding permits to excess heat gains in summer time and thermal heat loss in winter-season causing high energy consumption (increasing cooling and heating load requirements). (Wang et al. 2021) From an energy point of view, the DSFs system could be an efficient sustainable solution to enhancing glazed façade, overcome these issues and improving the building indoor environment. The second window was installed before established/development insulated glass to create a thermal buffer between two windows fig.(5). (Ulrich Knaack et al. 2007)



Fig. 5 Timber folding shutters installing for window to adapt to weather conditions changing, thermal insulation is created from the air layer between the glass and folding shutters.

The DSFs concept is not new, this advanced technology was appeared in Europe and adopted as façade system then spread to other regions world to manage the heat interaction between indoor and outdoor spaces of the buildings. Different resources indicated to the origin of DSF in central Europe where people utilized the box-type windows for increasing thermal

insulation. (Rezazadeh & Medi 2017) DSF is defined as a building enclosure that separated between interior and exterior environments of the building. The schematic fig. (6) compares between the single skin façade (SSF) and (DSF) in construction; the typical cavity wall designed with opaque cladding that is separated by an airgap which play a critical functionality to the wall through assigned thermal insulations to manage the moisture. In the same process DSF act a similar function by providing window wall, the air space can be opening and closing responding to the surrounding environment conditions. The concept of DSF that differ with SSF that efficient capability of ventilation purposes either natural cooling or providing fresh air to the interior space. (Mary Ben Bonham 2020) Also, DSF from a structural point of view has three functional layers; the exterior façade layer is single glazing usually which is separated from the interior glazing which forms the space enclosure and typically made of double glazing depending on a certain design, and the distance between two façade layers can be vary creating a thermal buffer, the ventilation openings are constructed either in external layer, or internal layer or in both. (Ulrich Knaack et al. 2007)

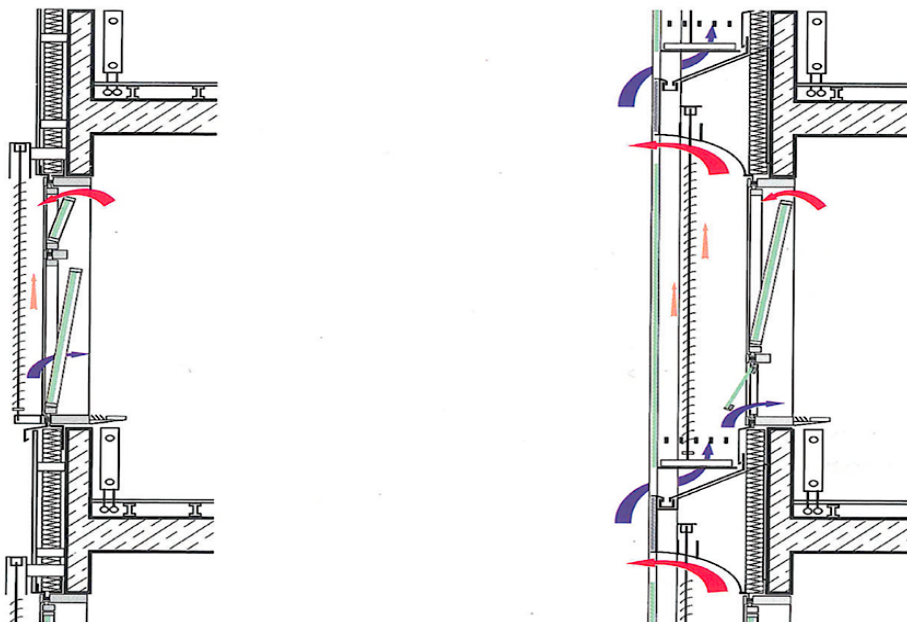


Fig. 6 Comparison of SSF (left) and DSF (right) construction. Source: Republished with permission from *Double-Skin Façades: Integrated Planning* (2001), courtesy Oesterle, Lieb, Lutz & Heusler.

The **present literature review** LR report is divided into the main parts: The concept of DSF, the history, the definitions of DSF system, the heat transfer process of DSF, the construction implementation of DSF, the classification (configurations) of DSF, DSF case studies locally and globally, and recent studies concerning in DSF performance.

2.2 THE CONCEPT OF DSF

During the Industrial Revolution (1750s-1850s), different new structural materials have been created and be available such as iron, steel and glass, since designed larger construction filled with transparent wall covering that clear appearance by greenhouses, galleries and railway stations such Crystal Palace in London by Sir Joseph Paxton (1851). (Saelens 2002) A new era of glazing façade building is emerging globally driven by innovative designs in Germany, Britain and Netherlands. (Arons 2000) Architects create a new typology of building envelope (enclosure), visually transparent façade with conventional curtain-wall design to be energy efficient, environmentally, and architecture stylish. but, new advancing design in fully glazed buildings faced physical and comfort problem such as overheating, condensation, heat loses and acoustical performance leading to enhance the performance of glazing façade by creating a new concept of building envelope design resulting in constructed DSF.

Although, the complicated design of DSF with different parameters effects on the building performance through enhancing indoor climate and reduce energy consumption, there is increasing tendency by architects to design DSF and use it functional. The DSF is a European architectural trend to; aesthetic desire purposes (increasing transparency), enhancing indoor environment (thermal comfort and visual comfort, acoustics comfort and ventilation) and reduction the energy use. The initial design phase based on the classification of DSFs by selecting the proper type and defined technical parameters which impact on the building performance (function) resulting into more accurate predictions.

Double skin façades (DSF) are building enclosures distinguished by the air space (cavity) which dividing the multiple glazed building skins. The cavity is buffer insulation against temperature, sound, and an adequate protected zone for installing a solar control devices and support the natural ventilation modes. (Mary Ben Bonham 2020)

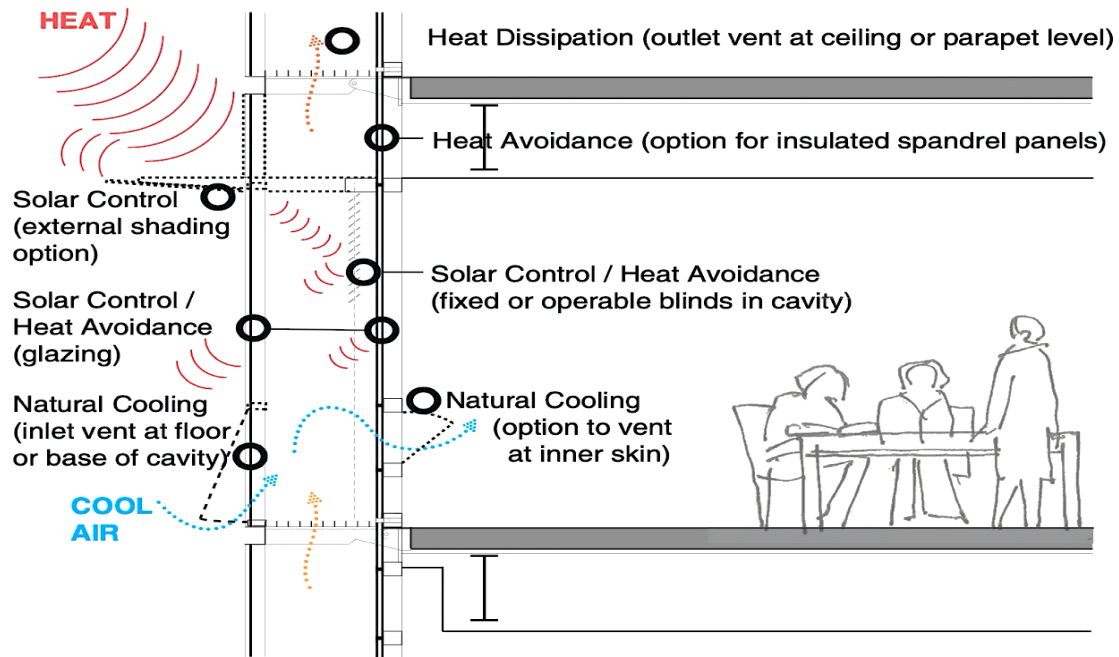


Fig. 7 Thermal Cooling strategies in DSF design- Bioclimatic concepts and strategies for double-skin façades.
Source: (Mary Ben Bonham 2020)

Due to the complexity construction of DSF, their multi skins layered with cavity space created a numerous solution to meet different design criteria. The schematic fig. (7) of the DSF concept illustrated by (Mary Ben Bonham 2020) highlighted the strategies of thermal cooling:

- I. Diffuse light and reduce heat transfer via outer glass layer that acts as initial screen for reduction the impacts extreme environment conditions, installing solar control devices to manage heat and light, and the inner skin integrated with IGU, low-e glazing and insulated spandrels.
- II. The proper cavity space enhancing ventilation mode (avoid extra heat and condensation) designed to extract heat by thermal lifting before thermal energy turning into inner skin. Designed airflow patterns through managing position, type and size of

openings within cavity. Hence, placed the air inlet vents away from air extract vents. Additional, preventing unwanted sound transmission.

- III.** The buffer zone of DSF created a natural cool space by moderating outdoor temperatures and mitigate wind pressure as well as ability filtration to improve air quality.

However, the concept of DSF functions and uses are depends on different parameters affect the building performance such as natural ventilation, daylight, acoustics, thermal and visual comfort, that's why identified the DSF system from different trends it is considered crucial. (Harris Poirazis 2006)

2.3 HISTORICAL BACKGROUND OF DSF

In 1849, the first idea to describe the mechanical ventilated multiple skin-façade by the director of the Industrial Museum in Brussels is Jean-Baptiste Jobard, he said that the hot-air between two glazing should be circulated in winter, but in summer it should be cold air. (Saelens 2002) After long period in 1914, Paul Scheerbaert listed the same idea in his book "Glasarchitectuur" at the same time, in cold climate different cases of non-ventilated DSF constructions were found in such as typical double windows and double façade constructions. In 1903, the first model of DSF curtain wall was constructed in Giengen, Germany in the Steiff Factory, the main purpose of this system to improve the day-lighting. It was constructed with the same DSF construction by utilizing timber structural material instead of steel due to financial purposes, the building has a three storey structure with a ground floor for storage space, and two upper floors used for work areas. (Heimrath 2005) during the early 19th century, the significant considering into thermal performance of buildings as designed with box-type windows in farmhouses in Murrin, Switzerland, the system able opening and remove the outer casements completely, during summer the inner-casements could be opened while the external glazing removed for surrounding conditions responding. (Brown 2016)

From 1904 to 1912, the Post Office Saving Bank in Vienna, Austria was constructed in two phases, it included a DSF aluminum skylight supported by steel pillars (columns) in the main hall. (Harris Poirazis 2006) At the last of the 1920's, DSFs were constructed in advanced, the Centrosoyous, La Cité de Refuge in Moschow was designed by Le Corbusier concept of "mûr neutralisant", his theory described that the transmission losses and gains would disappear by the circulation of air at room temperature through the building cavity. However, Le Corbusier couldn't release that air circulation requires energy/power to heat or cool. (Saelens 2002)

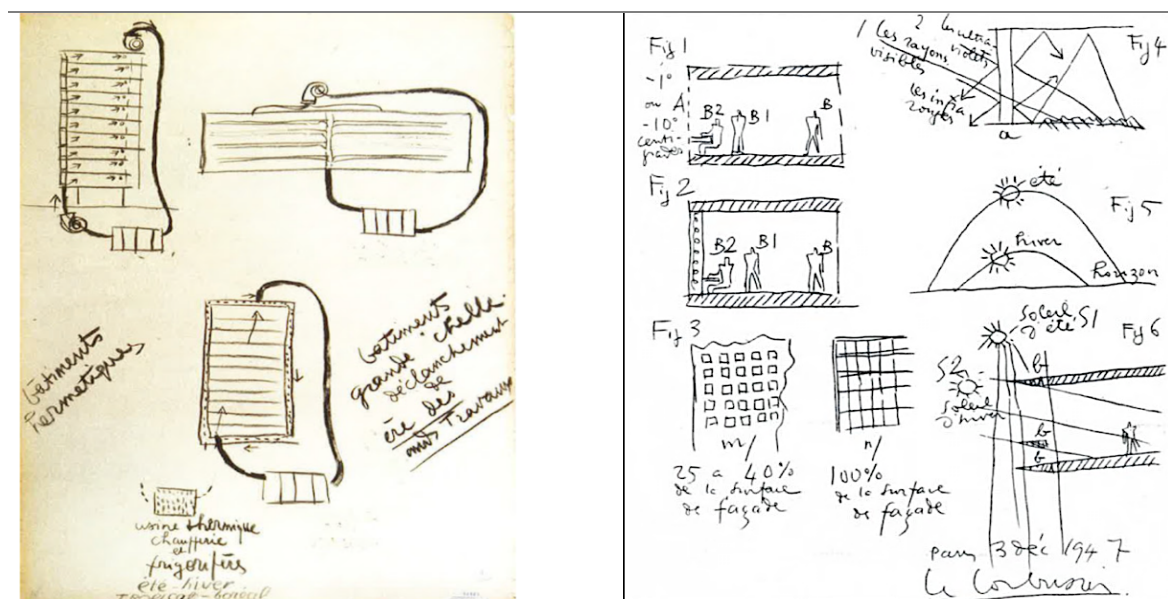


Fig. 8 (right) Le Corbusier sketches, illustrating his idea on the letter sent to Senator Warren Austin about the UN building in 1974 source: (Architectural Review, 1950), (left) "Mur neutralisant" and "Respiration exacte" diagram, 1929 as published in "Precisions"

Le Corbu became the first modern architect interested in mixing passive and active approaches of energy control for achieving comfort in building. He wasn't interest only in architectural language, but he paid his attention to identify the importance of combination between building design and active system and the both items natural ventilation and lighting. The building envelope required three different aspects as he coined; high air-tightness envelope to prevent air and heat flowing from inside to outside environment and vice-versa (the idea of sealed glass or opaque wall as "Mur neutraisant" concept as illustrated in fig.(8), a mechanical system of controlled ventilation (the idea of "Respiration exact" system and he suggested installing air

pipes within a sealed double glazed cavity to blowing treated air warm in winter and cold in summer to neutralized the outer conditions, permitting the glazed façade to act as external thermal envelopes and barrier to prevent heating flow inside-outside in winter and outside-inside in summer by installing water heat radiators between two parallel glazed surfaces.

During the early 70's and 80's, the system of DSFs construction had not achieved more progress till the oil crisis in 1979. That obviously lead to awareness on energy consumption, and impact in promoting the development of insulating glass as many advanced technology enhancements such as, low-emissivity coating and inert gas filled cavities. Two factors that significantly affected spread DSFs system in the 90's, from political and technical perspective and more environmental concerns create "*green buildings a good image for corporate architecture.*".(Harris Poirazis 2006) Moreover, the historical reviews of DSFs have also done by Bonham Mary Benedict in her book "Bioclimatic Double-Skin Facades" (Mary Ben Bonham 2020), she traced cautiously the development of DSF architecture from origins vernacular beginning in the middle of the 19th century to the earliest and current façade design integrated technology. This study summarized the development of DSFs into two parts;

- The 1st part is about the origins of DSF from vernacular and traditional facades which include the screened and glazed buffer zones. The climate and cultural issues are taken an important consideration for vernacular and traditional building techniques while the buffer zones act as spaces convert the building enclosure from a line of division into a flexible zone. The primary mode of buffer zones to avoid heating, it can be classified into two types; screened and glazed which both could be adjustability base on climate and interior environment conditions. Screened either fixed or adjustable with climatic conditions give

a.



b.



c.



Fig. 9 a) Mashrabiya at Suhaymi house museum, Cairo, Egypt, b) Jali at Salim Chisti Tomb in Fatehpur Sikri, near Agra, India, c) Building with galerias in La Coruña, Spain. Source: (Mary Ben Bonham 2020)

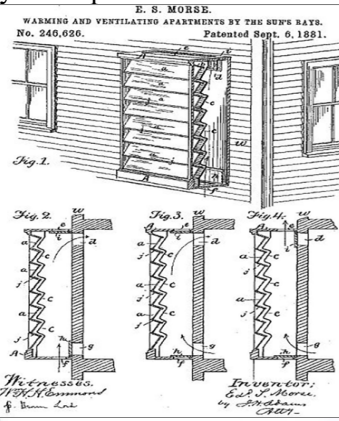
illumination, ventilation, privacy and preventing direct light and heat to the interior, while glazing if installed is used as secondary layer. *Jali* screens as called in India, are open latticework from different materials such as wood, stucco, ceramic...while *Mashrabiya* as

called in the Arab world, it is enclosure projected from the face of the main building structure and cladding in lattice screening may using stained glass, also it is famous in the complexity of geometric, arabesque and floral carved patterns. In Spain called *celosía* terms of latticed windows made of wood and masonry as shown in fig. (9). While in Europe and North America terms of glazing double- hung and casement sashes to manage the light and airflow by louver or solid shutters. Also, buffer zones referred to the terms of verandas which achieve a shaded space screened to avoid the space from heat, heavy winds and rain.

- The 2nd part which represents the development in construction materials and methods of DSF in the earliest instances in Europe and North America with timeline of DSF architecture from the middle of the 19th century to the current state.

The traditional buffer zones of screened and glazed resulting in appearance/emergence of DSF construction, due to development in technology of advanced construction materials and techniques assist transforming the façade from vernacular styles to advanced building façade modes. In general, the DSF construction development follows the history of curtain wall facades. Bonham identified in his book milestone of DSF development architecture by collecting data of the whole DSF constructed projects from 1840-2016 then classifying timeline of DSF architecture each parallel group with same time period in different themes; light, heat, thermal comfort, ventilation and energy. The following table (1) summarized the developments of DSF architecture in different groups:

- i. Mid-19th Century: *Glass for Light and Heat*
- ii. 20th Century: *Glass for Health, Thermal Comfort, and (Sometimes) Ventilation*
- iii. Mid-20th Century: *Ventilation and Acoustics in Early DSF Architecture*
- iv. 1970s: *Energy Focus Feeds DSF Development*
- v. 1980s: *Experimentation*

Timeline of DSF architecture and milestone technology			
Year	Theme	Case Study/Example	
Mid-19 th century (1840-1900)	light and heat	<i>Solar wall patent, Edward Morse 1881. Morse's "Warming and ventilating apartments by the sun's rays,"</i>	 E. S. MORSE. WARMING AND VENTILATING APARTMENTS BY THE SUN'S RAYS. No. 246,626. Patented Sept. 6, 1881. Fig. 1. Fig. 2. Fig. 3. Fig. 4. Fig. 5. Fig. 6. Fig. 7. Fig. 8. Fig. 9. Fig. 10. Fig. 11. Fig. 12. Fig. 13. Fig. 14. Fig. 15. Fig. 16. Fig. 17. Fig. 18. Fig. 19. Fig. 20. Fig. 21. Fig. 22. Fig. 23. Fig. 24. Fig. 25. Fig. 26. Fig. 27. Fig. 28. Fig. 29. Fig. 30. Fig. 31. Fig. 32. Fig. 33. Fig. 34. Fig. 35. Fig. 36. Fig. 37. Fig. 38. Fig. 39. Fig. 40. Fig. 41. Fig. 42. Fig. 43. Fig. 44. Fig. 45. Fig. 46. Fig. 47. Fig. 48. Fig. 49. Fig. 50. Fig. 51. Fig. 52. Fig. 53. Fig. 54. Fig. 55. Fig. 56. Fig. 57. Fig. 58. Fig. 59. Fig. 60. Fig. 61. Fig. 62. Fig. 63. Fig. 64. Fig. 65. Fig. 66. Fig. 67. Fig. 68. Fig. 69. Fig. 70. Fig. 71. Fig. 72. Fig. 73. Fig. 74. Fig. 75. Fig. 76. Fig. 77. Fig. 78. Fig. 79. Fig. 80. Fig. 81. Fig. 82. Fig. 83. Fig. 84. Fig. 85. Fig. 86. Fig. 87. Fig. 88. Fig. 89. Fig. 90. Fig. 91. Fig. 92. Fig. 93. Fig. 94. Fig. 95. Fig. 96. Fig. 97. Fig. 98. Fig. 99. Fig. 100.
(1900-1950)	Health and comfort	<i>Multi-story buffer1903, the 1st all-glass curtain wall as double skin. the Steiff toy factory in Geingen, Germany. 3 story glass wall with 25cm air space and steel frame.</i>	
(1950-1970)	Ventilation and acoustics)	<i>corridor buffer ext. vent. St. George's school Wallasey, UK 1961</i>	
(1970-1980)	energy	<i>multistory buffer ext. vent. 1978-1981 Occidental Chemical Building Niagara Falls, NY, USA Cannon Design. Is early DSF building</i>	
(1980-1995)	Experimentation	<i>corridor ext.vent, air supply. Galeries Lafayette Berlin, Germany 1991-1995</i>	

(1995-2001)	Expansion	<i>Box-window buffer Ext. Vent. air supply. City hall London, UK 1998-2002</i>	
		<i>Corridor- buffer, ext. ventilation air supply. Genzyme center Cambridge, MA, USA 2000-2004</i>	
		<i>multi-story internally ventilated Shanghai tower, China 2008-2015</i>	

Table 1 Timeline of DSF architecture & DSFs development case studies from the mid of 19th century to the current time. Images of building republished from Bonham, 2020 “Bioclimatic Double-Skin Facades” book (Mary Ben Bonham 2020)

The time-line integrated the development of DSF architecture with technology structure from 1840-2016 expansion.

Highlighting on the DSFs: The initial publication on the DSFs topic is “Double-Skin Façades: Integrated Planning” has done by Eberhard Oesterle in 2001, then followed by hundreds of papers and research projects established cases for DSF systems. T.Boake, 2014 mentioned in her study that “Understanding the General Principles of the Double Skin Façade System”, given at the National Building Envelope Council (of Canada) Conference in 2003, on the other hand, the construction of DSF has persisted increase despite lack of certain data for proving energy benefits. (Boake et al. 2014)

2.4 DEFINITIONS OF DSFs SYSTEM

DSFs system have numerous definitions providing overview of glazed building integrated with DSFs. This section described briefly how authors defined DSFs. Regarding to the collecting data concerning the DSF for texts and websites, the types of this system have several labelled and expressions such as *active façade*, *double façade*, *wall-filter façade*, *multiple-skin façade*, *intelligent glass façade*, *environmental façade*, *twin skin façade*, *airflow windows* and more.(Poirazis 2004a) The following introduced briefly some of the DSF definitions:

Depending on Belgian Building Research Institute (BBRI), (2002), “ *An active façade is a façade covering one or several storeys constructed with multiple glazed skins. The skins can be air tighten or not. In this kind of façade, the air cavity situated between the skins is naturally or mechanically ventilated. The air cavity ventilation strategy may vary with the time. Devices and systems are generally integrated in order to improve the indoor climate with active or passive techniques. Most of the time such systems are managed in semi automatic way via control systems.*”(Harris Poirazis 2006)

Saelens, (2002) used multiple-skin façade to defined DSF as “*A multiple-skin facade is an envelope construction, which consists of two transparent surfaces separated by a cavity, that is used as an air channel. The system includes three main elements: (1) the envelope construction, (2) the transparency of the bounding surfaces and (3) the cavity airflow.*”(Saelens 2002) the fig. (10) below shows the air-flow nature includes about 6 components featured the main Multiple-skin facades (DSF) terminology that installed naturally and mechanically ventilated.

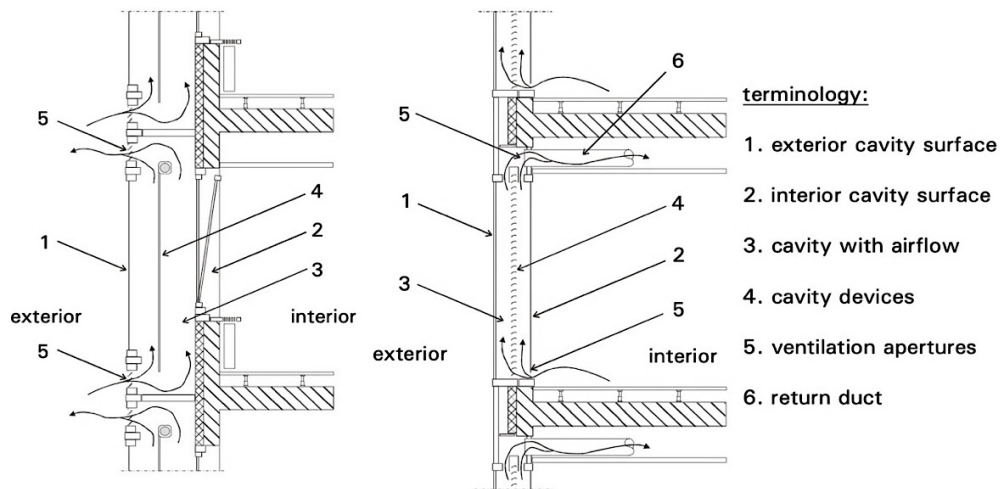


Fig. 10 Terminology of multiple-skin facades for (left) natural ventilation and (right) mechanical ventilation. Source: (Saelens 2002)

Arons (2000) described DSF as “airflow windows” *featured by including two membranes at least between the interior, occupied space and the exterior environment, blinds placed between the inner and outer leaf of façade, air passes through the channel.*” (Arons 2000)

Boake T. Meyer (2001) defined the DSF as “a pair of glass “skins” separated by an air corridor. The main layer of glass is usually insulating, the air space between the layers of glass acts as insulation against temperature extremes, wins and sound, sun shading devices are often located between the two skins. All elements can be arranged differently into numbers of permutations and combinations of both solid and diaphanous membranes.” (Boake, Terri Meyer 2001)

DSF is formed by two skins, commonly are glazing skins separated by air cavity (buffer space) which evacuate the heat flow through the façade elements via air ventilation system either natural or mechanical. The second glass layer achieved insulation against extreme exterior conditions (high temperature wind, and sound), with shading devices usually positioned in between the two skins to mitigate the direct solar radiation. (Aldawoud, Salameh & Ki Kim 2020)

2.5 FUNCTIONS OF THE DSFs

Understanding the functions of DSF with respect to enhancing energy performance is essential task to understand the factors and strategies in design phase, also to predict the optimal façade performance. The main functions of DSFs based on energy performance of building envelope respects with passive design strategies of solar heat gain control, daylighting and natural ventilation.(YELLAMRAJU 2004) applications of DSF have been investigated in different climates over many previous studies, the first DSFs structure function was applied basically in Germany to avoid cold climate and strong winds.(Wang et al. 2021)

2.5.1 NATURAL VENTILATION

The building envelope integrated DSF system refers to ventilated façade. The ventilated façades or window can breathe by different three strategies as identified by ‘Permasteelisa’ company; outside ventilated, inside ventilated and hybrid ventilated as shown in fig. (11). (Arons 2000)

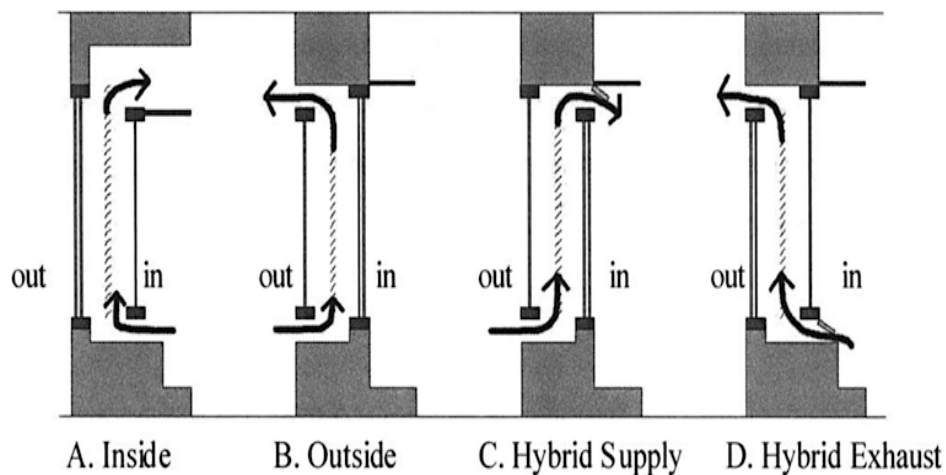


Fig. 11 Ventilation modes of DSF. source:(Arons 2000)

The outside-ventilated strategy permit pass outside air inside the air cavity and vent it back toward the outside. The inside-ventilated mode carry air from the occupied space through air cavity then exhaust it to the plant unit. Hybrid modes bring air inside the cavity from either indoor or outdoor and vent it to the opposite side. The external ventilation derived by natural buoyancy and convection force in the cavity. In addition, improving air flow by installing fans

within the cavity or window to force the natural air convection as Saelens pointed. (Saelens 2002) The external glazing of DSF design is creating a buffer zone (air cavity) next to the external glazing skin of the building which is not affected by the direct high solar radiation and high wind velocity. This buffer might accessible by occupants for natural ventilation. (YELLAMRAJU 2004)

2.5.2 SOLAR HEAT GAIN

Another important function should take in consideration is the process of responding DSFs to the solar radiation. Also, identifying the glass facade functions requires realized the process of response glazing to solar heat gain. The light spectrum components involve infrared and visible light referred to short wave (high frequency) solar radiation. The general rule indicates that the longer the wavelength, the lower carrying energy. (YELLAMRAJU 2004) In general, the typical clear glass transparence to the high frequency solar radiation as illustrated in fig. (12), and it is acting as barrier for the long wave radiation (low frequency). When the solar heat energy passing through glazing pane leading to warm up the different internal surfaces by absorption at the same time the heated surfaces re-emitted the heating (heat radiators) in low frequency and trapped inside the room resulting in rising heat (air temperature). (YELLAMRAJU 2004)

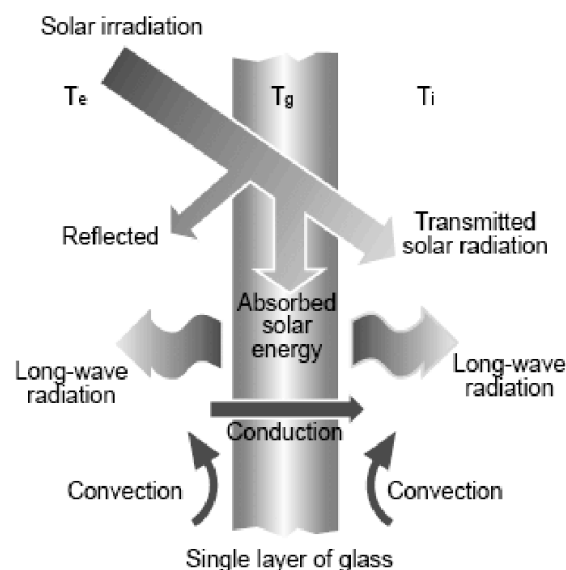


Fig. 12 The heat transfer through single clear glass. (YELLAMRAJU 2004)

DSFs system can manage the solar heat gains due to the shading devices parameters and the potential of air buffer (cavity) to absorb some of the solar radiation resulting in mitigate the air temperature inside the room. The composition of DSF is outer glazing either double or single glazing, intermediate air cavity, and inner glass skin. The heat transfer process of DSF as illustrated in fig. (13) synchronization (organization) with convective, radian, and conductive heat transfer presence in the whole DSF system. Whereas, the incident solar radiation irradiates on the exterior glazing skin; one part of solar radiation reflects back, another part transmits into the DSF while the rest of radiations absorbed by glasses and other medium. On the other hand, the air flow within the cavity reduces (take away) the absorbed heat by glasses and blind. The both visual (optical) properties and the air flow in the cavity are coupling play significant role with heat transfer process. (Wang, Chen & Zhou 2016)

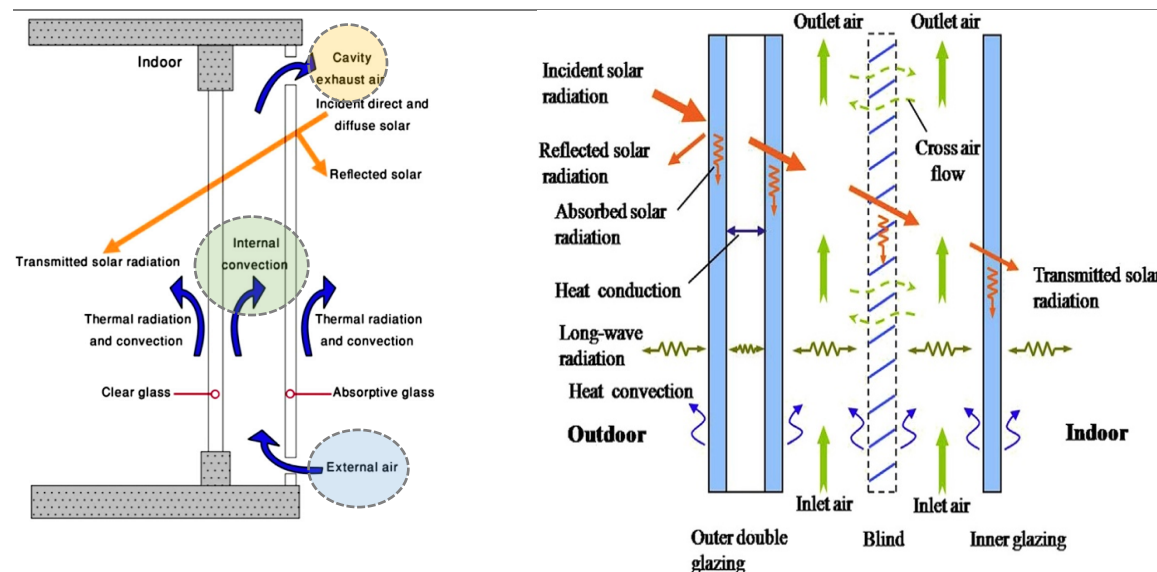


Fig. 13 (left) The heat transfer process and air movement inside the cavity of DSFs, (right) schematic diagram of heat transfer. Source: (Wang, Chen & Zhou 2016)

Regarding to the heat transfer process in the air cavity: The heat transfer in cavity represents by the potential of air space itself as illustrate in fig.(13) by draw off some of incident direct solar radiation within the cavity space, then heated air are carried by convection currents upwards and after that extracted to the outdoor by opening vents at the top of cavity. (Boake et al. 2003)

2.5.3 DAYLIGHTING

The DSFs can improve the access daylighting with adequate amount and quality to reduce electrical lighting and reduction the glare in the room. Increasing glazing layers enhancing the access of daylighting within space. The shading devices of DSF reduce the heat gains and glare. (Boake et al. 2003)

2.6 CONSTRUCTION OF DSFs (COMPONENTS, SYSTEMS AND PARAMETERS)

Double skin façade DSF set of parts and components

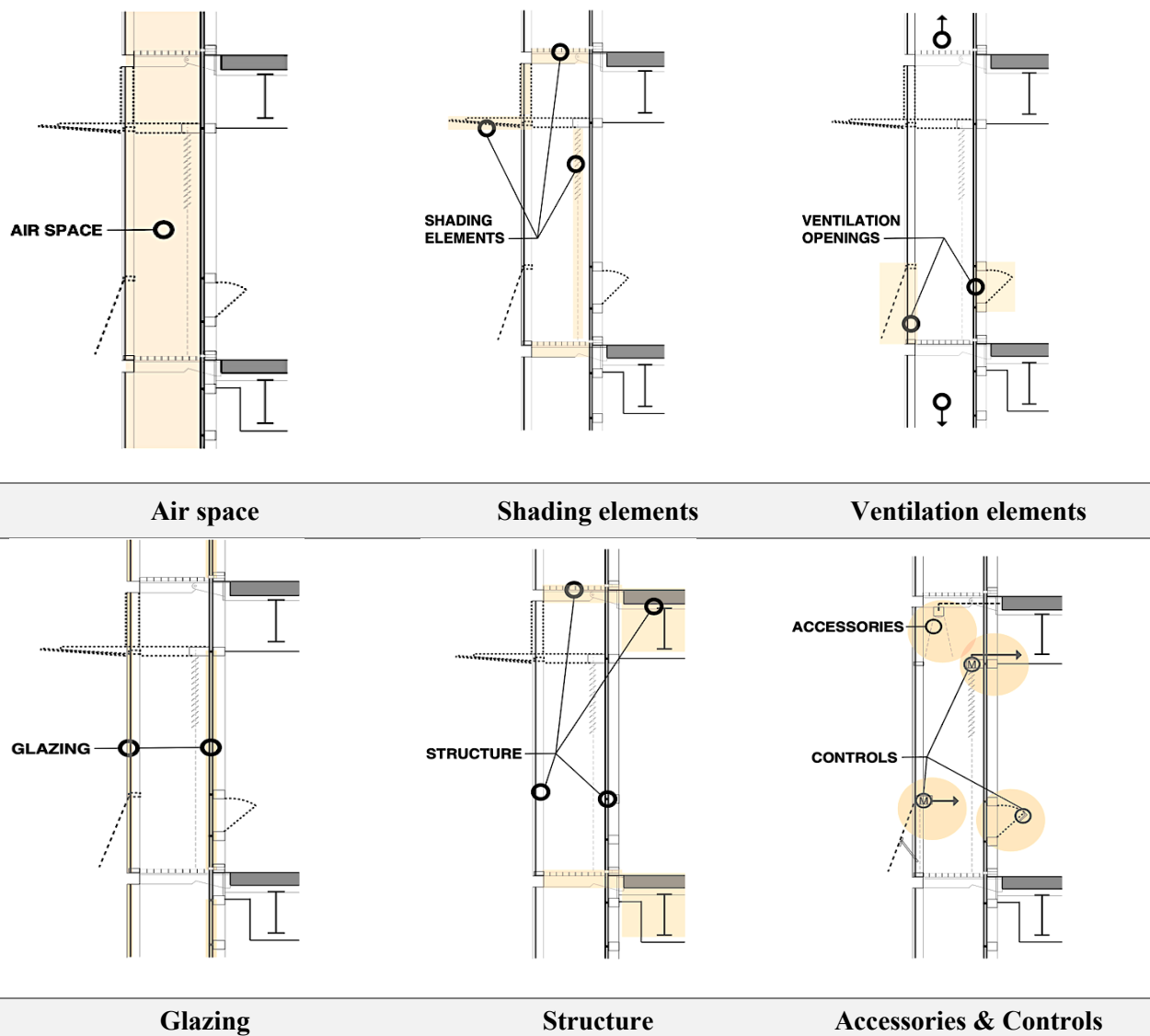


Fig. 14 The main components, construction parts of DSF system supporting the design concept and strategies. Source: republished and arranged from (Mary Ben Bonham 2020)

This section provides a short overview of the DSFs construction system. The fig. (14) illustrates the main components and the main functional elements of DSF can be evolving (changing) to create a special DSF construction for adapting with sites and different design factors. These elements required an extensive understanding in relative with climatic conditions, construction practices, human factors and building physics. The DSF components increase recognizing of the basic architectural design concepts and strategies that influence building façade performance. Mary Ben Bonham, (2020) arranged the main components and parameters of DSFs by creating bioclimatic design matrix with thermal concept for DSFs can be used to analyze existing buildings and also to plan new building facades. Bioclimatic design concepts are drawn from Vector Olgayay's "*factors influencing architectural expression*". (Mary Ben Bonham 2020) **The set components of DSF can be integrated into design strategies are:**

- I. **Air space:** providing an air space separate between two glazing layers is the key feature of DSF system. which called cavity or shafts, also, it can be different depth either thin profile or thick profile. The cavity partitioning system identifies the common configurations of DSF (Box Window, Shaft Box, Corridor and Multi-story). But un-partitioning cavity creating pathways for flames and smokes spread vertically or horizontally through the building facade. The air cavity space with vary depths range from about 20-250 mm; thin profile reached about 1 m (about 3 ft) while thick DSF profile is deeper where custom air space. The size and shape of natural ventilation inlets and outlets can be aerodynamically optimized for the desired air movement and velocities.
- II. **Shading elements:** the sun shading elements integrated with DSF to control the solar gains and diffuse daylight for enhancing the daylight quality, either installed exterior of the building façade or interior of DSF which is usually placed. The shading elements usually operable also in fixed state with variations designed such as louvers, roller shades,

translucent, perforated and other devices. Placing shading elements inner DSF reserved from outdoor conditions and internal damage. However, more accuracy design must be accounting the shading device which impacts on the air flow and thermal performance.

- III. **Ventilation elements:** The ventilation openings are key parameters of DSF influence the thermal performance of building and diffuse the direct impact of wind. Openings configurations such as position either one or both glass skins or placed at the top or base of air shaft, the type and size. Also, it can be static conditions (fixed) louvers or slots and dynamic form involve dampers, louvers, and window vents automated or manual running. Responding the openings ventilation to the external conditions can be identified the air flow mode either external ventilation, internal, air supply, air exhaust or buffer.
- IV. **Glazing:** The main feature of DSF is adding second glazed layer that supported with different framed systems (mullions) to manage façade performance and appearance aesthetic. The glazing surface and framing elements must be specified appropriate properties and specifications that influence the building performance such as, thermal resistance, light transmission, transparency and sound transmission. Usually, DSF model created by insulating glazing unit (IGU) act as primary exterior barrier, air space, and single glazed skin façade. The most popular is clear glass transparent low-emissivity coating.
- V. **Structure:** Selected the DSF structure elements based on the façade properties and materials by introduce lateral and vertical resistance to the wind and other exterior forces, the structural affect the construction, thermal mass of building façade and building performance. Skins used different structure methods such as, curtain walls, massive wall construction with punched window, stick built, and unitized. Usually, the outer skin layer in thick cavity supported by bracket, truces, rods and cables, while thin profile used framing integrated in prefabricated and unitized modules for inner and outer layer.

VI. Accessories and controls: The elements of dynamic façade such as blinds, dampers, vents, and fans usually required motorized control which supplied by building management system BMS which can switch mounted to window mullion helps occupant running the blinds, and may place an interior window latch. which also connected sensors can observing wind-speed, temperature, humidity, carbon monoxide, and light within the cavity.

2.7 CLASSIFICATION OF DSFs AND TYPOLOGIES

DSFs systems are usually classified according to specific characteristics and different modes such as the type of construction, the geometry, the ventilation mechanisms in the cavity, and the different flow paths (airflow typology). (Harris Poirazis 2006).

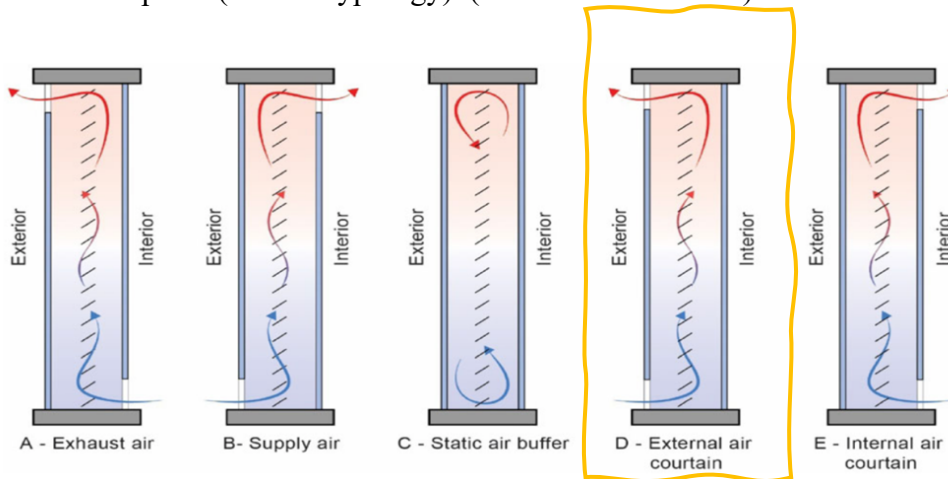


Fig. 15 Possible air-flows in DSF system, EAC is the ventilation mode selected of the proposed DSF system in this study. Source: (Haase, Marques da Silva & Amato 2009)

Dirk Salens (2002) classified the DSF in terms of the origin air flow as illustrated in fig.(15) which impacts finally on the average temperature of the cavity (Saelens 2002) the following are different categories regarding air-flow:

- Supply: flowing outside fresh air into the cavity to the inner space of building.
- Exhaust: opposite of supply system, the inside air flows to the outside through the cavity.
- Air-curtain: this system hasn't air exchange between inner and exterior side of DSF, but the air left the cavity at the same side it came in. the system can be an exterior- air curtain (EAC) that generally for natural ventilation or interior- air curtain (IAC) usually integrated

with mechanical ventilation. The shading yellow line illustrate the selected mode (EAC) in this study for natural ventilated DSF system.

Saelens (2002) described the multiple-skin facades to provide clear view of functional and physical modelled as illustrated in fig. (16) Compartmentalization of the façade, the term Façade refer to: when multiple-skin extends along the height and width of the building, the cavity along façade without intermediate divisions and the air space is along whole height of the building, Shaft: the air cavity is partitioned into vertical sections along the height of façade, Corridor: the air cavity divided into horizontal partitions, commonly at each level story of the building, Window: the air cavity carries the both horizontal and vertical subdivided with windows, Box: the façade is divided into horizontal and vertical divisions with transparent envelopes. (Saelens 2002) Partitioning façade described the cavity between two glazed skins referred to physically divided glazed façade. (Heimrath 2005)

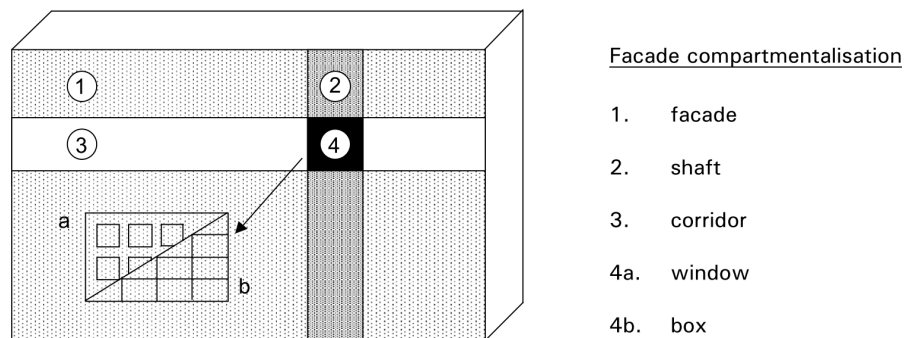


Fig. 16 Compartmentalization of the building façade. Source: (Saelens 2002)

On the other hand, very similar in approach Eberhard Oesterle (2001) in his book “*Double-Skin Facades: Integrated Planning*” classified the DSFs system based on the type of the cavity (geometry) as following

- I. **Box-window type:** this system was the first type of DSFs established in the building industry, the form of Box-Window system is designed by divided the façade horizontally and vertically partitioning along the building into smaller and independent boxes or for each window separately. The external skin includes openings at bottom and top that allow

fresh air to flow into the cavity. It also commonly used for retrofitting buildings easily to apply to enhance their performance. The air circulation within one façade element.

- II. **Shaft-Box type:** this system based on box-window type, it also developed by the *Alco Company* to improve the system by using stack-effect with harvesting solar radiation. (Hilmarsson 2008). The form of shaft-box includes units of box-windows horizontally connected to the vertical segment on each storey by special (particular) openings. The stack effects in vertical segment draw air from box-window to create airflow in the whole façade. The air rises in a vertical shaft alongside the façade and draw the exhaust air from adjacent façade elements within it.
- III. **Corridor façade type:** in this system the façade is divided into horizontal partitioning for each story, so the cavity is open along the horizontal length of building to improve the acoustical, ventilation and fire security purposes. A great air pressure difference at corners for closures. (Hilmarsson 2008) The air circulation within the cavity horizontally across one story.
- IV. **Multi-Storey façade type:** a different approach in structural and functional is used in this system. Multi-story cavity not divided horizontally and vertically at all, the air intake is near to the bottom and the top of whole building to improve the stack effects. The external skin of Multi-Story doesn't require distribution openings over its height. (Hilmarsson 2008) this system does not have a partitioning between two skins, but the air cavity ventilation is achieved by large openings from close to the floor and the roof of whole building. The air circulation across the entire façade area within the unrestricted cavity between two layers. (Brown 2016)

All types of DSF can be combined with mechanical and natural ventilation lead to varieties of its configuration. The DSF system can classify by cavity geometry and ventilation mode. The

classification of DSF according to the structure of the cavity as shown in fig.(17).(Oesterle et al. 2001) (Lucchino et al. 2019). The table (2) below shows the comparison between the four types of DSF based on partitioning cavity includes (geometry of elevation, section and plan) of each cavity type. the blue and red arrows represent the air flowing (circulation) within the cavity and façade.

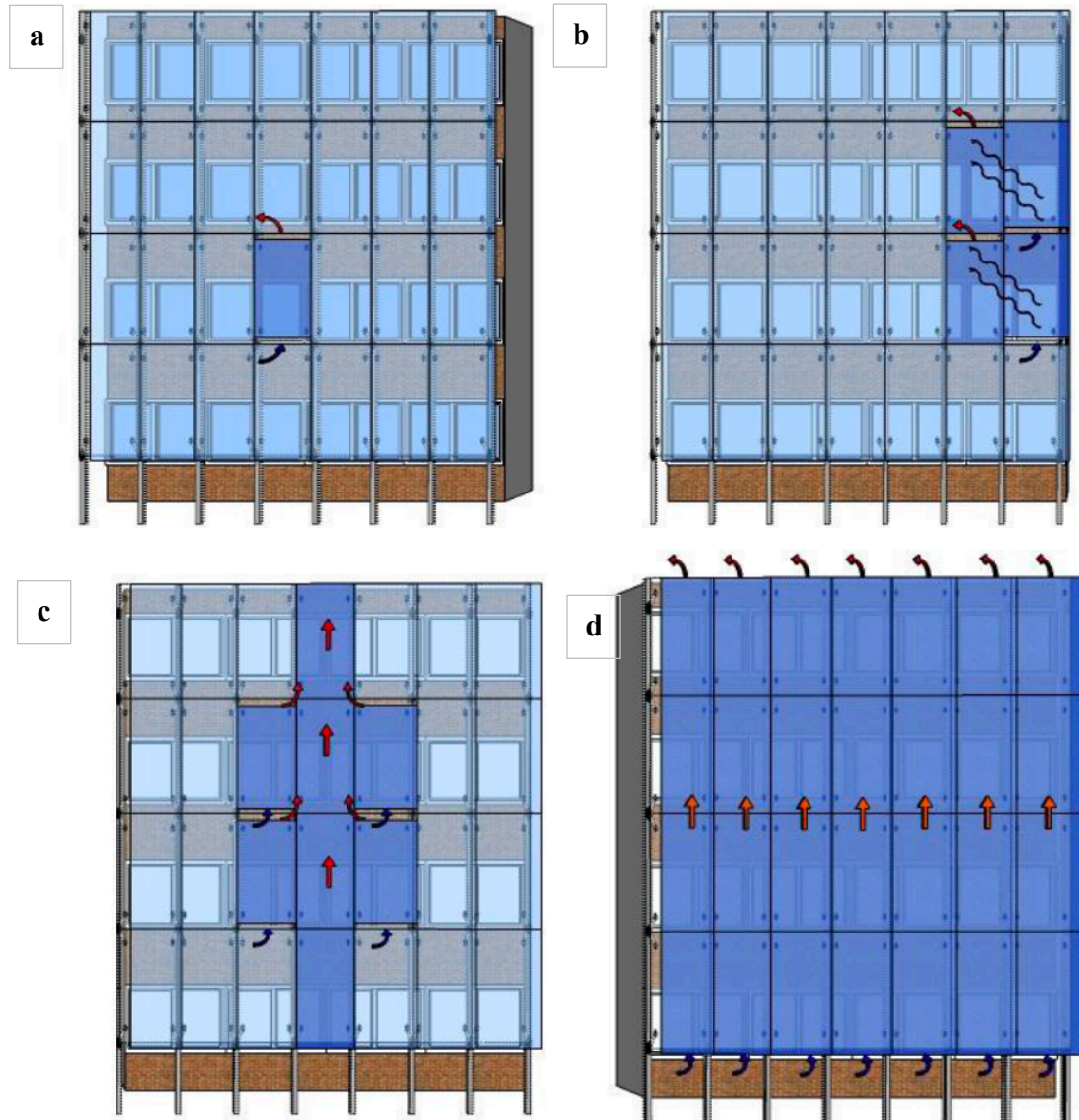


Fig. 17 Four types of DSF based on partitioning types of façade construction (geometry) were clasified by Oesterle et al. a)Box-window, b)Corridor façade, c)Shaft-Box façade, d) Multi-Storey façade. Source: Reublished by (Pomponi 2015)

Cavity	Elevation	Section	Plan
Box - Window			
			ventilation: through horizontal and vertical partitioning, separate ventilation for each bay. The divisions of the facade intermediate space are set on the construction axes.
Shaft Box - Window			
			ventilation: via shaft box, stack effect, there are side openings in the shaft divisions in the facade intermediate space
Corridor Façade			
			ventilation: through horizontal partitioning, Air flows on the diagonal to prevent vitiated air from the lower story being sucked in with the air supply of the floor above
Multi-Story Façade			
			ventilation: through large openings the bottom near the floor and the top of the building, the intermediate space can be ventilated in all directions

Table 2 Comparing the four types of DSF based on partitioning cavity (geometry of elevation, section and plan of each cavity type. the blue and red arrows represent the air circulation within the cavity and façade. Source: Republished with. (Mary Ben Bonham 2020)

Another DSFs system categorization into three types formulated by Werner Lang and Thomas Herzog as shown in fig. (18), the three systems of ventilation method are significantly in reduction total energy consumption, usually accepted by American community and the same classification has been investigated by Terri Meyer Boake of University of Waterloo in her research. (Boake et al. 2003)

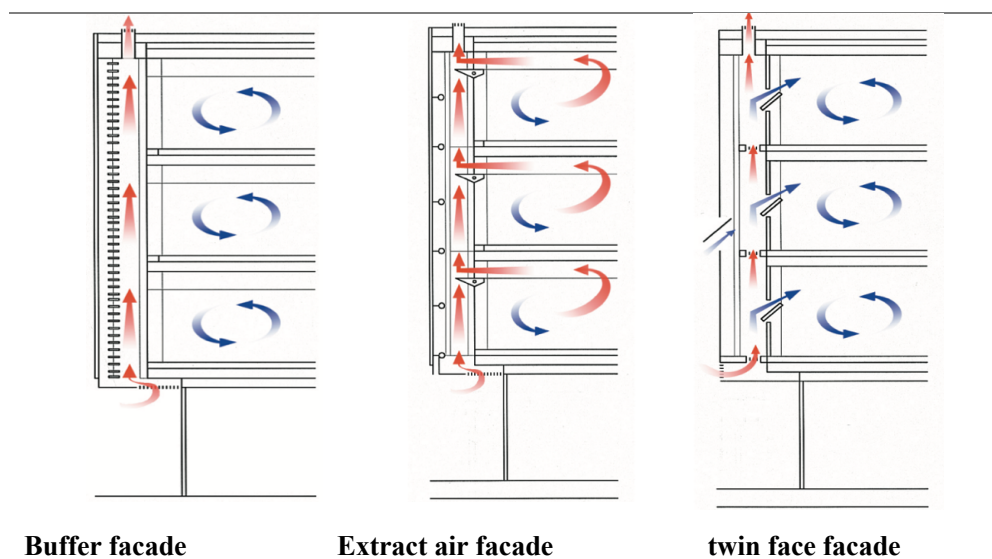


Fig. 18 The main three typologies of ventilation method DSF refer to the North America. Source: (Boake et al. 2003)

- a. Buffer system: the system includes double layers of single glazing with 250-900 mm space in between layers, sealed (enclosed), the exterior fresh air flow into the building by HVAC system or box type windows that cut overall the DSF with shading sometimes.
- b. Extract air system: this system involves second single glazing layer positioned on the interior of double-glazing façade. Additionally, the air space in between glazing layers is part of HVAC system. Via the cavity where extracted the heated used air between glazing layers with use fans thus tempers inner glazing while the outer insulating layer reduced heat transmission loss.
- c. Twin face system: this system includes traditional curtain wall within a single glazed building skin. The inner space is about 500-600 mm able cleaning, while the openings

allow natural ventilation. The outer skin for protecting the cavity against extreme conditions.

However, the following fig. (19) illustrated the imaginable concepts to form all of ventilated DSF basis of three main criteria are used to classify ventilated DSF combinations, the concept which is applied in practice is not applied in all climates. (BBRI. et al. 2005)

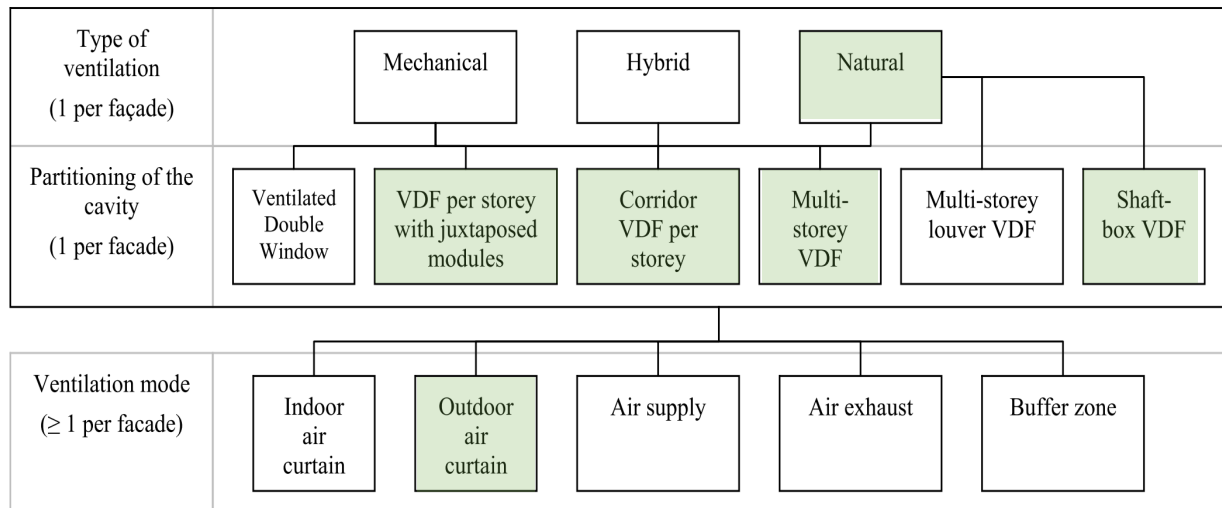


Fig. 19 Different concepts of ventilated DSFs by integrating 3 classificatory criteria. the shaded green refers to the tested selected process approach for 4 DSF proposal types of this paper. Source: (BBRI. et al. 2005).

2.8 APPLICATIONS OF THE DSFs IN THE UAE AND GLOBAL

The fig. (20) shows the William Farrell Building- the TELUS Building, Vancouver in North America, the building façade system is DSF twin-face added to the south and west sides of the building with 1.20m width cavity runs from the base to the top of building. The section of room includes exterior glazed wall mounted operable windows, clear glazing and ceramic fit glazing to absorb some of sun heat and block certain amount of solar gain, and user control provide access to natural ventilation the retrofitting structure of the north-east façade. The system achieved natural ventilation by design operable windows for both exterior and interior facade. The cavity stretches to cover the full height of the building, the cavity creates air space which acts as buffer zone against the exterior environment. Due to achieve energy saving purposes, the building was installed double glazed aluminum curtain wall framed in order to minimize

ventilation and heating demands. The fig. (20) shows the airflow in the summer condition, the façade is fully vented and allowing occupant managed natural ventilation. In addition, the cavity includes ventilation fans and louver with dampers at the top to flush air which linked to the photovoltaic cells. The existing windows adjusted to operating system which achieved environment and cost efficient(saving), operable mechanized window where built-in new glazed wall allow fresh air flow inner space. While the curtain wall supporting by steel brackets. (Boake, Terri Meyer 2001)

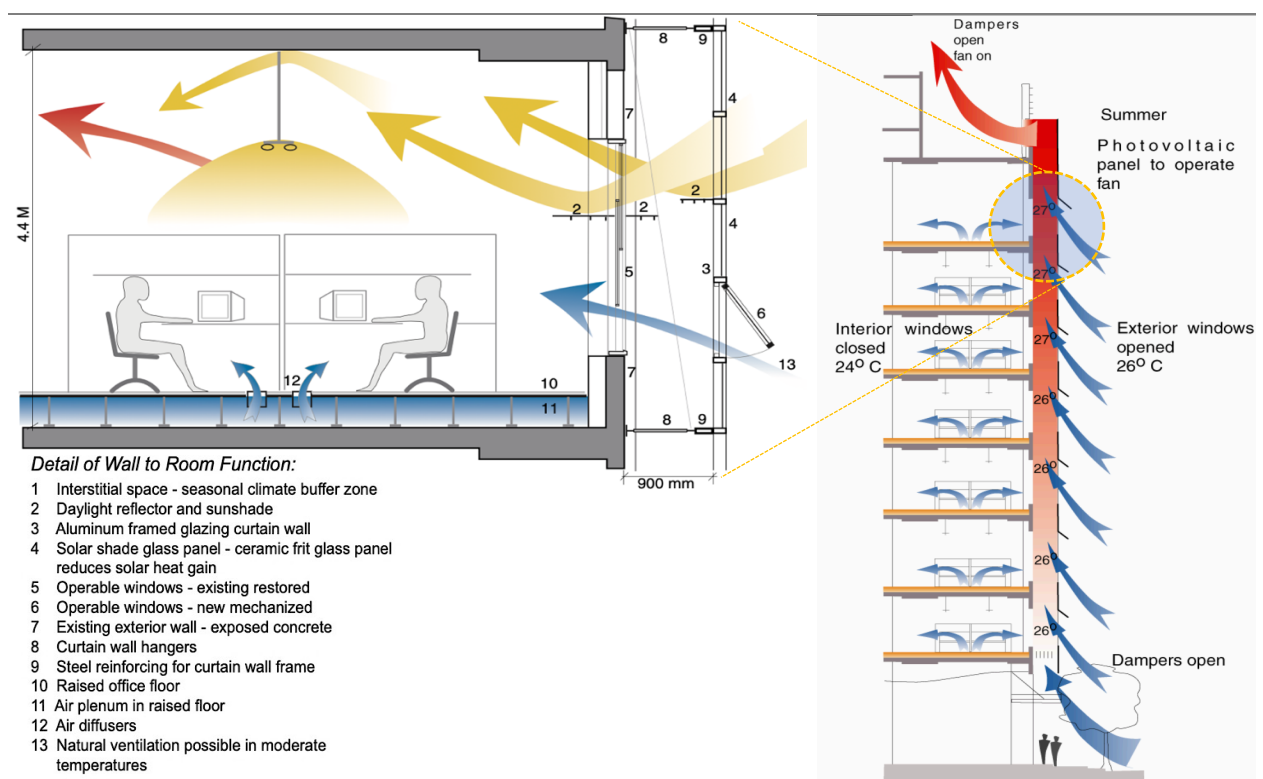


Fig. 20 TELUS Building, Vancouver, Busby Associates, 2001. source: (Boake, Terri Meyer 2001)

Different applications of DSFs constructions in hot climate in the UAE have been investigated to identify the major principal design influences in the cooling loads. (Johnny 2018) This section listed different case studies integrated with DSF types and applications in in hot climate in the UAE:

The 1st case study is Cleveland Clinic, Abu Dhabi (2015), used a special DSF system design. The DSF cavity is multistory ventilated type is open from the bottom to the top as shown in fig. (21) to create a stack effect hence helping building to breath. The building envelope construction made up of hollow/ tubular structural steel diagrid to support the external layer of glazing buffer system, the internal layer is sealed curtain wall, and grated walkways span to access to the cavity, cleaning, and ventilation flow. The multistory cavity is supported by outer skin single glazed and insulated glass curtain wall inner skin glass, sealed internally ventilated DSF to avoid entering particulate sands and remove heat by running air flow within cavity. The

The Cleveland Clinic Abu Dhabi (2015), applied multistory cavities (complex DSF system) in the hospital block facades that made of outer single glass skins and insulated curtain inner skins, the system used sealed internally ventilated DSF to prevent access sand particulates and control air flow to reduce heat within the cavity. (Mary Ben Bonham 2020)

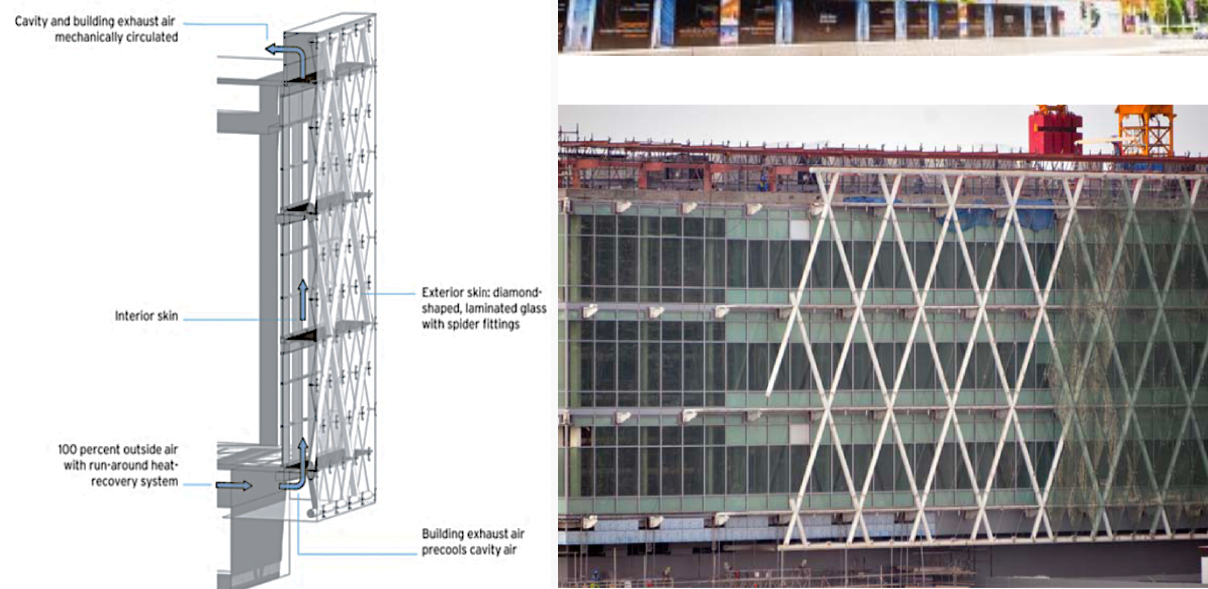


Fig. 21 (Right) The installation of DSF layers, (left) the double building envelope section axonometric.
Source: (Boake et al. 2014), <https://www.pinterest.com/pin/534239574525811501/>

DSF system in the hospital is distinguished, it has designed to LEED™ Gold principles to be the 1st ever used in hospital by using conditioned air from the interior space that recycled two times before it is extruded external space, the exhaust air from the hospital interior is passed in pipes by the building fresh air intakes to precool incoming air before chilled for using in the hospital, the next directed exhaust air into the wide multistory air spaces which wrap the building perimeters, in contrast the relatively cooler air in cavity creates a buffer against extreme high external temperature. Other heating conducted via façade is carried away through convection. The DSF of the hospital is internally ventilated multistory type, the air circulation flow easier due to stack effect, when the outer skin warms the air space by solar radiation the air rises reaching the top of the cavity then vented to the exterior by sand-filtering louvers. This system reduce the cooling loads resulting in saving cooling costs about 33% of tower building. (Boake et al. 2014)

The 2nd case study is the Capital Gate tower, Abu Dhabi. It is an iconic land mark with 18° inclined backward to the west. The tower floors offset to create the backward lean created two types of spaces with two types of DSF systems; the large metal mesh canopy (splash) climbs the façade which beginning at the entry level as sun shade for the lower office floors and car-drop off area till the pool level projecting at the 19th floor as shown in fig. (22). The mesh screen 90% open is supported by exposed structural steel frame, it avoiding 30% of solar radiation striking the office spaces curtain wall. The double façade design used fixed shading screen for the external element instead of a glass layer to avoid the solar radiation from the south-west and south-east facing as shown in fig. (23) at the 19th floor level where hotel rooms are located, the external layer of DSF system used diamond shaped prefabricated curtain wall while the internal layer using glazing system. This modified façade system creates a buffer

insulation between the cool interior and the hot exterior by recycling the internal air from guest rooms to the cavity. The air is filtered, reconditioned and reused in rooms.

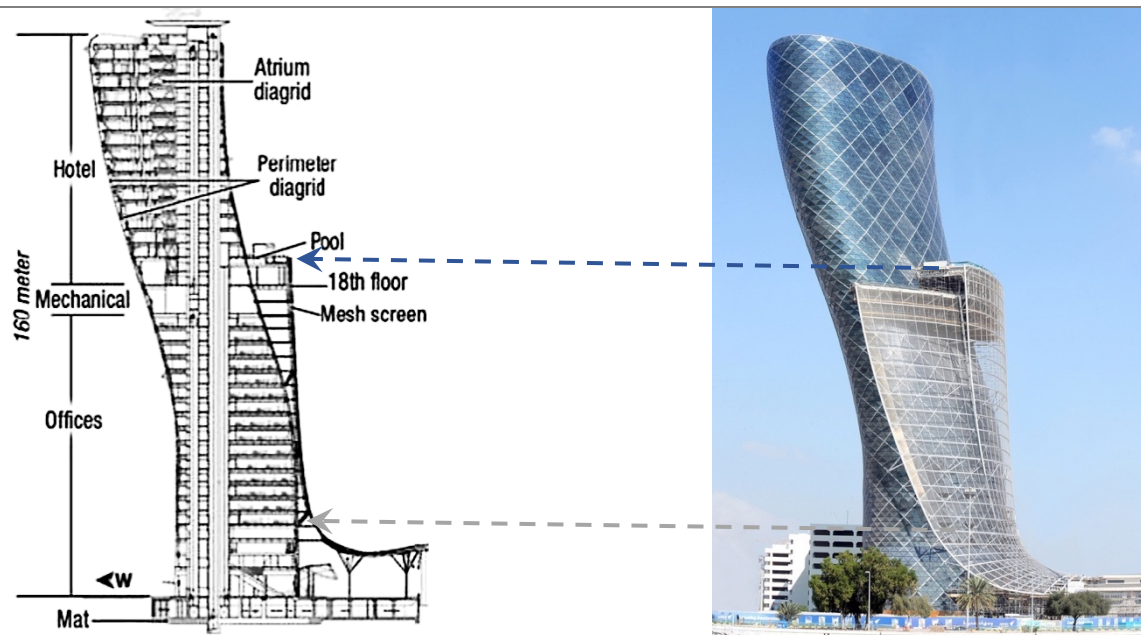


Fig. 22 The Capital Gate construction, Abu Dhabi/RMJM Architects

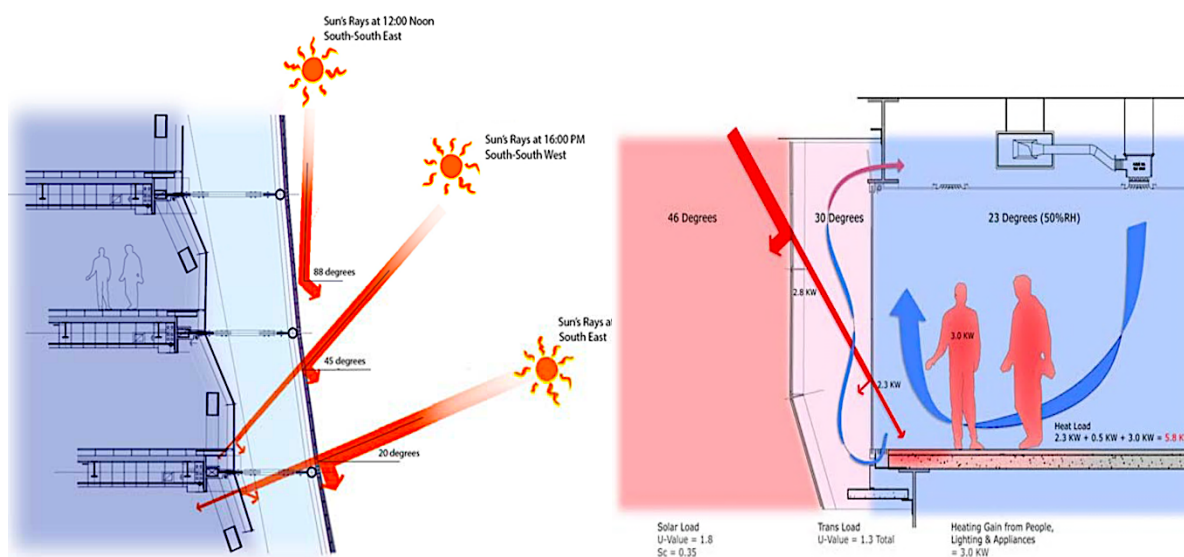


Fig. 23 Avoiding solar radiation by the exterior shading skin of tower on the lower office levels, (right) the DSF system of the hotel levels with wide air corridor. Source: (Boake et al. 2014)

2.9 RELATED WORK CONCLUDED FROM RECENT STUDIES ABOUT THE BENEFITS OF DSFs

Overview: theoretical framework based on LR is considered the major step to prove the problem statement and the hypothesis of this research. The main purpose of this section to

provide an overview of numerous related studies concerning with DSFs system specifically to application influences of this system in hot climate.

Recent studies have been claimed the potential of investigating DSFs system in saving energy demands and enhancing thermal comfort in building. This section highlights different (set) parameters play an essential role for improving the ventilated DSFs system association with enhancing efficient energy performance and thermal comfort of building mostly in hot climate. The recent studies discussed the main parameters (variable characteristics) influenced the performance of DSFs system are: **glazing properties in DSF**, **air-cavity depth (air buffer space)**, **position of solar shading devices SDs**, and the **cavity's openings and air flow** as well as **the DSF geometry** (mostly based on the width and height of the cavity). The most previous study focusing on the energy performance of DSFs buildings, identifying a state of literature about the DSFs designs, application technologies, constructions. studies were investigated with respect to different levels of DSF building performance varying from multi parameters that effect on the building envelope performance. The most studies reported significant benefits of DSF system in saving energy consumption and enhancing thermal performance.

2.9.1 GLAZING PROPERTIES IN DSFS

This section focusing on previous studies have adapted a glazing material for DSF system for improving energy performance of building. Also, assigned different materials construction and combination design on DSFs components. Mainly, the amount of heating and cooling loads consumption depends on selected an adequate glazing system. Glazing units and thermal properties play a vital role on solar heat transmission improving energy performance of building envelopes. A different glazing types have been investigated by Aldawoud (2017) in hot humid climate in Sharjah-UAE for eight stories office building and comparing its thermal performance and annual energy consumption of building. The results observed that the single glazing is very poor in contrast to the double and triple glazing which represent better energy

performance. The best glazing performance are the greatest insulating properties also utilizing spectral selective glass shown significant reduction in energy consumption due to reduce the heat gains and blocked the direct sun radiation. The gas fill between glazing panes impact on the energy performance resulting that Argon and Krypton gas increased efficiency performance to 15% and 5% respectively are better than air fill. The triple glazing low-e coating with argon gas fill reduced energy consumption to 33% compared to the single glazing of base case. In hot-humid climate lower SHGC and U-value are significantly impact on reducing cooling loads. The study established guidelines of efficient building envelope made up of adequate glazing system. (Aldawoud 2017)

Johny (2018) investigated DSF performance in typical high rise building under hot-arid climate in UAE by using different construction materials in outer skin of DSF; phase change materials PCM, transparent glass and opaque concrete. He used conventional multi-story DSF with 1.0 m cavity depth with inlet and outlet 30×1 m dimension. The study concluded that all materials constructed minimize solar gain to the inner environment spaces, resulting in lower temperature than outdoor ambient leading into reduction annual cooling loads. The glazing materials of DSF saving energy building from 8% to 20%, for a PCM from 30% to 50% while 15% to 45% for a concrete, resulting found that increasing thermal mass of DSFs achieving energy saving of building.(Johny 2018)

Ghaffarian Hoseini (2016) reported that little studies have observed thermal characteristics of glazing types with energy performance of DSF systems. they found a study for achieving the optimal performance of DSFs based on altering typologies of glazing window, the final observation found significant energy consumption by changing the outer and inner layer of glazing type (3.4% to 18.8%). a study in Korea has tested 27 and 20 types of parametric window glazing types; the inner and outer DSF layers based on thermal performance then found that inner layer has stronger effect on thermal behavior than outer layer. the energy

consumption of building integrated the DSFs system depends totally on thermal heat transfer and solar heat gain which altering with altitude location. (GhaffarianHoseini et al. 2016)

The optimal energy performance of building with DSF through altering variations of glazing properties, by testing the single glazing on the inner skin layer and double glazing on the outer layer can be effective in minimizing the heat gains in the building resulted reduction energy performance due to higher thermal insulation of the outer double glazing. as study done by Chan et al. (2009) applied DSF in a typical office building in Hong Kong with different types of glazing properties clear, absorptive and reflective, to their layers position inner or outer pane and glazing layer types double or single material. The fig. (24) shows different glazing layers properties have selected by Chan et al., the findings showed that cases (b) and (d) are relatively close, the double glazing reflective outer pane with single glazing inner pane reduced annual cooling loads of building to 26% it is better thermal insulation property and reduction heat gain. That is indicated, that installing double glazing in the outer pane of DSF is the efficient in saving cooling loads and reduce heat gain by cavity.(Chan et al. 2009)

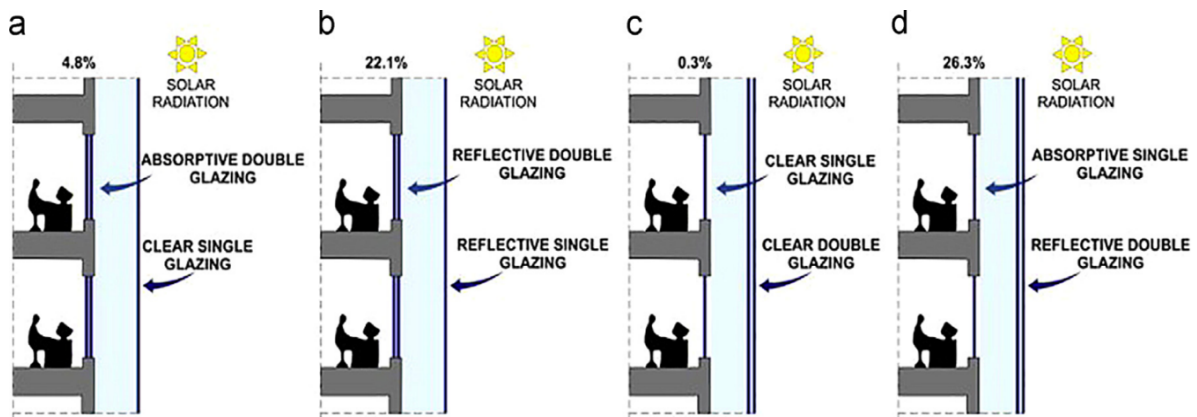


Fig. 24 Performance of building with DSF under variations of the glazing properties. Source:(Chan et al. 2009)

Another study of examining the glazing properties in improving energy performance was done by Ardiani and Koerniawan (2017) proved that lower SHGC reduced the cooling loads for UMN building Campus located in Tangerang, Indonesia at hot-humid climate, this study

created different DSF's material properties combination with metal perforated and glass by selected only the third floor for DSF's observation, the analysis concluded that the perforated metal DSF achieved the highest demands based on the annual energy consumption while the triple glazing has the least demands in compare to the other materials due to have a high thermal resistance value with low heat transfer coefficient value good material for insulation, the study supported the theory of Dewi, 2014 that the lowest U-value and SHGC has better energy performance and reducing total annual cooling loads. They found the total annual electricity required for cooling the space with triple glazing DSF is the lowest against other tested materials with (100374 kWh) while the perforated metal model was (126674 kWh) by 5% to 23.16% more energy for cooling compared to glass DSF, the single glazing DSF and perforated materials are higher cooling loads than double and triple glazing.(Ardiani & Koerniawan 2017)

Barbosa and IP (2014), reviewed the main parameters that affected on thermal performance of the natural ventilated DSF, from relevant studies found that application glazing with single glazing (higher transmittance) instead of double-glazing effect on thermal performance, so inner layer of DSF should be higher thermal insulation to decrease the radiative and conductive heat transfer across the building façade. They found adequate combination of glazing system is essential to make balance within the air cavity between the stack effect and heat transfer to occupant room.(Barbosa & Ip 2014).

Yellamraju (2003) evaluated DSFs performance by analyzing two offices buildings in two cities under hot climate in India. He concluded that, in spite of transparent layers decrease the overall U-value of the building facade, the cavity temperature increasing due to the radiative and convective heat transfer. The study applied different strategies with different SHGC and U-value materials and design on the DSF to assess its effects on cooling loads of the building. The results found that transparent layers with single glazing in both outer and inner is not

efficient in reduction cooling loads only slightly from (4% to 8%) lower than base case, the second strategy with inner double-glazed unit and single layer outer was more efficient in saving cooling than the 1st strategy with (4% to 10%). In contrast, the combination of brick layers and double skin glazed openings indicated the most cooling loads reduction was (13%-28%) below the base case for the opaque outer skin and transparent glazed skin. Findings resulted that transparent layer minimizing the overall U-value of façade system, but still increasing in the cavity temperature due to radiative and convective heat transfer. Also revealed that DSF can be achieve energy efficiency by using suite combination with different materials with right transparency and orientation. The final results not more efficient than conventional wall of base case in hot climates. The study found that layering, transparency and shading, and orientation are main parameters effect on DSF performance. (YELLAMRAJU 2004) Another estimation for DSFs system in reduction cooling loads through comparing single skin façade SSF and DSF in terms of thermal comfort and energy consumption have done by Saber Sabori (2012) by employing DSF at the west wall bungalow house in Malaysia under tropical region. He observed that double glazing (outer reflective metal colored DSF and inner clear pane) integrated with external blind achieved the most efficient energy saving by 20.3% of cooling loads. In contrast, integration internal blind with double glazing reduced efficiency of energy consumption. (Saber Sabouri 2012)

Radhi, et.al. (2013) assessed the DSF from different view by testing the impact of climate interactive façade systems CRFS on reduction cooling loads with fully glazing façade of multi-storey building in the new campus of UAE University in Al Ain city in hot arid climate the UAE. The CRFS proved potentially on reduction solar gain inside the space but increasing air temperature within the cavity. Further it minimized the cooling loads ranged between 17% and 20% energy savings. Different factors affected the final outputs; the storey level to the screen

height is the most affective following by glazing properties and cavity depth. (Radhi, Sharples & Fikiry 2013) another study of typical DSF applied box type window with shading of highly glazed office in Budapest, central Europe at moderate climate findings about 7% reduction in cooling loads comparing to double and triple glazed façade. (Gelesz & Reith 2015)

2.9.2 AIR-CAVITY DEPTH (THE AIR BUFFER SPACE)

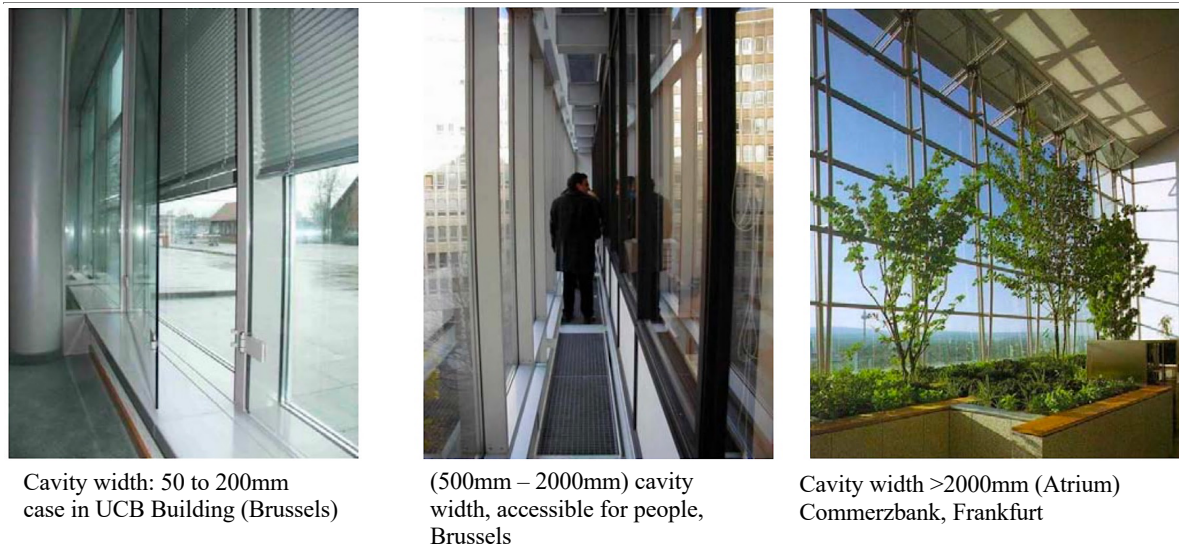


Fig. 25 Classification of the air cavity width with case studies. Source:(BBRI. et al. 2005)

The cavity depth is the most examined factors of DSFs system. It concerns with the energy performance, greenhouse effect and ventilation of DSF buildings.(Wang et al. 2021). The BBRI recommended classification of the cavity depth (width) as shown in fig. (25) set in range from (200mm-2000mm); 20cm such widths are rarely in practice in contrast, 200cm mainly in atrium and accessible for people. (BBRI. et al. 2005) the cavity depth needs to be considered in related with climatic conditions and oriented of the building. Different criteria take into consideration when designing DSF, If the solar radiation is great, then the façade has to be ventilated, the key parameter to avoid overheating are the width of cavity and the external ventilation openings size. The vents could be passive system by left open all time, or active system that mean open by machine. The air change within the cavity based on different factors

are; The wind pressure on the building envelope, the discharge coefficient of openings and the stack effect. (Harris Poirazis 2006)

Radhi et al. (2013) examined the potential of multi-storey façade systems fully glazed building with CRFS system achieved reduction cooling loads between 17% and 20%. The researchers compared between two tested cases (climate interactive façade system CRFS and classical single façade skin CSFS) in terms of cooling loads, airflow, air temperature. CRFS system has 2 layers, outer skin 12 m height with 3 openings along the single glazing screen from zero level with 0.60m height, inner windows are double glazing.

The tested case study is multi-storey air-conditioned building is the architectural engineering department building in Al-Ain,UAE university in hot climate with three studios, oriented toward the east where CRFS installed. Different parameter solutions (construction elements) were applied such as solar screen, louvers and CRFS. Velocity vectors and temperature contours were used to assess thermal performance of cavity; the CFD analysis observed that applying single glass as material of screen reduce efficiency of the system by 26%. the result found that greenhouse effect and different temperature through cavity encourage air flow within cavity, high pressure at bottom and low pressure at top openings creating opposite flow down to the openings. The study resulted that CRFS application on multi-storey reduced the solar gain into inner spaces contributed in reduction cooling loads. The floor level to screen height, glazing properties and cavity depth are tested parameters which impact on cooling loads. Findings resulted that 0.7m and 1.2 m are recommended optimization cavity size due to create a balance between air extraction. Cooling loads were measured by solar gain and heat transmission to the inner space. in terms of solar heat transfer stated that, the narrower cavities achieved accentuated stack effect and rising air movement, the heat transfer rates decrease as the cavity depth is reduced. lower convective and lower solar gain reduce heat transfer rate (Radhi, Sharples & Fikiry 2013)

According to Rahmani (2012) assessed the impact of air gap size on the lowering amount of solar heat transfer through the DSF envelope in south facing of fully air-conditioned office building in tropical climate in Malaysia. The paper determined the capability of DSFs in reduction the cooling loads and avoid overheating in the cavity through ventilating the solar heat built up within the cavity. they found that the efficient air gap size for that case is (1 meter) due to decrease conduction heat transfer and solar heat gain, but more than 1 meter air gap size is reducing the efficiency of DSF in lowering solar heat gains due to reduction in stack effect of DSF envelope. *the recommended cavity for DSF system is 1000 mm as it enhances the performance of DSF in lowering the solar heat gains. However, the system does not work efficiently if the cavity is more than 1000 mm.*(Rahmani, Kandar & Rahmani 2012)

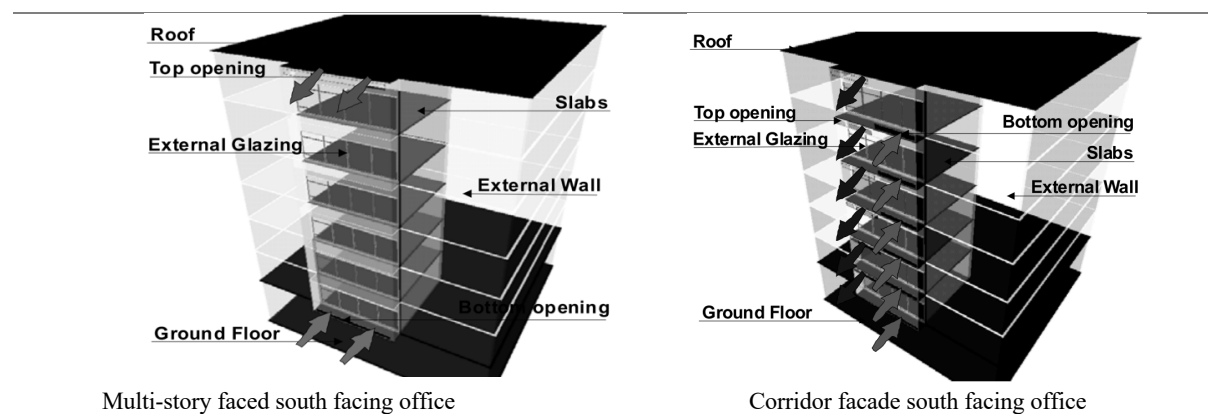


Fig. 26 left) Multi-Story façade south facing office, (right) Corridor façade south facing office. Source: (Torres et al. 2007)

Another study examined the impact of cavity and external openings dimensions for reduction energy consumption is done by Torres et al., 2007 through created two DSF models for office building corridor and multi-story typologies as shown in fig. (26) under Mediterranean climate in Barcelona, Spain with four different cavity depths 40 cm, 60 cm, 80 cm and 100 cm and three external openings area. The findings resulted that increasing external opening area has obtained more impact on reduction annual cooling loads than cavity depth, the bigger opening area the lower energy demands for annual cooling loads. In multi-story façade the larger

openings with narrower cavities achieved better performance to diminish cooling loads due to increment the ventilation rate that enhancing stack effect for extracting the warm air from the cavity. Further, the multistory façade with narrower cavity demands lower energy on annual cooling loads than wider cavity due to higher ventilation rate and enhancing occurring stack effect within the cavity, as well as the air inside this space heats up rapidly due to the large distance between exterior bottom and top openings leading a higher temperature gradient along the height of the cavity. The results demonstrated that optimum cavity ventilation is required for saving energy through efficient design dimensions of height, width and depth to avoid overheating cavity. Simulation findings showed that larger openings area in the cavity decreases the flow-resistance, leading to greater amount of air flow through the cavity. The researcher found that increasing the opening area at top of DSF resulting in promote/enhance greater airflow which assists in extract warm air from the cavity. They concluded the narrow cavity is preferred in air conditioned building as it demands less energy consumption due to accentuated stack effect within the cavity which minimizes the heat transfer to inside the occupied space.(Torres et al. 2007) Another study related to the LR done by Ghaffarian Hoseini et al.(2016) provided a comprehensive analysis of DSF design, they reported the influenced of construction material in efficiency of DSF, the findings verify a significant benefits from applying DSF system, that decreasing the cavity depth of DSF is reduction in energy consumption as well. (GhaffarianHoseini et al. 2016)

Gan (2006) investigated the effect of cavity width on buoyancy induced ventilation rate, found that the optimum cavity width between (0.5 and 0.6 m) on ventilation rate which increase with cavity width also ventilation rate reduced from bottom to top for each floor. he revealed that buoyancy within the façade cavity is increasing with variation of cavity size till reaching a point where is no significant change. (Gan 2006) In general, assumed either thin or deep air

cavity will efficient perform is difficult as Poirazis (2004) reported because in one case the cavity temperature and other case the blinds will be higher as study of “*Modelling the Air Infiltration in the Second Skin Façade*” in 2001, concluded that “*thin cavities are more useful, because they can deliver a higher and hotter air flow compared to the air flow delivered by thick ones*”. (Poirazis 2004b) Another result from study conducted on typical office building in Phnom Penh city in Cambodia, hot-humid climate by Lim and Ismail (2018) shows that the optimal performance of DSF is combination parameters of 500 mm cavity depth, bronze laminated glass for both internal and external layers of DSF and external louvers by reduction annual energy demands about 34%. (Lim & Ismail 2018) another results from the study conducted on office buildings in a temperate climate by Regazzoli (2013) show that the most efficient façade construction combination is the 1000 mm Multi-Storey Double-Skin Façade with a regulating cavity. This combination managed to achieve an annual energy saving of about 16% as compared to the base model using a conventional single skin façade. (Regazzoli 2013)

2.9.3 SOLAR SHADING DEVICES SDs POSITIONS SYSTEM

Applying adequate design of solar shading devices SDs is required for DSF design. installing SDs with DSF play a significant role to prevent the interior space of the building from the direct solar radiation, decreasing solar gains resulting in reduction overall cooling loads, leading in saving energy demand of the building, achieving adequate daylighting with decreasing glare and permitting thermal buoyancy without restricting airflow. The position of SDs (blinds) is essential decision in reduction heat gains, installing SDs near glazed layer triggered in increasing temperature on the glazing surface, causing heat gain to the interior space and heat loss to the outside. (Brown 2016)

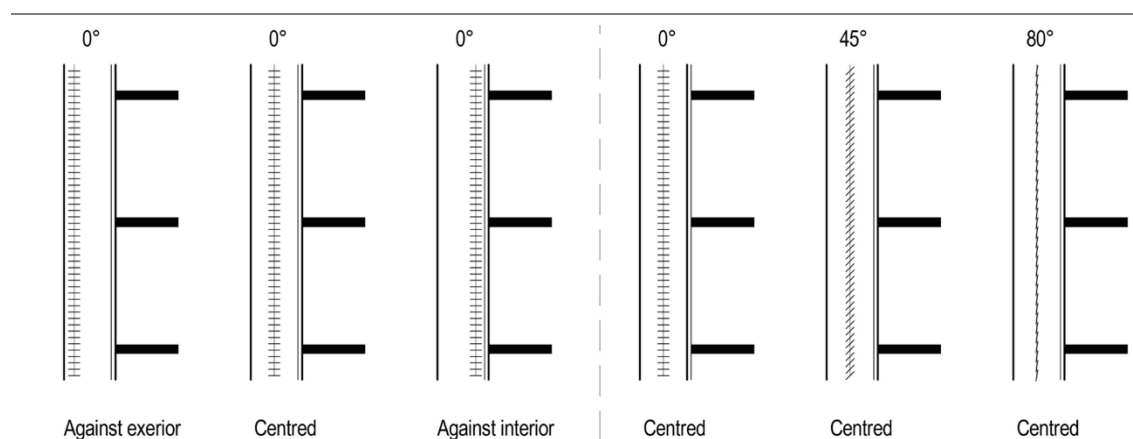


Fig. 27 Location and angle of solar shading devices in respect with the skin. Source: (Brown 2016)

Brown (2016) introduced the design principles and function of DSF in North America. The location of SDs in the air cavity in respect with skins and incident angle can be effect on airflow deriving from thermal buoyancy as shown in fig. (27) describe the tested blinds of SDs in cavity within 3 positions. The study found that middle location is the best thermo-circulation , while adequate ventilation was occur on either side of SDs. (Brown 2016)

According to the study by Terri Meyer Boake, (2014) in “Hot Climate Double Façades, Avoiding Solar Gain” conducted that applying DSF system in hot climate scenario is continue faced many obstacles, that leads to primary interest of SDs and addressing efficient used of the DSF system. The benefits of employing SDs with DSF system to avoid passive solar gains resulting in saving cooling loads could be easily creating a comparison with base curtain wall that using internal blinds. She analyzed different case studies (projects) as shown in fig. (28) which integrated different types of DSF in hot climate (extreme desert climate) regions in the UAE and Qatar where the range of temperature 45C and 80% average of humidity. The case projects in Gulf region provided a clear view of the potential DSF system in adapting in order to prevent solar radiation, two types of DSF have adapted to respond to the extreme hot climates; one placed ventilated screen element (*mashrabiya*) instead outer glazing layer, and

one keeps the glazed properties of DSF system and focusing on the creating a buffer air to reduce heat transfer. Terri Boake's view in DSF construction system relative in the UAE could be mostly useful for shading purposes. (Boake et al. 2014)

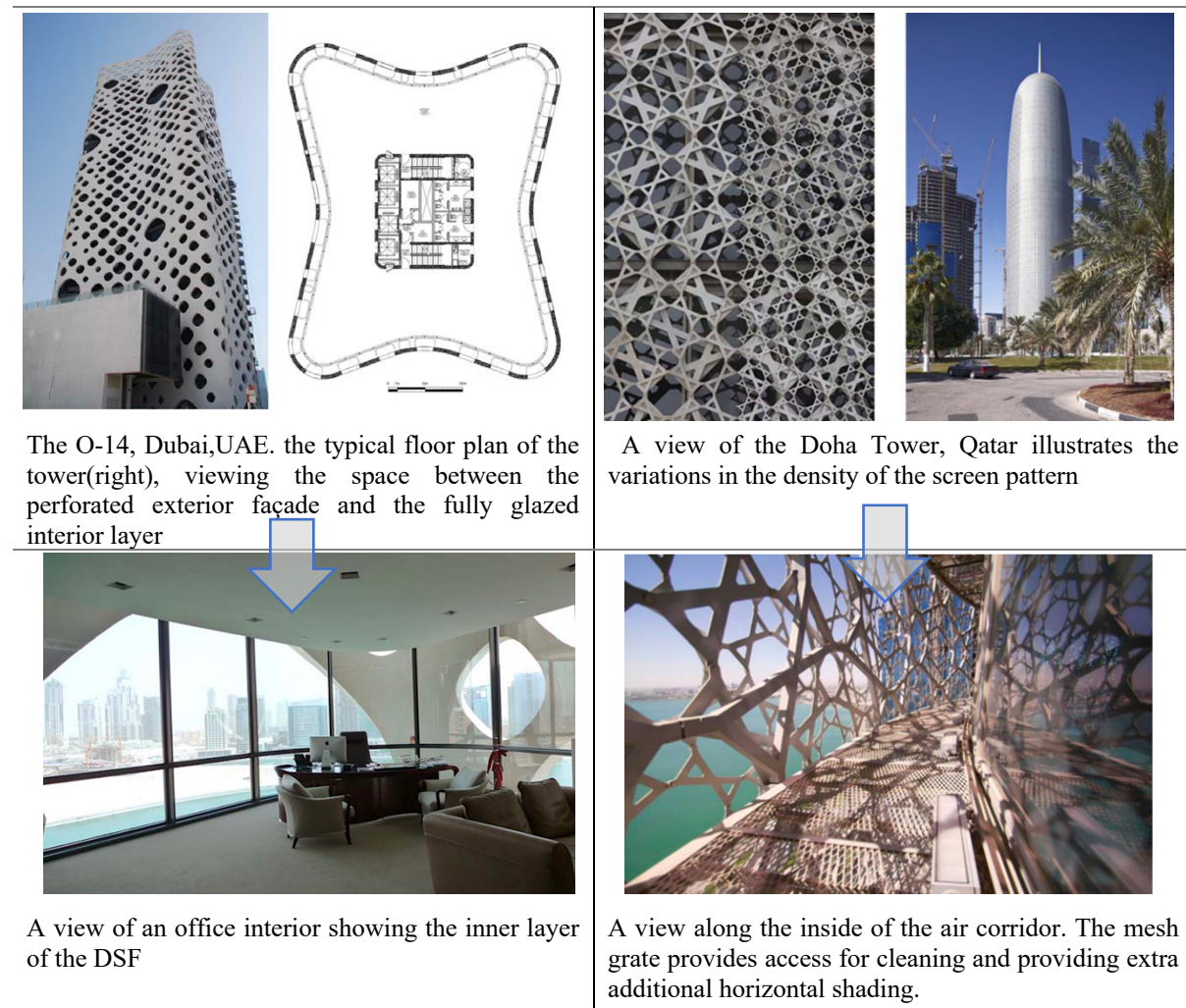


Fig. 28 Case studies of DSFs system in hot climate, Gulf regions. Source:(Boake et al. 2014)

Another study “*The most efficient position of shading devices in a DSF*” done by Gratia and De Herde (2007) tested the influence of position and colour of the SDs in reduction the cooling loads in DSF of office building of *International Energy Agency, Solar Heating and Cooling Program* in Belgium by using TAS software for thermal analysis. He placed SDs in different positions; SDs against a faced, SDs far from the facade, the air cavity can be divided into different zone and analyzed the air movement. The shading position influence the heat transfer

rate within the cavity and amount of thermal stress on the glazing surfaces, The study identified that external SDs the most efficient position of SDs. The study analyzed colored blinds integrated in the cavity of DSF; 1st position placed against the window of inside skin, 2nd position against the windows of outside skin, 3rd position in the middle of cavity. Thermo-circulation is well established in the middle; the air of the zones close to the interior skin rises due to the heating of the blinds and the temperature of the interior facade is definitely lower than resulting in reduction cooling loads. The SDs should be positioned toward the exterior glazed pane for air circulation in both sides. The results found reduction in cooling energy by 13.5% to 14.1% when the blind changed position from close inner glazing to the middle of the air cavity. The external SDs position are the most effective solar protection result. while, installing SDs near either glazed will rise the temperature on the glazing surface leading to inadequate airflow, conductive and radiative heat transfer around the blind resulting in increase heat to the interior space. However, the heat reserved by SDs will increase the air temperature of air cavity, so creating **opening** vents in both bottom and top of DSF will release the hot air flow up through stack effect then escape to the outside. If SDs is located near by the internal façade, insufficient air flow surrounding the device could happen, increasing the radiative and conductive heat transfer to the interior space. The final results achieved up of 23.2% reduction cooling loads by take in account to location the blinds, the blinds color and the openings of DSF.(Gratia & De Herde 2007).

The openings of DSF impact on reduction the cooling loads by 7.4%12.6% with placed blinds on the outside skin. The most common position of shading devices within the air cavity in between the two skins of DSF. (Penić, Vatin & Murgul 2014) Fahmy, et al. (2020), tested integration of SDs with natural ventilated DSF in hot climates in Greater Cairo, Egypt for hotel building. The results of applying natural ventilated DSF with highly reflective SDs showed the

lowest operative temperature °C and highest air velocity (m/s) which are better performance in terms of thermal comfort and ventilation rates of south, east and west orientation. Where the temperature difference ambient and room's operative are 1.51°C, 1.85°C, and 1.78°C respectively of three orientations. The north façade with applying naturally DSF without SDs achieved the acceptable performance and the lowest temperature followed by the east, west and south. While the west has the highest air velocity followed by the north, east and south. (Fahmy et al. 2020)

Another study found that the placed venetian blinds could be influenced the SHGC, temperature and air distribution through altering the blind positions from inner glazing surface position to the center of cavity (Jiru, Taob & Haghighat 2011) Oesterle et al. identified that the DSF system with only external glazing reduced a minimum of 10% of the solar irradiance, while placed louver blinds inside the air cavity of DSF achieved more reduction of about 50% to 60% compare with interior blinds. (Lee, Alshayeb & Chang 2015)

Lee, Alshayeb and Chang (2015), analyzed different scenarios based on SDs configurations to observe the relationships among airflow patterns, the air velocity, the air temperature and the annual energy consumption. The tested model DSF is a one-story tall corridor type DSF with vertical SDs and a DSF air cavity is designed with 4-meter height. The air temperature and airflow patterns were highly dependent on the shading device configuration identified the optimal shading devices type of horizontal and vertical devices at 0°, 30°, 60° and 90° angle, the analysis results of numerical data found that the horizontal and vertical shading at 0-degree angle achieved a higher vertical convective current and air temperature distribution for both sides of shading device within the cavity. In contrast, the horizontal devices at 90-degree angle run to increased air temperature in external surface side's air cavity, the horizontal and vertical shading devices saving annual energy consumption. In this study the horizontal shading

devices are more effective in energy consumption than vertical shading. The simulation results showed that the heated air which transmitted by solar irradiance through external glazing was stagnated inside the narrow space of horizontal devices between each piece as shown in fig. (29). Different behavior of air temperature distribution in cavity. Horizontal SDs at 30-, 60-, and 90-degree angle were more effective to reduce the energy use by 0.4%, 2.6% and 6.4% respectively (Lee, Alshayeb & Chang 2015)

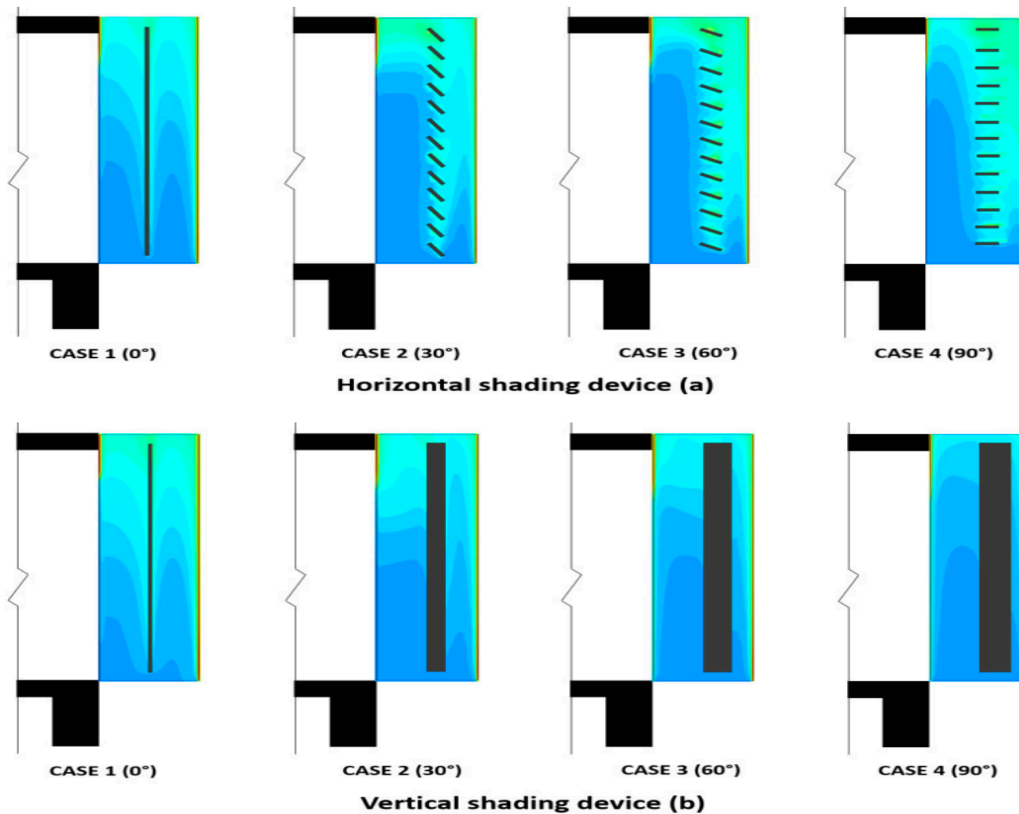


Fig. 29 (a) Air temperature distribution in horizontal , (b) Vertical shading devices SDs. source: (Lee, Alshayeb & Chang 2015)

2.9.4 THE CAVITY OPENINGS AND AIR FLOW

Koo and Bokyoung (2017) compare the performance of 2 tested windows were mounted on the lab chambers in order to reduce solar heat gains (amount of heat flowing into the building) in South Korea; the 1st case is double skin window with 20 mm ventilated air cavity and the 2nd case is triple low-e glazing window with a certain dimension as described in fig. (30) decreasing insolation inflow indoors could be achieved by making ventilated the air cavity of outer layer glass, reduction the air temperature of air cavity and glass surface resulting to

minimize the amount of heat flowing into the building. The final results showed that ventilation air cavity influenced on reduction total power consumption by about 3% since decreasing cooling loads in actual building could be achieve. the results show reduction in SHGC for the case A and B with ventilation air cavity by about 28%, and 53.9% respectively in comparison with case without ventilation air cavity. Furthermore, the mean temperature was 0.6K with ventilation air cavity lower than case without ventilation air-cavity. Furthermore, this work achieved reduction in a cumulative power consumption by about 3% thanks to installing ventilated air cavity which effect on the saving cooling energy. (Koo, Bokyoung 2017)

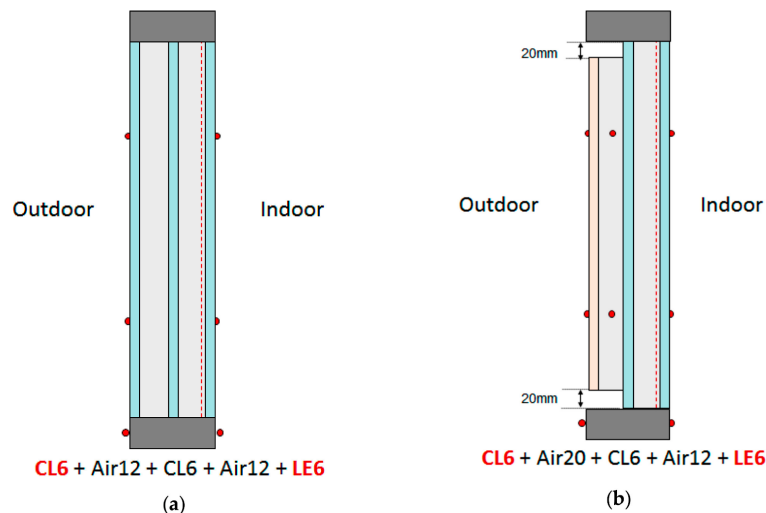


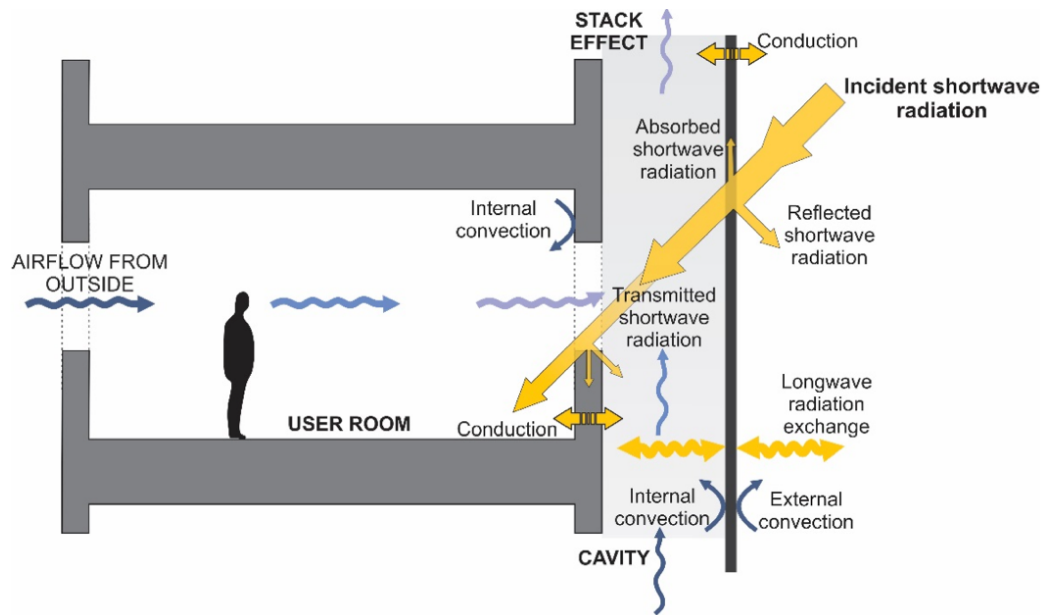
Fig. 30 Measurement point of window temperature, (a) triple Low-e glass, (b) ventilated double-skin window. Source: (Koo, Bokyoung 2017)

Barbosa Sabrina (2015) examined different design variables influenced in performance of naturally ventilated DSF outdoor air is supplied from openings in the opposite façade and passes through the occupant space before entering the cavity of office building in the Rio de Janeiro city under hot humid climate in terms of enhancing thermal comfort level in the space. outdoor air is supplied from openings in the opposite façade and passes through the occupant space before entering the cavity. The researcher used IES VE software to simulate the base case and 16 studied cases with DSF modeled and tested by thermal dynamic simulation. The variables which refer to the scenario cases are; shading devices cavity depth,

cavity height, wall to window ratio WWR and inner skin material. After that, he evaluated each parameter separately, then selected the optimized design case. Regarding with SDs and inner skin material; results show that SDs made of concrete is higher thermal mass was applied within the cavity, resulting in higher cavity temperatures due to the higher absorptance property of the material, whereas aluminum material observed lower cavity temperatures, both relative to the base case. The findings concluded that the SDs positions is the most efficient design variable in improving thermal performance followed by the cavity depth and inclined external layer. Increased the cavity as high chimney above the building enhanced thermal performance. The final results reached to 70% of the occupied hours for acceptable thermal comfort. The study concept as shown in the cross section below fig. (31) described the mechanism of the air-cavity of natural ventilated DSF, from the opposite side facade the external air is supplied from the openings then pass through the occupant space before entering the air cavity. This air is heated by solar and conduction gains then rise up causing lower air pressure continue drawing air from the adjacent rooms, generating a continuous convective air current. The main variables identifying the air flow is the height of thermal chimney, location of the openings, area of cross section and the air temperature variation between external air and air within the cavity. As described in the empirical equation 1. (Sabrina Barbosa 2015)

$$Q = C_D A \sqrt{2g\Delta H_{NPL} (t_i - t_o)/t_i} \quad \text{Equation 1}$$

Where: Q = air flow rate, m³/s; CD = discharge coefficient of the opening; A = area of the opening, m²; g = acceleration due to gravity, m/s²; ΔHNPL = vertical distance from the neutral pressure line (NPL) to the aperture, m; ti = air temperature in cavity (higher temperature), K; to = outdoor temperature (lower temperature), K.



*Fig. 31 Cross section of SF and adjacent office floor with heat transfer and airflow mechanisms.
Source: (Sabrina Barbosa 2015)*

Thorough review done by Sabrina Barbosa and Kenneth Ip (2014) related to the natural ventilated buildings with DSF by identifying the main parameters affecting energy performance of the buildings with DSF system, the results found that; narrower air cavity leading in greater air ventilation rate in the space due to emphasized attack-effect. The openings affected the air temperature and buoyancy force in cavity, larger openings area decreases the flow rate resistance resulting in greater amount of airflow within air cavity as well as larger opening top area enhancing greater airflow. The taller cavity space achieved higher buoyancy effect leading on greater airflow. Outdoor conditions and geometry structure DSF features affect the efficient performance of vent openings. In terms of natural ventilated DSF, increasing air temperature within cavity is important to achieve greater airflow. (Barbosa & Ip 2014)

Alberto et al. (2017), analyzed heat exchange through DSF to evaluate the effect of DSFs in energy efficiency of the building in Southern Europe featured with relevant solar gains which is significantly affect the DSF performance. by using Design builder and Energy plus for CFD module. The base case is office building with single glazed façade was selected from BEST

FAÇADE project in the city of Porto, in Portugal. The results found that applying different ventilation strategies to the cavity leading to reduce the office temperature up to 18C with 30% openings at external layer, and 13C decreasing is achieved with top and bottom ventilating. The airflow has significant impact on the saving cooling loads, the outdoor air curtain achieved the higher ventilation flowrate. The multi-storey and shaft box achieved higher ventilation flow rate about 2.75 % times than corridor and box-window. The findings result that multi-story façade with maximized openings integration with outdoor air curtain OAC air flow was achieved the most efficient DSF structure against other types, about 30% fewer HVAC related energy consumption. Orientation is importance for DSFs, as this difference decreases to 9% when single glazed facades are analyzed. changing the direction of a DSF from north to south results in an increase in solar gains up to 8.4 times on average. (Alberto, Ramos & Almeida 2017)

Zomorodian and Tahsildoost (2018) selected the optimal DSF for Persian Tower office building with 138m total height in Tehran. The office wall is single layer (double glazed unit) With 60% window to wall ratio at south east and north west side. The study used experimental method and simulation tools by Energy- plus simulation engine and the Design-Builder graphical interface to evaluate the natural ventilation and energy performance of buildings with DSF. Through changing different façade configurations, shading properties, and cavity ventilation. The final model minimizes energy consumption from 7.9% to 14.8%, and applying different ventilation strategies to the cavity in warm months reduced the office temperatures up to 18C, while 30% openings on the external layer are approximately 13C reduction is achieved by ventilating the DSF from the top and bottom. The final results achieved enhancing thermal conditions for all alternatives, the Box-window DSF increase office temperature more than other alternatives by 7.9C, while Multi-story DSF improves the thermal conditions in the

offices with and without shadings, show the minimum effect by 1.8C on increasing office temperature.(Zomorodian & Tahsildoost 2018)

2.10 SUMMARY OF CHAPTER 2 : LR

Overview of DSF Parameters and Observations (key clarifications)

Parameter	Author/year	location	variation	tool	Major outcomes/observations
Glazing properties	<i>Aldawoud (2017)</i>	Sharjah-UAE	comparing thermal performance & annual energy consumption of building	Design-Builder tool	<i>Argon and Krypton gas fill between glazing panes increased efficiency performance to 15% and 5% respectively the both are better than air fill. The triple glazing low-e coating with argon gas fill reduced energy consumption to 33% compared to the single glazing of base case</i>
	<i>Johny (2018)</i>	UAE-hot-arid climate	<i>Investigated different materials (phase-change, transparent glass, & concrete) at outer skin that affected DSF performance,</i>	IES-VE software Apache	<i>All DSF variants minimized solar heat gain, saving annual cooling demands from (8.7% to 49.9%) in high-rise building. The glazing materials from 8% to 20%, PCM 30% to 50%. also increasing thermal mass of DSF achieved better performance in cooling saving.</i>
	<i>Chan et al. (2009)</i>	Hong Kong	<i>Altering position of different types of glazing properties clear, absorptive and reflective in DSF</i>		<i>the double glazing reflective outer pane with single glazing inner pane reduced annual cooling loads of building to 26%as compared to a conventional single skin facade with single absorptive glazing</i>
	<i>Ardiani and Koerniawan (2017)</i>	Tangerang, Indonesia at hot-humid climate	4 selected materials; perforated metal, single, double and triple glazing in DSF	Autodesk Revit and Green Building Studio	<i>the lowest U-value and SHGC has better energy performance and reducing total annual cooling loads. triple glazing at outer pane recorded the least demands in compare to the other materials due to have a high thermal resistance value with low heat transfer coefficient. Is excellent insulation material</i>
	<i>Yellamraju (2003)</i>	Hyderabad and Delhi in hot climates		Ener-Win 2002	<i>layering, orientation and transparence are effect on the DSF performance, inner double-glazed unit and single layer was more efficient in saving cooling energy consumed with (4% to 10%) than, opaque external layer and glazing in internal layer achieving 13028% lower cooling loads than base.</i>
	<i>Saber Sabori (2012)</i>	Kuala Lumpur		Design-Builder	<i>DSF with double glazing outer skin and clear inner skin showed best values in saving energy comparing with SSF. Installing external blind with double glazing saved more energy by 20.3% of cooling energy consumption & achieved best annual thermal comfort</i>

	<i>Radhi, et.al. (2013)</i>	Al Ain city in hot arid climate	Design-Builder,RANS CFD and PHONICE S-FLAIR	<i>The optical properties of the layers are the most effective way to reduce cooling loads, with a particular influence the direct gain and stack effects. Multi-Storey façade with CRFS system minimized the cooling loads ranged between 17% and 20%. temperature. Single glass decreases the efficiency of CRFS by 26% Glazing with lower SHGC & lower convective decrease heat gain.</i>
	<i>Joe et al. (2014)</i>	Korea,Seoul	GenOpt 3.0 compined with EnergyPlus	<i>Optimization multi-story DSF façade by altering inner and outer layer of window, and range cavity depth from 8cm to 148 cm decrease the energy consumption by 5.2% in total energy consumption Decreasing the cavity depth achieved reduction energy consumption</i>
Cavity depth	<i>Harris Poiarzis (2006)</i>	-	LR methodology	<i>the cavity depth needs to be considered in related with climatic conditions and oriented of the building</i>
	<i>Radhi et al. (2013)</i>	Al Ain city in hot arid climate	Design-Builder,RANS CFD and PHONICE S-FLAIR	<i>Decreasing the cavity depth, reduce the mass air flow rate in cavity & heat transfer, resulting in minimizing temperature. Different temperature at each floor, the airflow rate increase from G.F to S.F which is the highest rate.</i>
	<i>Rahmani (2012)</i>	tropical climate in Malaysia	FloVENT Software	<i>the system does not work efficiently if the cavity is more than 1000 m and reduction stack effect through DSF, 1meter enhance DSF performance increased the efficiency of lowering SHGs</i>
	<i>Torres et al., 2007</i>	Mediterranean climate in Barcelona, Spain	TAS simulation	<i>the multistory façade with narrower cavity demands lower energy on annual cooling loads than wider cavity. The bigger opening area the lower energy demands for annual cooling load</i>
	<i>Ghaffarian Hoseini et al. (2016)</i>	-	LR methodology from several studies	<i>Reported comprehensive overview of the significant benefits from using DSF system sustainable performance in (thermal comfort, energy saving, ventilation enhancement,)</i>
	<i>Gan (2006) (Lim & Ismail 2018)</i>	London	FLUENT	<i>optimum width for an open cavity where the buoyancy- induced flow rate reaches the maximum and the optimum cavity width between 0.55and 0.6 ventilation rate in DSF of four-Storeys vary from floor to floor due to buoyancy, rate high increased with the cavity width but the increase was small</i>
Shading devices positioned	<i>Lim & Ismail (2018)</i>	Phnom Penh city in Cambodia	Energy-Plus software version 8.6.0	<i>the optimal performance of DSF is combination parameters of 500 mm cavity depth, bronze laminated glass for both internal and external layers of DSF and external louvers by reduction annual energy demands about 34%. 500mm is the optimum cavity depth offers a better stack effect to remove excessive heat from air space.</i>
	<i>Brown (2016)</i>	North America		<i>location of solar devices in the air cavity in respect with skins and incident angle can be effect on airflow deriving from thermal buoyancy.</i>
	<i>Gratia and De Herde (2007)</i>	Belgium	TAS software	<i>23.2% reduction cooling loads by take in account to location the blinds, the blinds color and the openings of DSF reduction</i>

Vent openings				in cooling energy by 13.5% to 14.1% when the SDs blinds changed position from close inner glazing to the middle of the air cavity. Location SDs near by the internal façade, insufficient air flow surrounding the device could occur, & increasing the radiative and conductive heat transfer to the interior space. External solar protections are more effective than internal shading
	<i>Fahmy, et al. (2020),</i>	hot climates in Greater Cairo, Egypt	Design-Builder V4.6.015 software	The north façade with applying naturally DSF without SDs achieved the acceptable performance and the lowest temperature followed by the east, west and south. While the west has the highest air velocity followed by the north, east and south.
	<i>Lee, Alshayeb and Chang (2015),</i>	Kansas, U.S.A.	FloVENT	horizontal and vertical shading at 0-degree angle achieved a higher vertical convective current and air temperature distribution for both sides of shading device within the cavity. horizontal shading devices at 30-, 60-, and 90-degree angle reduce the energy use by 0.4%, 2.6% and 6.4% respectively.
	(Koo, Bokyoung 2017)	South Korea	Field experiment by using test cell	Ventilated air cavity double glazing window reduced accumulative energy consumption by around 3%, decreasing SHGC was around 0.08 with ventilation which is lower than triple glazing window without ventilation about 0.17. reduction in SHGC for the case A and B with ventilation air cavity by about 28%, and 53.9% respectively in comparing to case without ventilation air cavity
	(Zomorodian & Tahsildoost 2018)	Tehran, Iran semi-arid climate	Design-Builder & Energy-plus	Utilizing a DSF of an office tower reduced total energy consumption in all the alternatives, from minimum 28 to maximum 54 kWh/m ² . Simulations show that thermal comfort is achieved in the free running mode of DSF alternatives in more than 34% of the occupied time, while it is about 18% in a single layer façade. the energy consumption is reduced from 7.9% to 14.8% with all 4 DSF types. Multi-story DSF improved thermal conditions in the offices with and without shadings.
	<i>Barbosa, Ip and Southall (2014)</i>			Narrower air cavity leading in greater air ventilation rate in the space due to emphasized attack-effect. The openings affected the air temperature and buoyancy force in cavity, larger openings area decreases the flow rate resistance resulting in greater amount of airflow within air cavity. The taller cavity space achieved higher buoyancy effect leading on greater airflow
	<i>Barbosa, Ip and Southall (2015)</i>	Rio de Janeiro-hot humid climate	simulation software IESVE	Optimized models show that the incorporation of DSF is able to achieve approximately 70% of occupied hours within the acceptable comfort levels the most influential parameters on the overall building thermal performance are the application of shading devices within the cavity, followed by the cavity

				width. metal SDs within the cavity reduced the overall airflow in the offices improved the thermal comfort in the building by 9% in relation to the base case, while only 4 % improving thermal comfort by using concrete increased heat gains from cavity to the occupied space.
(Alberto, Ramos & Almeida 2017)	Porto, Southern Europe-mild climate	Energy-Plus & Design-Build		The most important aspect for the efficiency of a DSFs is the airflow path and the results found that the most efficient geometry was the multi-storey DSF with OAC achieving in average 30% less HVAC related energy demands. Internal. Changing the direction of a double-skin facade from north to south results in an increase in solar gains up to 8.4 times. DSF Outdoor Air Curtain facade (OAC) to the south orientation achieve less noticeable effect due to the increase in solar gains is compensated more effectively by heat dissipation through the facade, caused by an increase of the average volumetric airflow rate in the cavity
(Saroglou et al. 2020)	Mediterranean climate	EnergyPlus 8.8		Ventilated DSF design with the Low-E glazing as the exterior layer of the DSF reduced cooling loads by 15% on average, in comparison with a typical DSF design in temperate climates where

Table 3 Overview of DSF Parameters and observations (key clarifications)

CHAPTER THREE

METHODOLOGY

3. CHAPTER 3 METHODOLOGY

Several approaches connected with various investigation methods were used to study the performance of building envelope associated the DSF system in order to obtain the main criteria, factors and strategies affected the performance of DSF for improving energy efficiency of the building. The study based on investigation a good practice research through collecting and analysis many papers relevant to enhance the DSF performance in terms of energy efficiency. Several criteria and results have discussed and evaluated to achieve the optimal design of DSF in the buildings. Related to the previous studies, the main methods were investigated to assess the performance of DSF in terms of enhancing energy performance are literature review, parametric tools (simulation software) and field experiment.

3.1 LITERATURE REVIEW LR

A literature review LR is a critical evaluation, analysis and synthesis of existing knowledge relevant to research topic and it is part of bibliography. (Chris Hart, 2018) The LR method constructed a list of essential sources and collecting the most scholarly data relevant to the topic that help researcher to build the relevant idea with different strategies. The LR can obtain several things to help in development the relevant topic study such as definitions, hypothesis and theories. The LR of the DSF system applications and the case studies global and local introduced a solid foundation to this paper. Furthermore, LR method is mainly thorough tool of qualitative data, addressed the most aspects and configurations, covered wide range for analyzing data, focusing in comparative database, further connecting up-date ideas for enhancing research in progress as well as helping in build idea with different strategies to fill the knowledge gab.

3.1.1 PROS AND CONS SIDES OF LR

Pros sides	Cons sides
▪ Theories and the techniques are carried out in research to fill the knowledge gab. ▪ LR plays an important role in academic improvement. ▪ Providing evidence and justifying to support the research argument and develop advanced knowledge and skills. ▪ Improving critical thinking abilities at the existing research. ▪ Supporting debate and interpretation.	▪ Lack access and restricted of a certain scholarly academic date that relevant to the same topic of research. ▪ Long-time spending for acquiring and reviews data. ▪ Lack experience of personal skills analyzing and development map of research ▪ Durability (strengthen a weakness sources data). ▪ Bias and error for the study due to minimizing in techniques, the quality and creditability. ▪ Encompassed issues relevant to primary and secondary sources may in doubted for decision making.

3.1.2 EXAMPLES OF RELATED STUDIES THAT USED LR

A comprehensive analysis done by GhaffarianHoseini *et al.*, 2016 about thermal performance and energy efficiency of currently design for DSFs through reported overview several relevant studies focusing on various aspects technical of DSFs and construction characteristics influenced on the energy performance of building. The paper revealed different findings from the recent studies, and observed the influences of various types of DSF design in many climate conditions and locations. The performance of DSFs is diverse, for instance, in hot climates DSFs can lead to improve lower shading coefficient, in cold climates DSFs works similar to heat exchanger through keeping the temperature close to the inner skin façade. Aesthetic quality aspects of DSFs assist for more widespread and popular special in commercial buildings. From different perspective, in Central Europe using DSFs are still debatable. (GhaffarianHoseini et al. 2016)

Mary Ben Bonham (2020) afforded over 250 drawings illustrations and photographs to be an essential reference guide for analyzing and understanding the types and functions of DSFs. Her research covered more climate zones with case studies differ than other books which focusing mainly in early German examples. Through examined the historical and potential development of the DSF on different approaches, provided recommending of integrated DSF design process leading to application, wide selected of architecture samples belonged to the DSFs including basic design concepts and strategies of DSFs for manage thermal, luminous and acoustic performance as well as she addressed many alternatives of implications and constructions of the DSF high-performance buildings. “*Bioclimatic double skin-facades*” for Bonham could be beneficial source enriched for engineers, professionals and construction. (Mary Ben Bonham 2020) A similar study done by Terri Boak. (2014) conducted her research by collecting several innovative applications that applied the DSF system under hot climate in the form of case study method. The main obstacles for her research is related to the collection a numerical data of the selected project’s performance due to non-compliance of the building’s owner.(Boake et al. 2014)

The BESTFAÇADE project sponsored by energy intelligent Europe program published report of the most common projects constructed DSFs in 7 European countries analysis the DSFs types in details with different aspects, thermal behavior, indoor air quality, comfort, energy demand and consumptions...etc. comparing to the conventional building façade. The most studied buildings are office *and schools* with multi-story and corridor faced types. The project collected 28 facades of the different buildings in different European climate zone as shown in fig.(32) through using standardized questionnaire which includes data of location, building, façade construction, air flow within the façade, maintenance and cost. (Heimrath 2005)

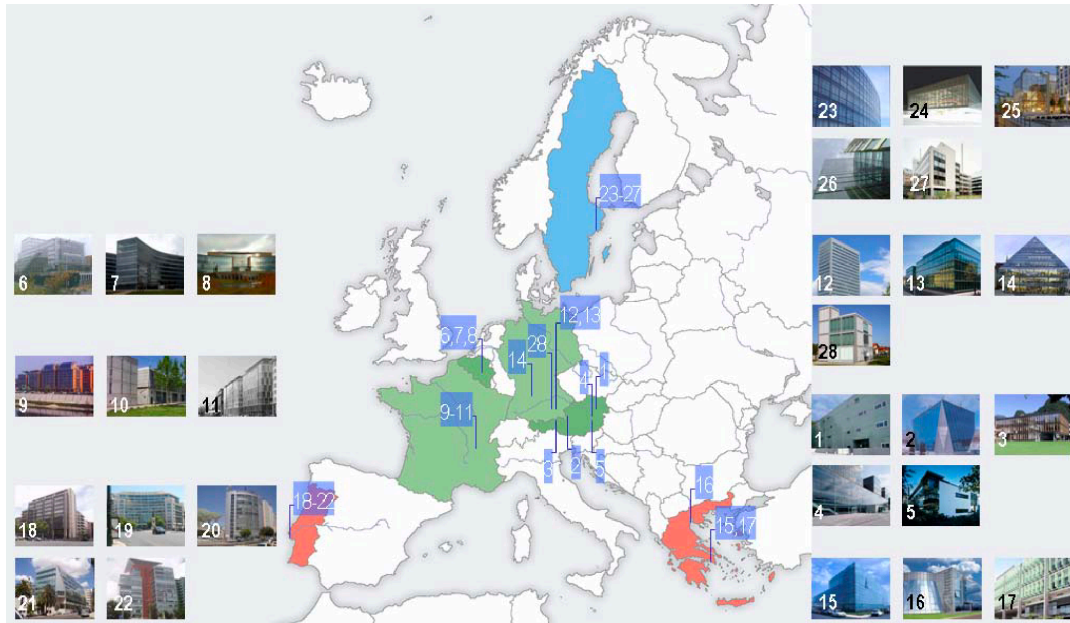


Fig. 32 The selected DSF buildings for analysis within the BESTFAÇADE project. Source: (Heimrath 2005)

3.2 PARAMETRIC TOOLS COMPUTER SIMULATION METHOD

Parametric tools include many computer simulation software tools for analyzing the building performance development. The software tool enable interaction with other energy simulation software tools. (Sousa 2012) the building performance simulation (BPS) tools have potential to enhance adaptive building facades as real-world implementation, prediction performance of improving building façade. The aim of BPS is quantification of the building performance aspects relevant to the design, construction, and operation buildings. (Wilde 2018) IES-VE software tool is one of the BPS tools able to integrate several physical domain thermal, airflow, daylight and building services (HVAC) during simulation run-time fig (33) IES-VE is one of the most widely used tools of BPS, most powerful modelling capabilities and most rigorous validation studies, the capability of simulation DSF system generally available in various building BPS such as (EnergyPlus, ESP-r, TRNSYS), while the accuracy relied on the selected calculation methods for cavity heat transfer, ventilation air path, the type of solar shading, also possibility to show DSF model by coupling thermal model and with airflow simulation tools, by providing specific model also. (Loonen et al. 2017) on the other hand, rising level of

understanding the complexity behavior of DSFs can be created by different advanced software simulation tools.

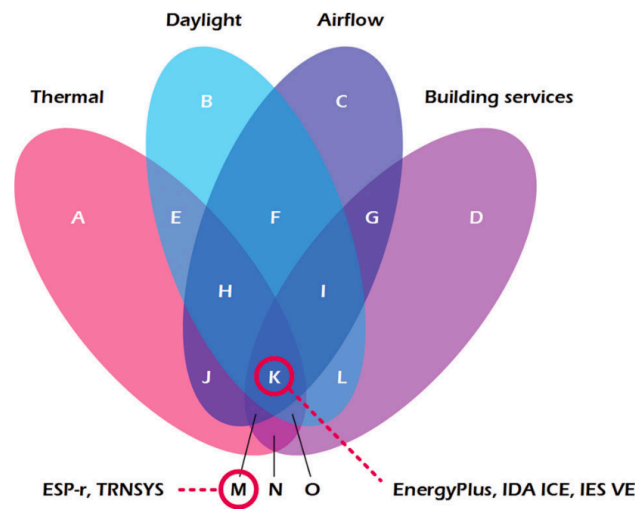


Fig. 33 Integration multi-physical domain needed to model adaptive facades, DSF in many BPS.
Source: (Loonen et al. 2017)

3.2.1 PROS AND CONS OF THE COMPUTER SIMULATION

Pros sides	Cons sides
▪ Capability to evaluate and modeling the building performance. ▪ Lower cost, limitation of time and wide use/available. ▪ Measuring different factors which can't be controlled in field experiment such as weather conditions. ▪ Decision-making in early phase by using data from simulation results, modifying geometry and quick testing of parametric modeling options with high accuracy. ▪ The output is easily obtained with easier analysis of interpret results. ▪ Model verification and validation are crucial in the development of a simulation model. ▪ Selecting the most proper tool regarding to researchers and designers needs	▪ Difficult achieving accurate representation of actual real building. ▪ Large number of independent variables, input parameters in early phase design. ▪ The results measuring usually not match the actual building due to discrepancies between actual building and virtual representation. ▪ The time and effort during collecting data, determined parameters create big challenge especially for large-scale application. ▪ More skill levels and understanding to operate and set up accurate ▪ The options need to be tested to ensure compatibility. ▪ No specific software able to analyze all parameter types. ▪ Well calibrated model is important for accuracy representation building for reliability in applications.

3.2.2 EXAMPLES OF RELATED STUDIES THAT USED PARAMETRIC MODELLING

Aldawoud (2017), created the study model by using Design-Builder tool to analyze the impacts of wide range of glazing system on the energy performance, he kept the WWR and openings of the base building over all generated scenarios, also assigned the weather profile of Sharjah city the same construction template of the reference building for all glazing variable scenarios. (Aldawoud 2017) IES-VE software has been used by Johny, 2018 to rendering three models of DSF constructed different materials for typical building in the UAE and investigated at the peak cooling time which is hottest hour at 15:30 on July 23. The findings show that all configuration materials in DSF vary in reduction cooling loads of whole building ranged from 8.7% for a glass DSF, 45.6% perforations in the outer skin to 49.9% for a PCM DSF with 1.9% perforations in the outer skin. Analyzed the temperature distribution of DSF cavity to observe the impacts of DSF and compare each case.

Ardiani and Koerniawan (2017) depended on using Autodesk Green Building Studio software for energy performance analysis and Autodesk-Revit for modelling to simulate two models in different DSFs material properties. They simulated the whole building of UMN to measure the total energy consumption affected by different options of DSFs materials. (Ardiani & Koerniawan 2017) The simulation results of the base-case model have presented and discussed by using Design-Builder software tool assigning different categories data of building physical properties such as construction layers, opening, and HVAC system (Saber Sabouri 2012)

The RANS CFD simulation tool has been used to analyze integration the screen glass by Radhi et.al. (2013) connected with indoor and outdoor conditions by setting up geometrical model with new construction multi story building, carried out a great number of CFD simulations. The geometric model of the case study developed by Design-Builder software based on the

boundary conditions identified by wind speed and direction, solar radiation and ambient temperature to investigate in CFD calculations, then transferring to FLAIR which able to solve the complexity formulation equations to assess convective and radiative heat flux by analyzing the airflow coupled simulation of convective and analyze heat gains from solar radiation. They evaluated the impact of CRFS on cooling loads and solar gain with assigning different configurations like site and design parameters have manipulated in simulation run. The design parameters have considered by implementing five altering cavity depths with three various types of glazing properties for three studio storeys. Also, measured the impact of storey level regarding to screen height was examined by changing the monitoring point height. For each simulation runs, he listed the total convective heat rate and coefficient of materials for external and internal layers and a single parameter was modified from listed for the base case. In regarding to the design parameters, the results found that the difference in heat transfer rates and solar gain were reduced when the cavity depths minimized, also it decreases the mass flow rate of air circulation within the cavity space hence reduces the temperatures inside the cavity. The researchers depend on integration BES and CFD software to develop the geometrical models in respect with numerical simulation also for improving the accuracy the work relied on outdoor and indoor conditions not only the cavity of CRF. The findings observed that the lower U-value thermal properties of glass not mean the smaller in the convective heat transfer coefficient.(Radhi, Sharples & Fikiry 2013)

Rahmani, (2012) used the (Flo-VENT) CFD software to simulate 6 strategies of 10 stories for fully air-conditioned office building through placed 6 monitor points in different positions x,y and z at each floor to record the temperature data in order to investigate the impact of air gap size on reduction solar heat gain of south face office building. The simulation strategies have run for 10 cm, 30 cm, 50 cm, 1 m and 1.5 m through installing altering typical glazing by

reflective glazing. The findings concluded that DSFs perform better than typical skin façade and the 1-meter air gap size for that context represent the efficient performance by lowering cooling loads 3° at fourth floor than typical façade. (Rahmani, Kandar & Rahmani 2012)

TAS simulation software is another software tool was adopted by Toress et al. (2007) to study the impact of different cavity depths (40cm, 60cm, 80cm, 100cm) and selected three different area of exterior openings for Multi-Storey and corridor DSF type on south facing double glazed façade in Mediterranean climate, Barcelona in order to achieve the suitable energy results. Tas software analyzed the dynamic fluid equations which are mass and thermal transmission of conduction, convective and radiation of building zones through utilizing hourly conditions relating to the local climate, taking in consideration internal loads, artificial lighting, infiltration, air exchange between zones and people load of the building. (Torres et al. 2007)

Fahmy, et al. (2020) analyzed thermal simulation results of natural ventilated DSF with shading devices of hotel building, the researchers tested three floors at the south orientation which has the extreme condition of operative temperature in August in hot climate, by using CFD simulations which have done by Design-Builder V4.6.015 software tool and compared all cases to the base case, the case 1 is single skin façade, case 2 is DSF, case 3 integration SDs. Assigned the building models' parameters; glazing material specifications of the base case for simulations, Fahmy used shaft-box type of the natural ventilated wall DSF, and maintain the same glazing layers for the single skin façade with 1 m cavity width, installing shading devices of Aluminum and placed them 20 cm away from external skin. The results of installing SDs with the natural ventilated DSF achieved a great enhancement in operative temperature and thermal comfort over all orientations except the north façade which is not highly affected by direct solar gain and due to the reflection solar gain from surroundings.

Lee, Alshayeb and Chang (2015), Used the CFD simulation software, Flo-VENT to calculate the air temperature and the airflow circulation within the DSF cavity through installing four cases (scenarios are: 0°, 30°, 60° and 90 angle) of vertical and horizontal shading devices inside the air cavity. While the (Sefaira) was used to run the energy performance (the annual heating and cooling consumption). the simulation required assigned the boundary conditions such as; ambient outdoor conditions, materials and dimensions (cavity width and shading device mm), glazing properties, for analysis. The numerical data have obtained for all configurations. (Lee, Alshayeb & Chang 2015)

Lim and Ismail (2018), used EnergyPlus software version 8.6.0 to observed the potential of DSF in improving energy efficiency in office building under hot-humid climate and identifying the proper design of DSF thorough analyzing energy performance of the building in three strategies; the 1st strategy includes 3 DSF configurations (500mm, 1000mm, and 1500mm cavity depth) to identify the optimum cavity depth, the 2nd strategy using two glazing materials, and last strategy determined the optimum shading devices of DSFs (internal shade rolling blind, internal louver, and external louver) comparing all strategies in respect with total cooling loads. (Lim & Ismail 2018)

3.3 FIELD EXPERIMENTAL MEASUREMENT

Field experiment is one of the most sufficient quantitative analytical tools by observing the response of the building envelope performance to the external real-climate conditions, through representing a wide range of quantitatively raw-data and carry out the test in real-world conditions to credibly. The main intend of this method that helps researcher interacting and conducting in the real- environment setting to create findings which are more realistic and reliable applicable with research development test. Moreover, precise measurement category making this tool more significant in field study to cover the main parameters and providing

accurate results. Salens (2002) stated that using experiments and numerical simulations for single storey of DSF were done under naturally and mechanical ventilation represented that perfect design and workmanship are important to achieve the desired performance by field experiments. (Saelens 2002)

3.3.1 PROS AND CONS SIDES OF FIELD EXPERIMENTS

Pros sides	Cons sides
▪ Higher validity due to natural setting reflects real life. ▪ Accurate, extensive and thorough data collecting. ▪ researcher can obtain deeper understanding into the research topic due to direct observation conduct with field. ▪ Increasing quality of data because utilizing more than one measurement tools for collecting data. ▪ Precise measurements and set up relationship between variables. It is considered interpretive method and relies on ability of researcher to record the exact data that researcher observed	▪ Long-time to complete final results. ▪ Impossible altering the variables and environment conditions due to applying test in real world, require high expertise research with proper qualitative measurement tools and input discipline across are required. ▪ Reapplying the test in the same conditions more difficult due to less controlling over external variables. ▪ Researcher's opinions not big deal on final result study ▪ The results can be affected by some external variables which are not expected for researcher.

3.3.2 EXAMPLES OF RELATED STUDIES THAT USED FIELD EXPERIMENT TOOL

Koo, Bokyoung (2017), used test cell to assess the potential of ventilated DSF windows without shading in reduction solar heat gains. The test cell was conducted in K Construction Company technical lab research center in Korea which is a three-story building, the test cell installed in 3rd floor with 2 rooms of 2.30 m height, as shown in fig. (34) the 2 assessed cases

of windows used triple low-e glass ($1.22 \text{ W/m}^2 \cdot \text{K}$) thermal transmittance and ventilated double skin glass ($1.38 \text{ W/m}^2 \cdot \text{K}$ thermal transmittance) and 20mm air cavity width. The researchers measured the outdoor temperature by places the sensors at 2 positions on external surface of test cell window, 2 positions within the air cavity and window, whereas the air temperature inside was calculated the mean temp. placed on 5 positions to study the windows impact on the indoor temperature. While the cooling loads analysis based on power consumption to assess the performance of 2 cases. (Koo, Bokyoung 2017)



Fig. 34 The position of window test cell. (Koo, Bokyoung 2017)

Joe et al. (2014) collected 360 pieces have recorded every 10sec in 1 hr of recorded data for existing DSF building in Yongin-Seoul, South Korea, by installed the sensors; T-type thermocouples and multi anemometers in southern façade from 1st to 4th verified for quantitative comparison between simulation and measurement. Then analyzed the optimal design of multi-story DSF of existing building in Yongin-Seoul, South Korea, in field experiment as shown in fig. (35) the researcher installed the sensors; T-type thermocouples and multi anemometers in southern façade from 1st storey to 4th floor. the revealed that thermal properties of the DSF cavity are vary depending on design of the DSF and its effect in adjacent air conditioning space, decreasing in cavity depth was suitable compared with initial design of DSF by saving the total energy consumption to 0.6%. The climatic conditions, the window glazing type and cavity depth are important to design an optimal DSF. (Joe et al. 2014)

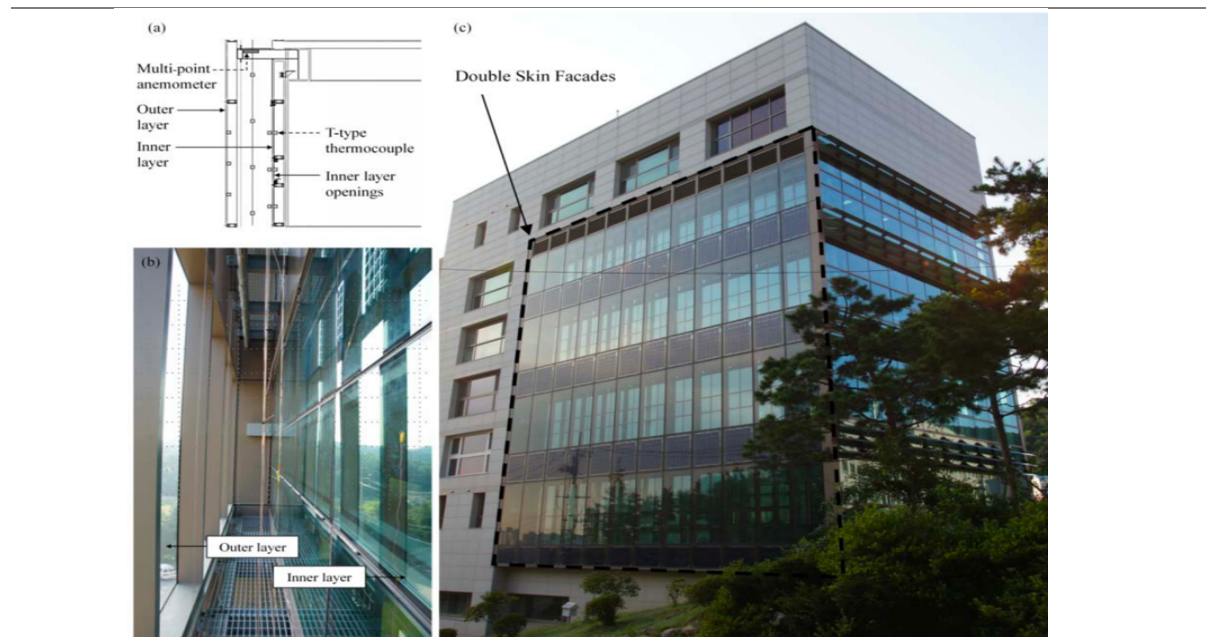


Fig. 35 Location sensors ,a) location of sensors, b) figure of cavity, c) view of the target building. Source:(Joe et al. 2014)

3.4 RESEARCH METHOD AND JUSTIFICATION

This study looks for adequate method to design an efficient building envelope of (DSF) identifying certain process by using parametric modeling software. The computer simulation analysis is the best choice as sufficient and robust tools in order to help researcher for making an early design decision. Parametric software focusing on built modelling process which required high accuracy relationships between different features and drawings. Decision the best parametric modeling based on many criteria not easy. The main features of simulation are; affording comprehensive explanations, quantitative and qualitative data validation, assistance researchers for quick, easier analysis and increasing suggestions/alternatives design, potentially changing inputs parameters with significant modified for each analysis parameter. carried out simulation for analysis energy performance help in improved accuracy and reducing test-periods. Most researchers prefer using this method due to the lower cost, wide variety of simulation tools, with accuracy of modeling outputs and default values. The field experiment

method can't be denied as one of the most sufficient quantitative analytical tools, also it is the strongest tool to observe the response of building envelope performance for external conditions and allowing researcher interact and conduct with research developed test. In addition, precise measurement category making this tool more significant in field study to cover the main parameters and providing accurate results to help in development qualitative data researches.

This study used IES-VE software for simulation energy modeling. The IES analysis tool offers wide range of variables during simulation building performance from early design stage of conceptual design, it joined analytical details functions with visual modelling interactive environment, affording environment detailing of the building system to present final results directly. The IES-VE simulation tool connected with variety applications for dynamic thermal simulation in terms of heat transfer process of the building such as, Apache Sim for thermal calculation, Sun-Cast, Macro-Flo and Micro-Flo (CFD) tools. The IES is qualified as dynamic model in CIBSE system of classification. (Sousa 2012)

This chapter presents analysis a wide range parametric study of DSF influencing on the building energy performance, has been chosen for achieved the simulation modelling. ...etc. This chapter examined the thermal performance of variation types of DSFs based on the climate of UAE-Al Ain city featured by hot summer $>35^{\circ}\text{C}$ and moderate winter, observing the potential energy performance of DSF based on the dynamic variables for each type.

3.5 THESIS STRUCTURE FRAME-WORK AND METHODOLOGICAL ANALYSIS

Thesis framework identified the key structure concept and describe the analytical process of this work. Through highlighted the workflow for sequence phases ordered analysis the DSF system integrated with different scenarios that provide paths for future decisions. The flow chart fig. (36) of this study based on the LR (theoretical study) concerning the DSF system

under same conditions and explain the research theories and problem, field measurement approach is essential stage in thesis work to verified the case study (validation) and confirm with simulation tool. The simulation phase analysis employing a new alternative design of building façade and provided final results of different DSF scenarios leading to accept the purpose of this study. Thesis framework involves different aspects; collection data, field trip including measurements results, and simulating geometry for current state and retrofitting model of four DSFs types. Analyze the conclusions, guidelines of DSF implementations, and assess their performance with recommendations based in enhancing the building envelope.

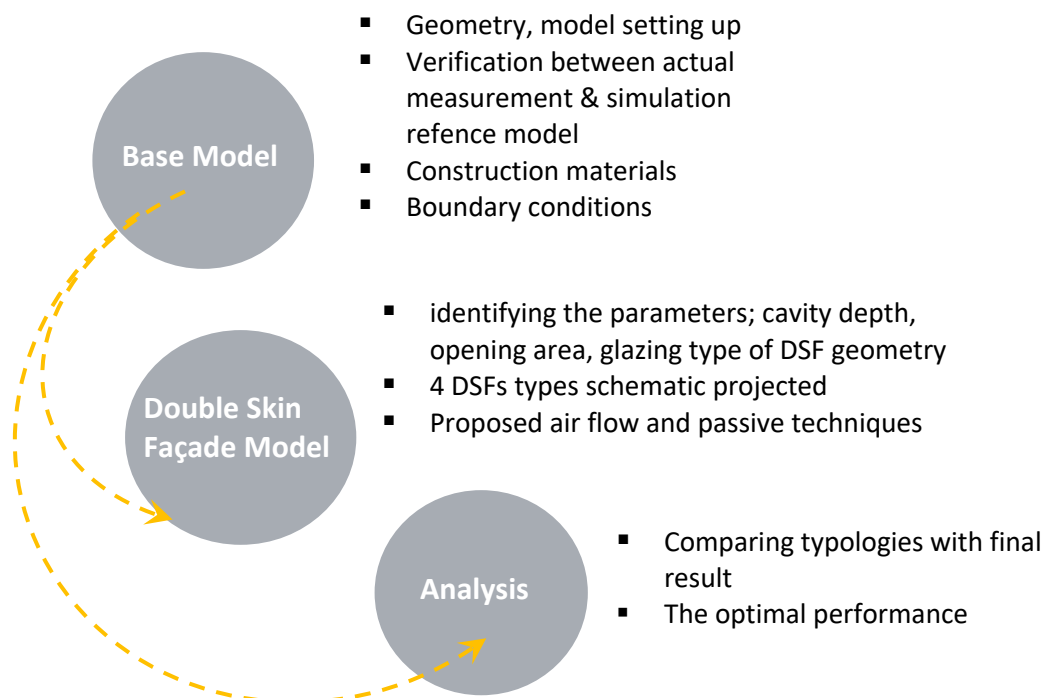
The models were used for prediction and analysis the energy consumption coupled with airflow and velocity. Overall, the paper will investigate the four types of DSF as Oesterle et al. (2001) classified based on structure and cavity combined with different DSFs parameters to apply on an existing building for maximizing the potential of DSF design. The final results will discuss the optimal design of the DSF configurations in the commercial building in terms of enhancing energy efficiency and thermal comfort.

Numerical method was adopted in this study due to the ability of software to analyze the interaction between the overall building (orientation, form, geometry and mechanical systems). The IES software tool was used for simulation energy modelling the process analysis involves; numerical approach, energy calculation, dynamic thermal performance, and combined with air flow characteristics to help in observation the influences of different criteria modifying to optimize the DSF performance of multi-used building respond with climatic conditions. Thesis approach depends on accumulative development, collecting data and analysis into developing process to create an optimal DSF configuration of the tested case study. supporting the design purposes to ensure the building façade appearance, construction, functional, and energy performance.

The IES-VE tool used to develop run simulations of proposed ventilated DSF system by established various tasks, the 1st task is creating 3D geometrical model combined with assigning construction materials relative with real conditions, the 2nd task established the boundary conditions (weather profile, materials construction, airflow thermal monument), 3rd task estimating energy modelling into algorithmic calculations, and measuring thermal performance in terms of cooling loads and annual total electricity demands, the last rendering in respect with analyzing air-flow and Micro-Flow CFD to evaluate the DSFs energy performance. The schematic diagram below shows a brief diagram of DSF variables for testing (investigation)

Methodological Map and research Structure

methodology diagram



Methodological Map and Research Structure

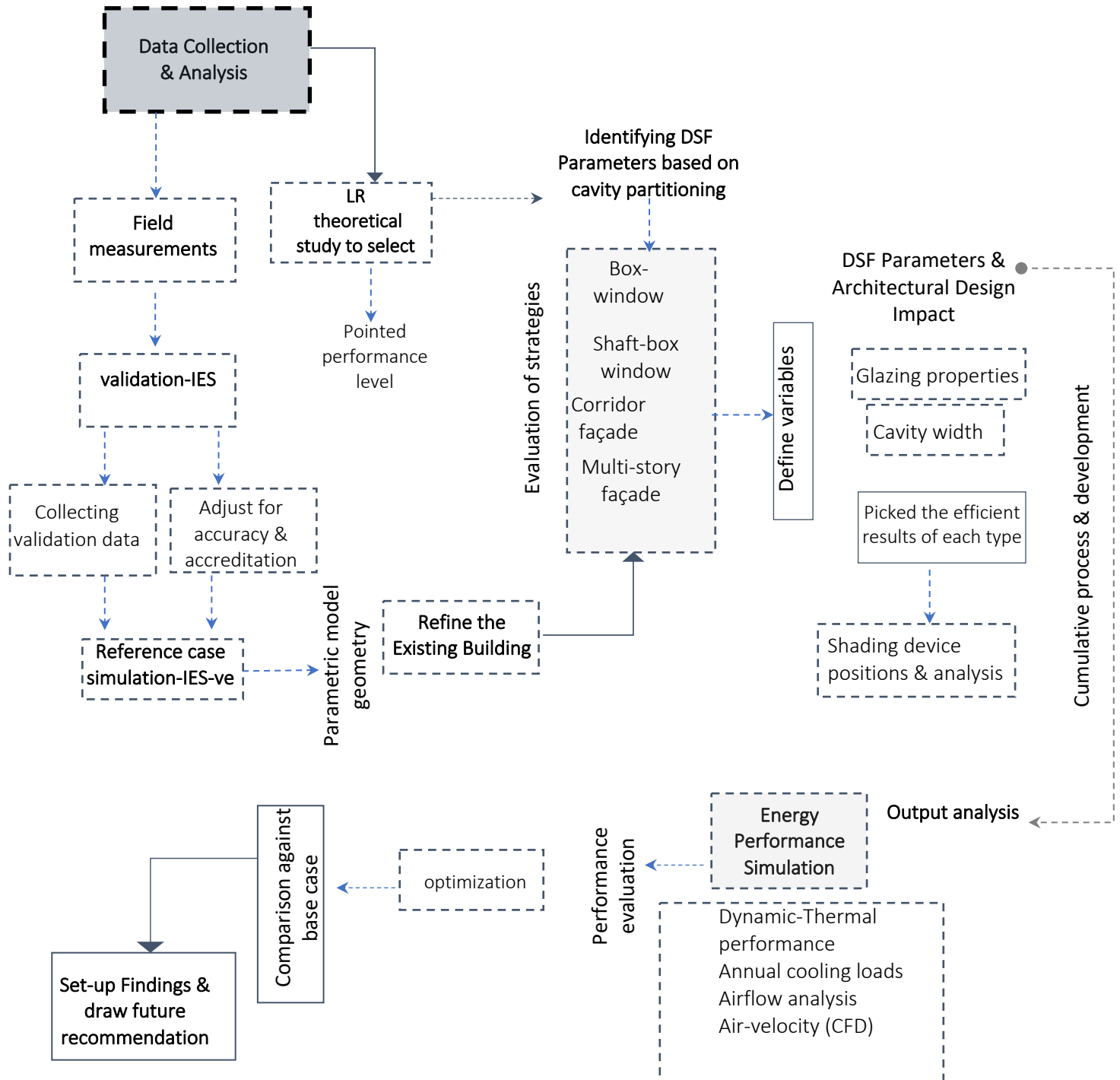


Fig. 36 Methodological Map and Research Structure (Author 2021)

CHAPTER FOUR

THE CASE STUDY

4. CHAPTER 4 THE CASE STUDY

4.1 OVERVIEW OF THE PROPOSED BUILDING

This paper selected an existing multi-used (commercial) building which is located in Al-Ain city in the eastern part of the United Arab Emirates (UAE) under hot-arid climate zone. The multi-storey building called (The Royal Building) was used as a reference base case study (model) for this work. To identify the optimum type of the DSFs by modifying the current elements of typical building envelope to advanced technical innovative sustainable façade design (DSF system), then assessed the impact of DSFs configurations on the thermal performance and the total annual energy consumption.

The reference base case is a rectangular shaped building is located in a strategic location where it is accessible for all modes of transportations. The fig. (37) and fig. (38) present a brief description about the whole building with plot area dimensions and the front elevation of the selected zone study. The building height is (23m) made up of five stories; basement floor for parking and services purposes; one basement for holding water tanks, two basement floors as parking for 62 cars, ground floor G.F. having 9 shops, 1st and 2nd floors have a total of 18 offices, 3rd and 4th floors have a total of 18 flats plus roof. The building has an open terrace in the 4th floor which is available for the tenants living in that residential flat, the terrace area is set back (2m) from the typical floor limit in the south-east orientation. Each unit in both residential and office stories have a shaded balcony. The table (4) below shows the main stories of the base building, included the land use category, the area (m²) and the floor height (m) of each storey. The Royal Building has sufficiently demonstrated compliance with the Estidama-Pearl 1-Rating requirements. The study selects the 1st, 2nd and 3rd floor to study the dynamic thermal simulation by applying the DSF system through replacing the existing façade. The

building data is collected directly from the architect designer and company who constructed the building.

Table 4 Total area in the building (G+4 Stories) and the height of each storey

Storey / Floor	Land Use Category	GFA(m ²)	Total Floor Area (m ²)	Height(m)
Basement 3	Water tanks	0	579.39	3
Basement 2	Parking	103.71	1372	3
Basement 1	Parking	262.49	1372	3
Ground Floor	Shop's retail	868.5	1372	5
1st Floor	9*2=18 Offices	1397.18	1447.79	3.5
2nd Floor	9*2=18 Offices	1407.25	1457.86	3.5
3rd Floor	9*2=18 Flats (Apartments)	1440.71	1491.32	3.5
4th Floor	9*2=18 Flats (Apartments)	1235.66	1286.38	3.5
Roof	Services	0	233.61	3
Total	5 storeys	6715	10612.4	23

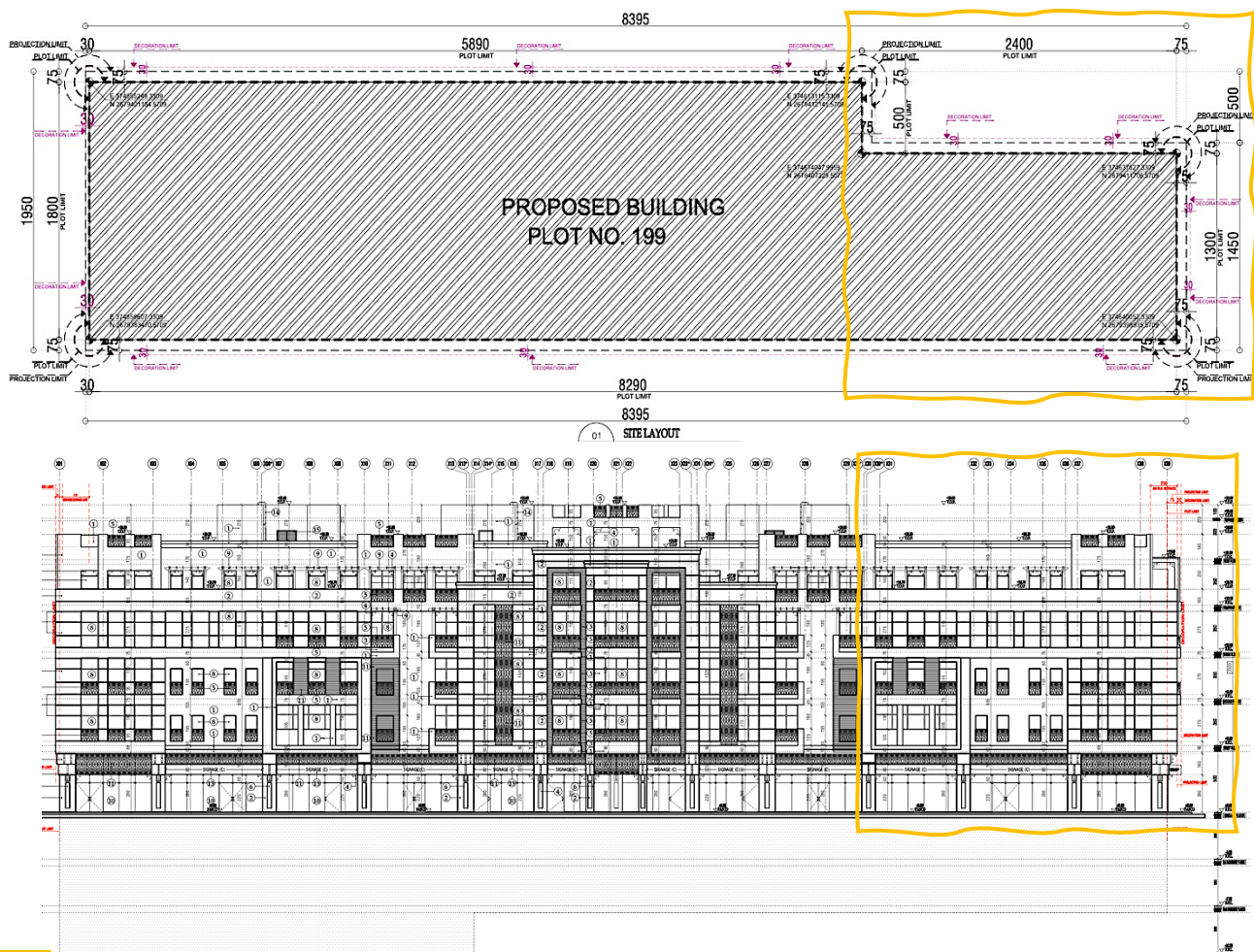


Fig. 37 The case building layout dimensions (top), (bottom) front building elevation south-faced, yellow line shaded indicted to the selected study model

long-section

Front-Elevation

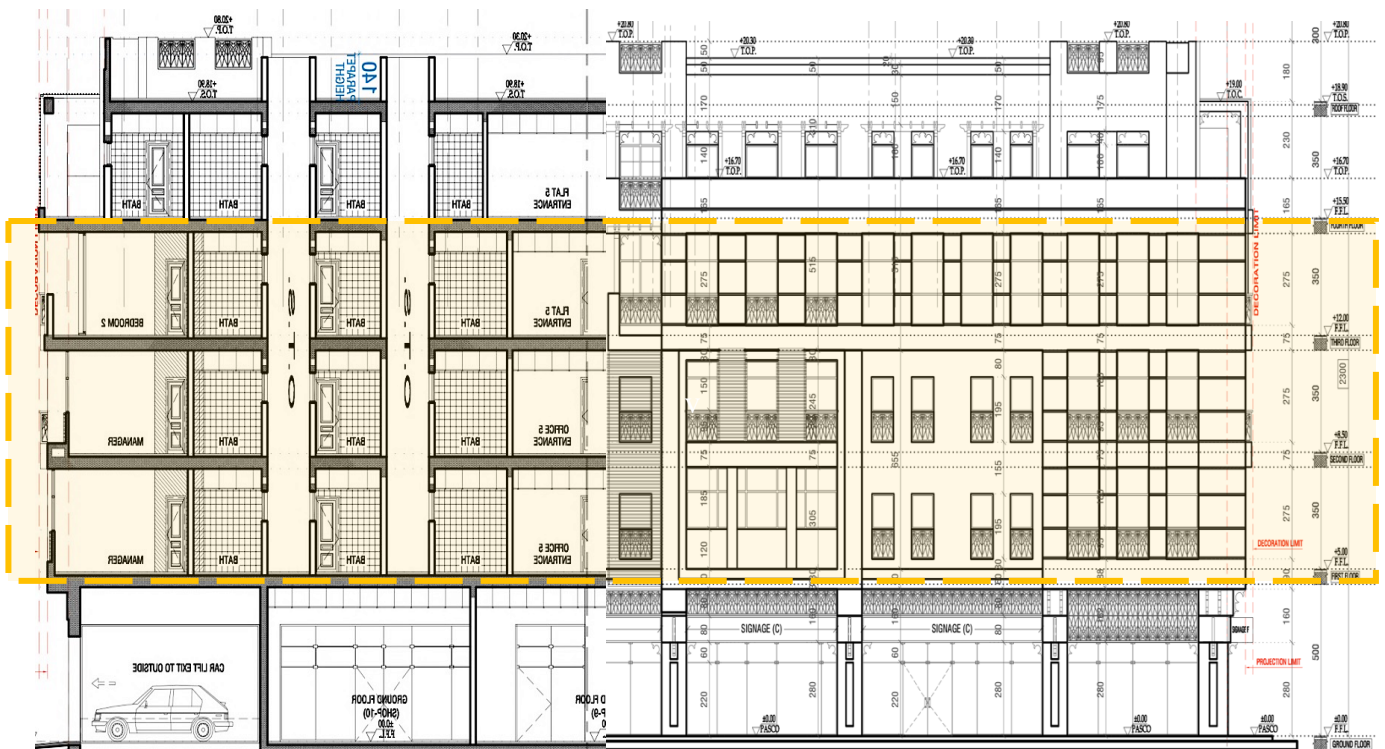


Fig. 38 The front elevation and the long section of selected zone of the base building

The fig. (39) below is related to the selected reference case study, describing the standard development conditions of the multi-used building prototype based on the terms of criteria for the using and development land in Al-Ain city assigned by Department of Urban Planning and Municipalities in the UAE. The MU-20 symbol is referred to the commercial lands (multi-use), these building prototypes are usually located within the city center, usually it is higher than the rest of other buildings. To achieve the target of this study with more accuracy observation and reliability, the study attempted to maintain the same ratio and physical characteristics of the existing building such as, the height of the building, the indoor rooms construction materials, the primary structure criteria and the municipality requirements such as the built area ratio and floor height. The study concept demonstrated by replaced the existing building envelope (conventional) by installing four types of DSF system (Box, Shaft, Corrido and Multi story), at the same time the model setting up development stage in (Model-IT IES-VE). However, the

new skin design of the reference building should be met the sustainable needs and requirements in order to make a comparison with the base case.

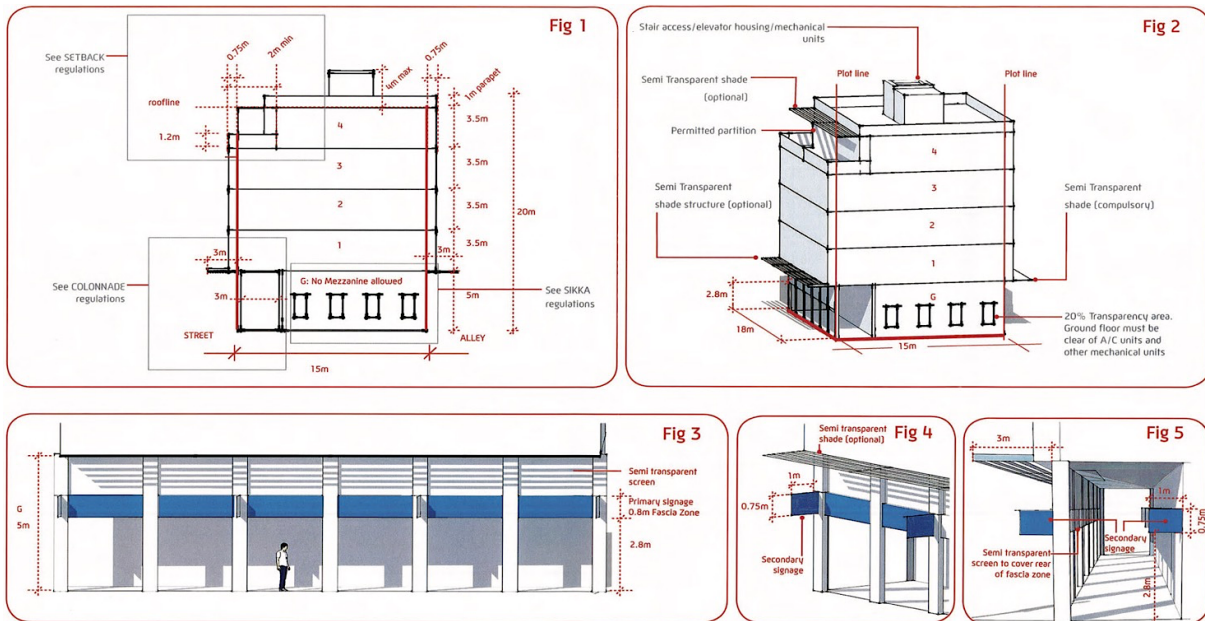


Fig. 39. Multi-used building prototype (MU-20) based on department of urban planning and municipality-UAE.
Source (Department of Urban Planning & Municipalities 2018)

4.2 SITE MICRO CLIMATE ANALYSIS

The map below illustrates the plot location as illustrated in fig. (40), the site is on the Plot 199, Al Qasida-Zayed Bin Sultan Street in Al-Ain downtown is located at intersection between Zayed Bin Sultan Street from the South direction at the front elevation of the building and Salahuddin street from the East and service road from the North. The commercial buildings (office buildings) from the West, in the East direction Al Shikha Salameh Mosque which is considered a unique land mark in Al-Ain city. The UAE is located in the tropical dry region, while the tropic of Cancer runs through southern part of the Emirate. Providing that regions an arid nature characterized by high temperatures thought the year and very hot summer. (Statistics Centre Abu Dhabi 2018)

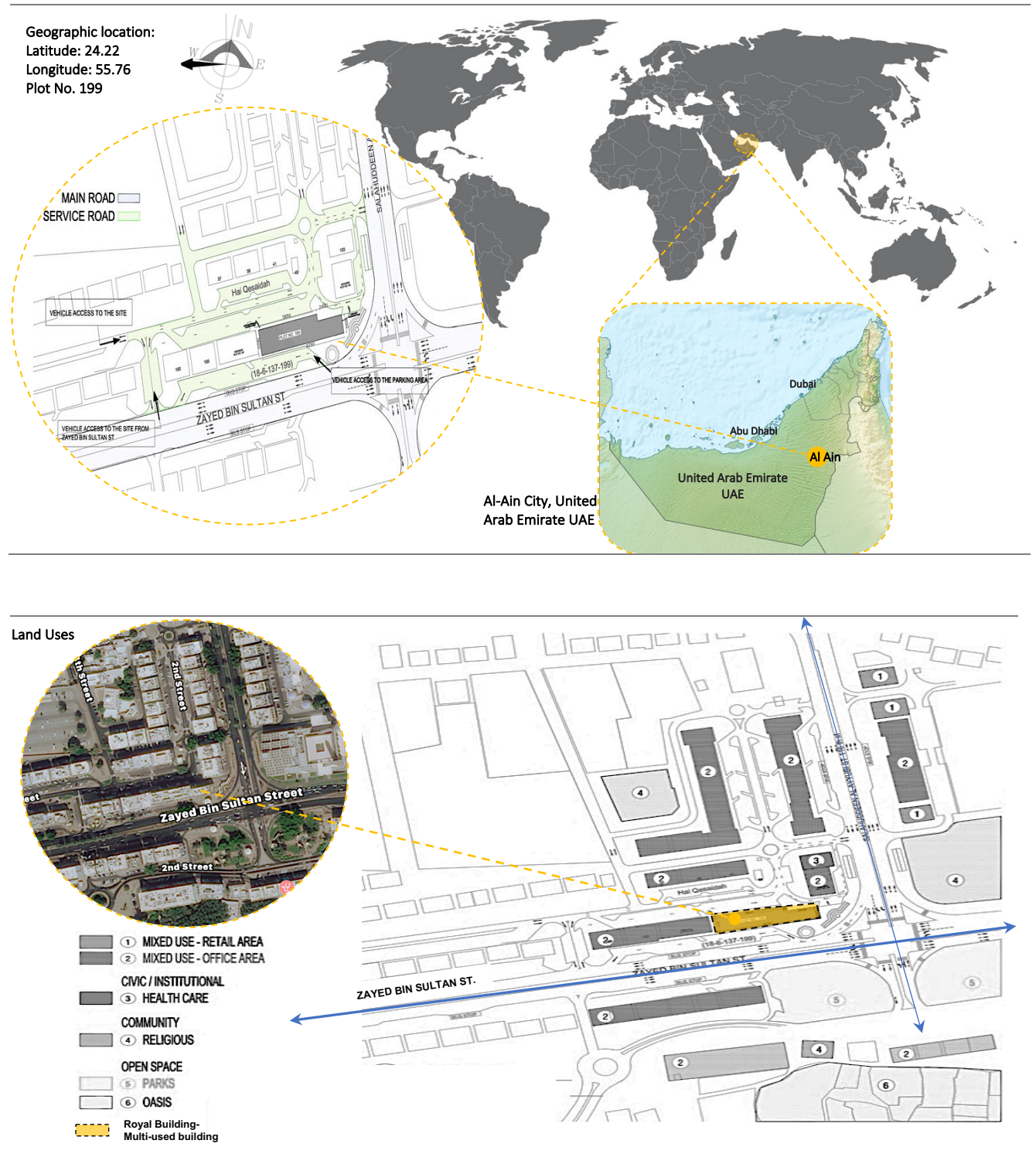


Fig. 40 Geographic location of the base building (top). Land uses surrounding the building case study (bottom)

4.3 CLIMATIC CONDITIONS ANALYSIS

The actual climate conditions are required for dynamic simulation analysis in IES-VE to evaluate the building performance at real situation for more reliability. The weather profile of

Al-Ain city includes data for different parameters such as, the air temperature, the wind speed and direction, the solar azimuth and altitude hourly per year. The weather profile format is (.epw file) derived from the energy plus website. (IES 2020). The following graphs provide analysis of climatic parameters derived from the climate consultant software which read the local climate in EPW energy plus weather format.

The United Arab Emirates (UAE) has a desert climate, featuring extremely hot summers and warm winters. The climate zone of the UAE generally it is subtropical, the north direction zones are in the subtropics while the south regions are in the tropical regions. which indicates to a much fewer rainfall, hot summers and warm winters. The study was done in Al-Ain city is located about 160 km east of Abu-Dhabi, and 120 km south of Dubai, the geographical coordinates are between 24.22° N latitude and 55.76°E longitude. It is elevated 305m above the sea level. (WorldData.info 2021) Al Ain city has two main seasons with two transitional periods as labeled in table (5); the winter season from December to March that recorded mean temperature max. to 31°C, while the summer season period beginning on June to September with 40°C mean max.(Industry 2018)

Winter season (December to March)	Mean temperatures 16.4°C to 24°C
	Mean maximum Temperatures 21.3°C to 31°C
	Mean minimum Temperatures 11.6°C to 19°C
1 st Transitional period (April to May)	Mean temperatures 26°C to 33.5°C
	Mean maximum Temperatures 32°C to 40.7°C
	Mean minimum Temperatures 20°C to 26.6°C
Summer season (June to September)	Mean temperatures 32°C to 37.2°C
	Mean maximum Temperatures 38.7°C to 40°C
	Mean minimum Temperatures 26.6°C to 31.4°C
2 nd Transitional period (October to November)	Mean temperatures 24°C to 30°C
	Mean maximum Temperatures 29°C to 37°C
	Mean minimum Temperatures 19°C to 25.2°C

Table 5 The main seasons months, temperatures and transitional periods. Source:(Industry 2018)

The line graph in fig. (41) shows the average temperature for every month over the year in Al Ain city. The average daytime temperature range between 25°C and 45°C depending on the seasons and the regions. The hottest days records from May to August indicates the maximum

temperature raised up to 45°C, while the blue solid line indicates the average minimum temperature 28°C. The warmest month is August, in contrast the coldest months is January when the coolest temperatures lower down to reach 14°C. The sunrise and sunset times are influenced by the UAE moderate northern position in the hemisphere so the average summer days in Al-Ain city are long and arid while the winters are short. (WorldData.info 2021)

The fig. (41) below shows the average hourly temperature in each month over the year; May to August months represent sweltering state. (WeatherSpark 2021)

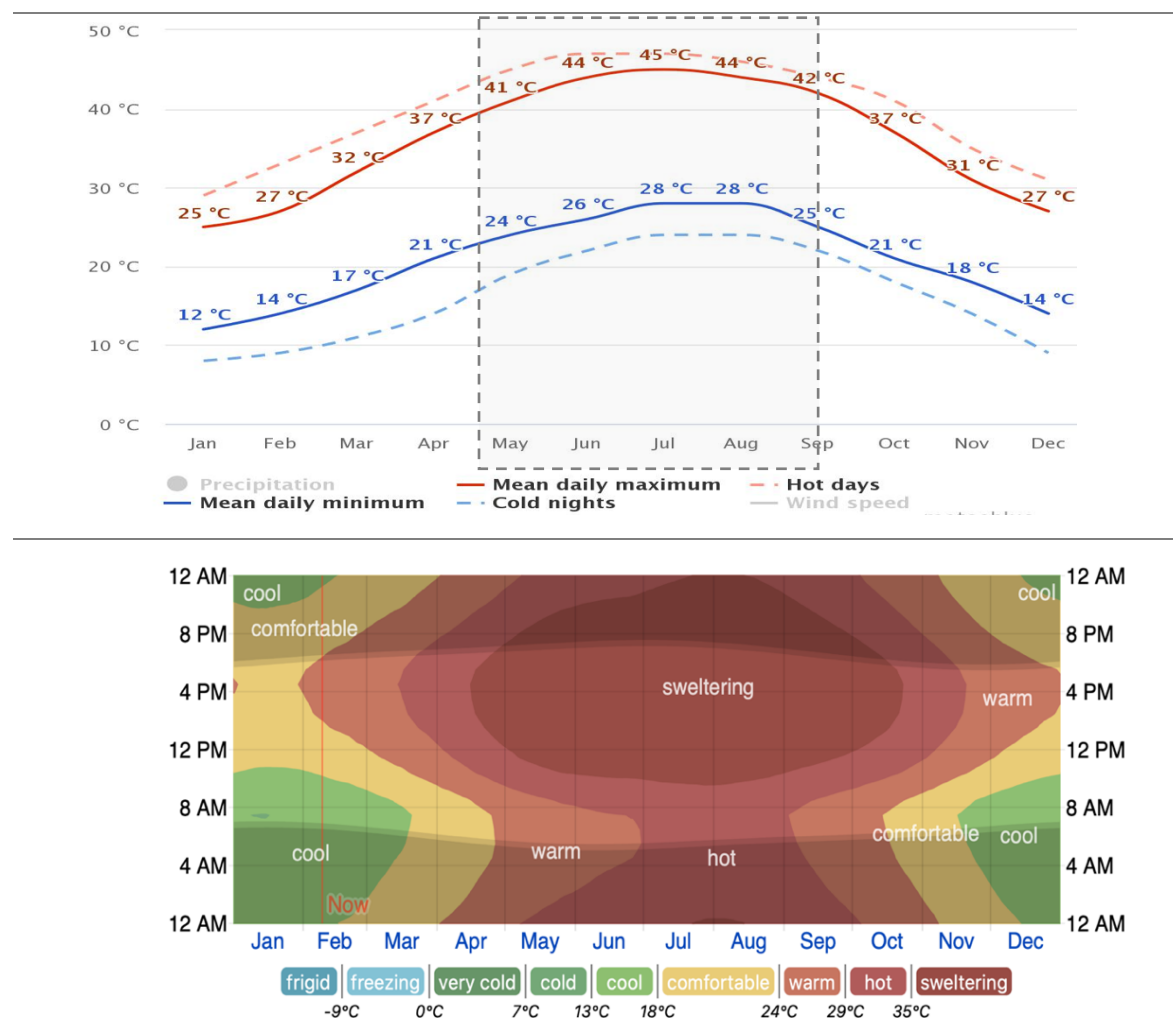


Fig. 41 The average temperature (°C) in Al-Ain city (top), the average hourly temperature in Al-Ain city. (bottom). Source:(WeatherSpark 2021) and (WorldData.info 2021)

4.3.1 SOLAR POSITION

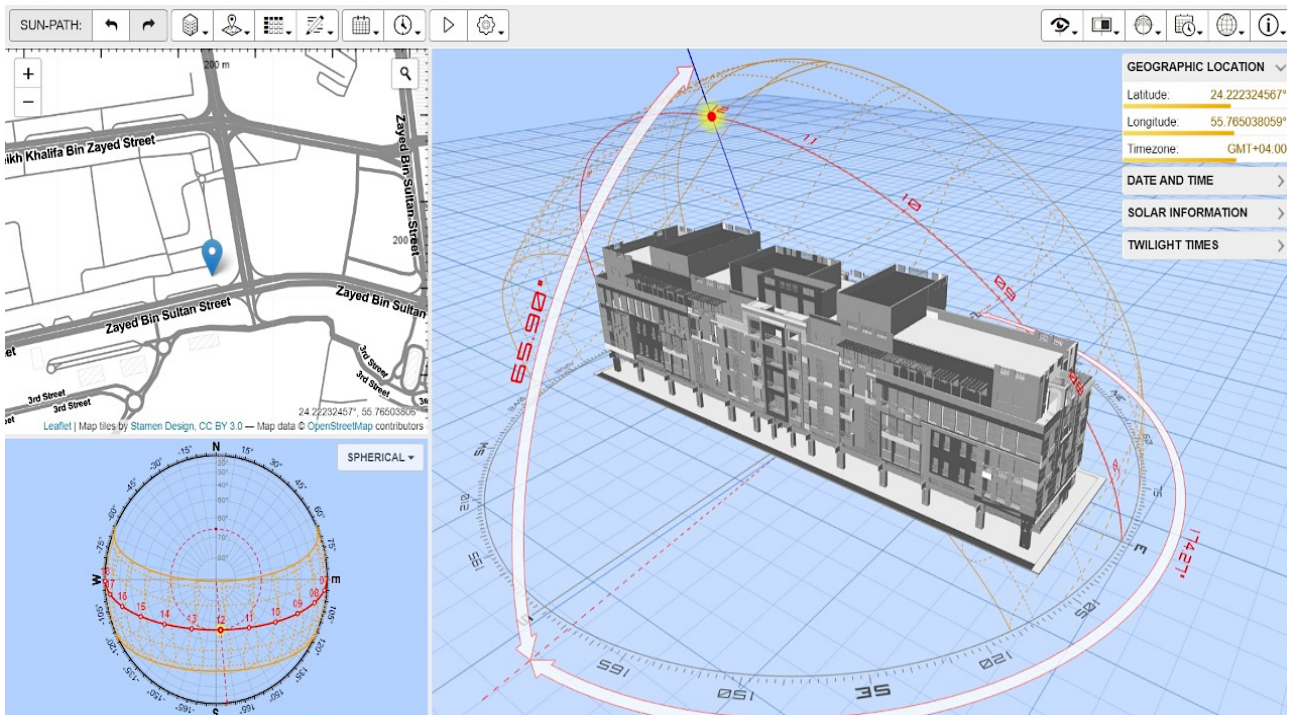


Fig. 42 The geographic location of the building case described the site oriented, sun azimuth angle and solar altitude.
Source: exported the case study 3D-model in drmarsh app. (Marsh 2020) (3D geometry done by author)

The fig. (42) illustrates 3D Sun-path, the relationship between geographic location and solar position over the year. The solar altitude in December 21 Winter solstice is 42.22° at noon, during summer solstice on 21 June the sun altitude angle is 85.63° and in the Fall equinox is 65.90° these values indicate that the sun angle in Al-Ain region is relatively high which affects the design of DSF particularly the shading device SDs positions, the type and the size where designed in the building façade in order to exclude the intensity of incident solar radiation. It clearly noticed that the long south façade has a higher exposure of solar gain which required adequate design to reduce the solar heat in the building.

4.3.2 SOLAR RADIATION (WH/M²)

The fig. (43) below illustrates the monthly diurnal averages in Al Ain city. The majority of dry bulb temperature sitting above the comfort zone which represents in grey shade. This indicates

that the climate is predominantly hot. The measurements indicates that this region is exposed to high level of a solar radiation (Wh/m^2) this mandate to improve the key building envelope parameters in order to decrease the heat gains. This data will investigate to identify the mostly cooling controlled.

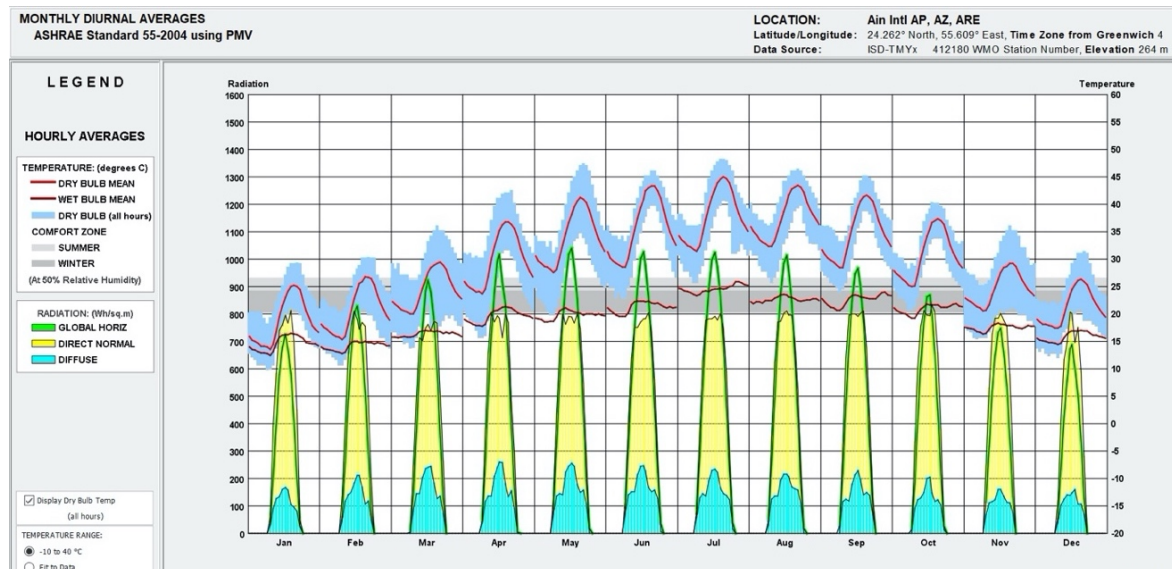


Fig. 43 The monthly diurnal averages radiation (Wh/m^2) & temperature ($^{\circ}\text{C}$) in Al-Ain city. source:(Climateconsultant 2020)

The fig. (44) below defines the solar day over the year (sunrise and sunset with Twilight) in Al Ain city; the earliest sun rise on June at 5:28 AM, while the latest sunrise at 7:02 AM on January. (WeatherSpark 2021)

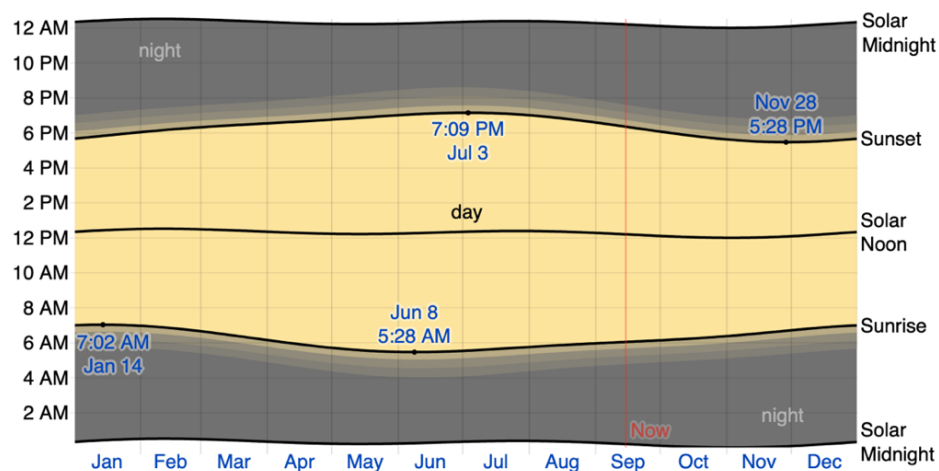


Fig. 44 sun rise and sunset with Twilight in Al Ain city. Source:(WeatherSpark 2021)

4.3.3 DRY BULB AND RELATIVE HUMIDITY (RH%)

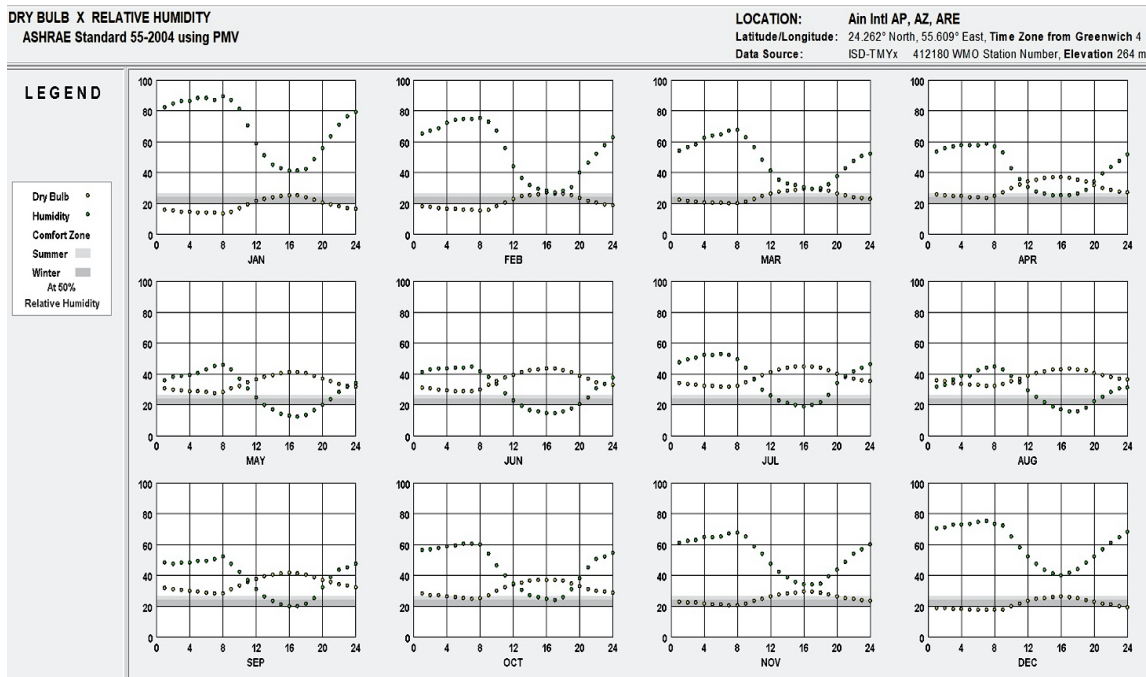


Fig. 45 Relative humidity and dry bulb in Al-Ain city. source:(Climateconsultant 2020)

The Relative Humidity (RH) is one of the main weather variables. It is expressed as the percentage; at 100% relative humidity, the air is full of water vapor which mean is saturated and at dew point. The humidity ranges in the UAE between 60-100% specially on the inhabited coasts also gets lower to the inland regions. Al-Ain city experiences substantial seasonal variation in the humidity. The monthly charts in fig. (45) presents the percentage of RH range between the lowest and the highest values. The green dots line is frequency of daily RH for each month over all year; the beginning of January is the peak values reach about 90% while, the mid of May, June and July represents the lowest RH percent about 15% to 20%, while December and June express the highest average percentage about 56% to 59 %. The graph indicates that Al-Ain city suffer from high RH level, the annual average of RH is 50-60%. That requires air flow movement to increase the evaporative capacity of the air and consequently the cooling efficiency. The natural ventilation should be considered as a primary cooling strategy.

4.3.4 RAINFALL (MM)

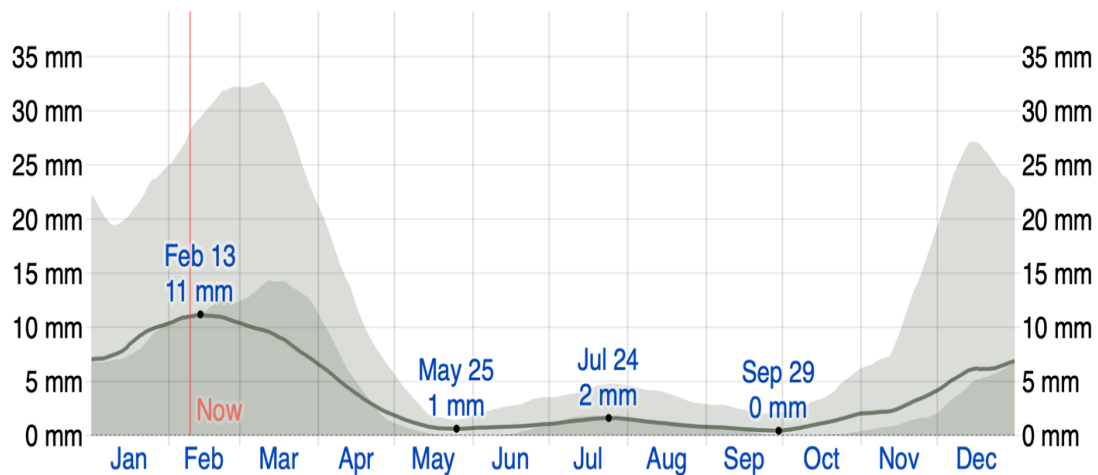


Fig. 46 The average monthly rainfall in Al-Ain city. Source:(WeatherSpark 2021)

The average precipitation of rainfall (solid line) in fig. (46) shows that February is the wettest, the average total accumulation rainfall could be reached to 11mm, while the driest month and least rainfall is September. The average amount of annual precipitation ranges from 2mm to 6 mm. Al Ain city doesn't experience significant seasonal variations in frequency of wet days.

4.3.5 WIND SPEED AND DIRECTION

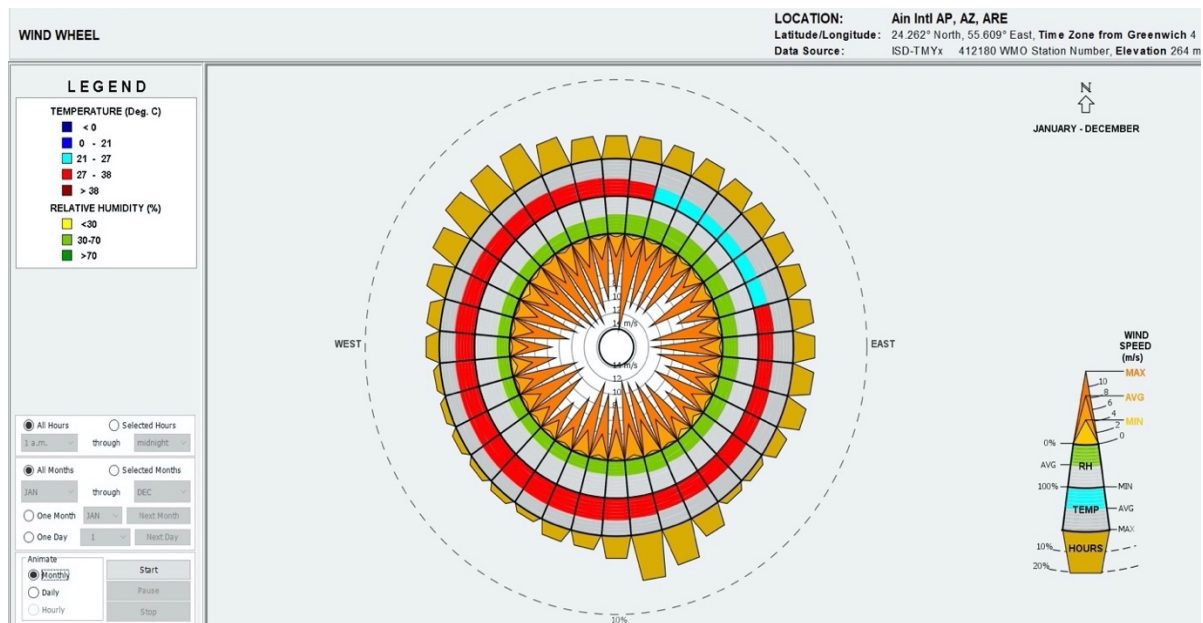


Fig. 47 The wind wheel rose over the year (Jan.-Dec.) in Al-Ain city. source:(Climateconsultant 2020)

Wind rose is one of the most variable weather conditions, it provides a brief description of the wind speed and direction which are usually distributed at a certain region in circular format. It

shows the frequency of winds blowing from certain directions, and indicates the dominant wind directions and the greatest wind speeds. The length of each spoke around the circle is related to the frequency of time that wind blows from a certain direction, while each circle shows a different frequency deriving from zero at the center to increasing frequencies at the outer circles. (University & Technology n.d.).

The wind rose of Al Ain as illustrated in fig. (47) shows wind patterns that occurred over the year. The wind patterns are fluctuated due to variations in atmospheric pressure, heating and cooling of the earth's surface. During the summer period the region can be expected to be affected by the Indian monsoon, that leads to rising temperature which may climb to 50°C.(Industry 2018). The wind in Al-Ain comes from different directions. The predominant wind direction blowing from the North-West experiences quite higher wind velocity.

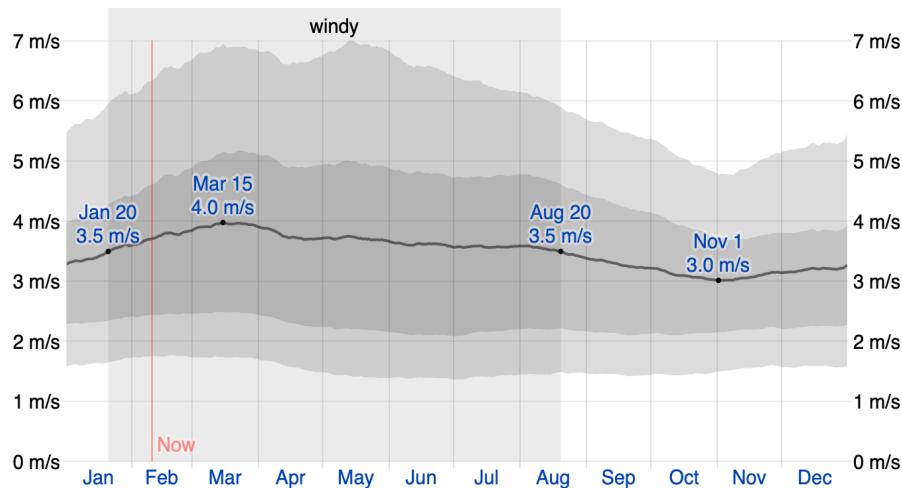


Fig. 48 The average wind speed (m/s) in Al-Ain city over the year. Source:(WeatherSpark 2021)

According to the fig. (48) the dominant wind is blowing from the north-west for seven months from Jan. to Aug. with average more than 3.5m/s wind speed, March records the windiest day over the year with average 4.0m/s. Whereas November has the calmest day with average wind speed of 3.0 m/s. (National Center of Meteorology (NCM) n.d.) However, the wind is a considerable natural motivation to the airflow behavior inside the cavity of DSF system. Further, the wind direction is important influence on the quantity and airflow direction through the air cavity of DSF.

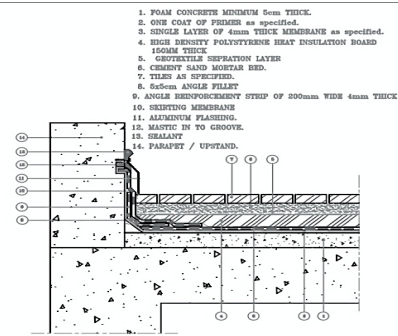
4.4 REFERENCE BUILDING CONSTRUCTION

Construction layers (Outside to Inside)	Thickness (mm)	Conductivity (W/m.K)	Density (kg/m ³)	Resistance (m ² K/W)
G.R.C. Concrete block	20.0	0.24	750.0	0.083
Cavity	10.0	-	-	0.180
Concrete block	70.0	0.51	1400.0	0.137
Expanded Polystyrene	300.0	0.035	25.0	4.571
Thermal concrete block	70.0	0.510	1400.0	0.137
Cement plaster-mortar	20.0	0.160	600.0	0.125

Window glazing properties double glazing pane, reflective side, colored, aluminum frame window SHGC=0.4

U-value 2.2 W/m². k

Glass sheets 6mm meet Estidama requirements



ROOF WATERPROOFING
TYPICAL DETAIL

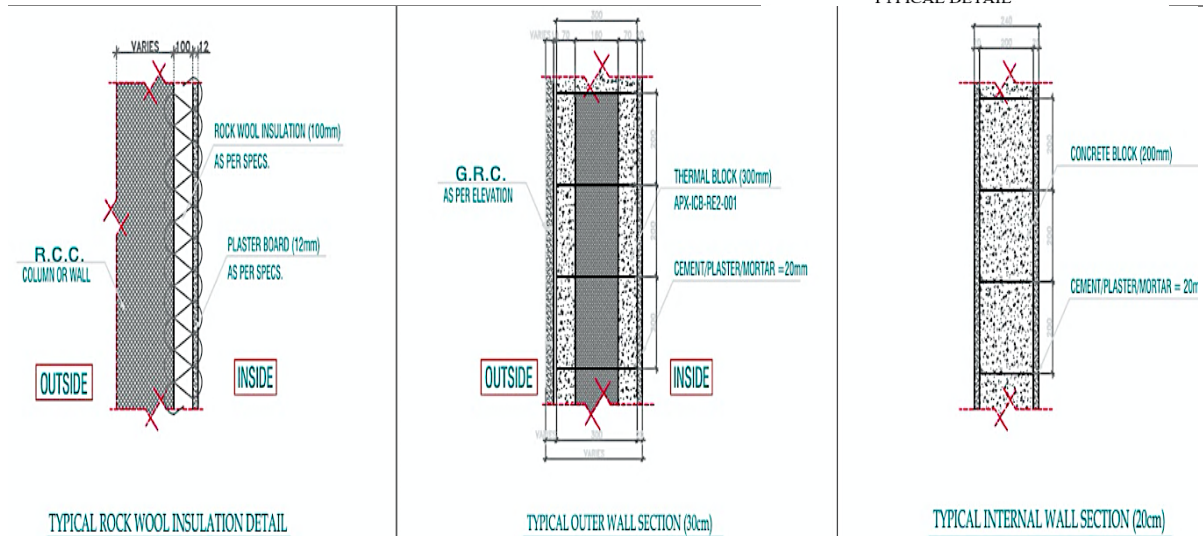


Table 6 The details of construction layers and thermal parameters of the typical wall sections of the existing building envelope (reference building). Source: (author) the schematic drawings derived after confirming from engineering office who designed

The construction layers of the reference base building envelope are made of conventional wall

façade system. In general, the construction base building wall comply with Abu-Dhabi regulations of construction features and specifications. The construction materials of the reference building envelope have been assigned by template building manger in IES-VE

software under the same boundary conditions of the existing building. The table (6) above describes the thermal properties and the construction materials specifications for the section walls and roof of the existing base building envelope which have assigned in the case study geometry model in IES-VE software to confirm the simulation model validity meeting the same conditions. External and internal walls of the base building are built with blocks described as "*fair face*". The typical section wall made up of external façade Insulated Concrete Blocks, insulation layer (Polystyrene) theoretical with 18 kg/m³ density.

4.5 IES-VE SOFTWARE VALIDATION

Verification the optimal design of the proposal DSFs types based on the verified between simulation model and actual measurement of the reference base case. The actual real measurements refer to the total electricity consumptions (elec. bills) of selected rooms and also conducted for measured levels of daylighting for tested rooms. As a result, the concordance/compatibility rate should be related between the energy simulation modelling and real measurements.

Investigated method; this research focused on analysis energy performance of DSF system. The field measurements were carried out on the single storey to validate the numerical model set up. Measured validity of IES VE software tool is based on accurately measured in a study and evaluate the building performance. For increasing the confidence, reliability and accuracy of the selected software tool, the actual output results (real situation) are comparing to the data which derived from dynamic thermal simulation in IES. However, the testing reliability of the IES-tool is carried out by calibration the data in terms of the building energy consumption and measuring daylighting compatibility in the building rooms. The discrepancy should be confirmed- authenticated after comparing the actual final results with software data tool to investigate. the credibility of the modeling results is validated based on comparisons of the

simulation results of the study with related experimental (real conditions) but some discrepancies have been observed due to different issues such as, climatic conditions, some data unexplained variations, and hourly weather profile data. The verification of simulation modeling analysis was conducted via IES. The whole reference base building-3D geometry of opaque and transparent façade is modelled by IES-VE under real conditions; assign thermal properties and physical parameters refer to the openings WWR, existing construction materials and Al-Ain city climatic conditions- weather profile in IES-VE of Al-Ain Intl Airport (SHRAE Climate Zone: 1B). The reference building has been constructed by using IES-VE software tool. For getting more realistic data, the study based on analysis the current existing building through assigning real conditions and parameters.

4.5.1 ENERGY CONSUMPTION VALIDATION

Simulation the annual energy consumption of the reference base case is the major part in this study and energy modeling was developed in IES in accordance with Estidama requirements. The simulation model of optimizing DSF types (target) based on verification model. It is essential process in the early design development stage to validate the IES-VE software tool, verifying base model and proving it accuracy before modifying the conventional building wall of the reference building. Hence, the study used weather data profile of Al-Ain, the geometry building identical to the base case, assigned material properties matching the base case, whole building condition temperature set point 24°C.

The total annual energy consumption results were verified against the actual electrical loads in the building of the 3rd floor in flat number 5 located in the south-east direction, it includes five rooms and services. The data of energy consumption is monthly electricity bills derived from the meter reading data of Al-Ain Distribution Company AADC which enclosed in the appendix of this paper. The final readings refer to the annual actual monthly consumption loads of the

selected apartment. The electricity bills were obtained from the 5th flat's tenant after approving visiting plan. The list table in fig. (49) below shows a comparison between the actual reading electricity bills (MWh) with the output final results of the data profile that derived from simulation the base case in IES-VE.

Clarification of thermal profile: This process needs established thermal profile of reference case study; the study selected the flat#5 at 3rd floor to validate tested model. Through assigned *APpro profile database* application in dynamic thermal simulation in IES tool as shown in fig. (50), in this stage the daily, weekly and annual profile were edited in relative with real thermal conditions data of tested flat, these data comprised the final readings of electrical consumption, electrical lighting, number of devices generated electricity and the number of people live in flat are related to sensible heat gains were derived from the flat's tenant (owner) by questionnaire to comply simulation thermal profile with actual data, hence conducting the thermal dynamic simulation (Apache) for simulation and achieved the output of annual energy consumption. APpro Profiles database (daily, weekly and annual) for editing project profile; based on Thermal performance editing via building template manger app. in IES such as space conditions and internal gains, final created the building energy profile under the real conditions, analysis using Vista-Pro to identify the outputs file results through specifying the main categories and variables such as the total electricity and room cooling plant sensible load.

Simulation results of energy consumption of the reference base case (model) are calibrated with respect to monthly electrical bills of the base building (tested flat). The total annual electricity (MWh) of the proposed DSF types analyzed to comply with the existing case. However, the discrepancy percentage between the actual readings and the simulation results measurement achieved the ranges between (0.04 % to 6.1 %) and the total is 1.20 % as

presented in par chart fig. (49). The findings result ensure the accuracy of data for rendering proposed scenarios of natural ventilated DSF building (the proposed study).

Validation - Total Annual Electricity Consumption (MWh) in IES thermal simulation and the Total Electricity bills of Flat 5 at 3 rd floor			
Date	IES-VE Total Electricity (MWh)	Actual Energy Bills (MWh)	Discrepancy Percentage
Jan 01-31	0.713	0.680	-4.85%
Feb 01-28	0.708	0.708	-0.04%
Mar 01-31	0.852	0.872	2.32%
Apr 01-30	0.905	0.863	-4.90%
May 01-31	0.597	0.562	-6.19%
Jun 01-30	0.806	0.841	4.20%
Jul 01-31	0.810	0.776	-4.42%
Aug 01-31	0.859	0.830	-3.54%
Sep 01-30	0.850	0.846	-0.44%
Oct 01-31	0.859	0.816	-5.26%
Nov 01-30	0.862	0.878	1.80%
Dec 01-31	0.728	0.763	4.57%
Total	9.549	9.435	-1.20%

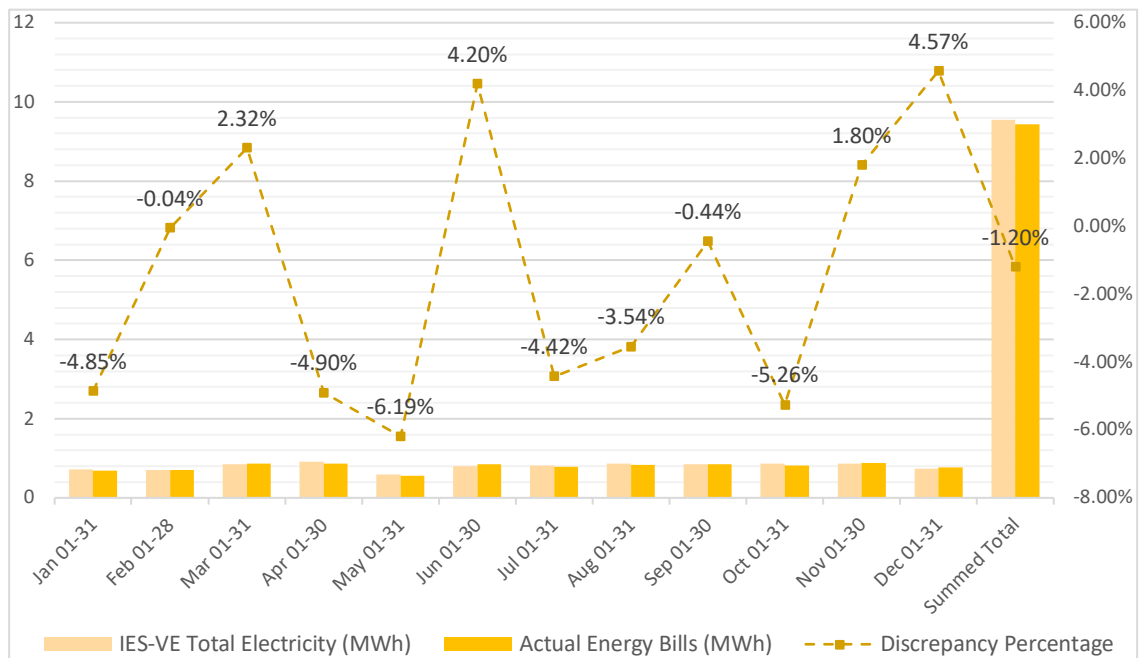
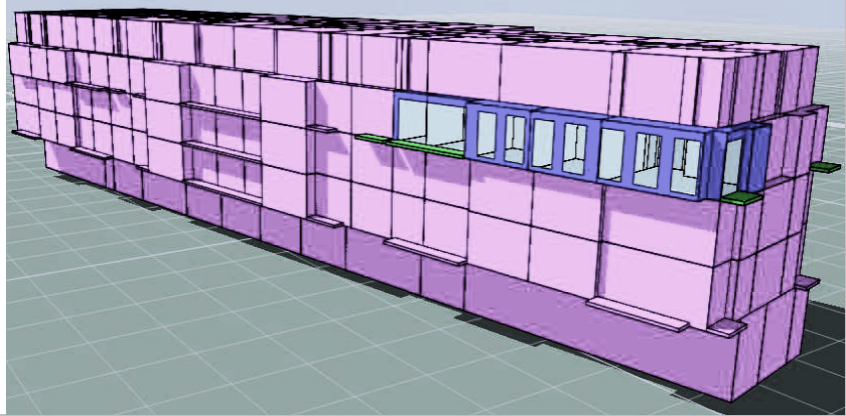
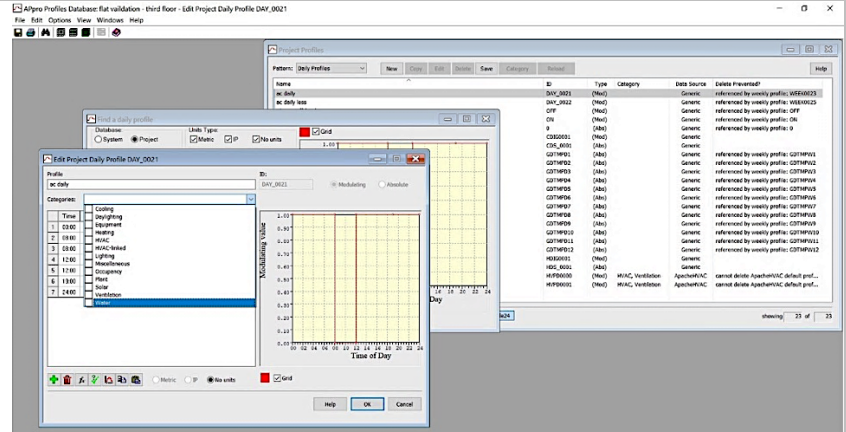


Fig. 49 The total monthly electricity consumption MWh validation and discrepancy percentage. IES-VE

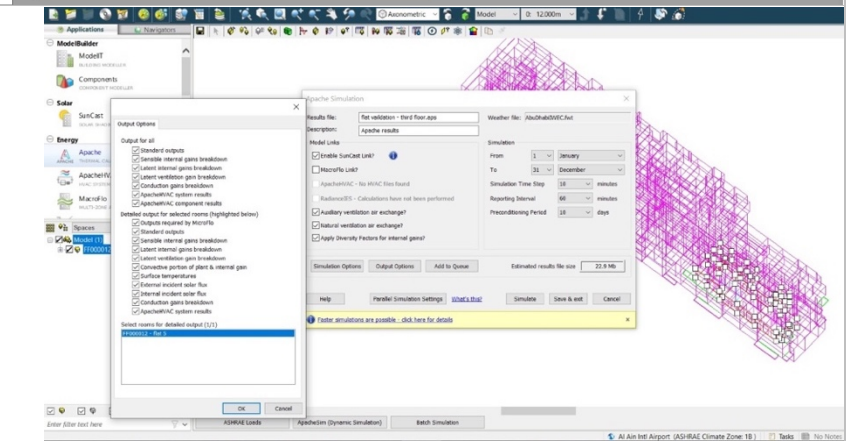
The tested flat#5 at 3rd floor to validate IES-VE software tool.



Assigned database of APpro profile and editing the daily and weekly profile.



Dynamic thermal simulation rendering by Apache-Sim app to calculate the total annual energy consumption from Jan-Dec.



The total annual electricity consumption results (MWh) of the tested flat.

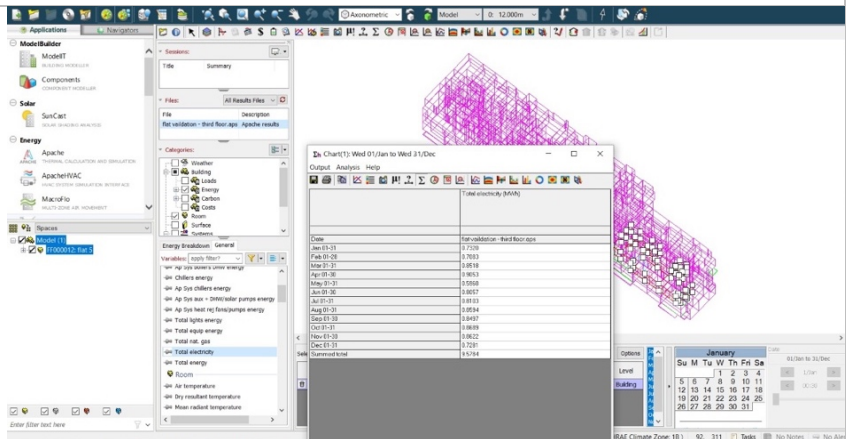


Fig. 50 The dynamic thermal simulation process to validate the IES-VE software tool calculation the total energy consumption of the selected flat (area). IES-VE

4.5.1 DAYLIGHTING COMPATIBILITY

Another aspect for authenticated the IES-VE software is measuring the daylighting in the building rooms. This study measured the daylighting for actual building during field experiment by using lux-meter tool is called EXTECT which is measure the total amount of light intensity received on the surface (illuminance levels) is expressed in lx (lumen/m²). The light tool holding the sensor in horizontal of the selected area. The IES software rendering the same selected rooms in order to validate (confirm) with actual field measurements.

During the site visit to the current building on 28th of October 2020 to measure the average daylighting levels by using EXTECT tool, three different times were selected under clear-sky conditions at 8:30 AM, 12:00 PM and 3:00 PM respectively. The light measurements had been taken in the 1st floor of selected five different room positions. The lux meter placed on three different points as identified on the figure plan below calculated the average illuminance levels (lux). The study focused on the south direction which exposed to the biggest amount of solar radiation and the windows in this façade have a high luminance level with variable illumination during the day. The recorded lighting values occurred during the daytime with a specific time as listed below as take in consideration holding light tool on table at 0.80m height above the floor for working plane to get accuracy measurements. The study selected five different rooms with different time as shown in fig. (51) in the 1st floor of refence building to measure Illuminance levels (lx), as well as recorded readings at each room in different positions were assigned by identified three points (P1, P2, P3) as following:

1. The 1st area is Manger room at office #5 in south-east oriented it has two sliding glass fenestrations at 8:30 am.
2. Manger room at office #4 it is located at north-east direction also it has two sliding glass doors at 9:00 am.
3. Reception room at office #6 during the mid-day at 12:00 pm, it has one sliding glass door faced south direction.

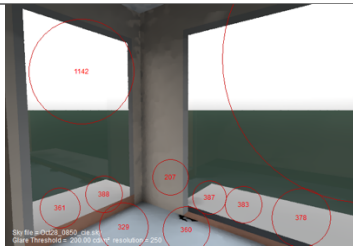
4. To the next office-room #6 the room in Office-room #7 similarly it has only one sliding glass door opened to balcony had measured by lux tool at 12:30pm.
5. The last lighting measurement had measured at 3:00 pm to the south-west direction at Office-room #9.



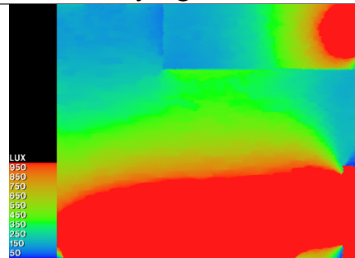
Fig. 51 The selected day-light measuring rooms in the 1st floor of actual building and the (P1,P2,P3) indicate to the point positions of lighting measurements by EXTECT lux tool during field site. Source:(author)

Illuminance(lx) and Radiance Contour for Manger Room in Office 5 at 8:30 am-South-East					
Position Points in Room	Field Measurement Illuminance (lux)			Day-light Simulation-IES-VE	Discrepancy Percentage
	Max. Value	Min. Value	Avg.		
P1			941	905	3.83%
P2			629	648	-3.02%
P3			532	535	-0.5%

Day-light Simulation-IES-VE



Glare-Threshold cd/m^2
Luminance Image



Radiance-contour lx

Shaded color indicates the estimated positions of (p1-Yellow, p2-Blue, p3-Green) for avg. Illuminance lx values under same conditions

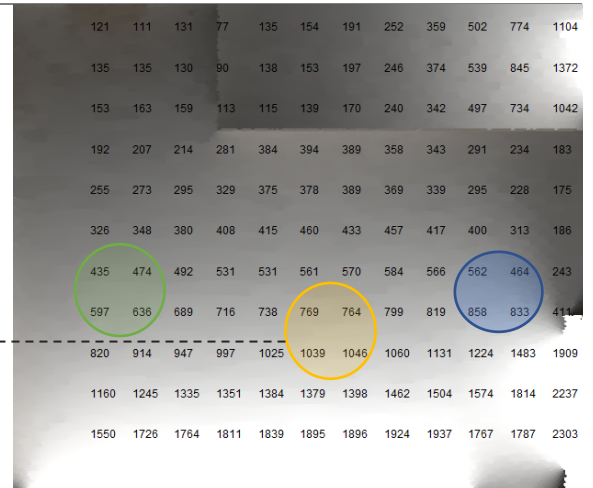


Table 7 Comparing Illuminance levels (lx) between the actual values by EXTECT lux tool and IES-simulation of P1, P2 & P3 positions for manger-room in office 5 at 8:30 am, south-east.(bottom) daylighting simulation by IES-VE. Source:(author)

Illuminance(lx) and Radiance Contour for Manger Room in Office 4 at 9:00 am-North-East					
Position in Room	Field Measurement Illuminance (lux)			Day-light Simulation-IES- VE	Discrepancy Percentage
	Max. Value	Min. Value	Avg.	Avg.	
P1			725	729	-0.55%
P2			418	407	2.63%
P3			127	125	1.57%

Day-light Simulation-IES-VE

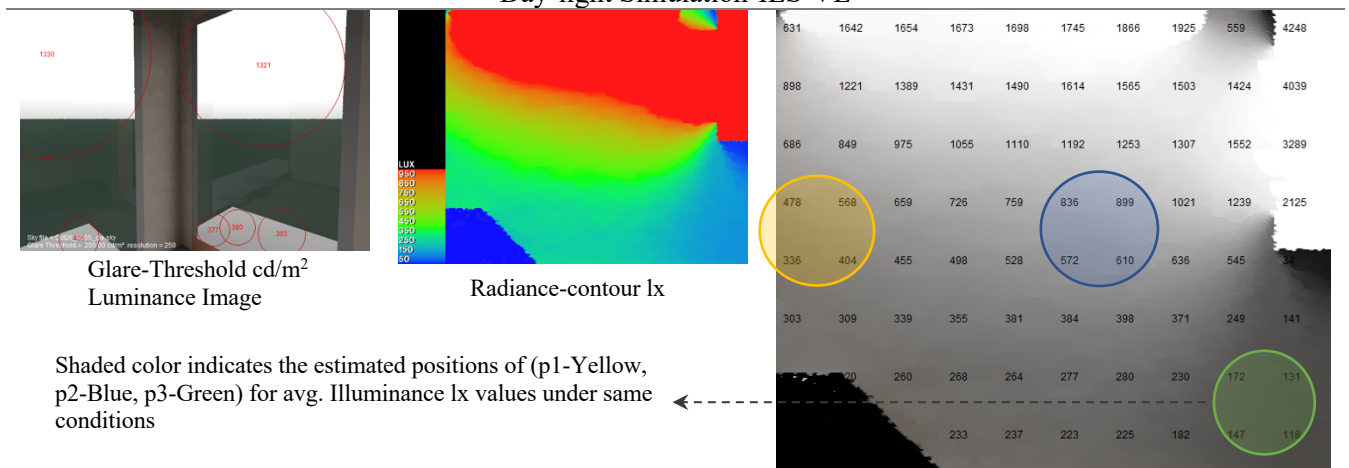
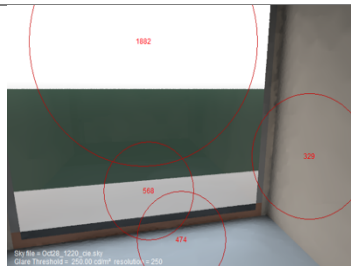


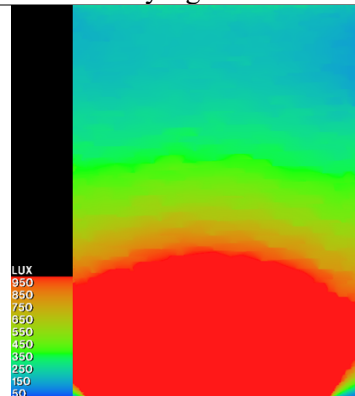
Table 8 Comparing Illuminance levels (lx) between the actual values by EXTECT lux tool and IES-simulation of P1, P2 & P3 positions for manger room in office 4 at 8:30 am, north-east.(bottom) daylighting simulation by IES-VE. Source:(author)

Illuminance(lx) and Radiance Contour for Reception Room in Office 6 at 12:00 pm-South					
Position in Room	Field Measurement Illuminance (lux)			Day-light Simulation-IES-VE	Discrepancy Percentage
	Max. Value	Min. Value	Avg.		
P1			919	913	0.65%
P2			504	502	0.39%
P3			475	481	-1.26%

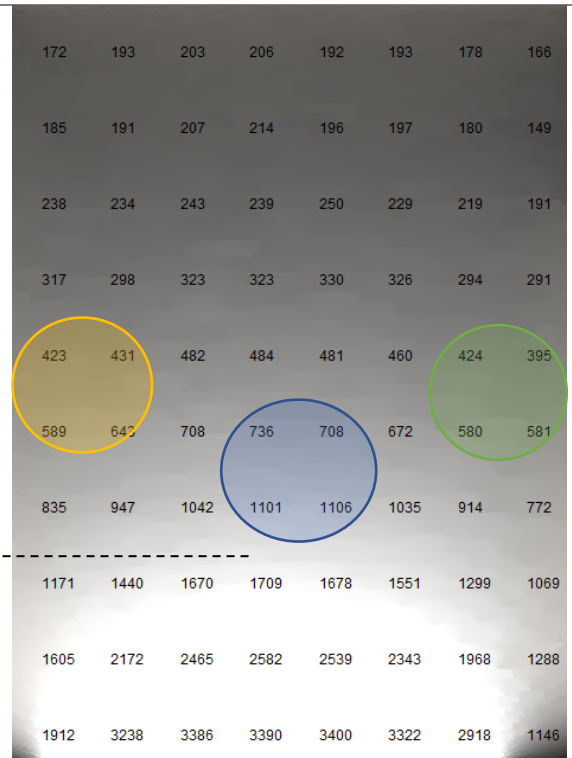
Day-light Simulation-IES-VE



Glare-Threshold Image
Luminance Image



Radiance-contour lx



Shaded color indicates the estimated positions of (p1-Yellow, p2-Blue, p3-Green) for avg. Illuminance lx values under same conditions

Table 9 Comparing Illuminance levels (lx) between the actual values by EXTECT lux tool and IES-simulation of P1, P2 & P3 positions for reception room in office 6 at 12:00 pm, south.(bottom) daylighting simulation by IES-VE. Source:(author)

Illuminance(lx) and Radiance Contour for Office Room 7 at 12:30pm-South					
Position in Room	Field Measurement Illuminance (lux)			Day-light Simulation-IES-VE	Discrepancy Percentage
	Max. Value	Min. Value	Avg.	Avg.	
P1			642	674	-4.98%
P2			324	335	-3.39%
P3			232	230	0.86

Day-light Simulation-IES-VE

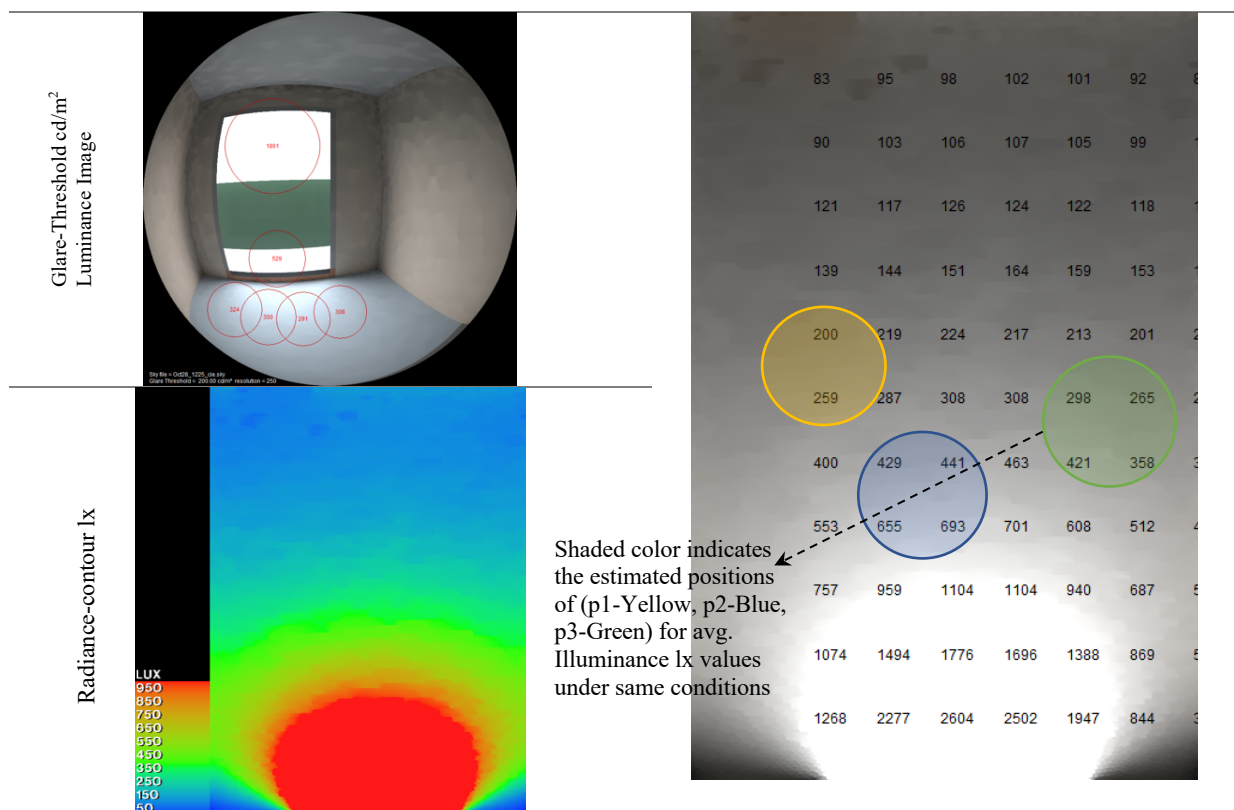


Table 10 Comparing Illuminance levels (lx) between the actual values by EXTECT lux tool and IES-simulation of P1, P2 & P3 positions for office room in office 7 at 12:30 pm, south.(bottom) daylighting simulation by IES-VE. Source:(author)

Illuminance(lx) and Radiance Contour for Manger Room in Office 9 at 3:00 pm-South-West					
Position Points in Room	Field Measurement Illuminance (lux)			Day-light Simulation-IES-VE	Discrepancy Percentage
	Max. Value	Min. Value	Avg.	Avg.	
P1	574	541	557	571.5	-2.60%
P2	492	408	450	452	-0.44%
P3	405	339	372	376	-1.07%

Day-light Simulation-IES- Illuminance levels in Room 9 at P1, P2, P3

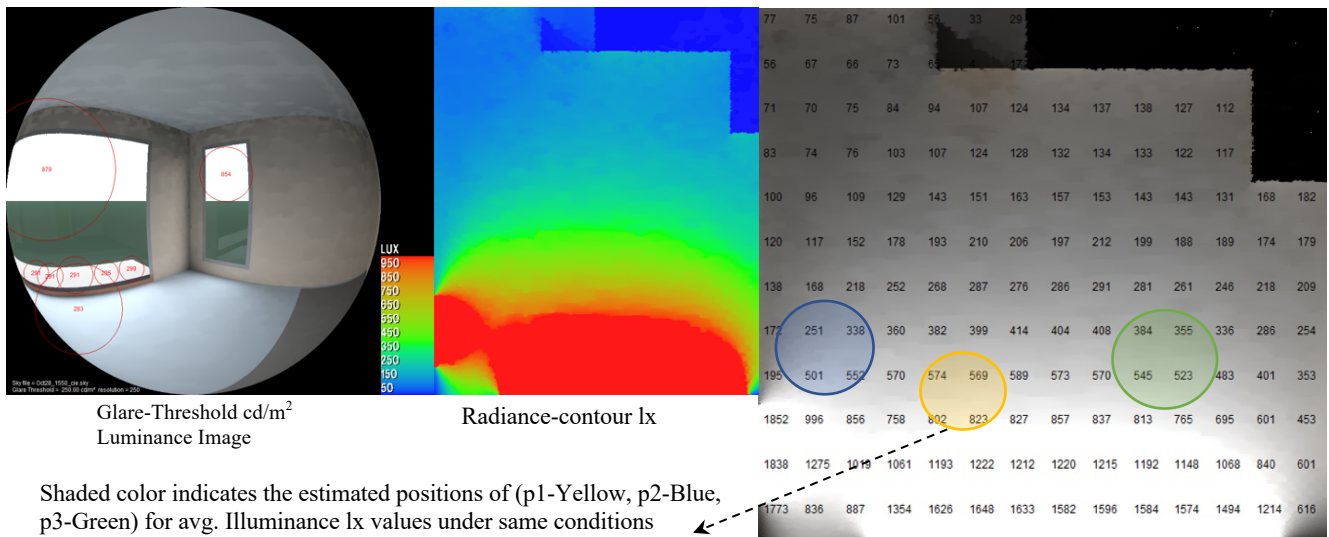


Table 11 Comparing Illuminance levels (lx) between the actual values by EXTECT lux tool and IES-simulation of P1, P2 & P3 positions for manger room in office 9 at 3:00 pm, south-west.(bottom) daylighting simulation by IES-VE. Source:(author)

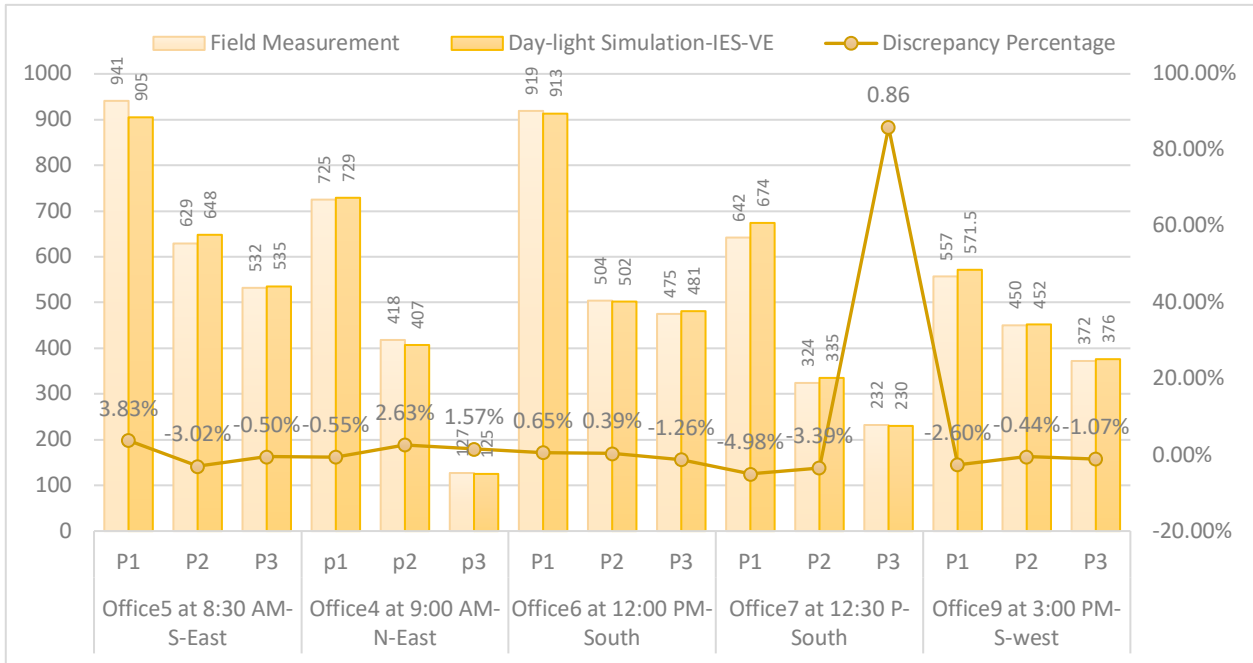


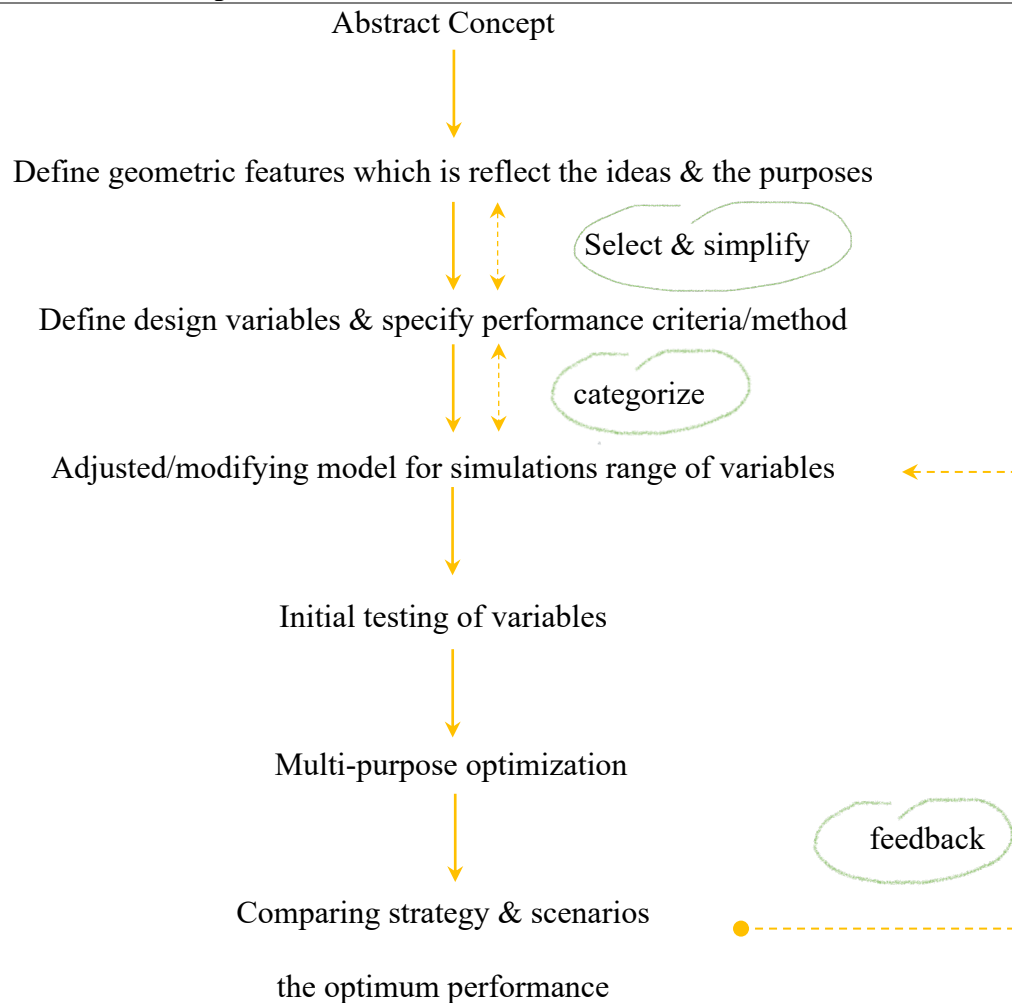
Fig. 52 Total daylight calibration measures between IES simulation software and the field measurement by using EXTRACT light tool.

The following tables from (7-to-11) above listed a comparison of the average Illuminance levels (lx) for selected study rooms between the actual field measurements and daylight simulation by IES-VE. The tables show the max. and min. levels have recorded under a specific time to measure the ratio discrepancy (%) of the average readings. Also, the figures in tables from (7-to-11) illustrates the average Illuminance values of P1, P2, and P3 as identifying in the actual site visit as clarified previously on the plan above fig. (51). The radiance contour describes the lux levels distribution of each space area and the illuminance image labels the glare (cd/m^2).

Overall, the comparison average discrepancy percentage of Illuminance levels for the five chosen study rooms between the IES-VE and conducted data in the field measurements ranges from 0.39% to 4.98% as illustrated in fig. (52). Hence, the final findings indicated validate utilizing IES software for the energy modeling simulation analysis.

4.6 DESIGN CONCEPT AND DEVELOPMENT

Design Process and development



Conceptual Design

- Collection data of existing buildingsite
- Conceptualization of solutions
- Development initial idea and analysis altering concepts

Preliminary (Initial Design)

- analysis gathering data
- Define design variables and performance criteria
- Raising the 1st phase of design on selected alternative concepts
- Initial measurements based on different categories
- Adjusting model for simulation

Final Design

- Complete set of Final Design
- Energy performance, build logarithm
- differential overview
- Report and outputs

Table 12 The process conceptual design and development for creating the proposed DSF and achieved the optimal solution.
Source: (author)

The table (12) introduces the main steps were investigated in modifying the existing building envelope. The study focused on satisfying the needs with settings design process: actual design procedures vary depending on the type and complexity of a project. The objective of the design process is to develop comprehensive design and construction settings including plans, specifications, Design elements are prepared in accordance with the concepts and guidelines presented in the various technical documents developed during the conceptual and preliminary design stage. The design process divided into three phases:

- I. Conceptual design: This phase includes data collection and analysis of reference model, site conditions and weather profile related to the existing conditions for compatible requirements as early decision. A numerous studies, algorithm and investigations have been adopted during this stage based on decision making. Most of the main decisions making related to this stage by creating the efficient idea. The process contains sketch drawings complying the base modeling ratio hence identifying the proposal efficient building envelope.
- II. Preliminary design: is the first phase of detailed design performed on a specific alternative. Usually, it based on the recommended alternative, which is identified during the conceptual design stage. Investigation the information related to the existing building figures, design inquiries DSF system with different concept options, functionality and solutions to end up with the final analysis figure. Exploration the compilation design concept report and summary of all work done through matrix table and flowchart. It provides a comprehensive record of data gathered, analysis data description and the conclusions reached.
- III. Final design: The model of final design is complete set of construction, ready for simulation stage therefore observing the energy performance of the building façade for meeting the target.

4.7 ENERGY MODELING SET UP

The process of creating the modelling prototype of the reference base case relied on using IES-VE simulation software by Model-IT application and associated with SketchUp software plugin to export the whole building geometry. Energy modelling simulation process is an essential stage in preliminary design to predict the physical building performance in the real world under boundary conditions. This stage assists designers to optimize modelling, assigned material construction, verified real measurements, affording analysis algorithmic of 3D-modelling, identifying analysis of physical building elements and principles, investigate many building parameters and prototypes, and improving virtual model design.

The selected case study building is a complex system connected with varied range of parameters. The simulation energy modelling is abstraction the real building, and comparing quantify the relative performance of the proposed design. The energy demand, thermal performance and airflow analysis are the main aspects of building simulation. Many factors affected the accuracy final results of rendering energy modeling process such as, the scale and complexity modeling set up, and saving running time of the whole building via IES software.

The study based on a shoebox-model analysis of the tested commercial building to reduce running time, providing higher accuracy and sufficient feedback within a few minutes for analytical each simulation concept and calibrate the results. The examined multi-used building was adopted to investigate the study target. The selected case study represents large scale geometry for assigning parametric study overall, difficult rendering capability, analytical whole building required extra time and efforts. Assessment of the energy performance required higher accuracy, saving time to investigate more aspects regarding to DSF design. Shoebox

modelling refers to single-zone model provides potential for engineers to investigate repetitive elements to improve energy use.(Anderson 2014).

The study adopted shoebox modeling by selecting a certain portion of building (3-stories) to analyze energy simulation, while rest of the building is adjustable building excluded from energy model to save running time in energy simulation.

The early stage of preliminary design in this study is based on divided the tall rectangular plan of the whole building into three zones as shown in fig. (53) based on the orientation and function as following:

- a. **Zone I** is located at south-east façade.
- b. **Zone II** is located to the south and north direction, in the middle of whole plan.
- c. **Zone III** is located at south-west direction, and blocked by adjacent high commercial building that impacts on the final result and calculations of the energy performance.

The selected study zone could be sufficient to cover the evaluation criteria of the proposed strategies of DSFs design to identify the thermal performance and observed the influences on reduction cooling loads over the year of the building envelope. The selected Zone I as shown in fig. (53) refers to (shoebox) analysis to ensure the accurate energy performance of existing building, comprising three storeys with (10.50m) height total; the 1st and 2nd floor are typical offices with (3.50m) height for each storey, and each floor has two main offices, the 3rd floor is residential area includes two main flats with (3.50m) height. It can be noticed that the last floor of (residential area) is extended about (1.35 to 1.50 m) from below floors in south and north façade specifically.

The study attempted to maintain the same layout building structure and the area plot ratio as existing reference case through replacing the shaded balconies, internal room windows and typical conventional walls (skins) by the proposed design of the ventilated DSF. In addition,

the study maintained the conventional wall in the wardrobe positions at east façade as illustrated in fig. (54)

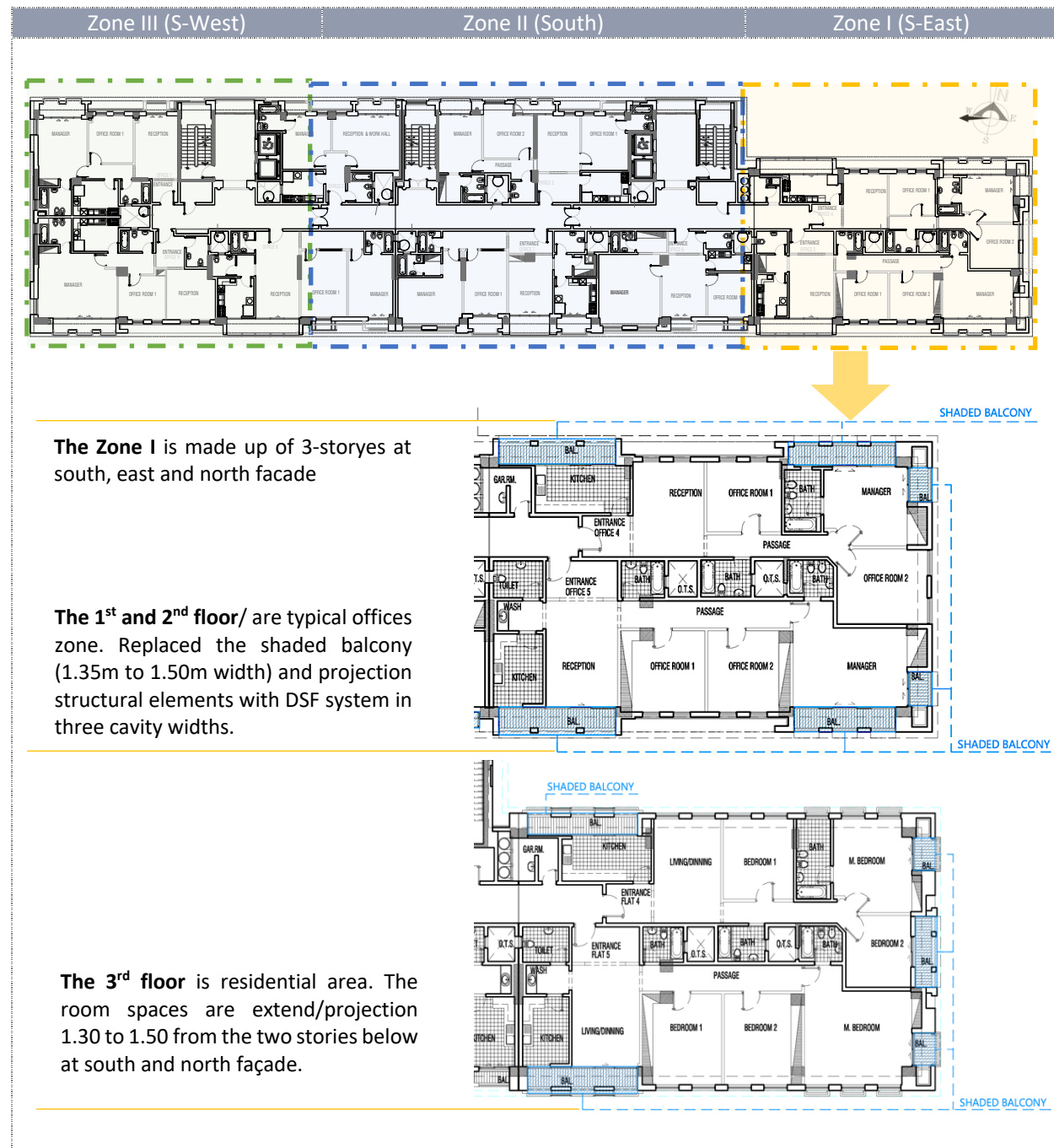


Fig. 53 The current plan of the existing building (reference case study) is divided into three zones (zone I, zone II, zone III) for analysis and simulation study. zone I at south-east is the selected test zone for analysis the proposal building envelope DSF system. Source:(author)

Overall, the study focused on the Zone I refer to the (refence base case) which carry out overall running simulation analysis, it should be sufficient for analysis the dynamic thermal

simulations and assessing the proposed DSF design. The surfaces building skins of Zone I are exposed to solar energy from multiple directions as shown in fig. (54) which is needed for studying DSF system. The front elevation is south façade which represent the greatest area exposure for solar radiation, east façade exposed to the main street as mentioned early in site analysis, and north façade at the back-side of the building where predominant wind mainly flowing with lowest solar radiation.

The typical building envelope as described previously will be the bench mark to compare with other proposed DSF typologies, and the energy consumption will be rendering all the year from Jan-Dec., it should be sufficient to provide an indication of DSFs performance during the whole year. Setting up four configurations of DSF based on cavity construction were modeled in IES, each type was employed in different parameters (variables). The base case of building has an annual cooling demand, also focusing on different facades direction under specific boundary conditions in hot-arid climate. The initial analysis rendering energy simulation of the conventional single skin façade SSF (typical wall) to create a comparable the base energy performance.

The **Zone I** (24.00 m * 14.50 m area) represent the selected study analysis façade, and employing the ventilated DSFs system around the south, east and north building facades as shown in fig. (54) retrofitting building façade based on replacing the typical existing wall by the proposal design and installed four different typologies of DSFs consisting a numerous effective parameter. The three floors were chosen for dynamic thermal simulation and analysis are 1st, 2nd and 3rd at south, east and north orientation, the long façade south orientation which is the extreme condition for high temperature.

Zone I plan shows the selected position of integrated the DSF around the south, east and north facing building envelope. The blue shaded indicates the proposed envelope area of DSF

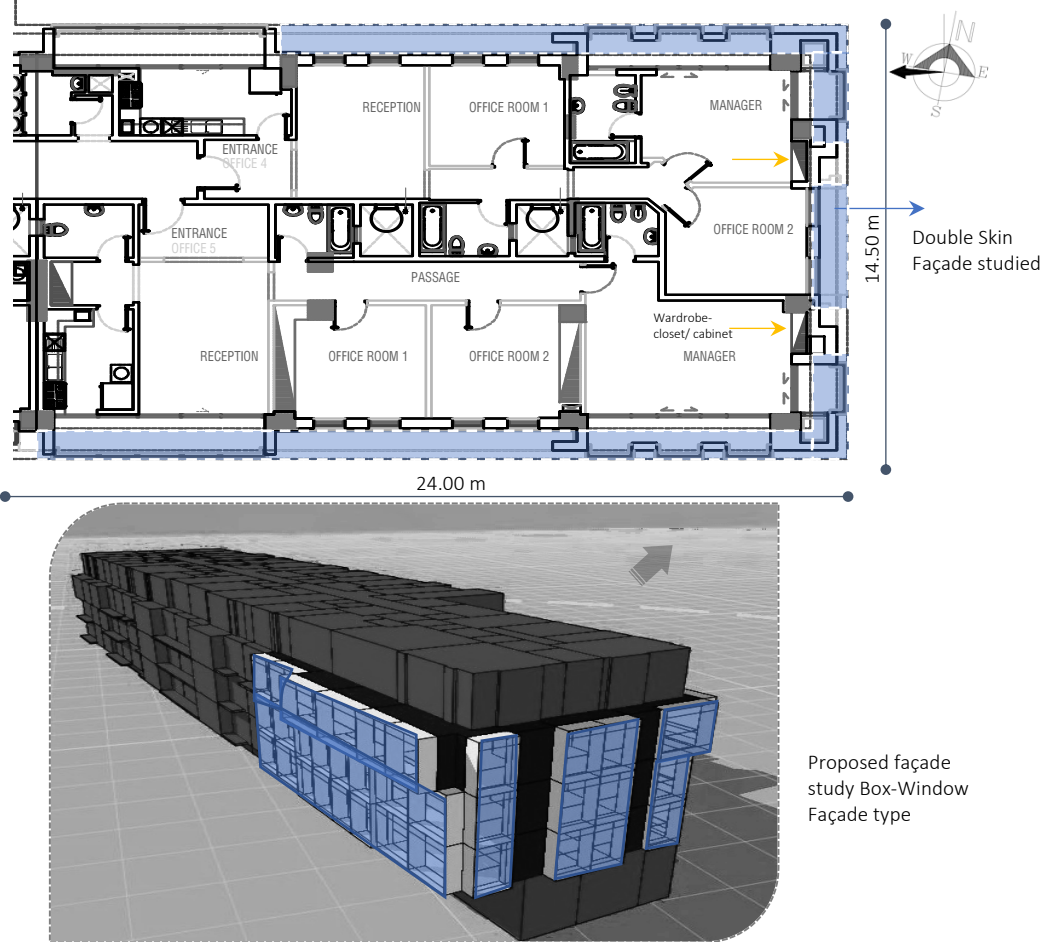


Fig. 54 (top) The selected tested study case (zone1) of the reference building, blue shaded illustrates the proposed DSF perimeter around 3 facing façades (south, east and north), (below) schematic description of the selected (zone I) with proposed concept of integration DSF system (BOX-WINDOW type) in three storeys with 10.5 m height. Source: (author)

4.1 DYNAMIC THERMAL ENERGY SIMULATION MODELLING OF THE REFERENCE BASE CASE

The dynamic thermal energy modelling is an accurate simulation tool and process utilized to predict the building façade responds when subject to external environmental factors and for assessing thermal performance, annual energy consumption and the environmental performance of the building. Hence, it is used to established the cooling loads of the building. Energy modelling depends on understanding the energy performance of the reference building which includes geometry tested model for employing the propose DSF system design building

energy simulation (BES). The reference base case modelling as established in fig. (55) by 3D sketch-up software-plugin in was exported to the IES-VE simulation dynamic thermal energy. For achieving high accurate level of results is required assigning the same boundaries and features of the existing building construction layers under the same real-conditions. This phase is considerable to specify a comparable reference base energy simulation measurement as a result of proposed DSF configurations. The study used the Model-IT application in IES-VE to modify a 3D base-model which required different input parameters and boundary conditions associated with real existing conditions for running simulation stage. On other hand, a wide range of permutations were assessed. Employing the dynamic thermal calculations to carry out the four types of DSFs system associated to the thermal performance.

The fig. (55) represents the main characteristics of the tested model of reference base case which are considerable in energy modelling for investigating and analysis the final results of designing the propose DSF system; such as fig.(55-d) opening glazing windows area ratio m^2 (WWR) of current existing building, take in consideration that the existing windows will modified (for area and glazing properties) in proposed design phase of DSF, fig. (55-e and f) show the sun exposure of the selected base case north, east and south facing, the level of global solar radiations KWh/m^2 indicates to the higher amount of sun exposures perpendicular to external skin. The south façade is facing the highest value of solar gain among other facades in range about (1077.6 to 1402.3 kwh/m^2) followed by the east and north façade. Al-Ain city is located at 24.2° north of equator, so these indicate that the shading system with adequate configurations for south specifically and east façade is essential requirements for minimizing the heat gains of the building.

Reference images- modelling set up

3D-Geometry of Existing whole building model/current state -SketchUp

3D Geometry via IES-VE. The main features of the selected zone of reference base case

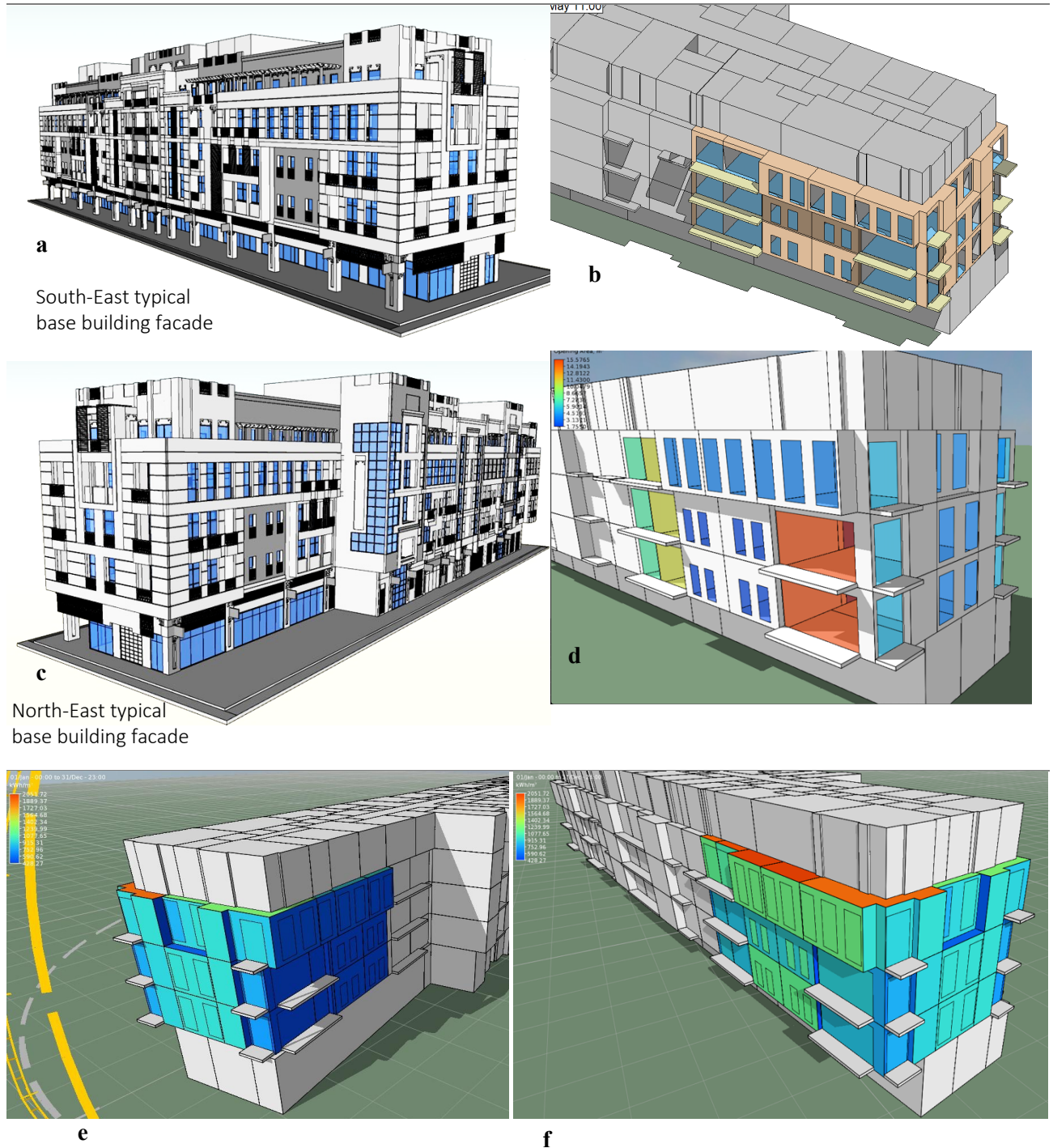


Fig. 55 The reference base case study images describe: *a)* the whole 3D-model of existing building south-east facing, *b)* 3D-geometry of the selected study includes 3-stories by IES-model IT, *c)* the whole 3D-model of existing building north-east facing, *d)* opening glazing windows area ratio m^2 of current existing building, *e)* the sun exposure (kwh/m^2) of the selected base case north-east, *f)* the sun exposure of the selected base case south-east. source: 3D-geometry via IES & SketchUp software tools done by (author)

4.2 DSF STRUCTURE AND CONSTRUCTION SEQUENCE INTEGRATED MAIN PARAMETERS

The DSFs in technical aspect involve three major components are; external skin layer facade, intermediate cavity space and internal skin façade. Identifying the DSF geometric is considerable task for running simulation design of each case analysis.

The structural design of DSFs based on improving the main layers from external to internal glazing layers, while SDs are integrated into the air cavity space for improving the thermal building envelope performance, also for ensuring the natural ventilation into cavity channel as passive design strategy, the both layers should include suitable openings vents.

The position of DSF in respect with load bearing structure is one of the essential considerations for building designing structure as shown in fig.(56) (Ulrich Knaack et al. 2007) In this work installing the DSF system lies in front of the building bearing structure.

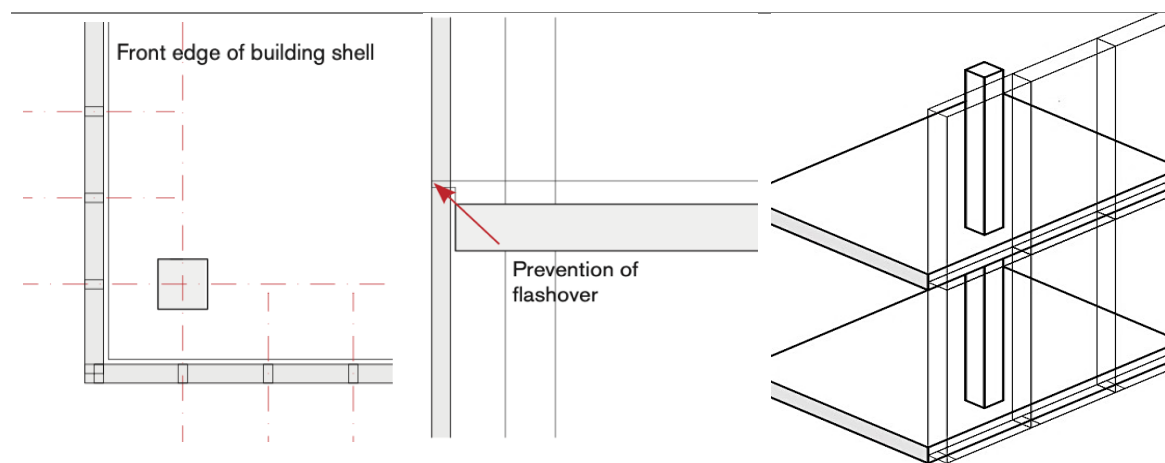


Fig. 56 The secondary structure façade is installed on the front of the primary structure of the building, the shape of ceiling in front of column can vary. An essential consideration requires for fire protection in the space between the shell & façade. Source(Ulrich Knaack et al. 2007)

Reconstruction the existing glazing windows of the reference base case building is followed by replacing the inner current design windows of each room with new segments pane design as illustrate in schematic section fig. (57); split awing window on the top, and bottom-hung open outward manually by occupants under specific condition allowing for ventilation with thin profile Aluminum structure frame. In contrast, the exterior glazing skin of DSF clipped to frame and with metal grating walk separated each story depends on the designing DSFs type. Energy modelling tested propose design of DSF alternatives which integrated with various options of glazing pane layers either (single pane, double and triple pane) will discuss in next section.

4.3 PARAMETRIC DESIGN OF THE PROPOSE DSFs (TECHNICAL ASPECTS OF DSF SYSTEM DESIGN)

Numerous parameters (variables) built up the DSFs configurations (structures) could play a vital role in improving the annual cooling loads and thermal performance of building. The previous studies were conducted in similar context have been assessed the main DSF components responding to the building performance from different views related to the climate conditions and buildings design. However, this research set up the major design parameters that effect on the DSF system in terms of the energy consumption and airflow performance. The following describe the key design of each parameter and properties for this study;

- 1. *The Air Cavity-Depth***
- 2. *The Glazing Properties and Components***
- 3. *The Vent Openings (Outlet and Inlet air vents)***
- 4. *The Shading Devices SDs Positions***

all are incorporating within the tested DSFs structure of the reference base case under hot-arid climate.

4.3.1 THE AIR CAVITY DEPTH

The air cavity also known as air space acts as thermal buffer insulation barrier against temperature extremes, noise and wind, located between the interior and exterior glazed layers (skin) of the building façade. (Boake, Terri Meyer 2001) In this study the air cavity ventilation system was designed to be natural ventilated mode of *external air curtain (EAC)* type. The air exchange between inner and exterior side of DSF and the air left the cavity. Basically, the DSFs functional based on the air cavity space which is an intermediate space for enhancing the air flowing, act as (thermal buffer) enable absorbed the heat energy of solar radiation resulting in reduction the heat transmission inside the room hence saving the cooling loads. The air cavity plays an efficient role to avoid overheating and radiative heat absorbed by the façade elements under hot climate via ensure the natural ventilation then evacuation hot air deriving from absorbed solar radiation of sun gains. Indirect solar gains resulting in raising temperature within cavity then transferred into adjacent inner space and caused additional cooling loads to the building.

Ventilation, greenhouse effect and the energy performance are the main physical aspects effect of cavity depth. The cavity depth influenced on the air velocity, as DSF width increases, the air velocity within the DSF cavity decreases. (Barbosa & Ip 2014) This study selected three different widths of the air cavity for all the tested DSF types is set systematically to be at (0.30 m, 0.90 m and 1.50 m). The schematic fig. (57) describes the cross-section design of the proposed natural ventilated DSF cavity throughout three façades direction south, east and north, the air cavity separated by metal grate catwalks between levels. The cavity dimensions are various from case to another based on the geometry design.

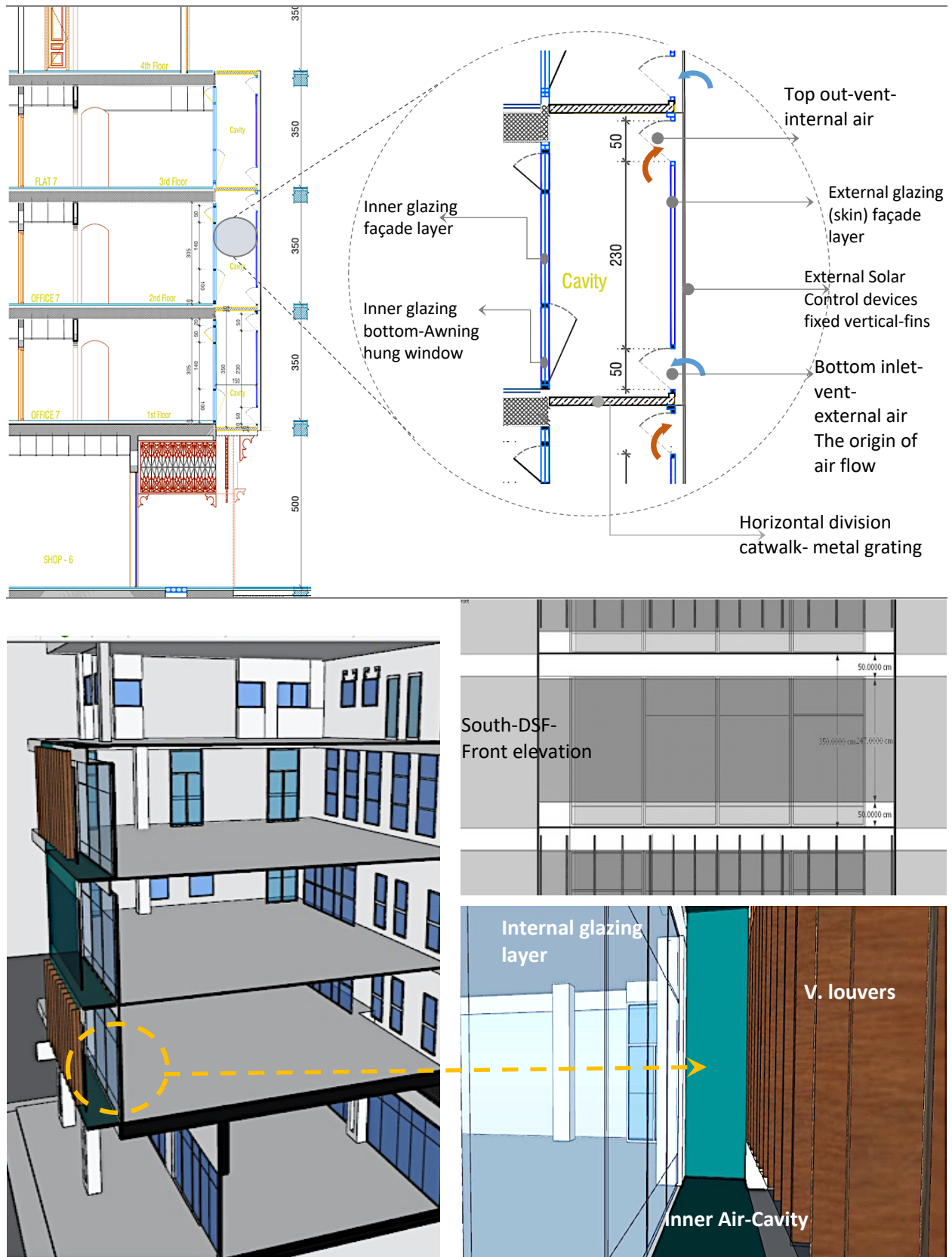


Fig. 57 Cross section wall sequence and dimensions of the proposed building envelope integrated DSF-at South-East and North façade, details describe the main components of DSF - schematic of the test cavity of DSF Geometry model.
 Source:(author)

4.3.2 THE GLAZING PROPERTIES AND COMPONENTS

Another importance task takes in considered the ability of glazing façade in responding to the solar radiation due to the nature of glazing materials transferring heat inside the room faster than insulated opaque wall. The glazing properties is key parameter for improving thermal performance of the building envelope. Selected an optimum glazing systems should be considered with high performance, energy efficient, specification and design contributed in achieving energy efficiency about 10-50% reduction in most climates. (Gregg D. Ander & Southern 2016). Selected glazing with low-solar gain based on many factors; climate, solar orientation, and cooling building dominated. (Mary Ben Bonham 2020)

Commonly, the DSF system applied double glazing layers at the inner pane and single glazing layer at the outer pane, the main layer of glass is usually insulating. (Boake, Terri Meyer 2001) (Chan et al. 2009) otherwise opposite order/changed positioned of these glazing types could be tested related to different factors. The main criteria should be considered to evaluate the glazing performance are; thermal conductivity U-value, solar heat gain coefficient SHGC, and glass visible transmittance $T_{vis-glass}$, additionally identified tints color and coatings for aesthetical purposes. A recommended specifications of the glazing properties as described in table (13) below for designers and engineers when they choosing the high performance of glass layers combination throughout the design and simulation phase for improving the energy performance of building façade. For residential and commercial applications with low SHGC values <0.40 , low U-factors <0.40 and with high transmittance visible $>0.70\%$ for daylighting applications, working well for cooling dominated buildings. Basically, a linear relationship for using glass with higher U-value lead to more heat transmission. The amount of SHG and thermal transmittance of glazing properties are the key features in building envelope thermal performance. Insulated glazing refers to IG unit (double glazing) as shown in fig. (58) includes two or more panes of sealed glass combined together around the edge with insulating layer of

air or inert gas in between to create an effective single unit which is efficient performance in reduction heat transfer (thermal improvement), also it could be the most effective barrier between internal and external environments. The common architectural IGU type is (6mm glass-12mm air-space-6mm glass). (Ulrich Knaack et al. 2007)

Table 13 Glazing properties with recommended specifications based on the building type and climate. the shaded yellow lines indicate to the main properties of the proposed glazing materials for this study. Source: (Mary Ben Bonham 2020)

Table 13: Glazing performance properties with recommended specifications relied on building type and climate				
U-value	Visible transmittance Tvis	Solar heat gain coefficient SHGC	Insulated glazing unit IGU	Light to solar gain ratio LSG
The capacity of glazing to withstand heat transfer	The fraction of light in the visible spectrum that is transmitted through a material or glazing system.	The fraction of incident solar radiation admitted through a window.	Specified with performance- enhancing features specific to project needs:	The ratio between visible transmittance (VT) and solar heat gain coefficient (SHGC).
The coefficient of thermal transmission (Wm^2/K) identifies the transmission heat by construction element based on the ambient temperature difference.	VT decreases around 10% when colorless low-E coatings are applied to reduce solar gain and improve thermal resistance.	Low-solar-gain low-E glazing (< 0.40) works well for cooling-dominated buildings.	• Airtight seals • Non-conducting 'warm-edge' spacers between panes • One, two, or three airspaces • Solar control coatings • Suspended or applied films • Colorless gasses in place of air in the cavity • Translucent insulation fillings	VT/SHGC measures how effectively glazing reduces solar heat gain with the least reduction in visible transmittance.
Lower U-value indicate higher insulating capacity	High VT (> 0.70) is desirable for daylighting applications.	High-solar-gain low-E glazing (>0.55) works well for passive solar heating.		Higher LSG ratios contribute to more efficient daylighting performance

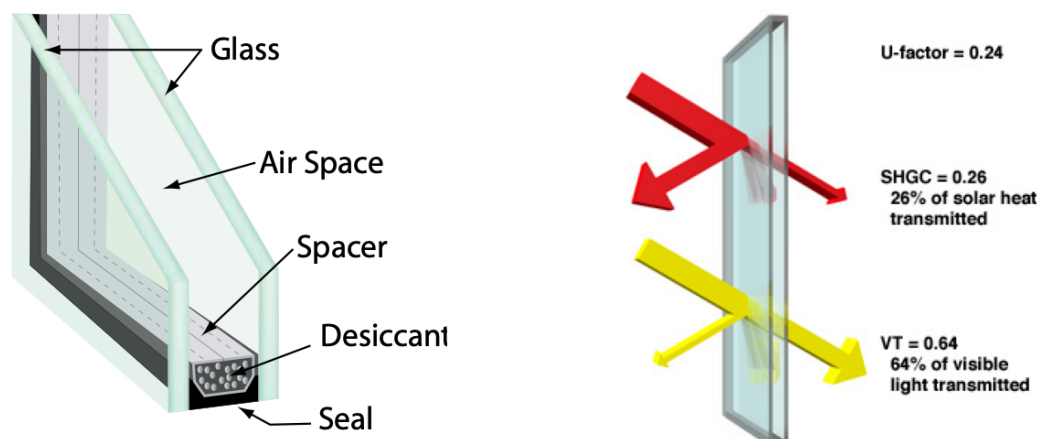


Fig. 58 (left) Insulating glass IG (Belis et al. 2019), (right) characteristics of a typical double-glazed window with low-solar gain. Source: (NFRC 2020)

This study selected three options of glass layers with different optical properties in proposed DSF design based on physical properties under hot-climate conditions as shown in fig. (59), each type involves different combination of glazing type for external and internal façade, focusing on higher thermal properties (thermal resistance, weight, structural strength, conductivity and light transmittance) that improving the energy performance of DSF system. The proposed three glazing options (scenarios) for all DSF types for this study as illustrated in the table (14):

1. Single-Double glazed (S-D) refers to **G1 scenario**
2. Double-Double glazed (D-D) refers to **G2 scenario**
3. Single-Triple glazed (S-T) refers to **G3 scenario**

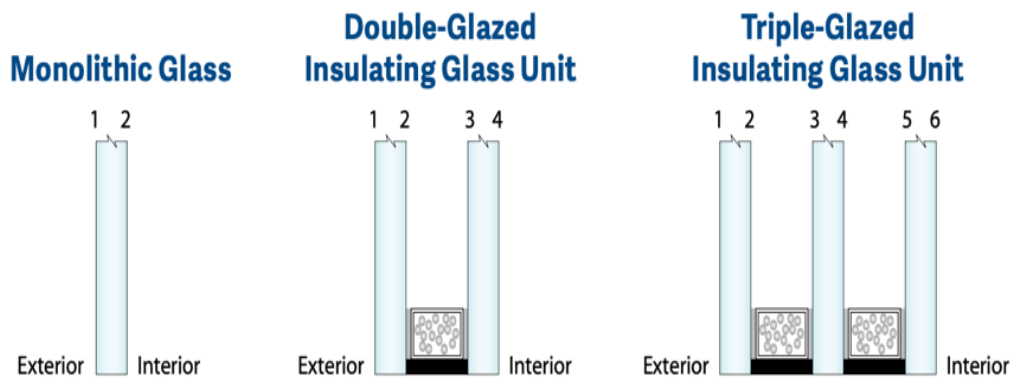


Fig. 59 The most common configurations of glazing, the numbers indicate the glass surfaces counting from exterior to interior. Source: (Belis et al. 2019)

The tested glazing options are, Double-glazed, Low-solar-gain and low-E glass which applied to bronze tinted which reflect the solar heat away from the building envelope with minimizing glare, with Krypton gas filling. The low-E glass keep internal environment cool during hot time and permitting sunlight inside a room without allow entering heat inner resulting in lower air conditioning loads. (WorldData.info 2021). Generally, the glazing properties meets the criteria for insulation required high insulation providing a low solar factor and low U-value minimizes cooling load of adjacent spaces.

However, the selected glazing layers for proposal DSF study comply with recommended specifications as illustrated in table (14). The single and double-pane glazing varies with a U-value of 0.9 to 5.6 W/m²K, SHGC of 1.2 to 0.4 (BS EN 410), double-glazed window with Krypton gas filling. Generally, these types refer to a Spectrally selective low-E glass (Mary Ben Bonham 2020) which is considered an ideal for the buildings where required high cooling demands due to their capability in reduction solar heat gain with keeping high visibility transmittance in the same time. Spectrally selective glass has relatively high visible transmittance and low SHGC. (Gregg D. Ander & Southern 2016) Thermal and optical properties of glazing types are essential to study the impact the transmission of heat gain should be examined through varying different U-value, solar heat gain coefficient SHGC and emissivity. **The window U-value** thermal transmittance U-value, it would be for complete window unit including frame not only the U_g center pane of glazing, but also the material of frame, because the thermal performance of the frame separating the external and internal environments. made by low conductivity aluminum of Aluminum. The performance of these small but essential elements can affect the thermal transmittance significantly. The fig. (60) shows the positions of glazing layers (layer1-outer skin and layer2-inner) of tested DSF system.

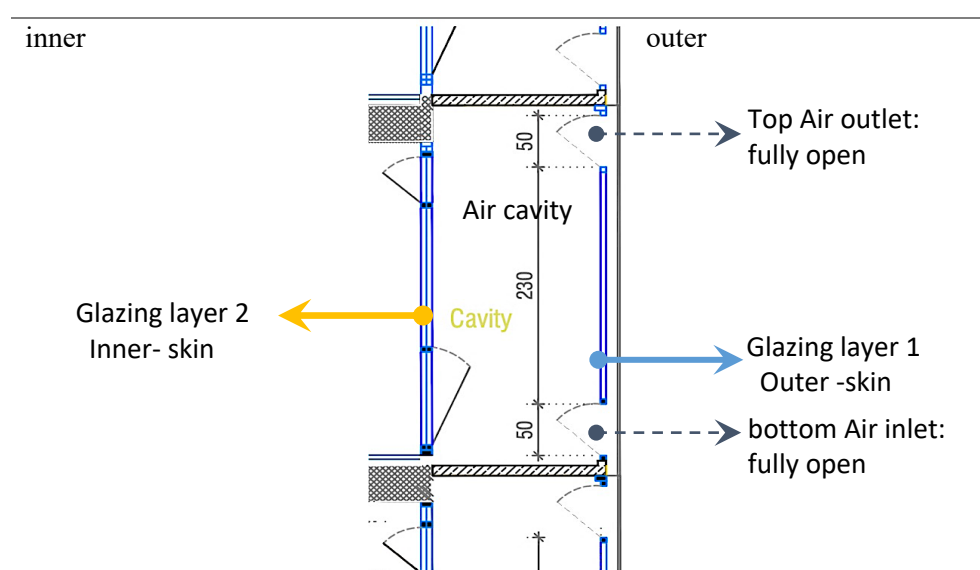


Fig. 60 Cross section of the DSF described the glazing layers location. Source(author)

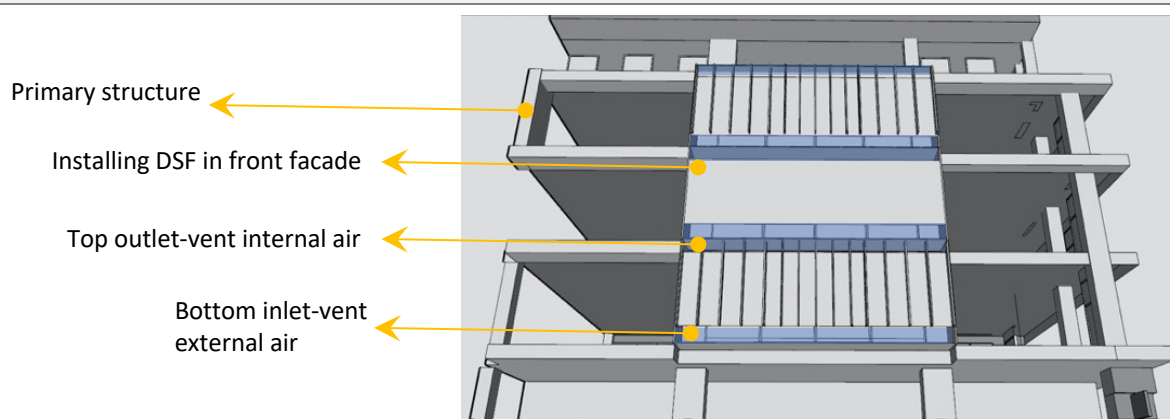
Table14: The proposed options of glazing combination layers & optical thermal properties

Glass 1 (G1) from (outside to inside)		
features	Glazing layer 1 (outer-skin)	Glazing layer 2 (inner-skin)
Single pane-Double pane with bronze tint (S-D)	single glazing pane, low-E coating	SunCool BRONZE 10/24 outer-Krypton cavity- Inner clear glass pane, low-E glazing, insulating glass unit IGU
Optical and Thermal Properties	Thickness mm	8 mm
	Conductivity U-value W/m ² K	1.0372
	g-value (SHGC) (BS EN 410)	0.3529
	Visible light transmittance t _v	0.41
	gas	Krypton
Possibility to open window	No possibility to open/fixed	Split frame window, awing towards outside hung up
Materials of window frame	5% of total area	10% thickness of total area Aluminum
Glass 2 (G2) from (outside to inside)		
features	Glazing layer 1 (outer-skin)	Glazing layer 2 (inner-skin)
Double glass pane-Double glass pane (D-D)	Double glass pane of SunCool Bronze Outer-Krypton cavity- inner clear glass pane	Double glass pane Low-E Outer clear glass-gas-inner clear glass IGU glass
Optical and Thermal Properties	Thickness mm	6mm-16mm-16mm
	Conductivity U-value W/m ² K	1.0343
	SHGC	0.4196
	Visible light transmittance t _v	0.41
	gas	Krypton
Possibility to open window	No possibility to open/fixed	Split frame window, awing towards outside hung up
Materials of window frame	5% of total area	10% thickness of total area Aluminum
Glass 3 (G3) from (outside to inside)		
features	Glazing layer 1 (outer-skin)	Glazing layer 2 (inner-skin)
Single pane-Triple glass pane (S-T)	single pane glazing, low-E coating	outer clear pane-Krypton-Inner clear pane-Krypton-SUNCOOL 10/24 BRONZE
Optical and Thermal Properties	Thickness mm	6
	Conductivity U-value W/m ² K	0.9129
	SHGC	0.3431
	Light transmittance t _v	0.41
	gas	Krypton
Possibility to open window	No possibility to open/fixed	Split frame window, awing towards outside hung up
Materials of window frame	5% of total area	10% thickness of total area Aluminum

Table 14 Description the selected glazing options /combination systems (G1,G2,G3) with optical thermal properties. Source: (Author)

4.3.3 THE VENTS OPENINGS (OUTLET AND INLET AIR VENTS)

Vents' Openings criteria of DSF system



	External skin layer	*Inner skin layer
Vents' position	Bottom (air inlet) and vent Top (air outlet) vent openings	Top and bottom operable vents
Openings' state	Fully open open all year (passive)	operable window/Top hung awning window and bottom hung awning window
height (m)	0.50 m	Top=0.50 m, Bottom=1.00 m
Ventilation mode	Exterior-air curtain (EAC),natural ventilation	manually operating/operable

* All openings of the inner skin glass window keep closing during dynamic thermal simulation.

Table 15 Opening vents criteria/characteristics of DSF system. source(author)

The table (15) above shows the opening vents characteristics of proposed DSF system. The vents openings are importance parameter affecting the DSF performance and determined the ventilation mode of the DSF system to be air stubbly, external...etc. It can affect the air temperature inside the cavity, buoyancy force and flow resistant. (Poirazis 2004b). The openings created buoyant effect due to differentiate between the incident heat and reflected heat of external and internal skins (difference in pressure within the cavity) resulting in improving the air flowing inside the cavity and avoiding overheating by extracting hot air upwards to top vent which accumulated on the upper level of cavity as well as to minimize the greenhouse effect within the cavity, these vents of DSF improving turbulent air flows (heat flux and heat reflected of glazing skin determined the convective heat transfer)

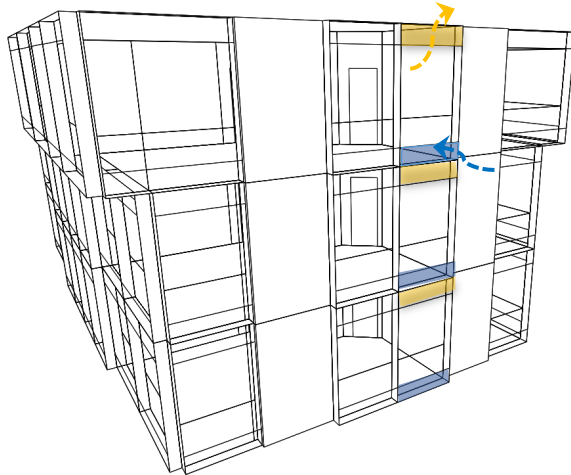
The vent openings either external or internal skins of DSF are designed with special properties supporting ventilation mode during natural ventilation mode. The height of both inlet and outlet vents are 0.50 m placed at external skin glazing. The position opening vents and size are significant factors in improving thermal performance of DSF. The vents openings are varied in dimensions (area m^2 and distance m) from one DSFs type to another, depending on the geometry design of the DSF configuration and partitioning of each cavity as mentioned in fig. (61).

The external vents of outer skin are activated and left at fully open all time (passive), but the internal vents (the awing hung window) are managed manually by occupants in responding with external environment conditions in order to maintain the interior thermal comfort actually it is operated during night time and cooling days at the period from Sep.-April. In terms of design airflow process, must be study the aerodynamic of the building form, wind speed and direction, solar radiation, ambient and inner temperature to understand the process of air pressure and temperature caused by buoyancy that influence air movements in the DSF cavity. DSF air cavity (air buffer) natural vented mode, the air-flow EAC. During summer time with cooling time demands, the cavity is designed with external fully vents openings to prevent overheating inside the cavity and ensure the air flow and evacuation the hot air. Air enters through horizontal openings vents from the base of the external glazing layer of DSF system. The ventilation mode of propose DSF design is EAC system, since the air flow to the cavity from the outdoor then immediately rejected towards the outside. Hence the ventilation cavity creates a curtain enveloped the outside façade. The origin of air flow inside the cavity affected the DSF performance, as ventilation mode related to the origin air flowing in cavity. This study was adopted the EAC ventilation mode.

The DSF has to be well ventilated specifically at south faced where solar radiation is high, in order to prevent overheating and sink heat in cavity. The air exchange between air cavity and

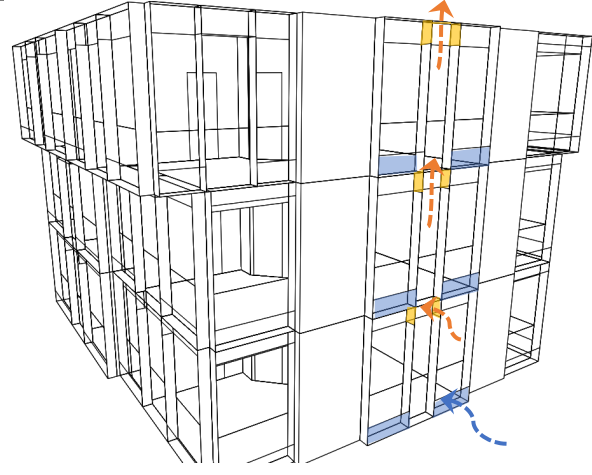
outdoor environment depends on the wind pressure, the stack effect and the discharge coefficient of the openings. (Harris Poirazis 2006)

The positions of the air-inlet-bottom (blue shade) and the air-outlet-top (yellow shade) in the external layer of each DSF type. Blue arrows indicate external air inlet-flow, red arrows indicate external air outlet-flow



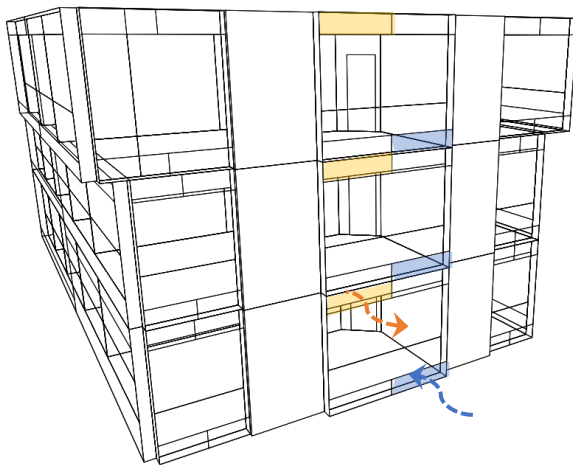
air space height: 1- story, about 3.50 m
area: box unit window width* 0.50 m height

Box-window cavity



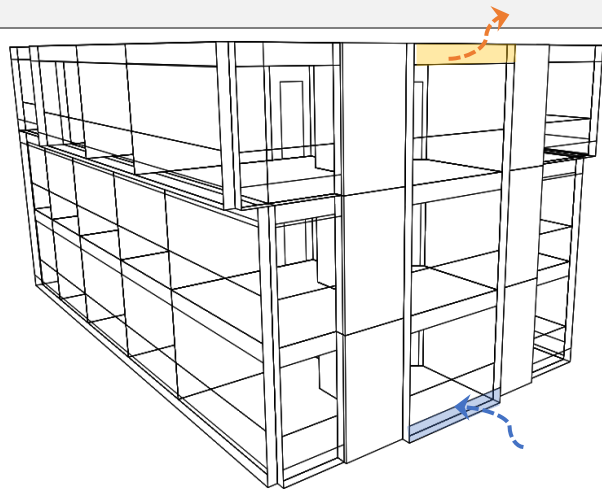
air space height: stack shaft =3-storeys, about 10.30 m, distance from inlet base shaft to the side opening is 1-story, about 3.50m
area:0.50 height*width of box unit
area of side opening :0.50m* varies (cavity depth)

Shaft-Box cavity



air space height:1-story, 3.50 m
area:0.50m height*half of external window each story
diagonal air-flow

Corridor facade



air space height: 3-storeys, 10.30 m
area:0.50m* width along the external glazing layer

Multi-Storey Facade

Fig. 61 The positions of the air-inlet-bottom (blue shade) and the air-outlet-top (yellow shade) in the external layer and vents openings dimensions of each DSF types (Box-window, Shaft-box, Corridor and Multi-storey facade). source(author)

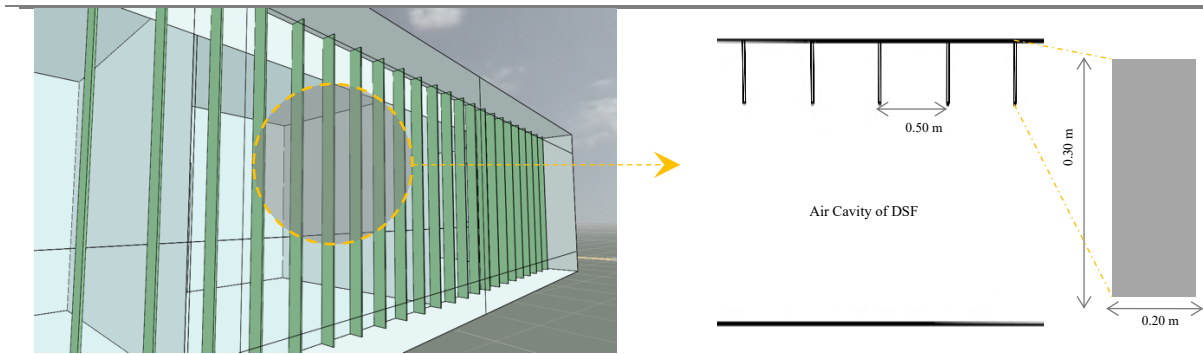
4.3.4 THE SOLAR SHADING DEVICES SDs POSITIONS

The solar shading devices (SDs) is one of the efficient components with DSF system especially in extreme hot climate conditions. Blocking and reflecting the sun helps lower the buildup of heat inside. The SDs play an efficient role to prevent overheating either fixed or adjustable design where placed in-between the air cavity. The SDs absorbed the solar radiation, the temperature increased inside cavity, thanks to stack effect about 25% of the heat within the cavity can be removed by natural air circulation. Heat extraction within the cavity depends on the shading device location, the concept of shading devices refer to its capability in blocked the solar radiation before reaching the inner building resulting in to reduced cooling loads.(Harris Poirazis 2006)

The study selected vertical fixed louvers, rectangular in shape with (0.30 m depth* 0.02m width* 3.0 m height) that arranged vertically 0-degree angled as shown in fig. (62). The vertical louver blades made from weather board timber construction material with 10.0mm thickness, (U-value=3.01W/m². k), thermal mass very lightweight 6.50 kJ/ (m².k), The vertical louvers reduce the heat transfer rate (solar heat gains), provides sun protection, avoid intercepted solar radiation in glazing façade resulting in saving cooling energy. This study focused on tested the impacts of altering shading devices position within the air cavity of natural ventilated DSF. The sun shading louvers are mounted within the air cavity of DSF into three positions in south, east and north elevation of the tested building as shown in table (16) this scenario is applied for each DSF case in the modelling of dynamic thermal simulation. The process of installing vertical louvers SDs strategy associated with the efficient results of (optimal scenario) for each type at 1st strategy in this work, The SDs vertical louvers are mounted within the air cavity in three positions:

- a) Placed against the windows of the internal skin (**internal**)
- b) Placed in the center of the air cavity (**middle**)

c) Placed against the external windows of outer skin (**external**)

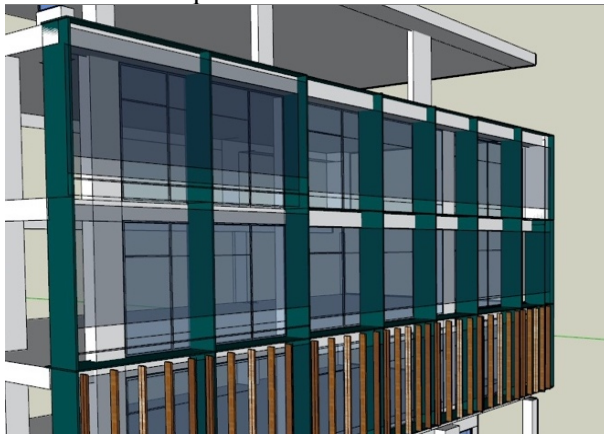


Internal shading devices SDs in front façade

- The louver blade is rectangular shape
- Dimensions 3.50 m height, 0.20 m width, 0.30m depth
- Fixed shading devices- SDs vertical louvers
- Material construction assigned is weatherboard panel

Fig. 62 Shading Devices SDs- vertical louvers characteristics and dimensions

3D-view of DSF-south elevation installing SDs at the external position at 1st floor



Cross Sections of the SDs vertical louvers positions related with air cavity of the DSF

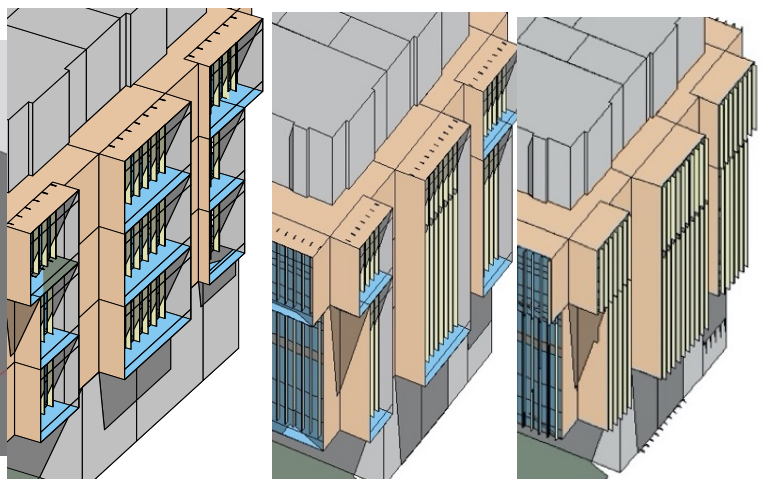
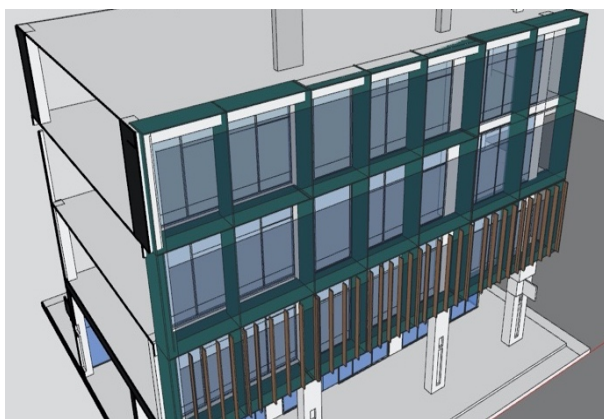
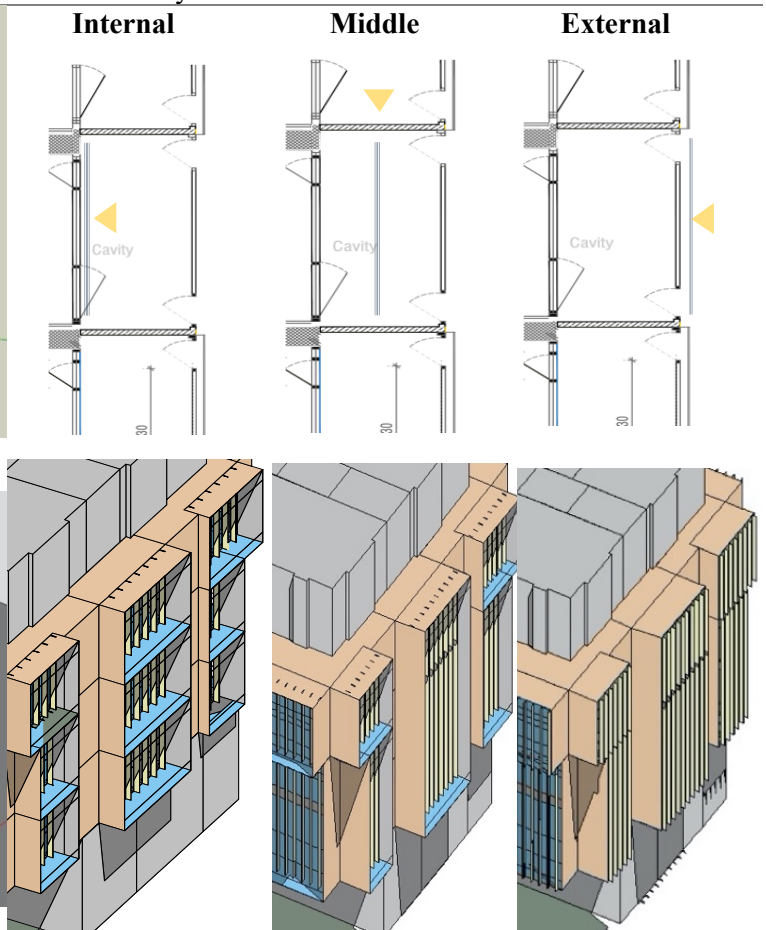


Table 16 3D-Section views and schematic geometry of shading SDs positions within the DSF cavity in three places at (inner the internal skin, the middle of air cavity, at the external of DSF layers). source(author) by IES & SketchUp tools

4.3.4.1 DAYLIGHTING ANALYSIS OF THE SDs

The following fig. (63) illustrates the impact of SDs positions in the daylighting performance for the south-east office room in the 1st floor. The radiance contour images Illuminance lux level under clear sky condition show that the external position of the shading device achieved acceptable levels followed by the middle position, enhancing the quality of daylighting artificial and natural performance, improving the building users' visual comfort by mitigation brightness and glare influences. Moreover, adequate design of external vertical louvers reduces the air temperature within the cavity by reflectance and distribution the solar-radiation entering indoor room resulting in saving energy consumption.

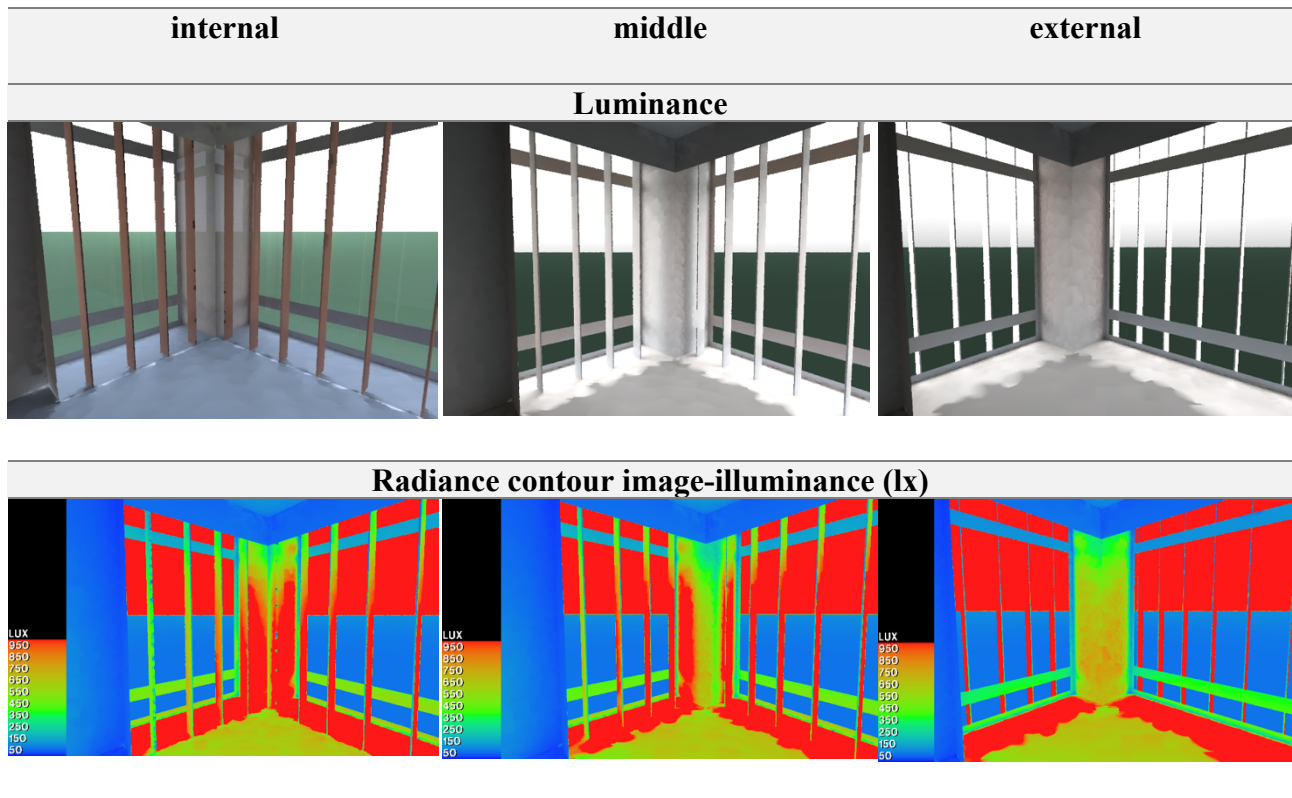


Fig. 63 Daylighting analysis; Comparing the luminance and radiance contour image under clear sky for three altering positions of SDs vertical-louvers (internal, middle and external positions) at South-East room in the 1st floor. source(author)by IES software tool

4.1 GEOMETRY MODELS SET-UP OF FOUR DSF TYPES

The modelling simulation of DSFs types is considered complex task, since different elements interact with each other affect the function of the cavity. Endeavor to model the cavity are

focused mostly on; air flow simulations and calculation of the temperature at different heights (Thermal Performance). The below fig. (64) describes the simulation model (3d-geometry) of proposed design of DSF system. The tested model exploded for showing the main facades that applying DSF system along 3-stories of reference building. Creating DSF system with three facing is setting up for simulation study and tested with different parametric study.

The study relied on Oesterle et al. categorizing method of DSFs systems through classified the DSF by the structure intermediate space (cavity partitioning). The fig.(from 65 to 68) show the proposed tested four DSF configurations models of (*Box window, Shaft-box window, Corridor faced and Multistory facade*) individually; each geometry model was designed with three cavity widths (300 mm, 900 mm, and 1500 mm) as illustrated in cross section fig.(65-68), There are openings vents along the external glazing skin façade across the height of each DSF type , the external outlet (top vent) with 500 mm height and external inlet (bottom vent) with 500 mm height and with horizontal metal grills separating the air cavity. Each DSF type has various openings features independently based on geometry design as illustrated in 3D modelling in fig. (65-68). The design of simulation tested modelling replacing the inner layer of glazing windows in reference case with (3 m) height glazing façade along each room. In early design stage, in terms of modelling DSF geometry, respect to the reference base structural building model (layout), the proposed design complied with building ratio the study takes in consider maintain the same area ratio (layout) of the reference building, the 1st and 2nd storey are typical office floors while the 3rd storey is residential floor stretched (projection) about 1.30 m to 1.50 m in south and north facade from the below two floors. On the other hand, the design process attempted to maintain the base wall construction parts at east façade which required presence the closet-wardrobe belonging design purposes of reference building.

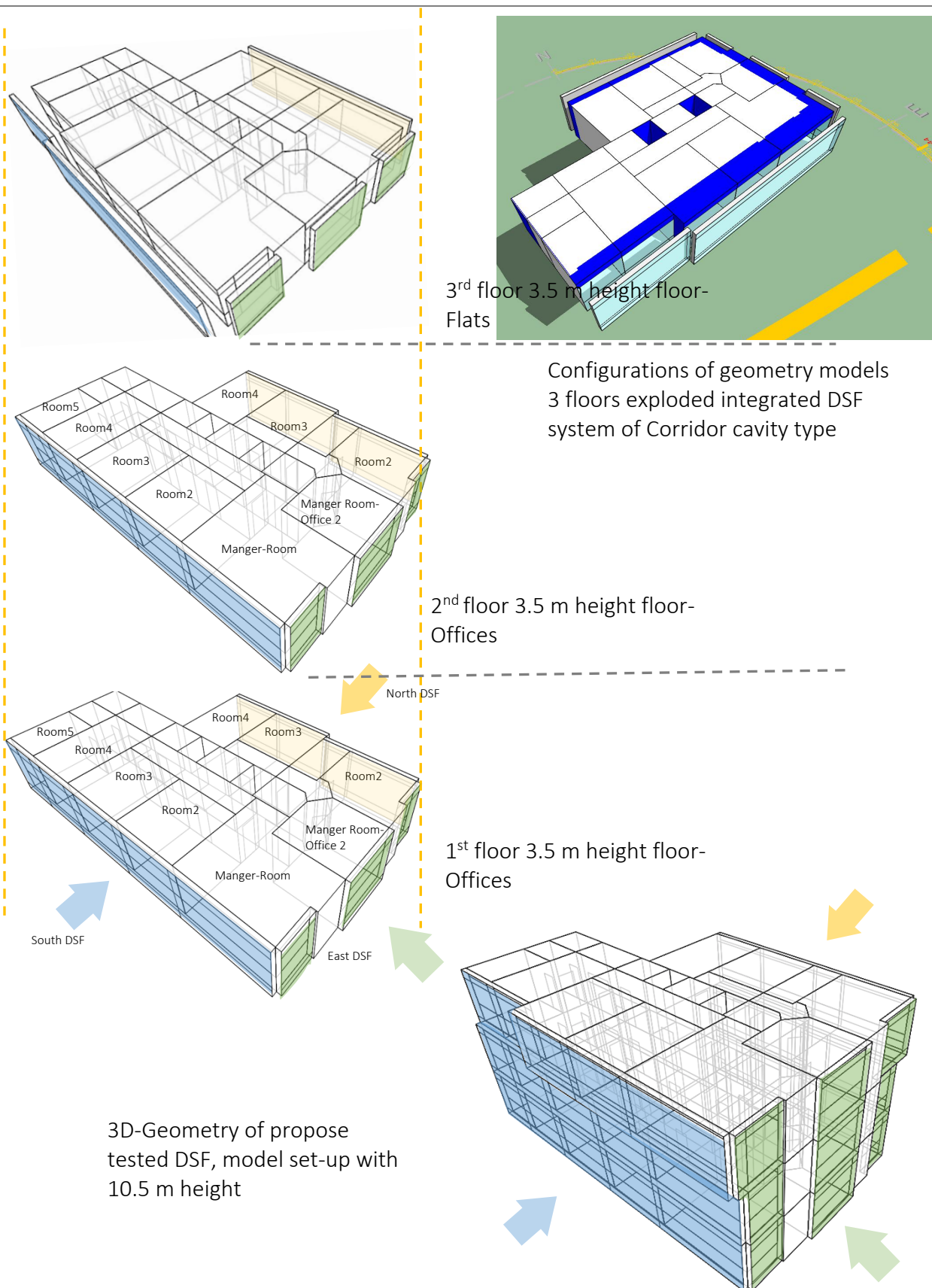


Fig. 64 Geometric illustration, exploded isometric view of DSF construction sequence around three facades of the building and schematic building façade exploded (propose DSF 3D-model). Source: author

4.2 DSF STUDY MODEL SET UP FOR SIMULATION

The simulation study divided into two strategies, each strategy varied by adjusting certain parameters; the 1st strategy includes 4-DSF categories (cases) based on the partitioning of the cavity along the façade (*Box-Window, Shaft-Box, Corridor and Multi-Story cavity*) are represented individually in fig. from (65 to 68), each case was modeled with 3-different cavity depth, and thermal dynamic simulations have illustrated independently for each cavity depth integrated with 3-different glazing properties. The 2nd strategy demonstrated by installing vertical SDs along the glazing façade with 3 different options (at the external layer skin, in the middle of the cavity and close to the inner skin glazing of the DSF air cavity). The Dynamic simulation process run on sequence recognized the efficient parameters of each DSF type. The tested parameters linked with range of variations were carried out in simulation numerical for comparison.

DSF represents an integrated one-unit system made up of various components, can affect each other and thus improved the whole system DSF performance for enhancing energy performance in varying proportions. The sufficient design requires high recommended specifications vary with the building type and climate conditions. This study arranged the main layers of DSF relative with hot-arid climate conditions of the UAE to ensure high-performance in energy saving. The proposed design of natural ventilated DSF divided into four configurations (cases), each case has different design and associated with similar parameters criteria affecting the energy performance of the building. The study specified wide range of tested parameters associated with DSF system for enhancing the energy performance and evaluated under **four headings**:

- I. In respect with **DSF Configurations** based on cavity structure (Case1-Box-window, Case2-Shaft-box, Case3-Corridor and Case4-Multi-story façade).

- II. In respect with **Air cavity depth** thicker or thinner profile (sim1=0.30 m, sim2=0.90m and sim3=1.50m).
- III. In respect with **Glazing combination properties** (G1, G2 and G3).
- IV. In respect with **placement SDs system** (vertical louvers) within the air cavity (in the middle, exterior and in the inner cavity skin)

4.2.1 CASE 1-BOX -WINDOW CAVITY

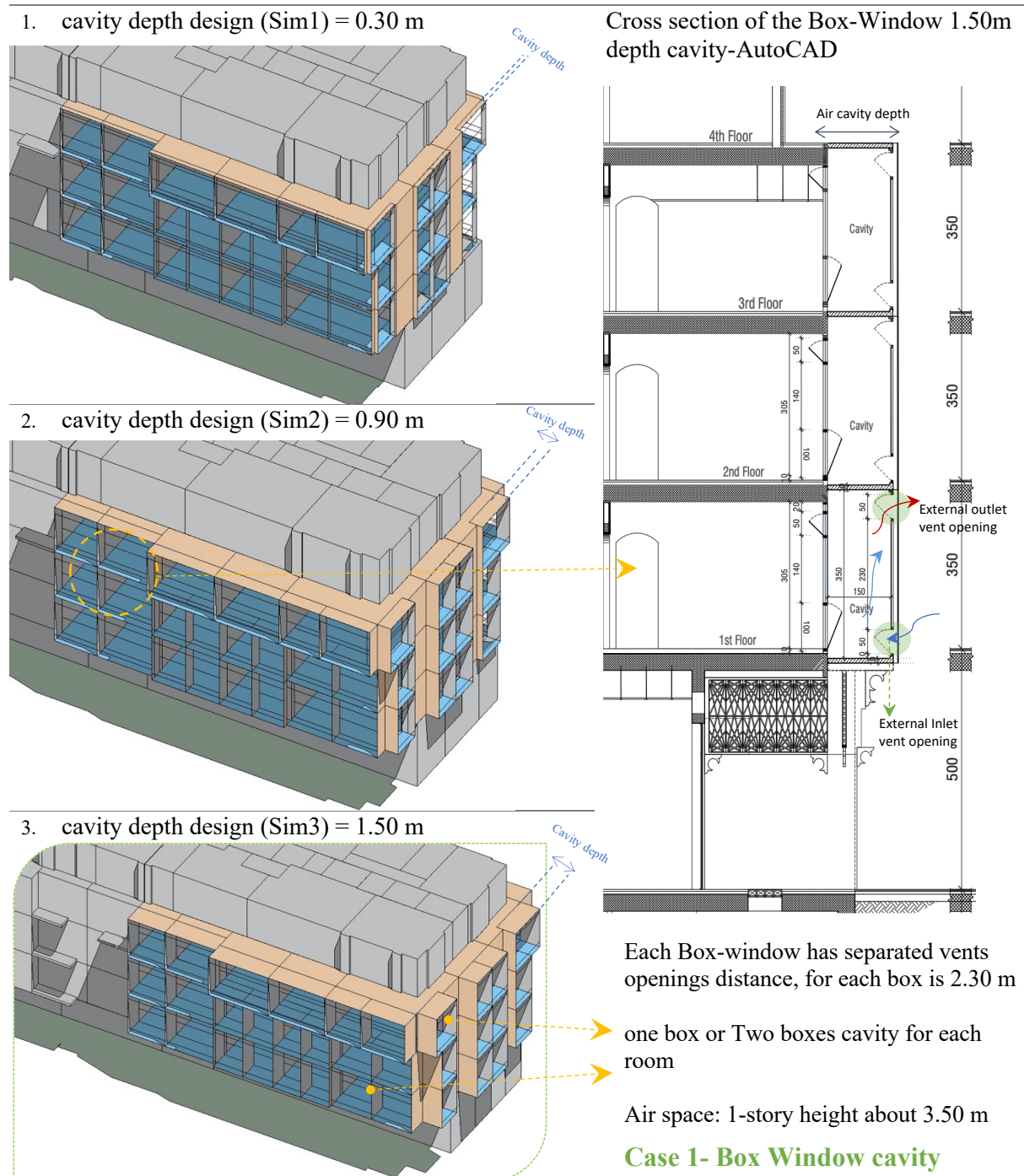


Fig. 65 Box-Window models with three different cavity depth (sim1, sim2, sim3) , view image 3D-geometry (sun-cast image view time@ 16 Apr. 11:00), (right) long cross section details of air cavity. source(author)

The Box-window as shown in fig. (65) was applied into three façades south, east and north by dividing each floor into multi boxes. The box form system is divided vertically and horizontally by mullions for each room separately, each room has one to two boxes depends on the room faces area with 0.50 m width vents openings at the external layer; inlet-bottom and outlet-top which allow fresh air flows into the cavity. Applying such this system is quite easily for retrofitting and enhancing the building envelope performance. (Hilmarsson 2008) The cavity box type is defined physically in horizontal and vertical by the module of the façade which has limited high to one story. The box window partitioned façade per story with box modules. Notice: the boxes window area different from facade to another based on design purpose of each floor.

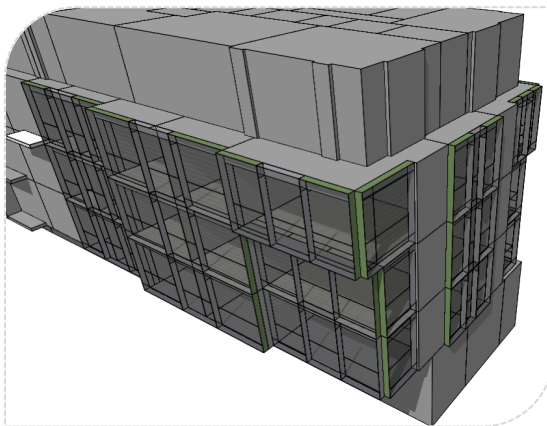
4.2.2 CASE 2- SHAFT-BOX CAVITY

The Shaft box cavity as shown in fig. (66) based on the box-window cavity type; it is obviously noticed that it improved more advanced system by applying shaft stack. The stack effect (chimney effect) is referred to the rising the hot air which is lighter than the cold air. The shaft-box cavity concept is based on a pressure differences force; when the air within the cavity is hotter than the ambient air has a tendency towards to escape (run away) at the top of the cavity leading to increase ventilation flow within the façade. (BBRI. et al. 2005) **The geometry** is divided each room horizontally by box-windows that connected to the vertical shaft stack section with specific openings design. The shaft box system includes two box windows horizontally divided on each story of the building envelope integrated with bottom inlet openings 0.50 m in the external glazing skin layer and connected to the vertical shaft section with inner side top openings at each segment to draw air from the box windows. While the vertical shaft section draw air from box windows since it is possible creating airflow along the whole façade. The shaft-box is comprised of box-window modules horizontally partitioned by story which connected to vertical ventilation ducts (increasing the stack effect) set up within

the cavity and extends to several floors. The air is naturally drawn into the stack ventilation duct and evacuated by the outlet located several floors above. The main concept of this type is to encourage the natural ventilation by creating stack effect.

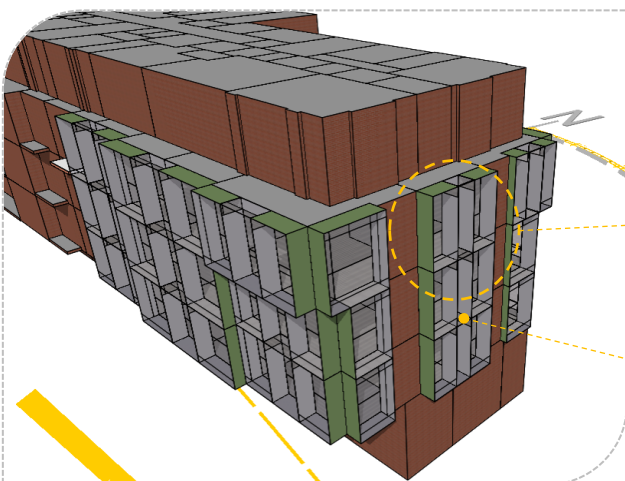
Case 2-Shaft-Box cavity

1. cavity depth design (Sim1) = 0.30 m

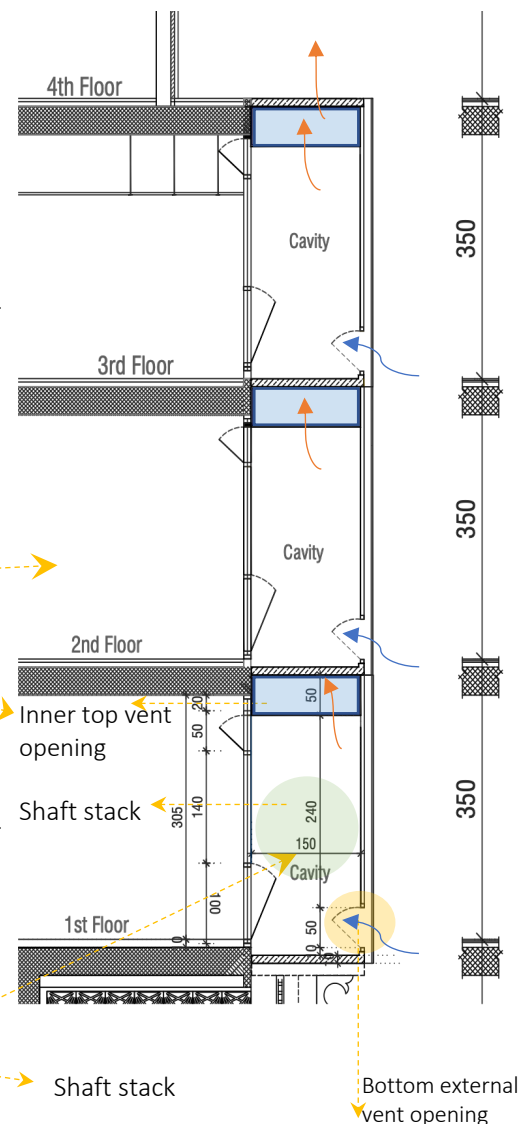
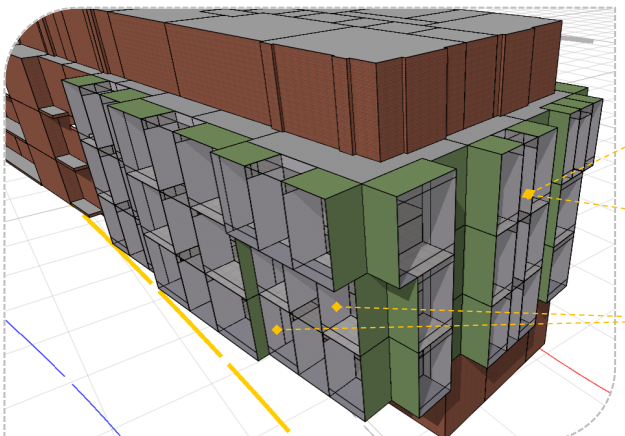


Shaft-Box section 1.50 m depth cavity- AutoCAD. Airflow uplift through external openings and special shaft stack vents

2. cavity depth design (Sim2) = 0.90 m



3. cavity depth design (Sim3) = 1.50 m



Case 2-Shaft-Box cavity

Fig. 66 Shaft-Box models with three different cavity depth (sim1, sim2, sim3), view image 3D-geometry (sun-cast image view, (right) long cross section details of air cavity. source(author)

4.2.3 CASE 3- CORRIDOR CAVITY

The large cavity is the main characteristic of the corridor façade fig. (67). The cavity is (divided) partitioned physically by each floor level and it is not limited horizontally but extended across many rooms an entire storey (each cavity is independent of one another). divided the whole building envelope horizontally partitioned for a long each story since the air flows diagonally entering the top and existing by the bottom cavity openings on external surface facade (air intake and extract openings arranged diagonally), the opening areas are different from façade to another based on design purpose for each storey. This system prevents entering air from lower floor to the floor above placed closed to the floor and ceiling diagonal positions. The openings vents are divided into top and bottom fully opening in diagonal position along the horizontal length of each room at one floor.

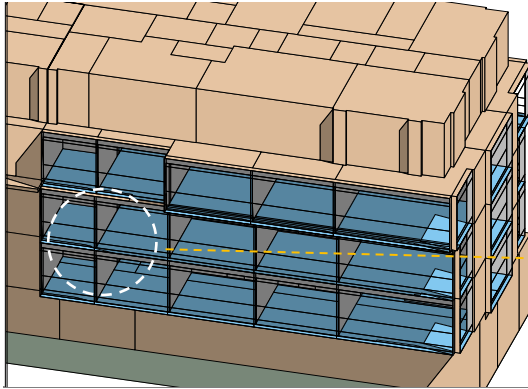
4.2.4 CASE 4- MULTI-STORY CAVITY

The Multi-Story facade as shown in fig. (68) is designed in different way functional and structure comparison with other previous DSF types. The cavity of multi-storey façade is not partitioned either horizontally or vertically, the cavity run all the building façade without any partitioning. It consists bottom external inlet opening vents (air intake) and top external outlet vent opening (extract air) along the building façade. This DSF system has the largest openings area. The cavity space between two glazed is forming one large volume, as well as the wide cavity is enough to access through for cleaning services, maintenance, etc. The façade of this type naturally ventilation and it has an efficient acoustical performance with regard to external noise. Air space design and the form geometry design are differed from façade to another; at east building facade the multi-storey cavity run over all 3-storeys height about 10.30m with two opening vents, in south and north façade the multi-storey run along the 1st and 2nd storey while 3rd floor is extended and it has own multi-story cavity (one air volume) along the floor.

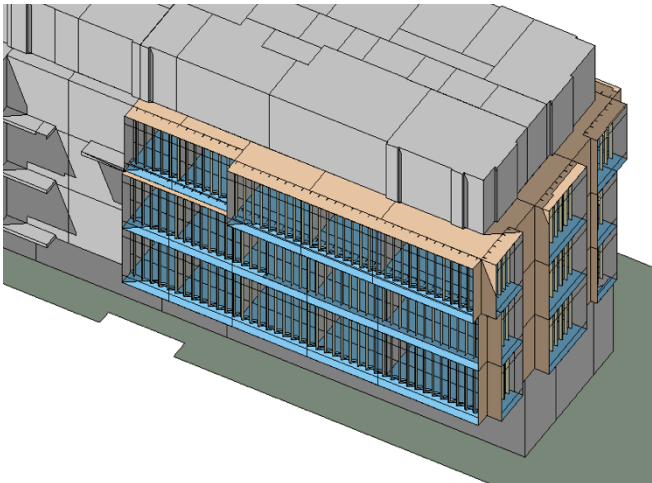
The design process takes in consideration design purposes such as the extended of last story area and the position of wardrobe being maintain the typical wall of existing reference case.

Case 3- Corridor cavity

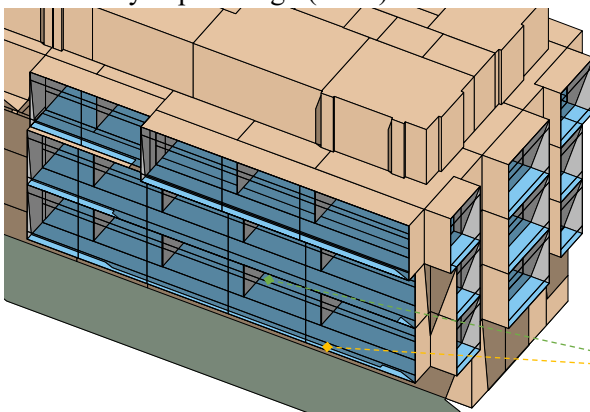
1. Cavity depth design (Sim1) = 0.30 m



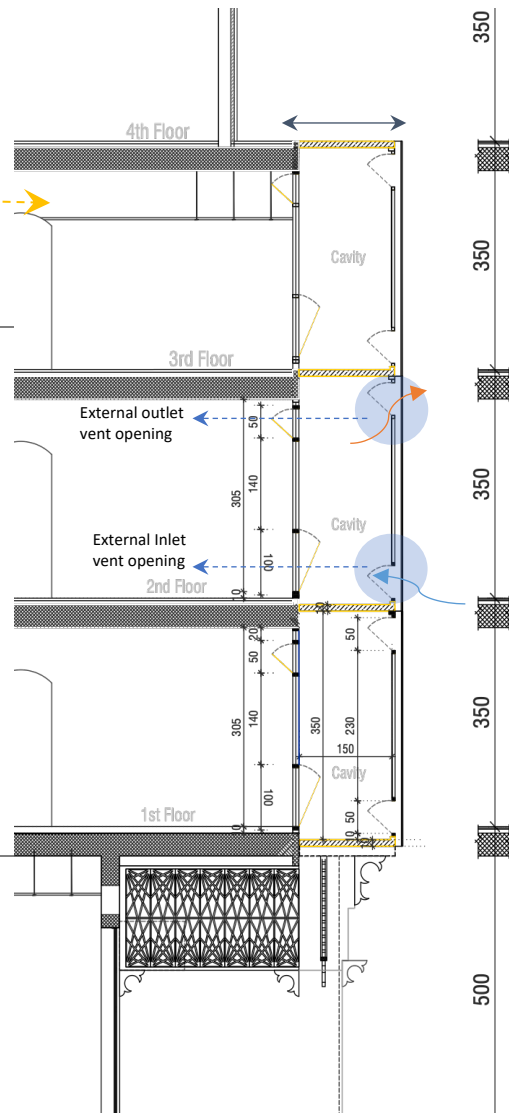
2. Cavity depth design (Sim2) = 0.90 m



3. Cavity depth design (Sim3) = 1.50 m



Corridor Cavity section 1.50 m depth
cavity-AutoCAD



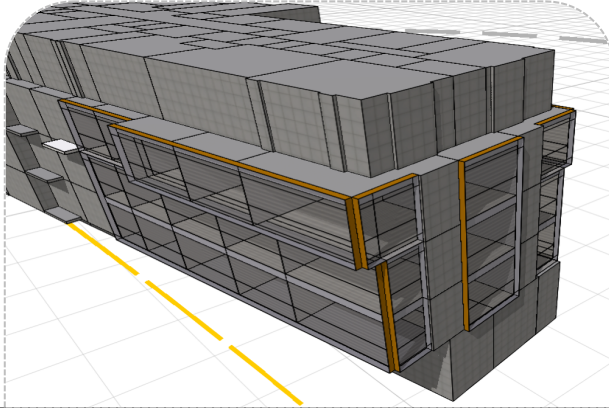
One corridor cavity has top and bottom
vents along each story
Diagonal vents

Case 3-Corridor cavity

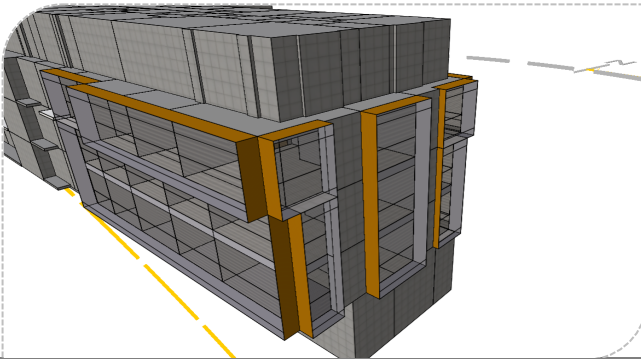
Fig. 67 Corridor cavity models with three different cavity depth (sim1, sim2, sim3) , view image 3D-geometry (sun-cast image view), (right) long cross section details of air cavity. source(author)

Case 4- Multi-Story Cavity

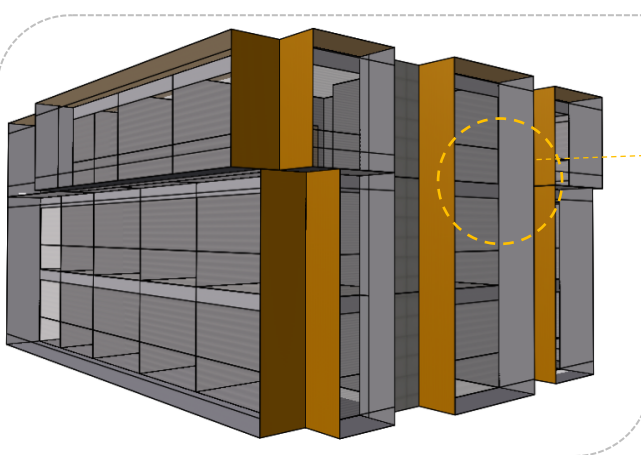
1. Cavity depth design (Sim1) = 0.30 m



2. Cavity depth design (Sim2) = 0.90 m

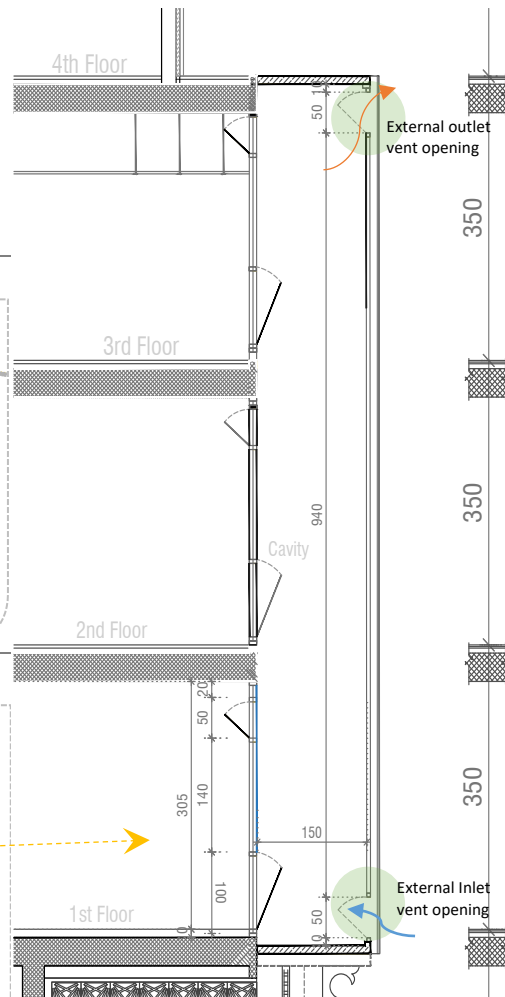


3. Cavity depth design (Sim3) = 1.50 m



Multi-Story Cavity section 1.50 m depth
cavity-AutoCAD

Vents openings at the top and bottom of
the multi-story cavity at external layer



multi-storey cavity has top and bottom
vents along building façade

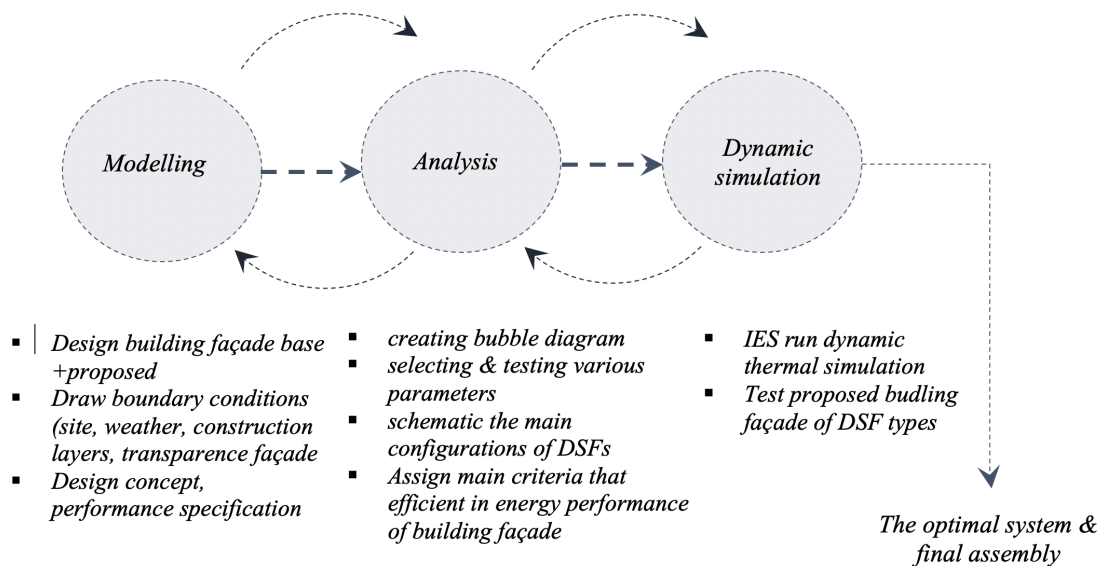
Case 4-Multi-storey cavity

Fig. 68 Multi-Story cavity models with three different cavity depth (sim1, sim2, sim3) , view image 3D-geometry (sun-cast image view, (right) long cross section details of air cavity. source(author)

Overall, this study investigated four-DSF types categorized by partitioning cavity (*Box-Window, Shaft-Box, Corridor and Multi-Storey facade*) for multi-used building. Tested potential propose of natural ventilated DSF design for enhancing energy efficiency of the building in hot-climate by using IES-VE. The simulation runs systematically was carried out each case independently. The final results of each simulation case were arranged into algorithmic tables. Comparing each case of DSF made up of different scenarios under a numerous parameter and obtained the efficient scenario in terms of the energy and thermal performance and airflow. The fig. (69) describes the methodology structure conducting strategies of this research.

The following flow chart describe the Designing process of façade; is not a linear but it relied on regular feedback.

Designing process of façade



Simulation Methodology Research Structure

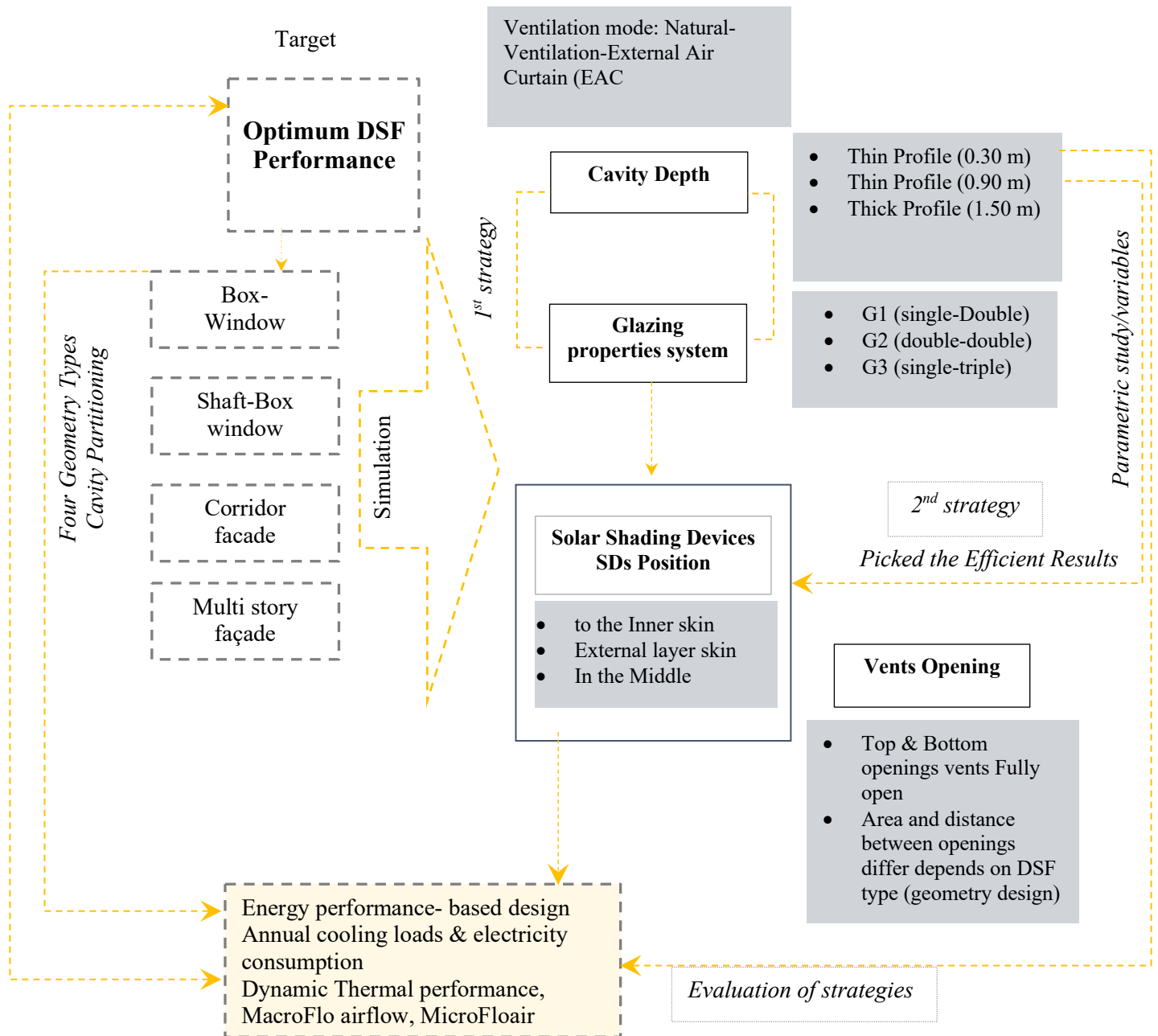


Fig. 69 Flow chart reflects the process of simulation the four DSF types methodology based on numerous parameters.
Source: Author

Table: Matrix of the proposal building façade design (DSF)

Case/ Structure Types	Design Parameter	Parametric design classification		
		Scenario	Static Variables	
1. Box-Window 2. Shaft-Box 3. Corridor 4. Multi-Story	Cavity depth	a. Thin profile (0.30 m) b. Thin profile (0.90 m) c. Thick profile (1.50 m)	Location(site) orientation Built area ratio	Al-Ain city-UAE
	Shading devices-SDs Vertical louvers	Position of vertical louvers within the cavity: a. Exterior layer skin b. In the Middle c. Close to the Inner skin	Ambient Outdoor conditions Weather profile	Temperature °C Relative Humidity% Air speed as described in climate analysis sec...4.3
	Cavity opening vents on the external skin	a. (0.50m) width of the top b. (0.50m) width bottom outlet and inlet vents c. fully open all the year	Existing structure construction of roof, floor, int. and ext. wall	As mentioned in base construction sec...4.4
	Outer & Inner skin glazing properties with combination system	Specific thermal properties sec... a. G1-Single-Double b. G2-Double-Double c. G3-Single-Triple	Dimensions (width, height, depth) 3.5 m each floor	
	Height of the cavity (m)	Varies from 3.50m to 10.50m based on DSF geometry type	Ventilation mode	Natural for external vents
			Space condition	24°C cooling set temperature point
			occupancy density m ² /person	All rooms are Default. There are 4 people live in validity flat
			Vertical louver solar shading width and structure parameters	perpendicular oriented faced with 0.20 m width, varies in height

*All DSF cases system will cover three building envelopes at (south, east & north facing facades), take in consideration the building area ratio, thermal material properties, construction requirements meet under Estidama code for sustainability and achieving higher efficient energy performance of the building.

Table 17 Matrix of the proposal building façade design (DSF)

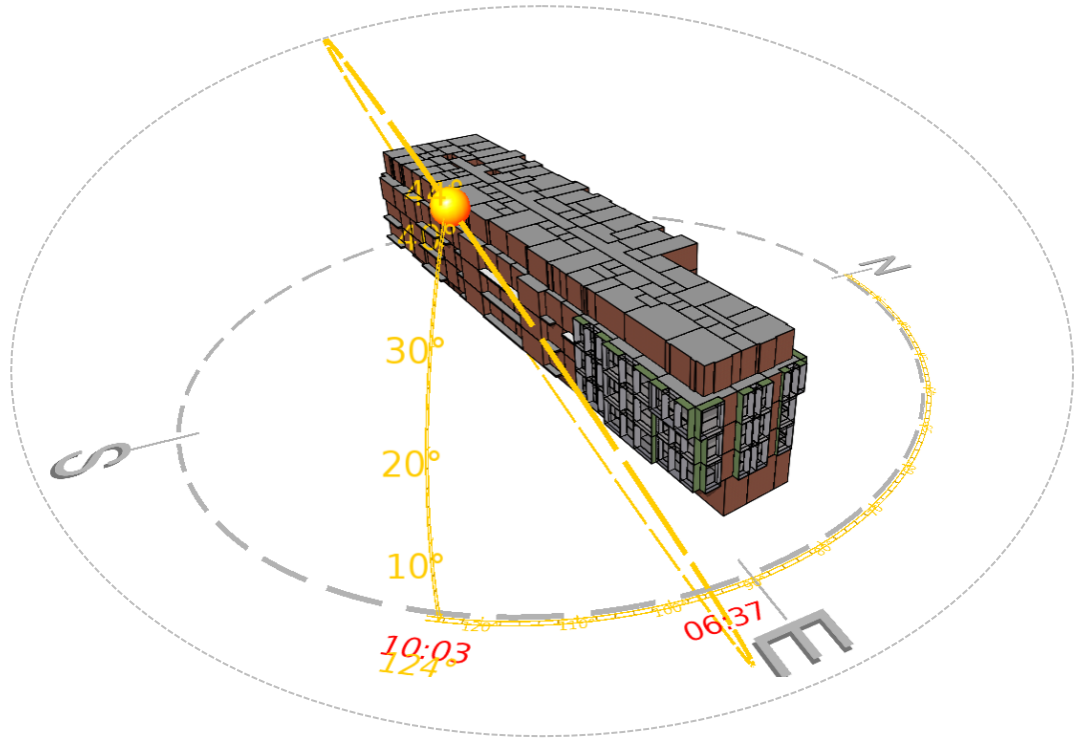


Fig. 70 Isometric illustrates the proposed DSF system employing on the existing reference base case. source(author)by IES software tool

CHAPTER FIVE

RESULTS AND DISCUSSIONS

5. CHAPTER 5 RESULTS AND DISCUSSION

5.1 OVERVIEW

This chapter will address the final results simulation of the proposed cases of DSF system associated with energy modeling were derived from IES-VE software. This study was adopted different applications in dynamic thermal simulation which play a key role in observing the relationship between the numerical values and virtual simulation for clarifying and understanding the proposed building façade design through providing prediction supported by other applications in order to analyze the final results of each scenario.

Determining the optimal performance of DSF design in hot-arid climate depends on observe the overall results by comparing each DSF type in respect with thermal performance and improving in reduction cooling loads against the current state of typical building façade (reference base). The final simulation results of all DSF configurations depends on analysis the energy modelling of each case of DSF system by introduce the following:

1. Dynamic thermal energy performance includes (the total annual cooling loads and total annual electricity for the reference base case and all scenarios of DSF configurations).
2. MacroFlo refers to the air flow analysis.
3. Computational Fluid Dynamic (CFD) MicroFlo refers to the air velocity analysis.

5.2 SIMULATION STRATEGIES

The following table (18) summarized the simulation map process of the whole study including the selected tested variables and parameters which assumed influenced on the energy performance of the DSFs building. The study includes four major models of DSF type divided into four tested cases (*Box-Window*, *Shaft-Box*, *Corridor* and *Multi-Storey facade*). Optimization analysis depends on assume different inputs parametric to run energy model, the

final results illustrate into algorithmic graphed to observe the efficient performance. However, the simulation strategies are divided into two strategies processes for testing the energy performance of DSF the total annual cooling sensible loads and total electricity (MWh) for each type separately under the same boundary conditions:

*Reference base case model validate & verified to this study								
1 st strategy based on changing glazing properties with various cavity depth								
Energy modeling simulation	Case1 Box-Window Facade		Case2 Shaft-Box Facade		Case3 Corrido Facade		Case4 Multi-Story Facade	
Scenario 1	Sim1 (0.30 m cavity depth)	G1 G2 G3	Sim1 (0.30 m cavity depth)	G1 G2 G3	Sim1 (0.30 m cavity depth)	G1 G2 G3	Sim1 (0.30 m cavity depth)	G1 G2 G3
Scenario 2	Sim2 (0.90 m cavity depth)	G2 G2 G3	Sim2 (0.90 m cavity depth)	G2 G2 G3	Sim2 (0.90 m cavity depth)	G2 G2 G3	Sim1 (0.90 m cavity depth)	G2 G2 G3
Scenario 3	Sim3 (1.50 m cavity depth)	G1 G2 G3	Sim3 (1.50 m cavity depth)	G1 G2 G3	Sim3 (1.50 m cavity depth)	G1 G2 G3	Sim1 (1.50 m cavity depth)	G1 G2 G3
2 nd strategy based on changing Shading Devices SDs position								
Energy modeling simulation	Case A Box-Window Facade		Case B Shaft-Box Facade		Case C Corrido Facade		Case D Multi-Story Facade	
Scenario A	Sim1 (0.30 m cavity depth)	inner middle external	Sim1 (0.30 m cavity depth)	inner middle external	Sim1 (0.30 m cavity depth)	inner middle external	Sim1 (0.30 m cavity depth)	inner middle external
Scenario B	Sim2 (0.90 m cavity depth)	inner middle external	Sim2 (0.90 m cavity depth)	inner middle external	Sim2 (0.90 m cavity depth)	inner middle external	Sim2 (0.90 m cavity depth)	inner middle external
Scenario C	Sim3 (1.50 m cavity depth)	inner middle external	Sim3 (1.50 m cavity depth)	inner middle external	Sim3 (1.50 m cavity depth)	inner middle external	Sim3 (1.50 m cavity depth)	inner middle external
MacroFlow for the optimal case of DSFs type around south, east and north direction								
MicroFlo CFD (the air velocity and the air temperature) for a selected area in south and east façade of each DSF type								
*Note: The function of each scenario derives 3 variables compare with fixed parameter (changed in each scenario) into 3 trials that leads to 9 total simulations of each case and 36 total scenarios of 4 cases. The study attempted to reveal the relationship between each other in enhancing the energy performance and thermal comfort of ventilated DSF in hot arid climate. similar thing for next strategy reached to 36 cases in total. Resulting in 72 scenarios runs simulation by IES								

Table 18 Simulation map process of all DSF tested cases. Source: (Author).

- **The 1st strategy** is to observe the optimum cavity depth and glazing properties of each DSF case by rendering the four DSF cases (Box window, Shaft-box, Corridor and Multi-story) without solar shading devices. Three scenarios of each DSF case were proposed based on different air cavity depth and glazing properties, the 1st category parameter refers to three different air buffer width called (sim1, sim2, sim3) setting by (0.3m, 0.9m and 1.5m width respectively), the 2nd category parameter refers to changing the glazing properties refers to choose three glazing options (G1, G2, G3) as explained previously in sec. table (18) the comparison based on analysis the total annual energy consumption for each DSF type.
- **The 2nd strategy** is to observe the optimum shading device SDs- vertical louvers positions used for each DSF type. The optimum results from previous strategy were applied into 2nd strategy for investigation. Similarly, three scenarios of different SDs positions were proposed of each DSF type refer to (internal, middle and external position within the air cavity). The 2nd strategy process picked the most efficient energy performance results for each type of DSF in respect with the 1st strategy (saving energy consumption) for achieving the optimal DSF performance and saving rendering time.

5.3 ENERGY CONSUMPTION RESULTS

5.3.1 THE REFERENCE BASE ENERGY MODEL (ANNUAL ENERGY CONSUMPTION OF THE REFERENCE BASE)

The energy performance analysis of the reference base; the numerical data is derived from dynamic thermal simulation IES software. The table (19) presents the total annual energy consumption represented with the total annual cooling loads and the total electricity of the reference base building of three stories as described earlier. It is clearly seen, that the hottest months from May to August records the highest readings of both cooling and electricity consumption loads in range between (27.24 MWh to 35.13 MWH). In contrast, the lowest reading in cooling loads is (12.06 MWh) in December. The total annual cooling plant sensible

of the base case and the total annual electricity consumptions reached to 246.21 MWh, 123.10 MWh respectively. These final records of the reference case are used for comparing and assessing the overall energy performance of the proposed design of DSF retrofitting existing building envelop.

The Reference Base Case		
Date	Room cooling plant sens. load (MWh)	Total electricity (MWh)
Jan 01-31	14.88	7.44
Feb 01-28	15.25	7.63
Mar 01-31	16.54	8.27
Apr 01-30	16.61	8.30
May 01-31	29.19	14.60
Jun 01-30	27.24	13.62
Jul 01-31	34.80	17.40
Aug 01-31	35.13	17.56
Sep 01-30	15.54	7.77
Oct 01-31	15.35	7.67
Nov 01-30	13.59	6.80
Dec 01-31	12.06	6.03
Summed total	246.21	123.10

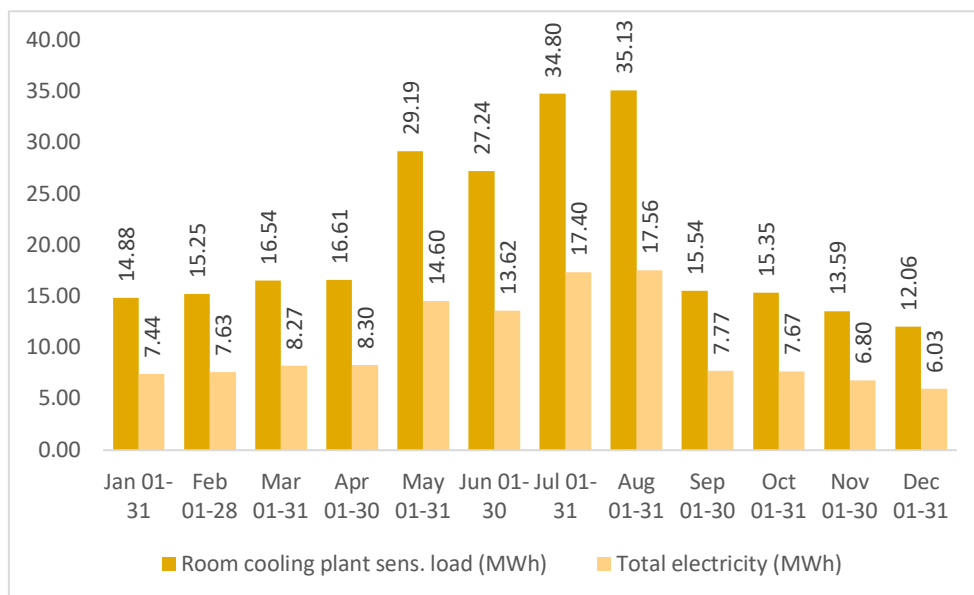


Table 19 The total annual cooling loads (MWh) and total monthly electricity consumption (MWh) of the reference base case as estimated by dynamic thermal simulation from IES-VE software

5.4 THE FIRST STRATEGY ANALYSIS (EFFECTS OF THE GLAZING PROPERTIES AND CAVITY DEPTH)

The first strategy based on adjusting the cavity width and glazing types characteristics for each case of DSF types independently without installing solar shading devices in terms of enhancing annual energy consumption of the building, and comparing the final results of each scenario with reference base case. The following tables from (20-23) listed the final results of annual energy consumption of dynamic thermal simulation for the four proposes design of DSF types (**Case1- Box-window, Case 2- Shaft-box, Case 3- Corridor and Case 4- Multi-storey**) setting up individually whereas each case has three scenarios:

1. **Scenario-1** is integration each DSF type at 0.30 m cavity width with three alternatives of glazing system, (sim1 with 3 glazing types G1, G2, G3)
2. **Scenario-2** is integration each DSF type at 0.90 m cavity width with three glazing system, (sim2 with 3 glazing types G1, G2, G3).
3. **Scenario-3** is integration each DSF type at 1.50 m cavity width with three glazing system, (sim3 with 3 glazing types G1, G2, G3).

5.4.1 CASE 1-THE BOX-WINDOW FACADE

The table (20) presents the total annual energy consumption results of the Box-Window-case1 comparing with the reference base case. The final result readings indicate that all scenarios show reduction in the total annual cooling loads and total annual electricity consumption with slightly various ratios compared to the reference base (recorded 246.21 MWh, 123.10 MWh) in total cooling loads and electricity consumption respectively. All scenarios are achieving relative reduction in the total annual cooling loads varies from 1.50% to 6% comparing with the base case.

In terms of scenario#1, the implementation of box window at 0.30 m depth with glazing properties G2 achieved the highest value in saving energy consumption resulted in 231.5 MWh of the total annual cooling loads and 115.76 MWh of the total electricity consumption, with reduction rate of up to 5.96% in cooling loads followed by 5.10%, 4.09% of G3 and G1 glazing respectively. In contrast, the scenario#2 at 0.90 m air cavity depth show lower efficiency of energy consumption than 1st scenario, reached to 237.3 MWh, 118.6 MWh of the total annual cooling loads and electricity respectively with a reduction ratio to 3.62% in cooling loads at G2 followed by G3, G1 (3.24% and 1.61%) respectively. On the other hand, the lowest value in reduction cooling loads reach to 242.65 MWh 1.45% represent secenario#3 at 1.50 m air cavity width integration with G1-glazing properties. It can be clearly seen, that the highest reduction in cooling loads was at (0.30 m air cavity depth) recorded 5.95 % comparing with others, followed by (0.90 m and 1.50 m air cavity depth) which are almost have closely equal results in decreasing energy consumption by (3.62%, 3.24% respectively).

Overall, the thinner cavity depth 0.30m continues to achieve the best effectiveness in saving energy consumption by integrating with the glazing G-2 characteristic which represented the optimal scenario (ideal glazing option) compared to others. The results indicate that the G-2 (double glazing at external layer and double glazing at inner skin) has the lowest value of SHGC reach to (0.1247) at external glazing layer and U-value conductivity (2.4773) resulting in decreasing cooling loads, improving thermal performance and achieved the highest efficient in reduction cooling loads of the DSF building. In contrast, the proposed glazing material G1 consumed more energy than G3 has higher the both of them has SHGC (0.2542) which used single glass at external layer. The findings indicate to, in respect with Box-geometry design, increasing heat storage capacity of the structure, encourage heat gain through cavity and enclosure of building. This indicates that the double glass has a higher capability to block solar

Case1-Box-Window

Cavity type: Box

Ventilation-mode: natural

The 1st scenario

The most efficient at 0.30m cavity width integration with G2 glazing system

The 2nd scenario

The 3rd scenario

The lowest reduction in cooling loads at 1.50m cavity width integration with G1 glazing system

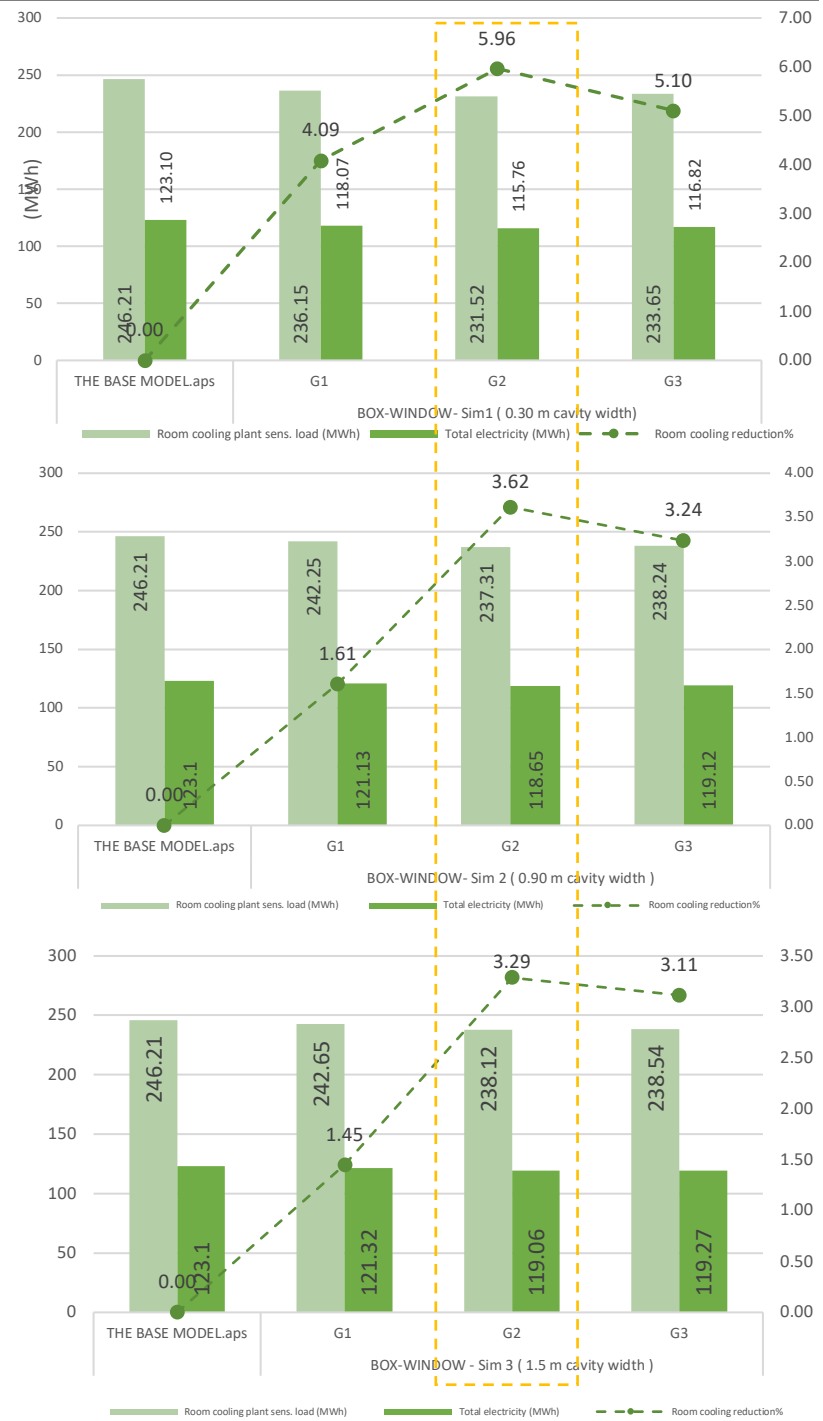


Table 20 The annual total cooling loads(MWh) & annual total electricity (MWh) of Box-window Fcade-Case-1 for 3 scenarios including 3 different cavity width (sim1,sim2, sim3) based on different glazing combinations (G1,G2, G3) comparing with (refence base case)comparing with (refence base case)

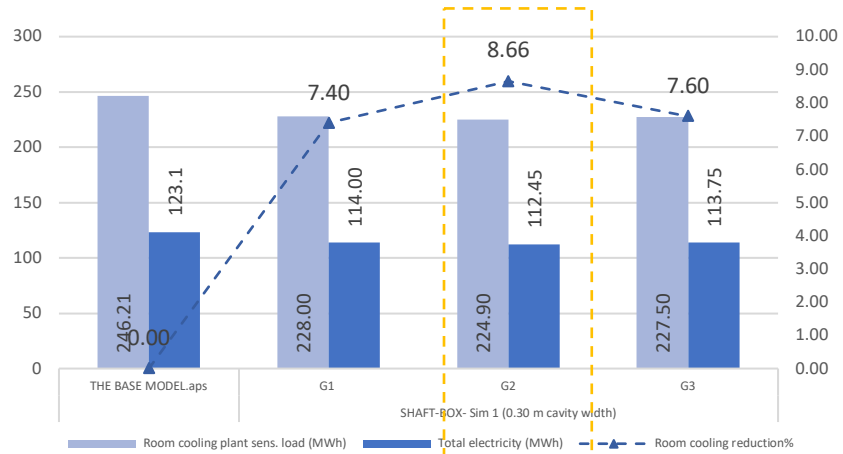
radiation through the window into the cavity and building. Besides, based on this finding, the bronze color of glazing materials could also help in reducing the heat transfer, thus heat gain into the cavity low-E low emissivity coating in IGU decrease heat gain transfer by reflecting long wavelength infrared radiation. Noticed: Glazing and cavity significantly effect.

Case 2-Shaft Box-Window

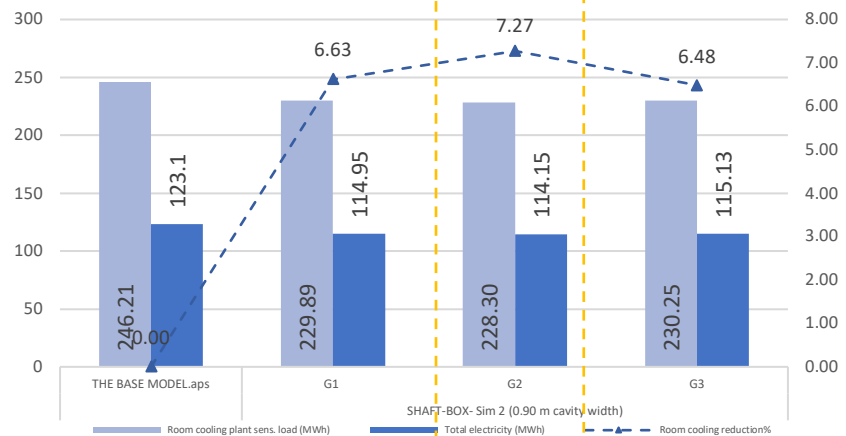
Cavity: Shaft-Box
Ventilation-mode: natural

The 1st scenario

The most efficient at 0.30m cavity width integration with G2 glazing system



The 2nd scenario



The 3rd scenario

The lowest reduction in cooling loads at 1.50m cavity width integration with G3 glazing system

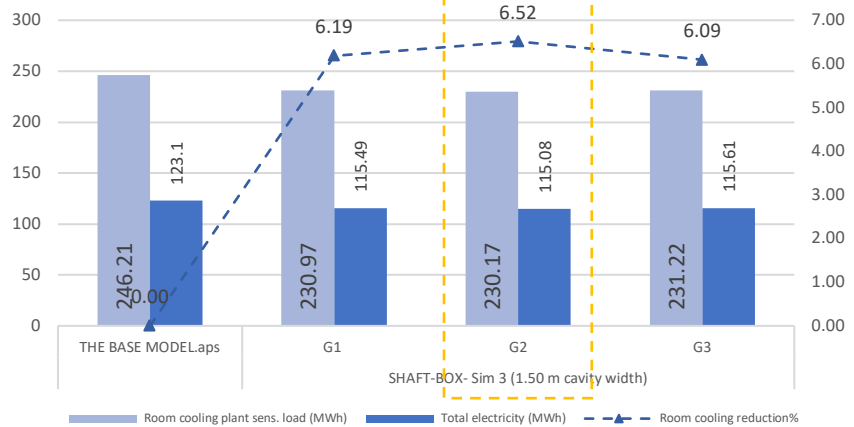


Table 21 The annual total cooling loads(MWh) & annual total electricity (MWh) of Shaft-Box Facade-Case-2 for 3 scenarios including 3 different cavity width (sim1,sim2, sim3) based on different glazing combinations (G1,G2, G3) comparing with (refence base case)

5.4.2 CASE2- THE SHAFT -BOX FACADE

The annual total energy consumption results of Shaft-Box-case2 table (21) achieved better performance than box-window-case3. In Box-window, the optimal reduction in cooling loads

is 5.96% while is about (8.66%) for the Shaft-box which indicate much higher improvement in energy efficacy than previous case thanks to the stack shaft design of this case.

All scenarios represent noticeable reduction in the total annual energy consumption, and experienced a steady slightly different levels in reduction energy consumption of all scenarios. In scenario#1 at 0.30 m cavity depth, the maximum energy consumption is 228.00 MWh (7.40% reduction cooling loads) at G1 followed by 227.50 MWh (7.60%) at G3, while 224.90 MWh (8.66%) at G2 shows the optimal scenario comparing with others. The results of both scenario#2 and scenario#3 indicate a slight approximately in saving energy consumption, at G1 the annual cooling loads reach to (229.90 MWh, 230.9 MWh for scenario 2 and 3) respectively. Similarly, at G3 the annual cooling loads are (230.25 MWh, 231.22MWh) for 2nd and 3rd scenarios respectively. The final result readings indicate that changing thermal glazing performance with the same cavity depth has not remarkable effect (does not considerable noticed) on reduction the annual cooling loads and shaft-box performance, comparing with box-window which clearly seen that glazing systems have remarkable difference between other scenarios. In contrast, it can be noticed that transition from thinner profile to thicker profile (sim1, sim2, sim3) decreased the total annual cooling consumption significantly from (8.66%, 7.27%, 6.52% respectively). Similar findings match to the Box-window that the final readings in terms of air cavity depth 0.30m integration with glazing system (G2) represent the efficient performance (optimal) among other scenarios. In contrast, the glazing system (G3) shows the lowest saving cooling loads 231.22 MWh reached to 6.09% reduction rate at 1.50 m cavity depth. On the other hand, the overall scenarios range of saving cooling loads are related approximately between 6.09% to 7.60% against the reference case, that indicated to the sufficient shaft-box design in mitigating accumulate heating within DSF cavity. These results concluded that the shaft-box window affected by stack shaft geometry design more than

glazing properties in terms of reduction cooling loads. the stack effect is the key parameter of improving the saving cooling reduction by decreasing accumulation hot air at the top of each box and extracted via top side vents opening where connected into the stack buffer (core) finally push air up from the top vent. In addition, the vents openings system characteristics differ than box-window openings vents. parallel with box-window that thinner air cavity profile achieved better in reduction energy consumption than 0.90m and 1.50 m cavity width.

5.4.3 CASE3-THE CORRIDOR FAÇADE

The final results of annual energy consumption for case-3-Corridor façade represents different trends in reduction annual energy consumption compared to previous cases as shown in table (22). It is clearly noticed, that all scenarios achieved great reduction with remarkable differences in the final results of saving annual energy consumption. Corridor façade achieved higher rates of enhancing overall saving energy consumption in comparison with previous results for both cases (Shaft-Box and Box-window). In scenario#1 at 0.30m cavity width integration with G2, the annual energy consumption reached to 224.54 MWh of annual cooling loads and 112.27MWh in annual electricity account the highest reduction cooling rate about (8.80%) among other scenarios. followed by scenarios G3 and G1 with (7.17% ,2.59% respectively). These results indicate that the corridor design structure influenced by changing the physical glazing properties more than cavity depth. Changing the air cavity depth from thinner to thicker profile (0.30 m to 1.50 m) show slight effect on final results of annual energy saving. In contrast, a remarkable difference in final results when adjusting glazing properties at the same scenario. The final results among all scenarios at G1 properties represents the lowest reduction in cooling loads rate about (2.60%, 3.4%, 3.7%) for the air cavity (0.30m, 0.90m and 1.50m respectively), these results indicate that employing the common system of glazing layers G1 (single-double) is not efficient in such this case. The other scenarios at (0.90

m air cavity depth and 1.50m cavity depth) integration with (G3) show better performance in saving cooling loads with related range from (6.38% to 7.10%).

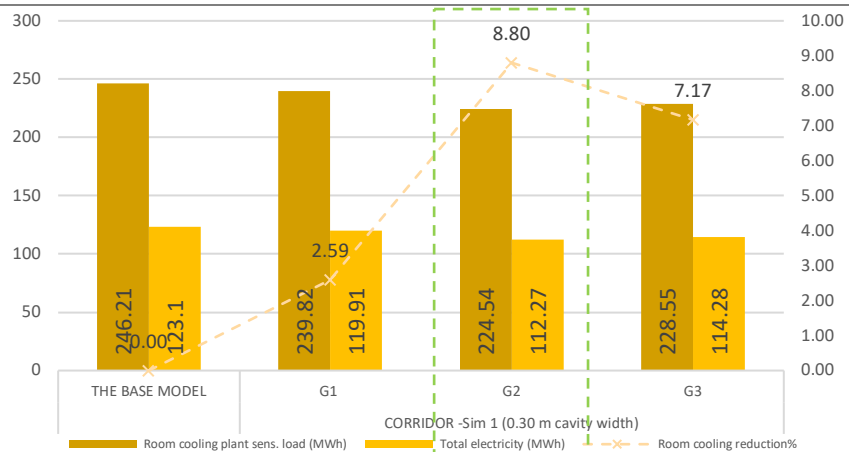
Overall, the trends clearly noticed (observed) that glazing properties has higher impact on the corridor façade performance than air cavity width. Improving the corridor façade performance in saving energy consumption depend on selecting proper thermal properties of glazed surface to improve the hating transfer process between façade layers. Corridor façade cavity design featured by wide glazing surface area covered along each story without vertical mullions (partitions). In addition, the physical thermal properties external layer skin of single glazing has higher SHGC= 0.2542 than G2 glazing properties.

Case 3- Corridor Facade

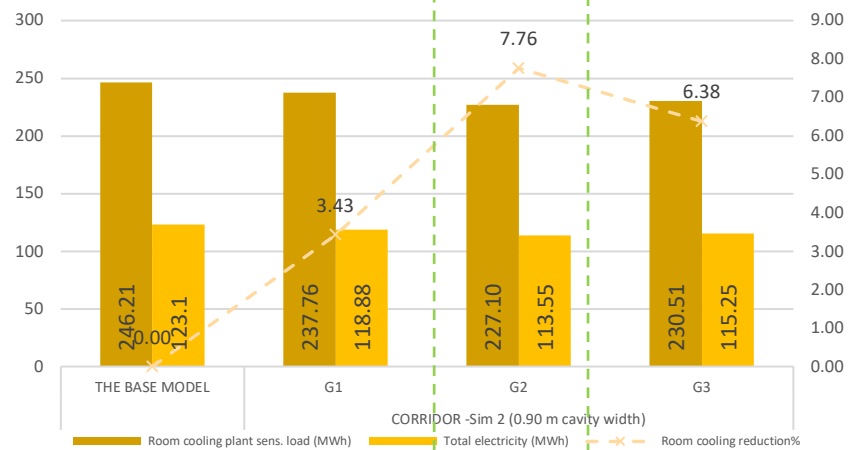
Cavity: corridor cavity

Ventilation-mode: natural

The 1st scenario



The 2nd scenario



The 3rd scenario

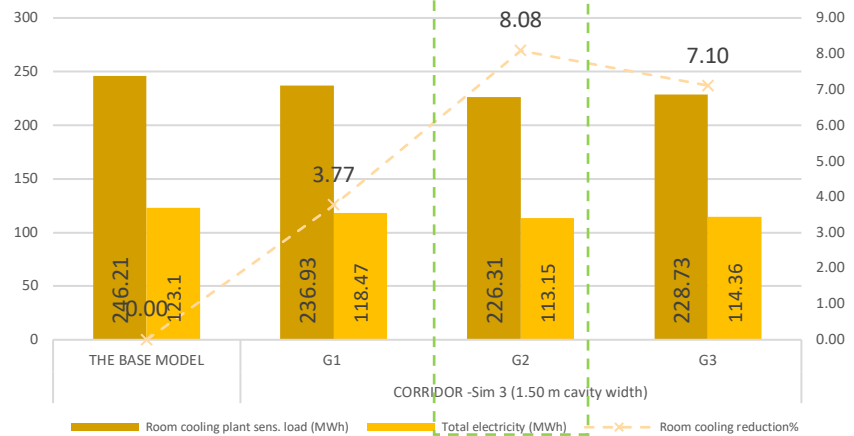


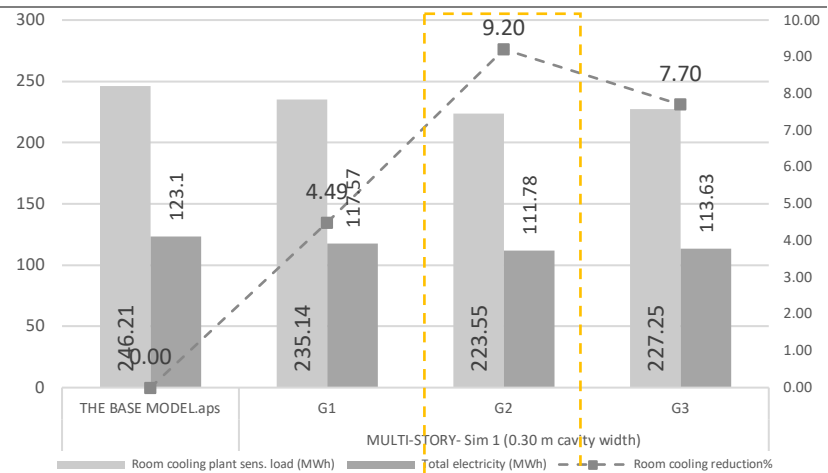
Table 22 The annual total cooling loads(MWh) & annual total electricity (MWh) of Corridor Facade-Case-3 for 3 scenarios including 3 different cavity width (sim1,sim2, sim3) based on different glazing combinations (G1,G2, G3) comparing with (refence base case)

5.4.4 CASE4-THE MULTI-STORY FACADE

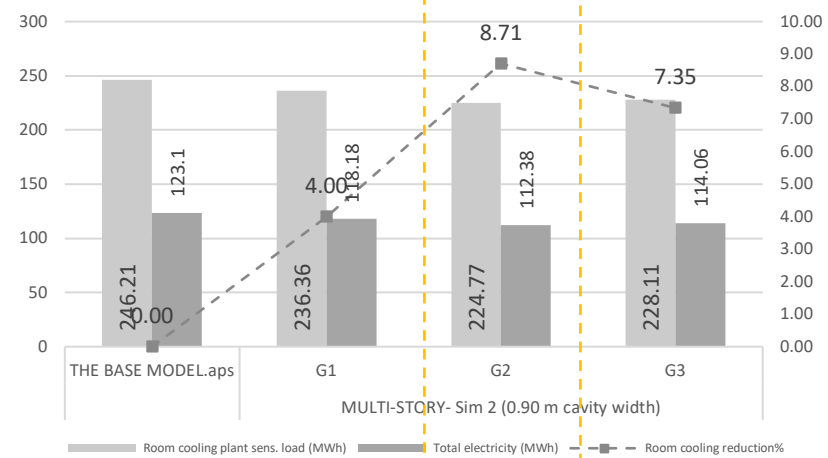
The Multi-Storey cavity-case4 contribute to the highest annual energy saving among all DSF types of about 9.20 % (223.55 MWh) as illustrated in table (23). The final results indicate that the Multi-Storey facade has a higher capability to decrease solar radiation into the cavity and building, resulting in significant reduction cooling loads.

All scenarios achieved remarkable decreasing in annual energy consumption in compare to the reference case; at G2 scenarios show a related range (223.5 5MWh, 224.77 MWh, 225.23 MWh) or about (9.20%, 8.71%, 8.52%) in annual cooling loads reduction for (sim1, sim2, sim3 respectively), followed by scenarios at G3 with slightly closed results (227.25 MWh, 228.11 MWh, 228.09 MWh) or about (7.70%,7.35%,7.36%) in annual cooling reduction also for (sim1, sim2, sim3 respectively). In contrast the scenarios related to the G1 type introduce the lowest results in improving energy performance with (4.49%,4.00%,3.82%) or about (235.14 MWh, 236.36 MWh, 236.81 MWh) in annual cooling loads for (sim1, sim2, sim3 respectively). The final results represent similar trend of saving cooling loads similar to the previous case of Corridor Façade. The significant difference in final results between scenarios related to glazing properties, , the glazing type has higher impact on the Multi-Storey façade performance than air cavity width. The results also match with previous results of Corridor, Shaft-Box, and Box window cases; that the thinner profile at 0.30m cavity width integration with glazing combination (G2) show the optimal scenarios in improving energy performance of the building. In contrast, the G1 scenarios represent the lowest results in saving energy consumption in compare with other glazing properties. The final results concluded that changing glazing type to efficient thermal properties highly insulated type reduced the cooling loads from 4% to 9%

Case4- Multi-Story
Cavity: multi-story cavity
Ventilation: natural
The 1st scenario



The 2nd scenario



The 3rd scenario

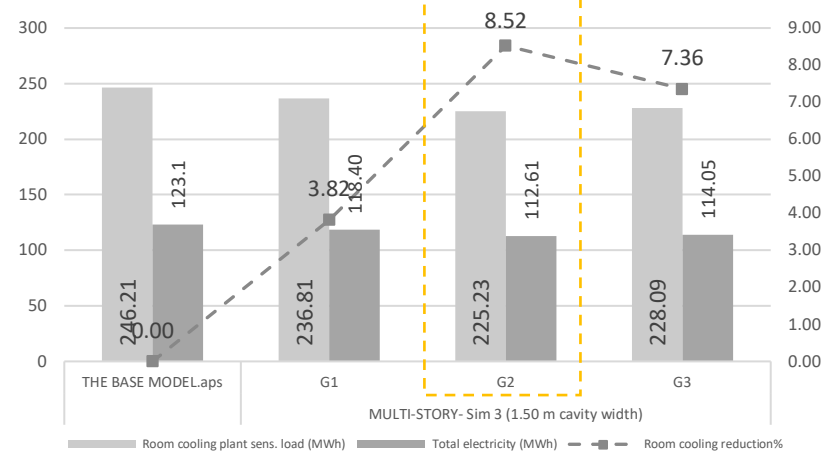


Table 23 The annual total cooling loads(MWh) & annual total electricity (MWh) of Multi-Story Fcade-Case-4 for 3 scenarios including 3 different cavity width (sim1,sim2, sim3) based on different glazing combinations (G1,G2, G3) comparing with (refence base case)

5.4.4.1 SUMMARIZED THE FINAL RESULTS OF THE 1ST STRATEGY

The fig. (71) presents an overall summarize of comparison the final results of the annual cooling loads represented by all scenarios of the 1st strategy for tested four DSF types (Box-Window, Shaft-Box, Corridor and Multi-Storey Façade) with the reference base case. Generally, all final scenarios results have achieved a reduction in annual cooling loads in various proportions ranging from (1.50% to 9.20%) compared to the reference base , thanks to the impact of the air-cavity, vents openings and the glazing properties of the double-skin, and DSF typologies (geometry) which are important for enhancing DSF performance. Above findings confirms that the natural ventilated DSF with multi-story cavity is sustainable construction solution offer saving for conventional building in hot climate. The final findings concluded:

- **With respect to the air cavity width:** The smaller air cavity depth, the lower energy consumption but with the slight gradual rate of reduction from 0.30m to 1.50m.
- **With respect to the glazing properties:** the more efficient glazing system the lower SHGC of external glazing layer, the lower energy consumption. the external layer glazing is the most effect on the total energy consumption.
- **With respect to the openings area size:** the larger ratio opening vents and the larger height difference between inlet and outlet, the lower energy consumption

The final findings were consistent/matched with relevant previous studies;

- a. Determining the optimal DSF case configuration system is the achieving the most efficient energy consumption, the final findings indicate that the Multi-Storey represents the best-case scenarios of DSFs, followed by Corridor, Shaft-Box and Box-Window facade. Employing DSF in hot region can decrease absorption of direct and indirect solar gain in adjacent rooms of DSF.

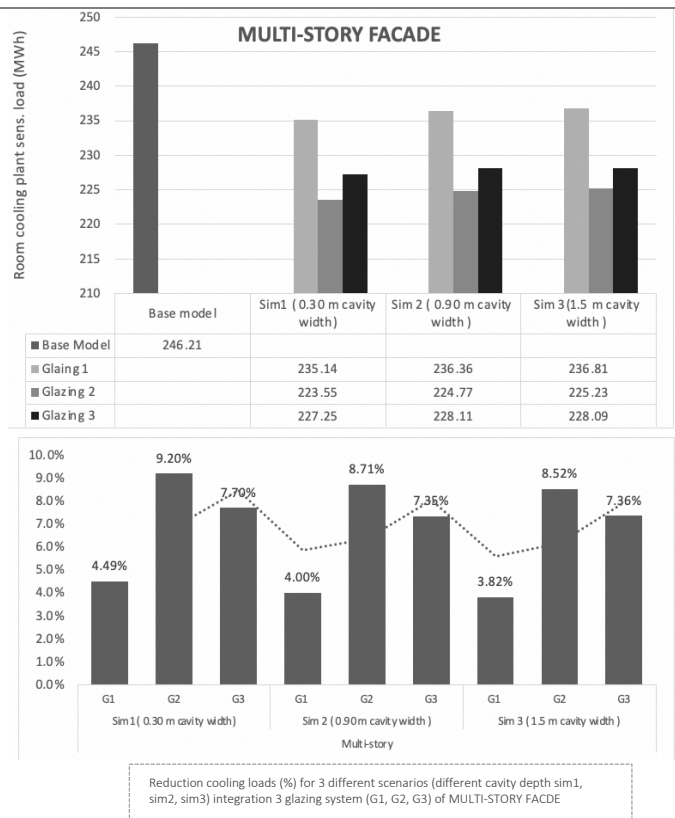
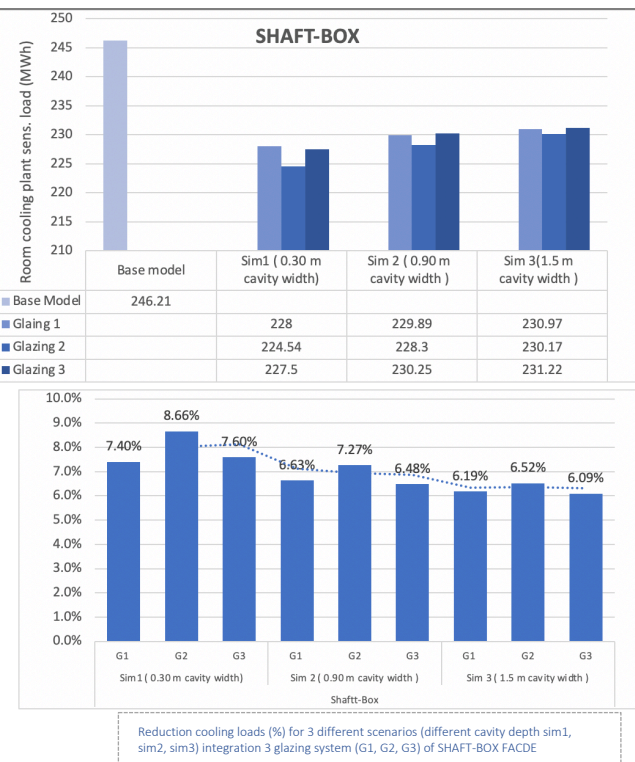
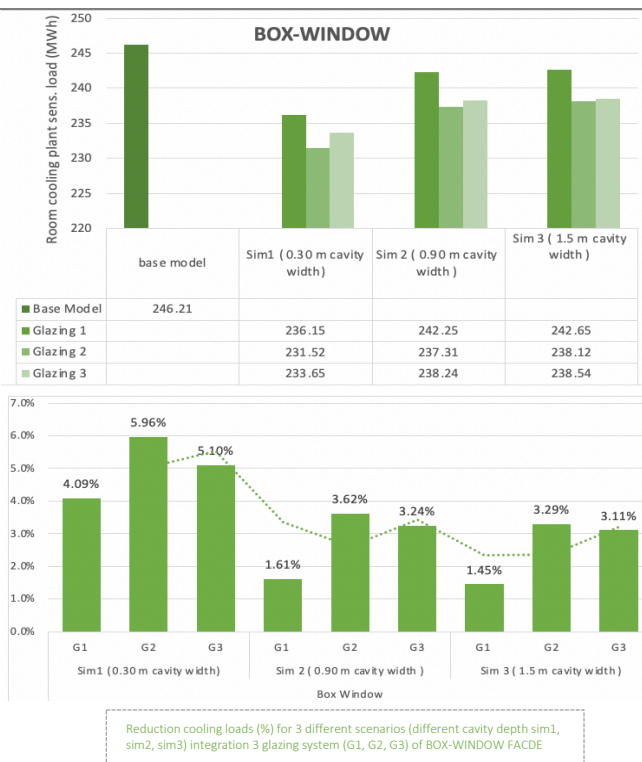


Fig. 71 Comparing the total annual cooling consumption MWh and the saving cooling reduction (%) between the 4 DSF types of the 1st-strategy and comparison with the reference base case

- b.** Changing the cavity depth is the major parameter influenced the efficiency of energy performance of DSFs followed by the glazing properties. Overall findings indicate that thinner profile cavity at 0.30 m width is the optimal depth in this case, decreasing the cavity depth (narrower air space) creating better performance in extracting the hot air rapidly than thicker profile. the results confirmed numerous studies stated that, (Velasco et al. 2017) found the lower the width of air cavity, increase the heat gains as it decreases the global heat transfer coefficient of the module, and (Lim & Ismail 2018) found that DSF with 500mm achieved the highest potentially to decrease the annual energy consumption, they found that thinner profile received lower solar radiation level than thicker profile (1000 mm and 1500mm), which received the higher solar radiation. also be due the optimum depth of the cavity offers a better stack effect to remove excessive heat from air space. (Regazzoli 2013) the energy efficiency of DSF increased between 200mm and 600mm cavity depth, while decreasing in efficiency at 1200mm. less efficient, the grater the cavity depth. In this study the most scenarios of all DSF models show gradually reduction of annual energy consumption from the DSF model with 1.50 m to 0.30 m. the DSF in 300 mm cavity depth consumed the lowest energy and saving energy of up to 9.20%.
- c.** Thermal properties of the air cavity of each DSF case may vary from case to another according to the difference of DSF types. Optimization air cavity depth reducing energy consumption by 0.6%(Joe et al. 2014) also the cavity depth related to influence on greenhouse effect and natural ventilation, so selected a suitable cavity depth depending on climate conditions in the region where building is located.
- d.** The external cavity's openings and the distance between the bottom inlet and top outlet the main affective parameters. The vents affect the air temperature, the buoyancy force and flow resistance within cavity. Optimal openings vents reduce greenhouse effect by promote

the air circulation within the cavity and evacuated the inner hot within the air cavity to the outlet.

- e. The geometry building façade and the physics heat transfer process of air buffer within the cavity and the box-window frame structure elements may play significant role in reduction the inner building temperature through blocking and reflecting the sun helps lower the accumulation of heat inside.
- f. The capacity of heat absorbing within the air cavity differ among all DSF types, it causing in different temperature increasing heat storage.
- g. Corridor case comparing to shaft-box under the same conditions achieved related cooling reduction by (8.80% and 8.66% respectively) both levels are almost close to each other just slightly lower. shaft-box depends on the geometry structure design of shaft box.
- h. The results indicate importance of external glazing layer properties in reduction solar heat gain in cavity. The glazing system G2 combination thermal properties provides the efficient performance might be the ideal type for the buildings that required high cooling demands, its capability in reducing solar heat gain. The SHGC of external glazing layer G2 reached to 0.1247 is the lowest value in compare with others and lower conductivity of the external glazing layer U-value reached to 2.4773 W/m²K, also filling with krypton gas which represents higher thermal insulation capacity.

Generally, evaluation the energy performance and comparing the four types of DSF are complex algorithm task and built under many criteria, according to this study the observations of the efficient energy performance façade might related to the geometry façade design, structure and construction materials of DSFs. It obviously noticed, the building with multi-story DSF type at 0.30m cavity depth integration with G2 properties gazing type provided the greatest reduction cooling loads among others due to its cavity-height follow by shaft-box and

corridor. That indicate the height of the building façade is crucial to the DSFs performance due to optimization the buoyancy effect through removing the internal heat by introducing cooler air ventilation across the cavity space. So, the multi-story, corridor and shaft-box could be the efficient types to avoid rising temperature inside the building and suitability for natural ventilated buildings. On the other hand, the box-window case shows the lowest efficiency in improving energy performance due to many reasons; thermal mass of geometry model, greenhouse effect, and the height difference between the air-inlet and air-outlet openings is smaller than multi-story and other cases, are increasing heat gains within cavity.

5.4.4.2 ANALYSIS AND COMPARING BASED ON THE GLAZING UNITS

The study draws another analysis graphs for more clarification of the final results as shown in fig. from (72-to-74) represents algorithm comparison of dynamic thermal simulation between each DSFs types in respect with glazing combinations (system) in order to observe the relationship between the glazing system and the DSF thermal performance:

a. Glazing (G1) combination of (single-double pane) scenario in fig. (72):

1. Shaft-box cavity depicts the best energy performance among the DSF's types at siml (0.30 m) cavity width, it achieved the highest reduction in annul cooling loads reached to 7.40% followed by multi-story cavity reduced cooling loads by 4.50% at 0.30 m cavity width. the results indicate that common glazing system of DSF is achieved better performance for Shaft-Box. The results assumed /pointed that the shaft stacks design is more influence than glazing properties in improving DSF performance.
2. The Box-window type at 1.50m cavity width represents the lowest results in decreasing the cooling loads by just only 1.45% (242.65 MWh) followed by 1.61% (242.25 MWh) at 0.90m cavity width. In contrast, decreasing the air cavity width to 0.30m improving

saving cooling rates to reach to 236.15 MWh by 4.09%. the results indicate that G1 combination reduce efficiency of Box DSF by increasing the greenhouse effect.

3. In corridor cavity type the sim3 (1.50) at thicker profile cavity represents the best scenario comparing with sim1 and sim2.
4. The total annual energy consumption of Multi-Storey façade and Corridor façade at sim2, sim3 experienced closely results about 236.3 MWh to 237.7 MWh. In contrast, the multi-story façade consumed lower cooling loads than Corridor façade at 0.30m there is relatively small difference in annual energy consumption about 4.68 MWh between (235.1MWh and 239.8 MWh respectively).

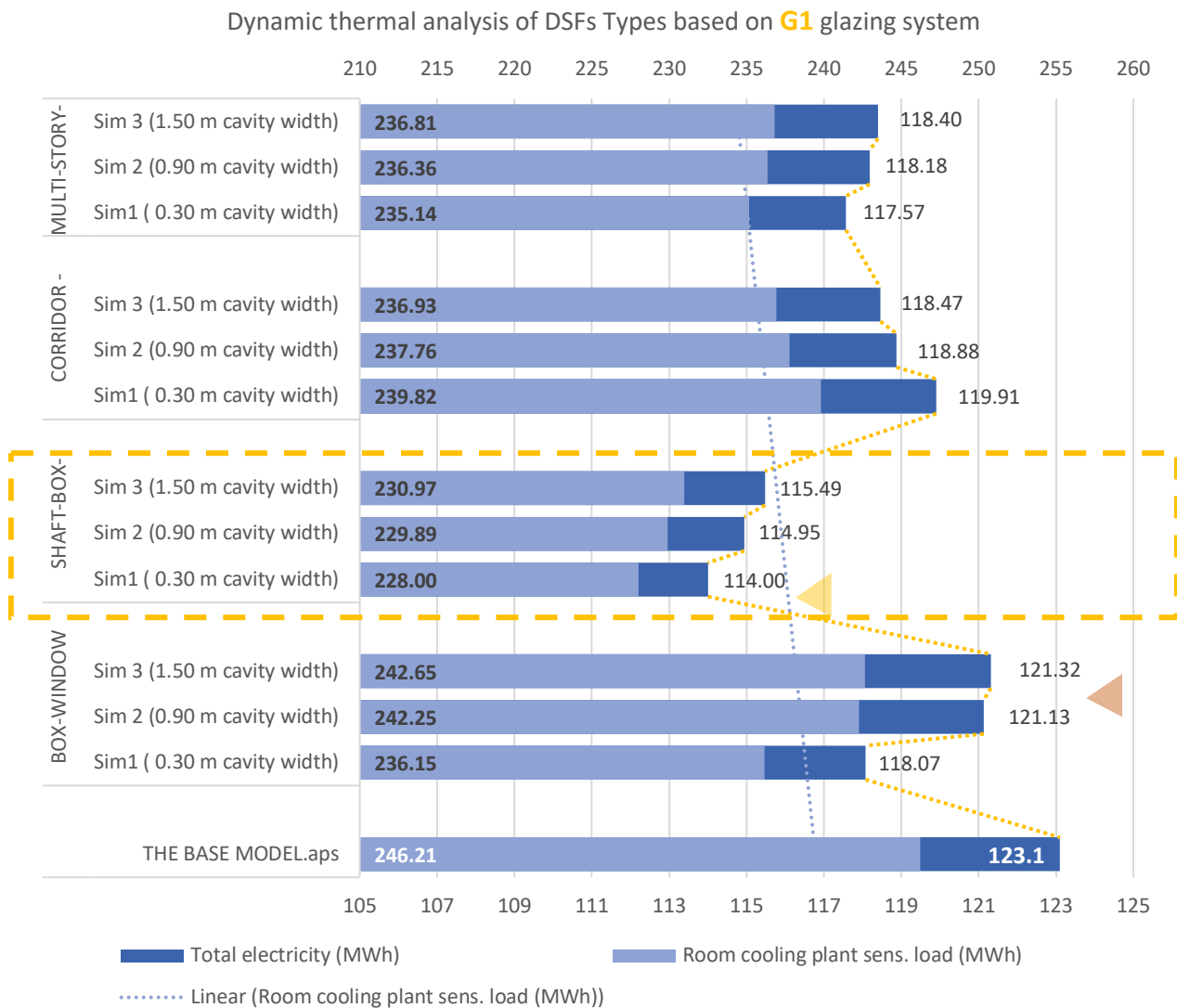


Fig. 72 Comparing annual cooling loads and total electricity of four DSF types for three different cavity widths (sim1,sim2,sim3) based on assigning glazing layers system (G1-Single-Double) with the Base Case

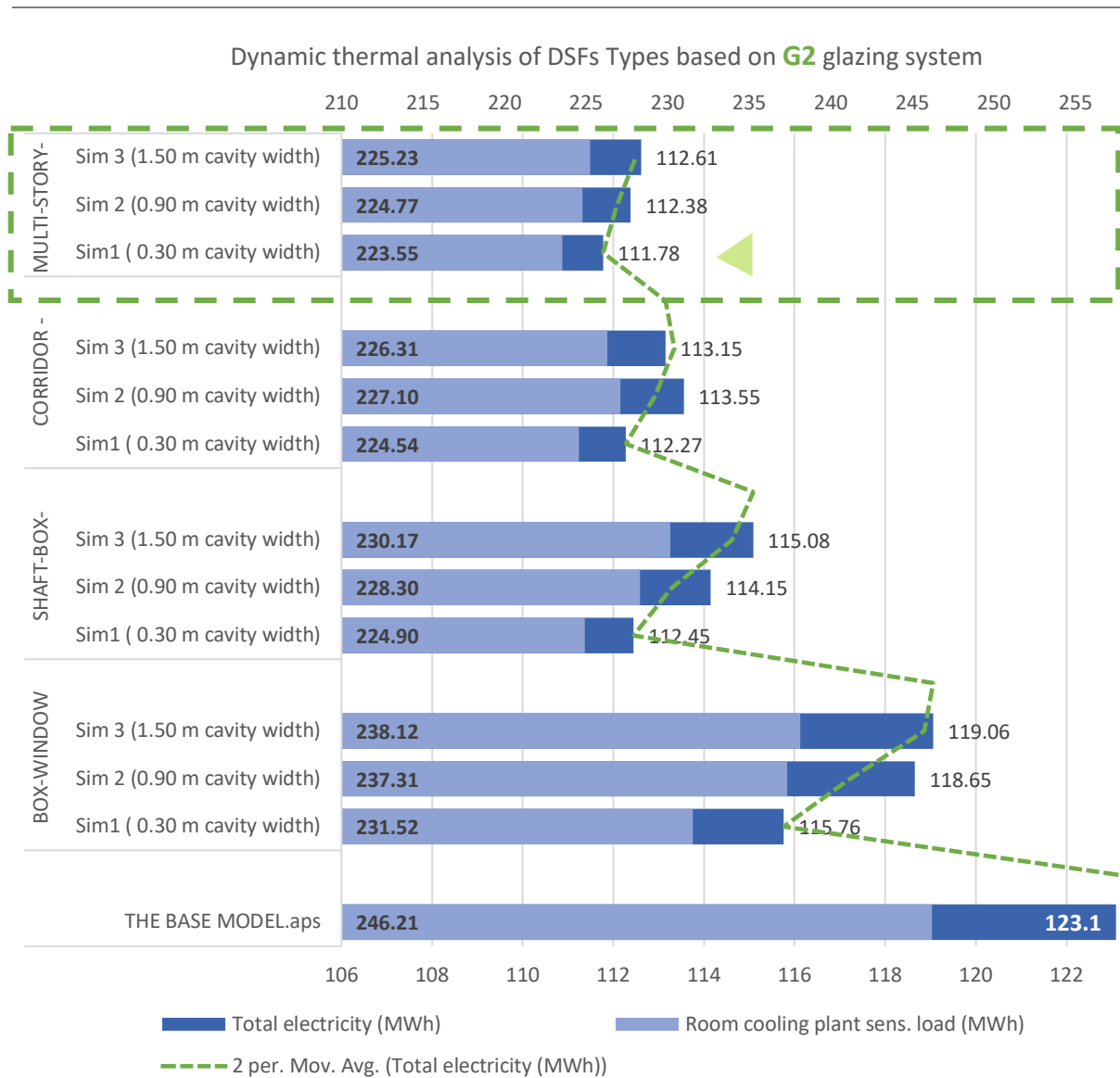


Fig. 73 Comparing annual cooling loads and total electricity of four DSF types for three different cavity widths (sim1,sim2,sim3) based on assigning glazing layers system (G2-Double-Double) with the Base Case

b. Glazing (G2**) combination (double-double pane) scenario in fig. (73):**

1. All DSFs results show better performance in improving energy consumption than previous glazing system G1. The results indicate, the importance of lower SHGC and U-value at external glazing layer when selected glazing system in DSF, increasing insulating capacity by reduction transmission of heat gain through cavity

2. The multi-story at sim1 (0.30 m) air cavity width achieved the highest reduction cooling loads reached to 9.20% comparing with other types followed by Corridor and shaft-box window at 0.30 m cavity depth to (8.80% and 8.66% respectively).
3. The saving cooling loads in box-window type at sim1 is 5.96% which represents the lowest levels comparing with other types, but, in general it achieved better performance than G1 scenarios.

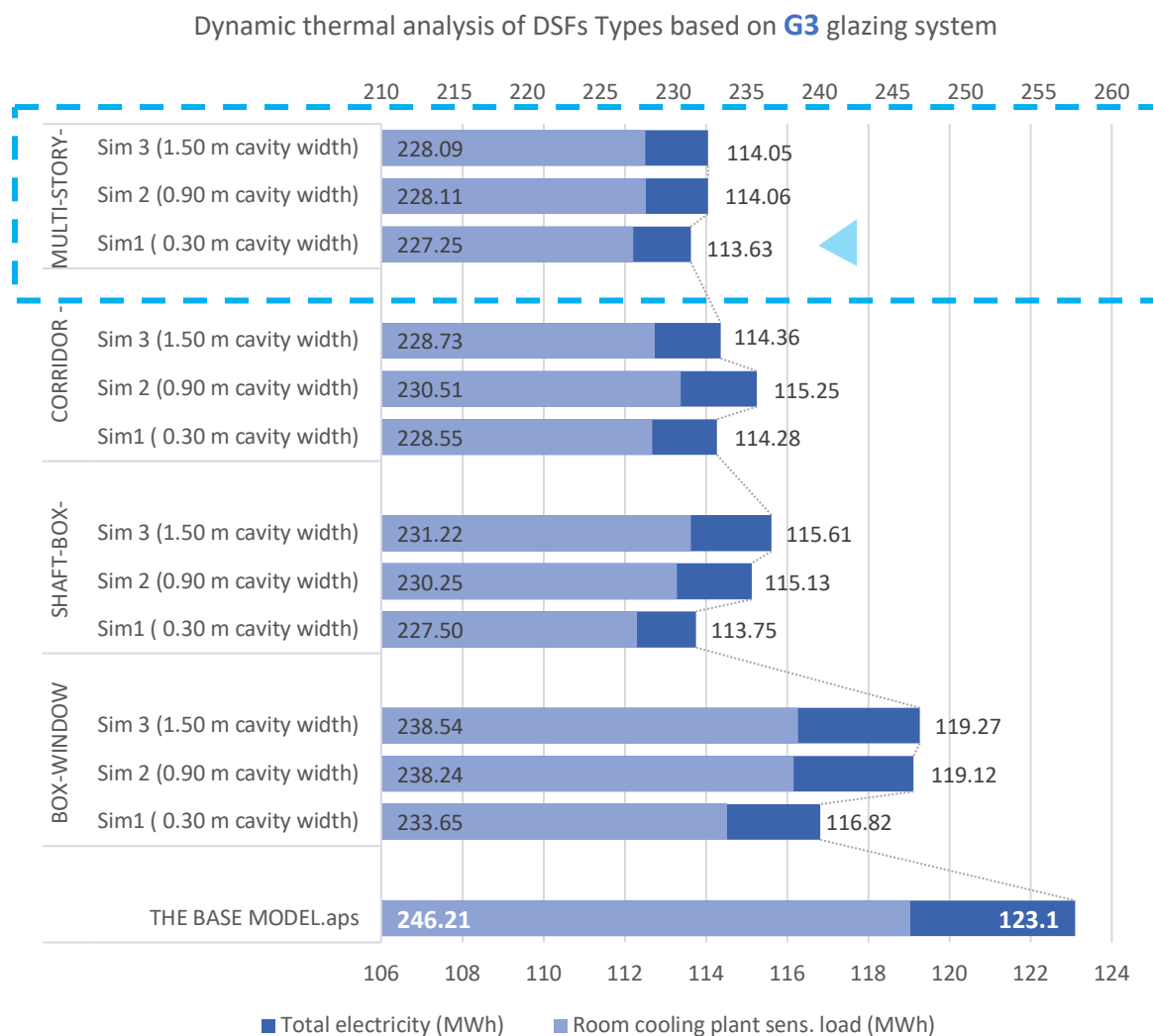


Fig. 74 Comparing annual cooling loads and total electricity of four DSF types for three different cavity widths (sim1,sim2,sim3) based on assigning glazing layers system (G3-single-Triple) with the Base Case

c. Glazing (G3) combination single-triple pane scenario in fig. (74):

1. All scenarios result of 4 DSF types show better performance in improving energy consumption than G1. The highest annual energy consumption for both Multi and corridor are relatively close at G3 about (227, 228) lower than (235, 239) at G1. Indicate that the G3 thermal properties better glazing layer than G1 with lower (U-value 0.9129) and (SHGC 0.3431) in internal glazing layer.
2. The findings resulted match the percentage saving cooling loads for multi-story, corridor and shaft-box by the highest ranges to (7.70%, 7.17%, 7.60% respectively) in compare to the refence base.
3. The box window still represents the highest annual energy consumption among other DSF types by 5.10% reduction of annual cooling loads.

In general, the ideal (optimal glazing properties) for all cases is the lowest SHGC at external glazing G2, followed by G3 with lower U-value at internal layer glass, while the G1 which represent common type of DSF glazing system represent the highest consumption in annual energy due to the higher (SHGC 0.2542) and (U-value 5.69) of single glazed at external layer increase absorbing heat gains and greenhouse effect within air cavity. also, **Krypton** gas increased efficiency performance of glazing is recommended and better thermal performance than air gas and argon in hot climate. The final results of glazing properties verified with previous studies.

5.5 THE SECOND STRATEGY ANALYSIS (EFFECTS OF THE SHADING DEVICES SDs POSITION)

The optimal DSF cases are chosen to investigate this section, based on the finding results observations consistent with the previous analysis in the 1st strategy. Through selected the best DSF types performance in terms of saving energy consumption (the total annual cooling loads and total annual electricity consumption) of the building, regarding with the glazing system and air cavity depth. However, the Solar Shading Devices (SDs) is another key parameter specially in hot climate for improving thermal performance and energy consumption of the DSFs. The 2nd strategy based on installing the SDs in different scenarios in respect with a certain position within the air cavity of DSF cases. The 2nd strategy observations made up of all tested 4 DSF cases; included the tested cavity depth ranges (sim1(0.30 m), sim2(0.90m), sim3(1.50m) integrated with the ideal glazing properties G2 (double-double pane) and SDs-vertical louvers. In order to evaluate the influence of SDs position in improving thermal performance of the building.

The proposed solar shading devices SDs are vertical louvers were mounted into three altering positions in related with the air cavity space around three facing facades for each type of DSF system individually as described:

- a) Placed against the windows of the internal skin (**Inner**)
- b) Placed in the center of the air cavity (**middle**)
- c) Placed against the external windows of outer skin (**external**)

The following charts in fig. from (75 - 78) represent the final results of the total annual cooling loads and annual electricity consumptions (MWh) for the four DSF cases which integrated the shading devices SDs system in (case A-Box-window, Case B-Shaft-Box window, Case C-Corridor Façade and case D-Multi-Storey Facade).

5.5.1 CASE A-THE BOX-WINDOW

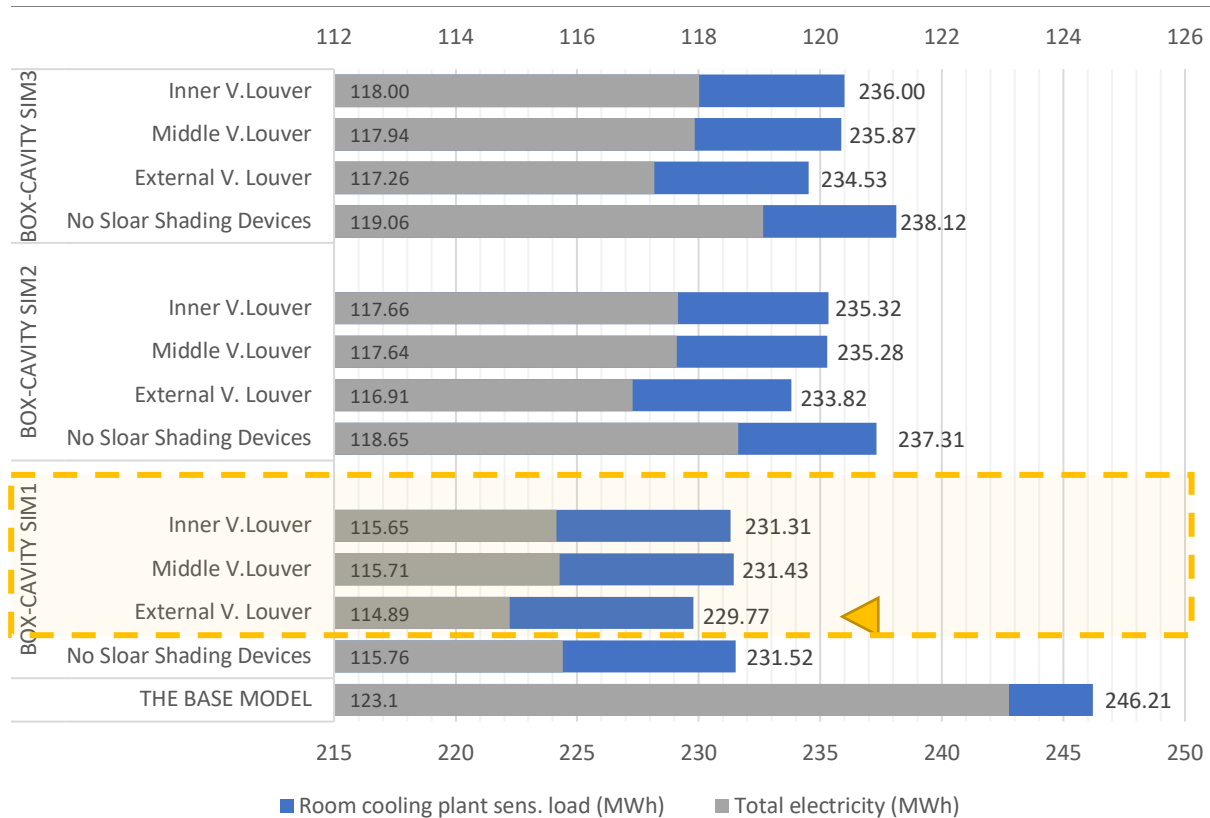


Fig. 75 Comparing the total annual cooling and total annual electricity (MWh) for three different cavity (sim1, sim2, sim3) of the Box-window integrated with three different positions of solar shading devices SDs-vertical louvers (inner, middle, external) within the cavity relative to the base case and box-window without shadings

Integration SDs with the box-window type represents better improvement in the saving energy consumptions for all scenarios by altering SDs positions comparing with the base case as shown in fig. (75) above, all scenarios achieved more efficient than box-window without SDs. Obviously, it can be noticed that scenario which placed the SDs-vertical louvers against the windows of outer-skin achieved the highest reduction in the total energy consumptions among over scenarios, thanks to their capability in reduction solar heat gains and mitigating excessive heat gain of whole glass façade. The box window at sim1 (0.30m cavity depth) recorded the highest reduction in total annual cooling loads and electricity consumption with 114.89 MWh and 229.7 MWh respectively with using external SDs vertical louvers position and achieved 246.21 MWh for the base model.

6.67%) in reduction cooling loads, in contradiction with the base case and the box cavity without SDs which represented (the ideal scenario in strategy#1) reached to 246.21 MWh and 231.52MWh respectively. Followed by installing the SDs at the middle position in the air cavity reached to 231.4 MWh of annual cooling loads and 115.71 MWh in annual electricity consumption. In contrast, the inner position of SDs against the windows of the internal skin represent the lowest efficiency performance in saving energy of the most scenarios reached to 236 MWh of annual cooling loads and 118 MWh in electricity consumption at sim3 (1.50m cavity depth). Similarly, energy performance at scenario#2 and scenario#3 the external SDs positions record the lowest energy consumption with (233, 234 respectively) in cooling loads, and (116,117 respectively) in annual electricity. On the other hand, the middle and inner SDs positions show slightly close results with range from (235 to 236) in annual cooling loads. That indicates the inner and middle position SDs in Box cavity not much affect in reduction energy consumption in compare with cavity without SDs. While, the external SDs positions mitigate the greenhouse effect within the air cavity of Box-Window.

The final results comply with previous studies that positions of SDs have an influence on the surface temperature of glazing window, when placed SDs inner-close to the glass surface within the cavity, resulting in increased the temperature of the glass. so higher solar heat gains leading to increase the heat transfer from the cavity to the interior space, thus increasing cooling loads in the building. (Gratia & De Herde 2007)As the total energy consumption of SDs in the middle position are (generally have related results) closely similar which could be slightly better than inner positions. Comply with previous study that the middle position of SDs could be created a thermodynamic circulation raised on both sides of vertical louver by air flowing. (Gratia & De Herde 2007)

Parallel to the previous strategy, the box-window at 0.30 m cavity width (sim1) still achieved the most efficient performance in reduction cooling loads against other cavity thickness.

Overall, employing SDs in different positions improve the energy efficiency of box window façade with a variety of difference values. Overall, it is noticeable that installing SDs-vertical louvers is remarkable difference comparing with scenarios without SDs, at external positions being blocked undesired solar heat gain, resulting in saving cooling loads improve thermal comfort and energy performance in the building.

5.5.2 CASE B-THE SHAFT-BOX CAVITY

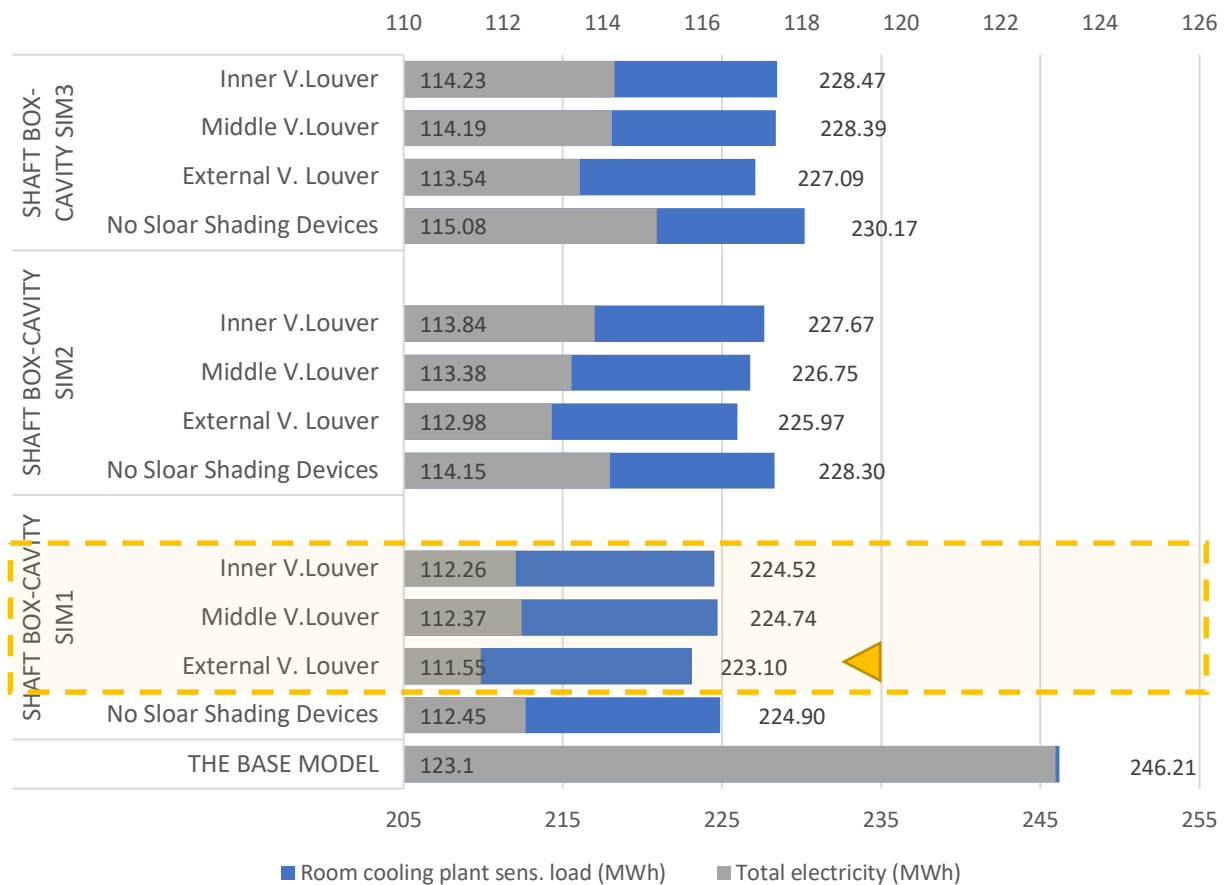


Fig. 76 Comparing annual cooling and total electricity for three different cavity (sim1, sim2, sim3) of Shaft-box window integrated with three different positions of solar shading devices-vertical louvers (inner, middle, external) within the cavity relative to the base case and Shaft-Box without shadings

The chart in fig. (76) provides a comparison of altering SDs-vertical louver positions within Shaft-Box cavity over all scenarios. In comparison with the reference base and the optimal case (without SDs) of Shaft-Box, the whole state of SDs positions achieved better performance in saving energy consumption. employing SDs in different positions over all three scenarios have

managed to improve the thermal performance of shaft-box façade by decreasing the total energy consumption.

According to the simulation results as shown in fig. (76), it can be noticed that scenario#1 at (0.30m) experienced the most efficient in reduction cooling loads comparing with other scenarios with integration SDs at external position improve the efficiency performance of shaft box window by achieved the lowest total cooling loads and electricity consumption reached to (223.1MWh and 111.55MWh respectively).

Changing SDs positions corresponding with adjusting air cavity depths had major effect on the energy consumption. Similar to the previous case, the most significant results at thinner cavity with external SDs followed by middle and inner positions. also, the difference savings between the middle and inner positions are related closed and steady. It can be observed the noticeable improving appears in external position compare with state without SDs. The external solar device attained the best performance by saving the cooling loads to (9.38% ,8.22%, 7.77%) for (sim1, sim2, sim3 respectively). Followed by the middle and inner location. The sim1 at 0.30m cavity width achieved the greatest minimizing energy performance with addition external SDs by 9.38 % of reduction cooling loads about (223.1 MWh) in cooling loads, and (111.55 MWh) in annual electricity consumption, while sim2 and sim3 slightly lower than sim1 saving cooling loads by (8.22%, 7.77% respectively) with (225.97 MWh, 227.0 MWh respectively) in cooling loads, and (112.98 MWh,113.54 MWh respectively) of annual electricity consumption.

The influenced of SDs position clearly noticed at Shaft-Box Cavity, at sim2 and sim3 either the inner and middle SDs position are record a significant difference comparing with cavity scenarios without SDs. In contrast, at sim1 the performance in reduction energy consumption the all scenarios of SDs positions are just slightly more than scenario without SDs.

5.5.3 CASE C- THE CORRIDOR CAVITY

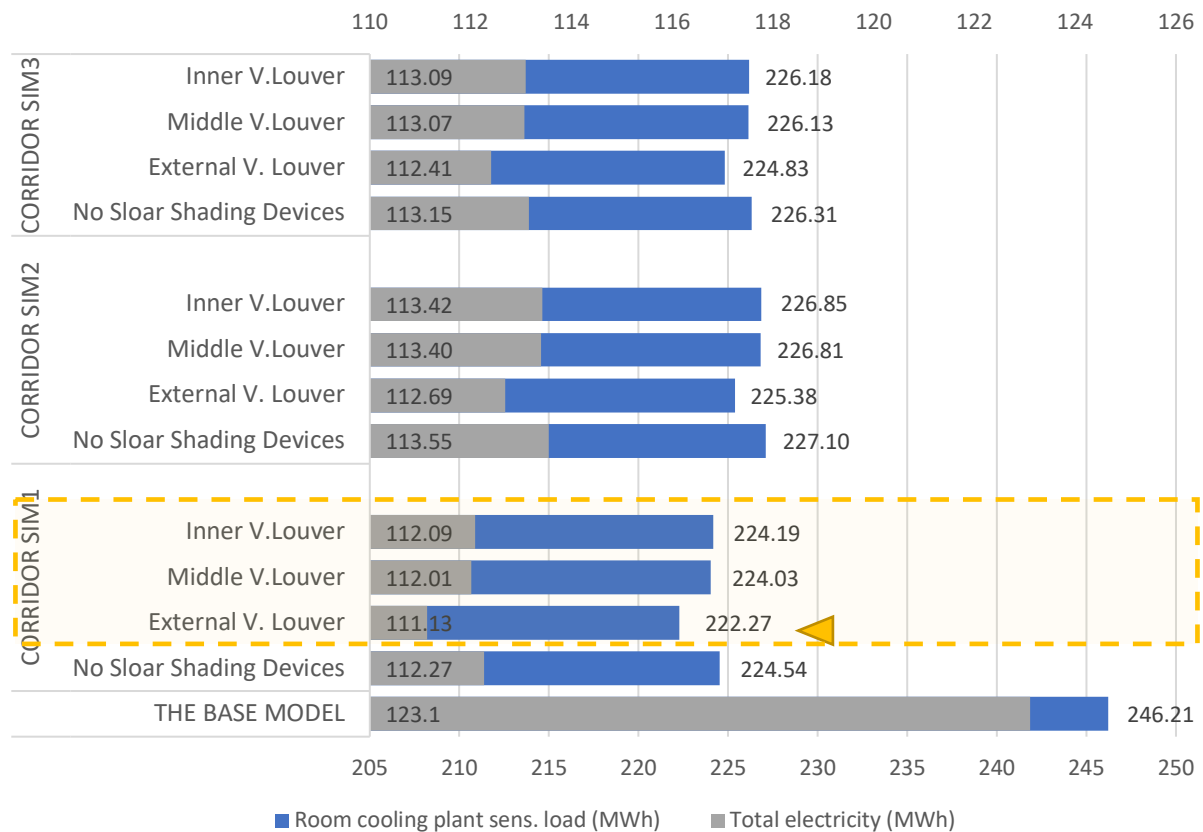


Fig. 77 Comparing annual cooling and total electricity for three different cavity (sim1, sim2, sim3) of Corridor cavity integrated with three different positions of solar shading devices vertical louvers (inner, middle, external) within the cavity relative to the base case and corridor cavity without shadings

The graph trend in fig. (77) seems similar to the previous scenario cases, that employing SDs in DSF can be reduced the annual energy consumption of all scenario in comparison with reference base and the Corridor cavities without SDs. The lowest total annual cooling loads and annual electricity consumption in sim1 with SDs at external position reached to (222.27 MWh, and 111.13 MWh respectively) by (9.72%) in reduction cooling loads. Followed by sim2, and sim3 with (225.38 MWh, and 224.83 MWh respectively) of annual cooling loads and (112.69 MWh, and 112.41 MWh respectively) of annual electricity consumption at external SDs position, with reduction cooling loads (8.46%, and 8.68% respectively). In contrast, the findings scenarios illustrate a small variation in decreasing energy consumption of each sim. (Cavity width) specially at middle and inner SDs positions independently with ranged about

(226 MWh) which represent the highest range in energy consumption among other scenarios. It can be clearly seen, that the amount of energy consumption either at inner or middle positions are just slightly more than the cavity without SDs. In contrast, a significant difference in comparison between the cavity scenarios with external SDs and the cavity without SDs.

5.5.4 CASE D- THE MULTI-STORY CAVITY

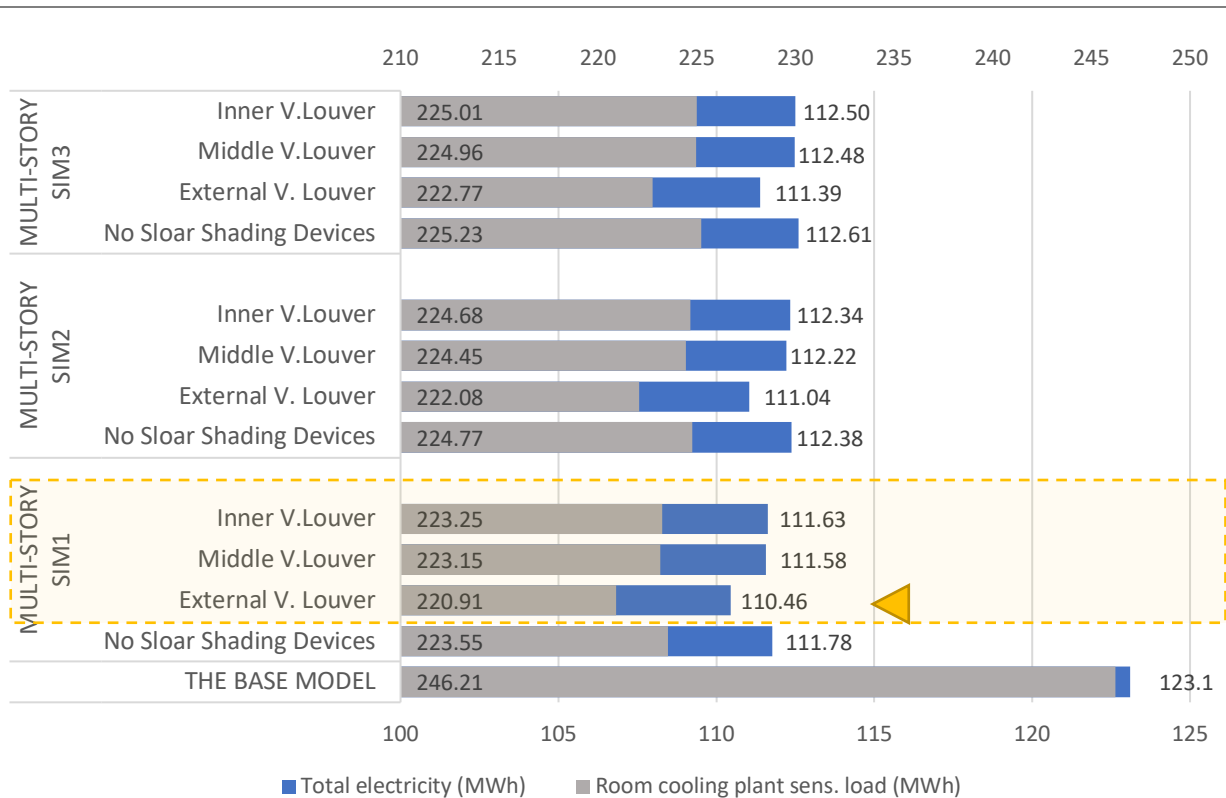


Fig. 78 Comparing annual cooling and total electricity for three different cavity (sim1, sim2, sim3) of Multi-story cavity integrated with three different positions of solar shading devices vertical louvers (inner, middle, external) within the cavity relative to the base case and Multi-story without shadings

The graph in fig. (78) shows similar performance with previous case of impact SDs positions in improving energy consumption of Multi-Story façade. All scenarios of Multi-Storey cavity either the SDs positions in inner, middle and external are decrease the total energy consumption in comparing with scenarios at cavity without SDs and with refence base. The final results recorded at inner and middle SDs positions are almost related over all scenarios in range

between (111 MWh to 112.50 MWh) of annual electricity consumption and (224 MWh to 225 MWh) of annual cooling loads, especially at sim2 and sim3. The lowest annual cooling loads reached to (220.91 MWh) by (10.28 %) saving cooling loads at 0.30 m (sim1) of external SDs positions, followed by (9.80% and 9.52%) at (sim2 and sim3 respectively). It can be clearly noticed, that the difference of amount annual energy consumption between the cavity with SDs and the cavity without adding SDs is slightly variation. These results indicate that the Multi-Story cavity with applying SDs is not significantly impact on total energy reduction in comparing with enhancing the size and area of vent openings could be more sufficient in managed the overheating temperature within the cavity.

5.5.4.1 SUMMARIZED RESULTS OF THE 2ND STRATEGY

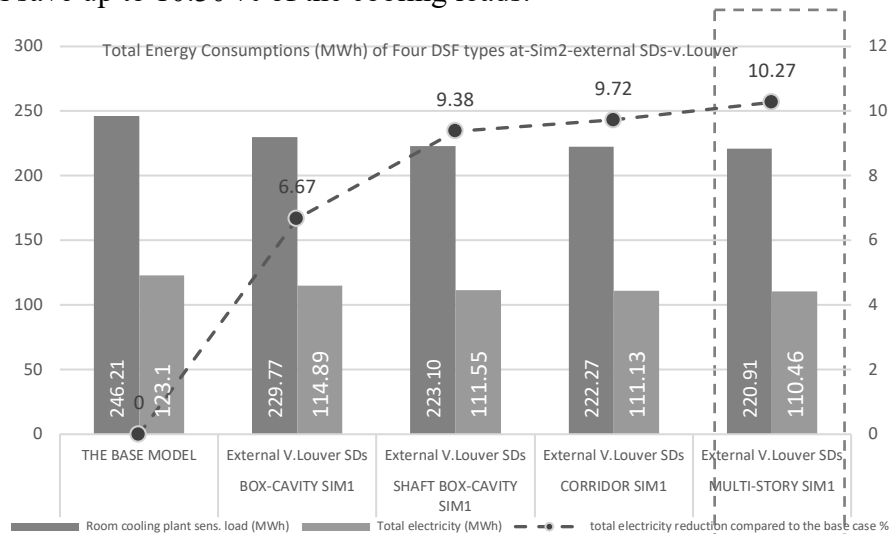
In general, the final results for all position scenarios over all cases found that the position of SDs in inner and middle positions are similar affect in thermal performance of DSF cavity, have recorded related similar amount of energy consumption. The fig. (79) shows summarizing the final results of the optimal scenarios performance in saving annual energy consumption for each DSF type at external SDs position in comparison with the reference base. Integration the SDs-vertical louvers with 4 DSF cases represent sufficient impact on improving thermal performance of the building by reduction the total annual energy consumption over all cases. Comparing to the reference base the maximum reduction in cooling loads was (10.28%) at sim1(0.30m cavity depth) integration with external SDs-vertical louvers for multi-story façade followed by corridor and shaft-box façade by 9.72%and 9.39% respectively, while the box-window records the minimum reduction annual cooling loads by (6.68%). Considerable reduction in the energy demand of DSF can be achieved by installing SDs external vertical louvers position. All scenarios of changing cavity depths demonstrate efficient performance in saving annual energy consumption. The concept of external SDs louver is blocked solar radiation before entering the building. (Harris Poirazis 2006) The position of the SDs elements

is greater influenced than the previous parameters in reduction cooling loads of DSF building.

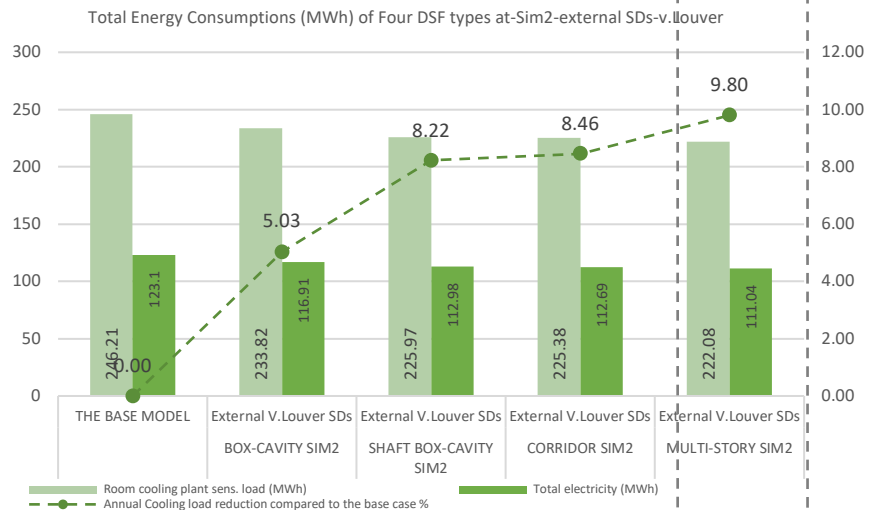
The position choice can save up to 10.30 % of the cooling loads.

Sim1(0.30 m cavity width)

The Multi-Story Façade is the Optimal DSF type in saving the total annual energy consumption



Sim2(0.90 m cavity width)



Sim3 (1.50m cavity width)

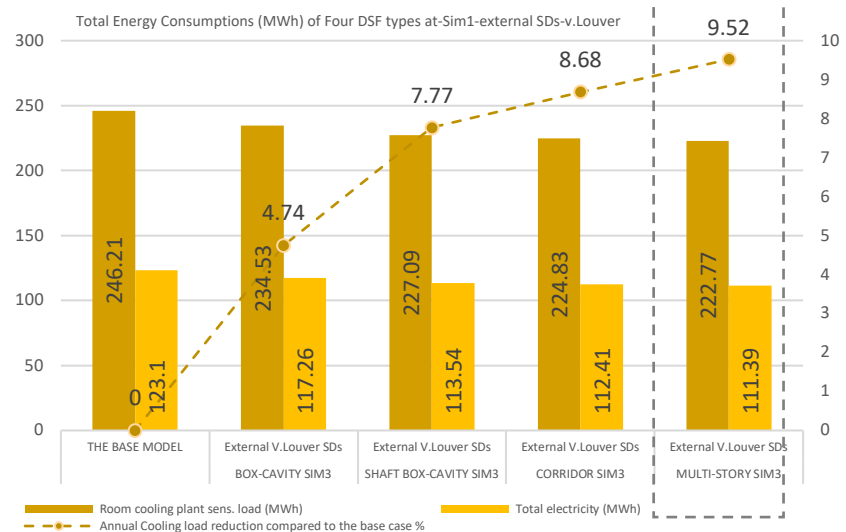


Fig. 79 Comparing the annual cooling loads, total annual electricity consumption and the percentage annual cooling reduction plant of 4 DSFs types for (sim1,sim2,sim3) integrated with external vertical louvers solar control

Final results over all strategies and scenarios:

The fig. (80) shows the final results of the optimal cases of all strategies for each case of DSF system. Exchanging the conventional typical wall of the reference base with natural ventilated DSFs (EAC) proved potentially in saving energy consumption of the building. The final results obviously found that the 2nd strategy by adding SDs element enhancing the performance of DSF in terms of decreasing the annual energy consumption at all DSF cases and perform better than 1st strategy of DSF without installing SDs.

The results exposed that the natural ventilated DSF at the thinner cavity space with (0.30m cavity width) combined with (double glazing system G2) at both skin and integration with external SDs- vertical louvers resulted in drop the annual cooling loads demands to (10.28%) in Multi-Story Façade in comparing with reference base. followed by the sim2 (0.90m cavity width) and sim3 to (9.80% and 9.52% respectively). Using SDs-vertical louvers at external position over all DSF glazing surface resulting in much reduced solar gain cause decreasing in cooling loads from approximately (246.21 MWh) in reference base case to (220.9 MWh) by (10.3% reduction cooling loads) at Multi-Story Façade followed by, Corridor, Shaft-Box, and Box-window facades with (222.27, 223.1, and 229.7 MWH respectively) by reduction cooling loads about (9.7%, 9.4 %, and 6.7% respectively). The findings found at each case that just slightly difference between two strategies on decreasing total annual energy consumption, that indicates the importance of geometry design, cavity depth and glazing properties parameter are more significant impact on DSF performance.

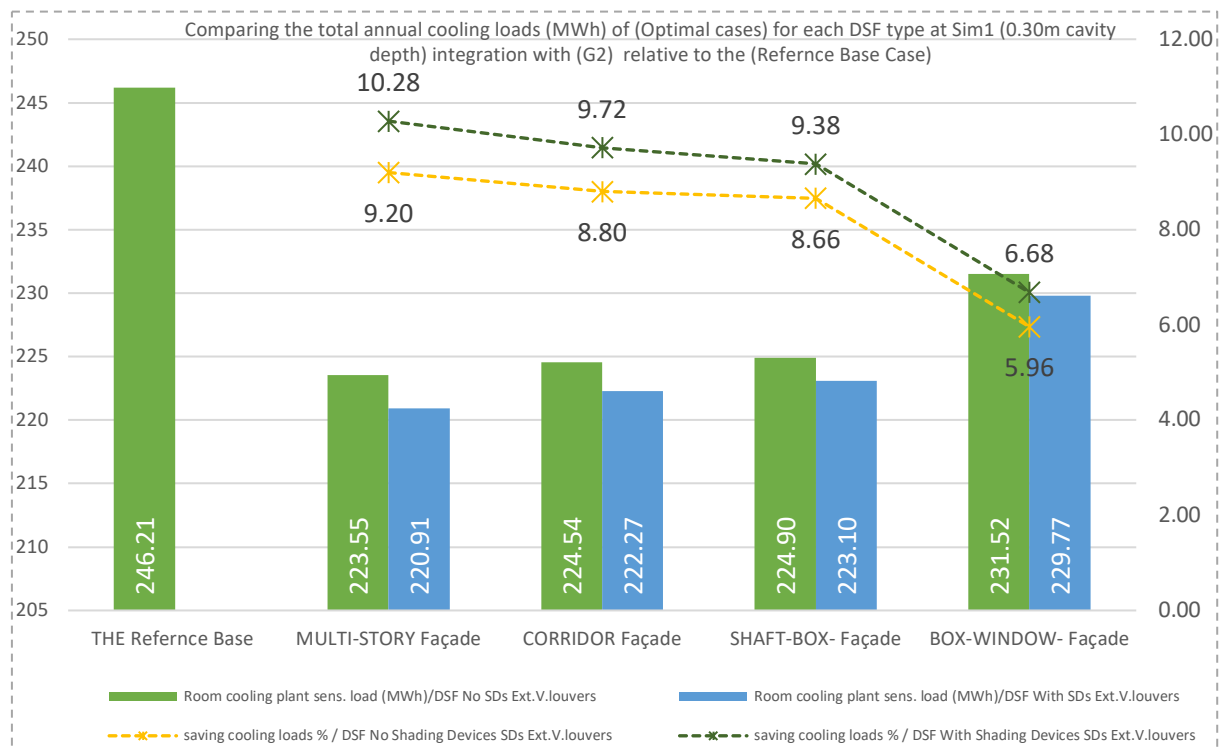


Fig. 80 Comparing the total annual cooling loads (MWh) of (Optimal cases) for each DSF type at Sim1 (0.30m cavity depth) integration with (G2) relative to the (Reference Base Case)

5.6 AIR-FLOW ANALYSIS

This section analyzed the airflow within the cavity of DSF types by using CFD analysis to predict buoyant air flow and flow rate within the cavities, CFD used for simulation airflow within cavities. The airflow analysis is considered a key factor to recognize/identify the cavity DSF design for enhancing energy performance. focused on the (aerodynamic) airflow and air velocity inside the cavity space of DSF in order to assess their affecting on thermal performance and reduction cooling loads. the airflow analysis within the cavity is important to predict the air temperature and air flow which effect the energy performance of building façade. The airflow modelling provides a clarification of the DSF performance and assessed the airflow movement (air volume rate) inside the cavity. There are many factors affected the airflow movements such as; building oriented, geometry design, wind speed, stacks sizing, penetration

(vents), window size and design. The earlier design stage of airflow analysis help engineering development to ensure the efficient of airflow along the building façade.

The airflow simulations (microflow and microflow) of DSF cavity types focused on: simulation the amount of air enters and lefts the cavity space (mass flow rate l/s), simulation of flow system in the cavity temperature distribution inside the cavity air temperature and the airflow in the cavity are interrelated parameters.

Observing the complexity behavior of DSF system depends on Airflow modellings of DSF. 3D-models of the optimal DSF for each case are simulated by using a specific application in IES-VE software called MacroFlo analysis tools based on dynamic thermal simulation Appache and assigned a certain boundary condition. The study selected the optimal case at narrow air cavity (sim1-0.30 m cavity depth) for each DSF case to conduct airflow simulation driven through wind pressure and buoyancy forces (stack-effect) along the height of cavity space for three facades oriented at south, north and east of each DSF type.

- **This study analyzed Airflow and heat transfer mechanism a cross the air cavity section of natural ventilated DSF system:**

The main factors generate the air flow within the air cavity are the thermal buoyancy caused by solar-induced and pressure differences resulting from the external wind around the building. Thermal buoyancy in the cavity creates a pressure variation which drives air flow as a function of temperature difference between the cooler air and warmer cavity air. (Sabrina Barbosa 2015) In hot climate mainly the ambient air temperature is hotter than inner temperature. The air temperature inside the cavity of DSF mainly relied on heat gains and amount of airflow. (Poirazis 2004b) In Natural ventilated-DSF (EAC) mode as created in this work, the airflow itself managed by the temperature differences with outdoor and by wind induced pressure differences; the air flow is typically highly erratic, furthermore, the wind force significantly

fluctuating based on external environment conditions. Analysis energy consumption shows the energy performance depends on the route of air circulation cavity return and changing enthalpy in air cavity. (Poirazis 2004b).

The bigger the difference air temperature between ambient temp and inside the cavity presents the better the buoyancy effect and improving natural ventilation. (Barbosa & Ip 2014) The air exchange between air cavity and outdoor environment depends on the wind pressure, the stack effect and the discharge coefficient of the openings.(Poirazis 2004b)

Air flow through the DSF based on two components; the buoyancy force and driving pressure by wind. The both components could be affected on the stack effect performance which mainly depends on the temperature, heat transfer and optical properties.(Poirazis 2004b) furthermore, the **cavity openings** paly an essential role for improving DSF performance, affecting on the air temperature inside the cavity, the buoyancy force and flow resistance. The study observed the relationship between the vents design and air flow. The fig. from (84 to 88) simulations that larger openings size higher airflow rate within the cavity than cavities with smaller vents. The **distance** vents openings have significant effect on the air distribution, velocity and temperature. For natural and mixed mode ventilation, controlling the vent openings for supplying and exhausting air from cavity could be enhanced the energy efficiency of DSFs through. (Jiru, Taob & Haghighat 2011).

The fig. (81) shows the wind-rose, a visual representation of the main direction and velocity m/s for the study case in Al-Ain city site, its settings from 01/Jan to 31/Dec. The wind is a considerable natural motivation to the airflow behavior inside the cavity of DSF. It plays a dominant role in motivating air movement in DSF and affecting the ventilation of façade cavity. Also, the wind direction has a great impact on the quantity and direction of airflow through the DSF cavity.

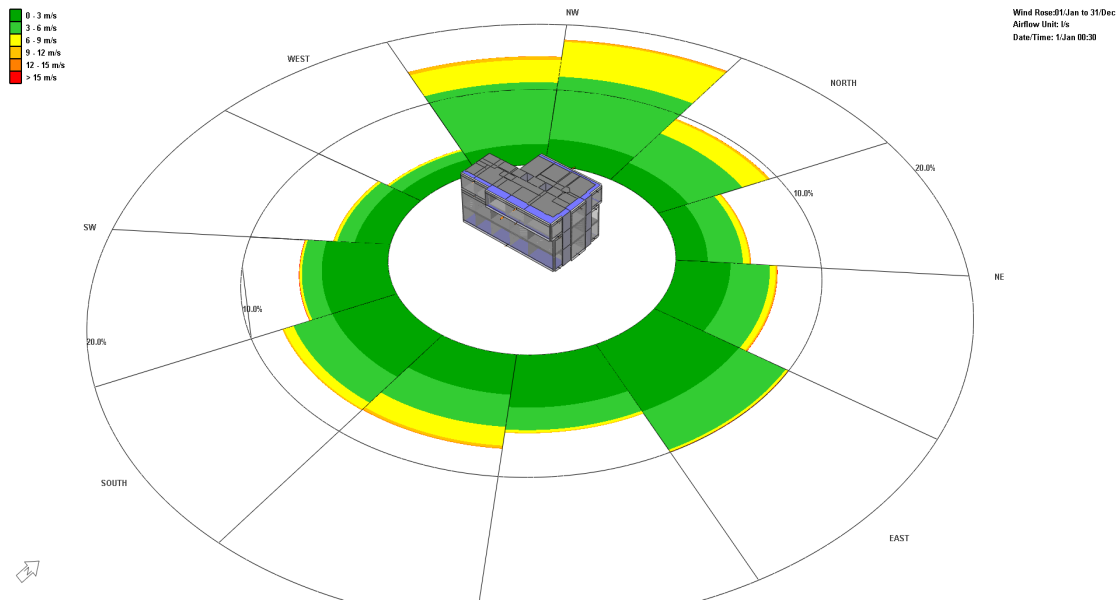


Fig. 81 wind-rose from (Jan-Dec.)in Al-Ain city. The base site location showing the wind direction and velocity of the DSF model. The predominant wind is from the north-west direction. Source: (Author) by using IES tool.

Almost the (Feb., March, and April) record the windiest day over the year with average (9-13 mph) or about (4.0 m/s) as shown in fig. (82)

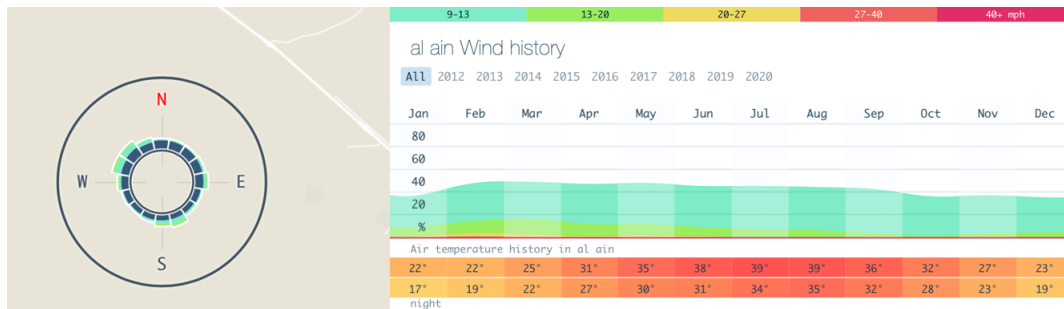


Fig. 82 Al Ain wind rose , annual wind velocity (mph) and predominant wind direction

Analysis airflow process in the cavities:

The study designed natural ventilated cavity of DSF with External Air Curtin EAC mode as described previously. The inlet and outlet vents openings are located in the front of external glazing DSF layer to enhance cross-ventilation and creating differential pressure within cavity. Further, each vent has an adequate air speed and volume, so the total volume of air entering to be equal to the volume of air exhausting.

Adequate design of DSF with vent openings can improved wind flowing over the façade and leading to difference pressures between the inlet and outlet encouraging air circulation. The lower inlet flows air into the cavity, next it heated (warming up) and become less density and thermally buoyant function promotes air movement resulting in continuous air rising upwards and removing heat from the cavity out to the outlet.

further, the magnitude of thermal buoyancy affected by height difference between openings within the cavity. The ventilated within the cavity could be maintain even without wind thanks to the stack effect. (Poirazis 2004b) the stack-ventilation is created in shaft-box cavity, it based on warmer air rising referred to buoyancy which is air-forced system, in other words the air heats up within the cavity due to solar radiation then rising upwards. Using a vertical stack helps the air to stratify and exhaust the warmth air at the top vents. So, the vents openings and stack effect should be designed accurate to ensure the air path. potential of stack driven and wind driven pressure in order to prevent (radiating heat to the inner environment of building) preheating air flow inside the cavity.

5.6.1 DESCRIPTION AIR FLOW ANALYSIS IN MODELLING SIMULATION

The following fig. from (84-88) illustrate the results of Macro-Flow modelling simulation of four DSFs cavity cases individually. The schematic figures describe bulk airflow visualization with label coloring arrows flowing between inlet and outlet vents to predict the ai circulation within cavities, the different colors indicating the direction and volume of airflow unit (l/s).

The airflow results as shown in fig. (84-88) are different between three facades due to different amount of solar radiation where façade is received.

Increasing the height of thermal storage space (cavity) rising pressure difference between inlet and outlet leading to greater air change rate on each story especially in upper floors such as multi story and shaft box. In shaft box-window the top outlet air promotes higher airflow rate

within the cavity space, focusing on the stack ventilation potential of the DSF. In corridor façade, diagonal vent openings affecting the air circulation since opposite side location enhanced the cross-ventilation, promoted air mixing, while the stack effect created more air movements through assigned outlet higher than inlet. All cases illustrate variation in air flow rate around three facing facades, also the flow rate difference from floor to another floor due to varying buoyancy, the results consistent study with (Gan 2006) air flow volume rate increased from bottom to top floor.

However, there are **many factors influenced the air flow-rate** circulation have predicted through rendering Macro-Flo modelling of the DSFs types within the cavity:

- a.* The size (area) of vent openings inlet and outlet.
- b.* The distance (height difference) between inlet and outlet.
- c.* The height and width of the air cavity space. A taller cavity creates a stronger buoyancy force, resulting in producing a larger airflow rate. (Barbosa & Ip 2014)
- d.* Geometry façade design, the physics of heat transfer process occurring within the cavity.
- e.* wind is a key natural motivation to the thermal and airflow performance of DSF, resulting in varying flow rate around facades.

5.6.2 THE BOX-WINDOW AIR-FLOW ANALYSIS

The predominant wind directions blowing mostly from north-west as mentioned earlier. So, the north facing façade shows the highest fluctuating airflow volume rate due to exposure to the dominant wind that stimulus the airflow behavior and movement inside the cavity of DSF and increasing different pressure between inlet and out let vents. The south façade facing the highest solar radiation increasing the difference temperature between inside and outside the cavity leading in promotes the buoyancy effect within the cavity. The façade with more solar radiation exposure can performed better than others when using DSF. The air supply l/s is mostly concentrated at south-upper area as shown in fig. (83). Furthermore, arrows indicate air directions the air flow is typically highly erratic (changeable), the large openings show the larger flow rate, also with different levels airflow rate around the three façades as illustrates in fig. (84), the bottom floor lower total air flowrate than the top floor, for example from bottom the inlet and outlet openings at south facing had (190l/s in +190l/s out) while in the top (211l/s in +217l/s out) as pointed in fig. (84). These results indicate that volume flow rate through openings varied from floor to floor due to difference in buoyancy. The air flow rate increase from bottom to top. Furthermore, the total flow rate at each façade is varied, the north facing represents the highest air-flow rate due to exposed to predominant wind, followed by south facade which received to the highest amount of solar radiation, the last one is east façade.

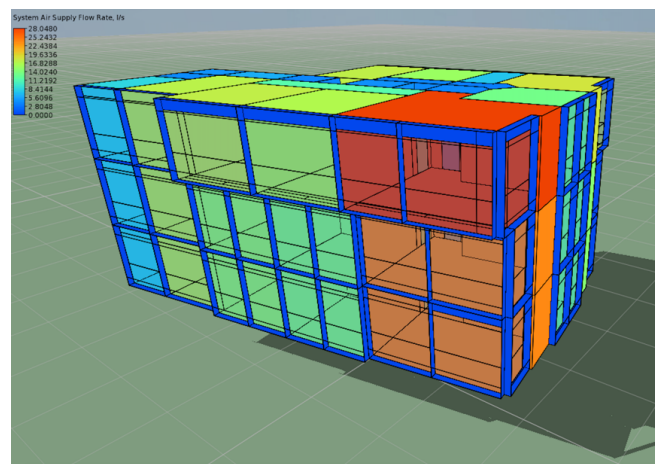


Fig. 83 Air supply flow rate l/s of the Box-Window type mostly is concentrated at south corner of the building. Source:(author)-IES

Box-Window type -Airflow

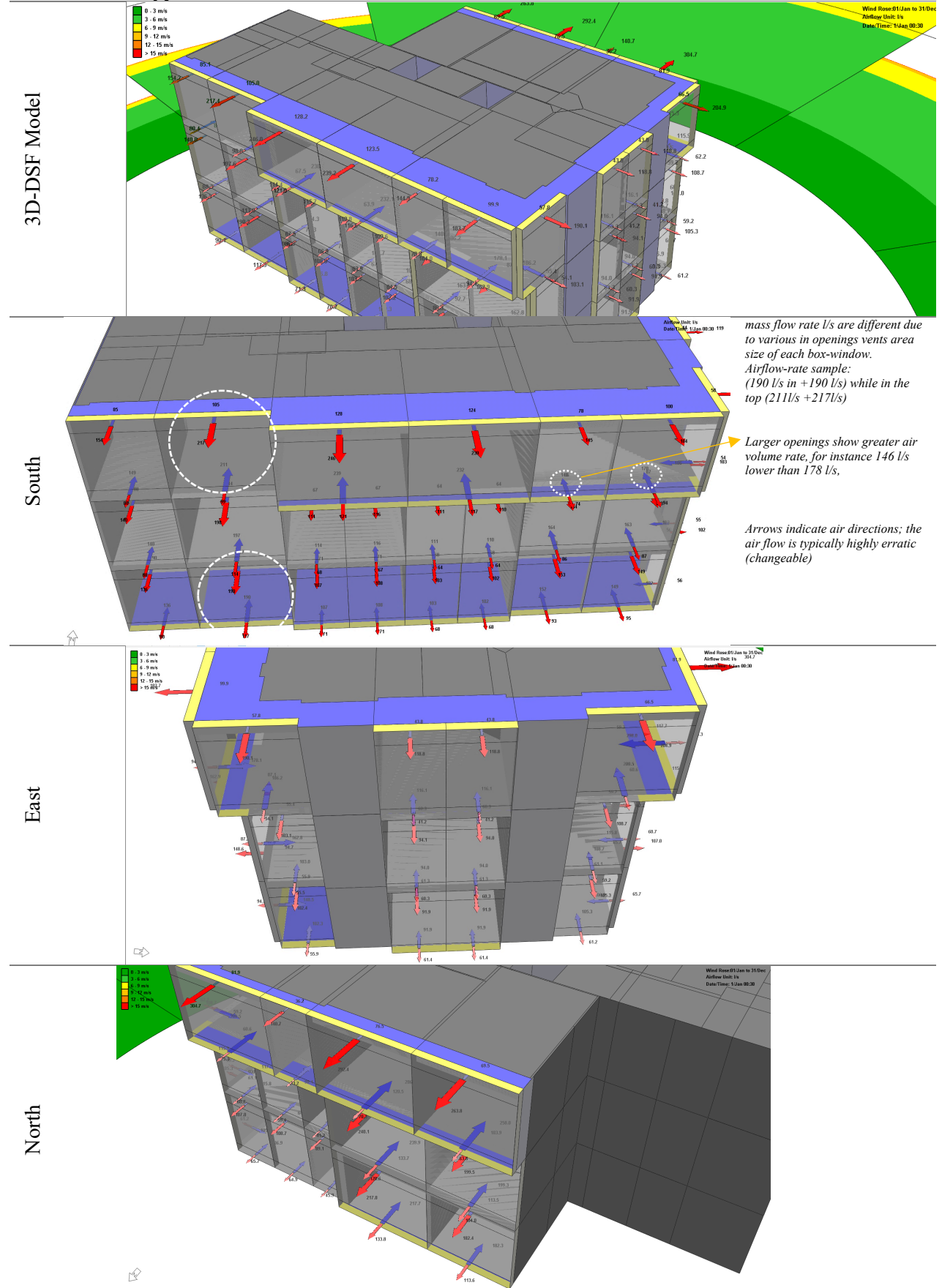


Fig. 84 MaccrFlo-airflow rate (l/s) process within the cavity of Box-Window Façade, blue arrows indicate external air inlet, Red arrows air outlet. Source:(author)- by MacroFlo app.in IES

5.6.3 THE SHAFT BOX AIR-FLOW ANALYSIS

The shaft-box façade represents another route of air flow due to thermal buoyancy caused by special design of stack effect (vertical chimney) which promotes the air circulation within the cavity and creating higher thermal differences. The Shaf-Box design airflow process is different from other DSF types, it is featured by intermediate shaft box (stack effect) separated boxes units with side openings at top of each connected box. Each façade divided storyes into many box-windows separated by the vertical shaft box with certain openings vents. Resulting in different area and size of inlet and outlet openings.

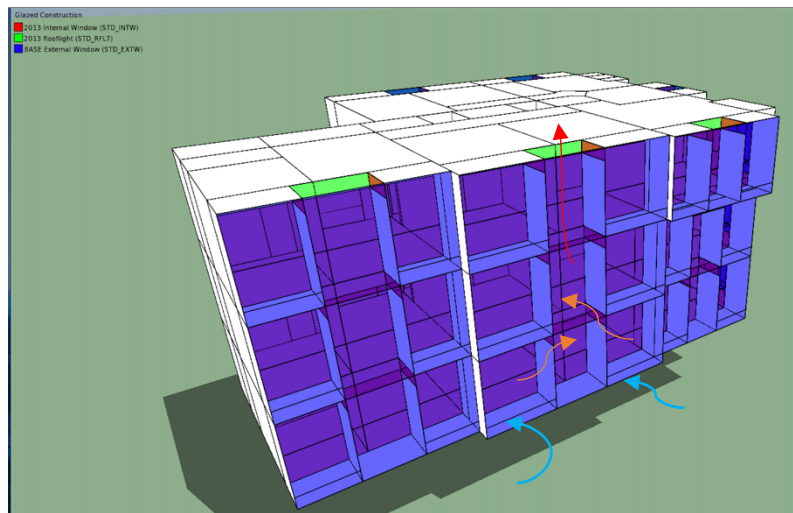


Fig. 85 the airflow concept of Shaft-box façade type. Source: Author-IES

The concept of shaft-box: refer to stack effect estimated by phenomena as “warm air rises, cool air sink” based on shafts to create the stack effect. The density of air within cavity affected by the changing temperature. when air warmed, resulting in higher active and less density of air molecule, then the air become more buoyant and rises within cavity since warmer air rising up to the external top vent vertically, resulting in significant pressure difference and escaping the heat to the top vent. The pressure difference is the triggering force for stack effect, and resulting in remove excessive heat from the air cavity. Stack ventilation depends on warmer air rising due to buoyancy (forced air system) as shown in fig. (86)

The potential of stack-effect ventilation can be expected during design process by using the following equation (2). (Kwok & Grondzik 2000)

$$V = 60 K A [g h (T_i - T_o)/T_i]^{1/2}$$

Equation 2

V is the estimated air flow rate (cfm); K is a factor that accounts for orifice characteristics (assumed = 0.65); A is the smallest value of inlet, stack “throat,” or outlet areas (sq ft); g is the gravitational constant (32.2 ft/sec²); h is the stack height (ft); T_i (inside) is the higher of two differential air temperatures (°R); T_o (outside) is the lower of two differential air temperatures (°R).
From

Many variables affected the flow rate of stack-effect from a design perspective during architecture decision making:

- The areas of inlet and outlet openings, locations and the stack size.
- The height (difference in elevation) between inlet and outlet.
- the difference in dry-bulb air temperature between the stack inlet and outlet are depends on weather conditions (climate). (Kwok & Grondzik 2000)

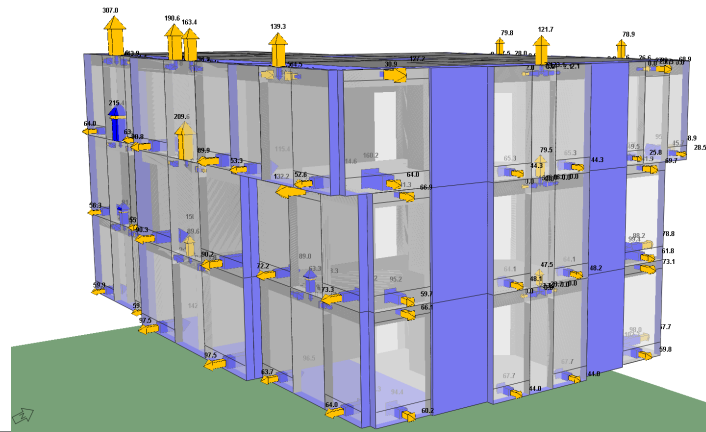
5.6.4 CORRIDOR CAVITY AIR-FLOW ANALYSIS

The airflow represents different performance in air circulation within the air cavity of Corridor Façade in compare with previous cases. The air flows diagonally circulation between inlet vents and outlet vents for each story level, in order to prevent air from the lower floor being sucked in the inlet vent (air supply) if the above floor. The air flow rate increase from bottom to the top level of the building as demonstrated in details in fig. (87). The highest flow rate at North and South facing followed by East cavity façade.

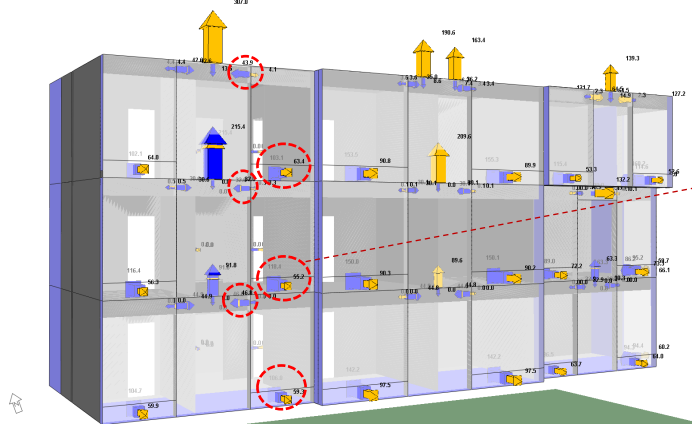
5.6.5 MULTI-STORY CAVITY AIRFLOW ANALYSIS

The multi-story façade fig. (88) is creating the greatest ventilation flow rate within the cavity of all facades oriented, due to presence the bigger vent openings area across the cavity, that leading to maximize the amount of air flow rate across the cavity and reduce the flow resistance.

3D-DSF Model

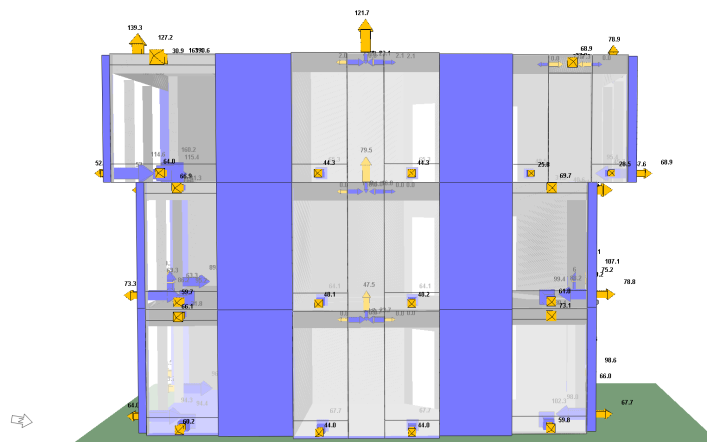


South



Air-flow rate-sample:
 Inlet opening +top side opening at
 each box=
 1st floor (106 l/s+46 l/s)
 2nd floor (118 l/s+32 l/s)
 3rd floor (103 l/s +43 l/s)
 ▶ Vertical shaft-box from bottom to top
 outlet (91 l/s, 215 l/s, 307 l/s)
 Note:

East



North

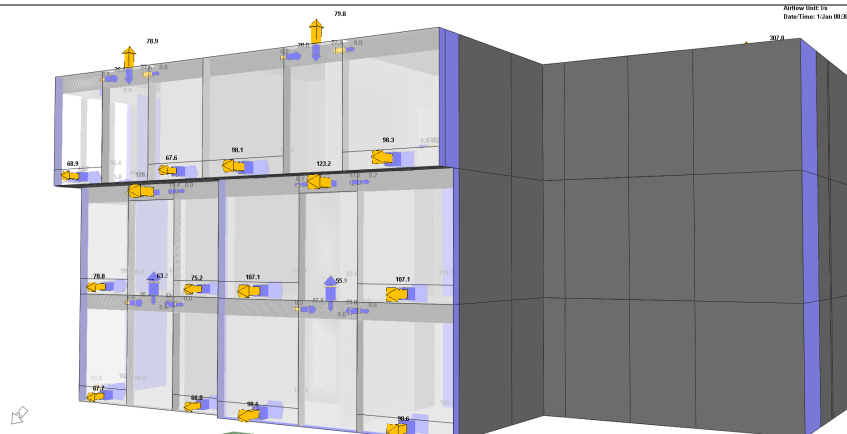


Fig. 86 MacroFlo-airflow rate (l/s) process within the cavity of Shaft-Box Façade, blue arrows indicate external air inlet, Gold arrows air outlet. Source:(author)- by MacroFlo app.in IES

Corridor Façade- Airflow

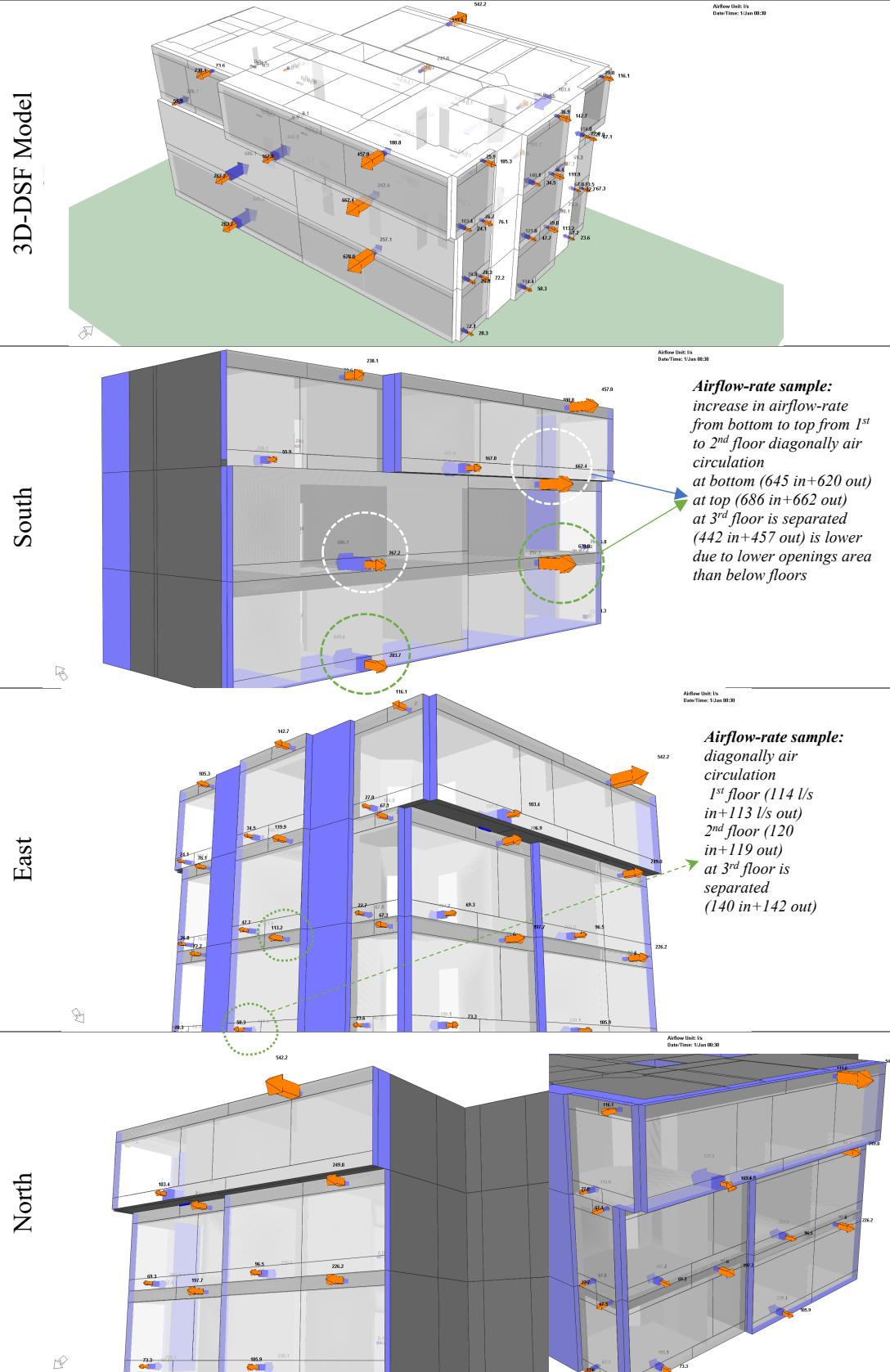
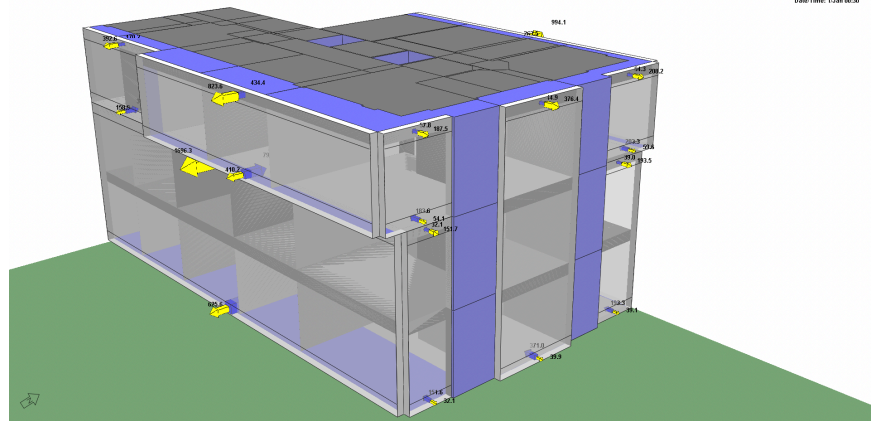


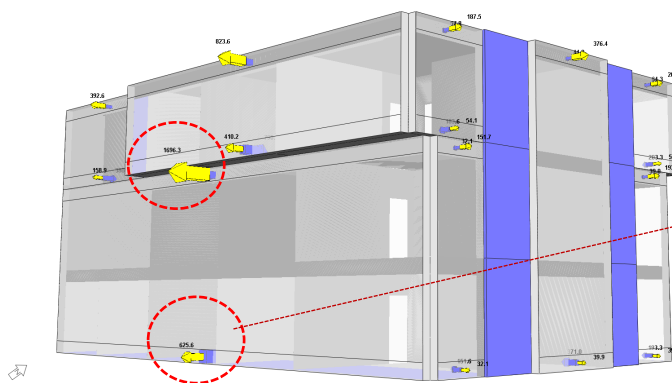
Fig. 87 MacroFlo-airflow rate (l/s) process within the cavity of Corridor Façade, blue arrows indicate external air inlet, Orange arrows air outlet. Source:(author)- by MacroFlo app in IES

Multi-Story Façade Airflow

3D-DSF Model

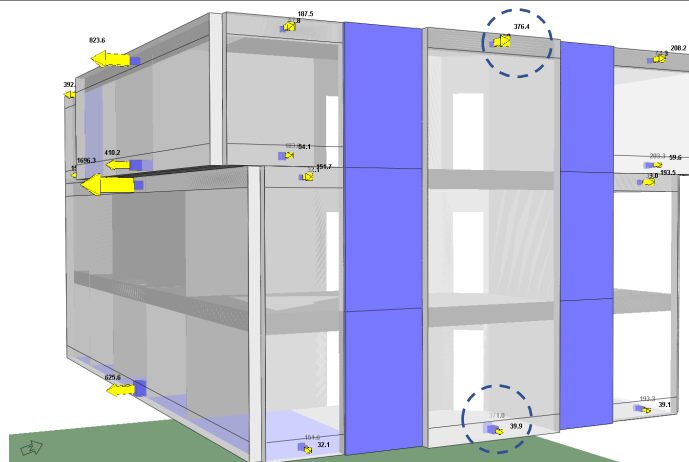


South



Airflow rate sample:
Flow-rate continuously increased with cavity from bottom to top floor, with largest openings area and height difference between inlet and outlet (higher stack height). The flow rate in multi-story much higher than previous cases. 1st and 2nd floor (1690 l/s in + 1696 l/s out)

East



Airflow rate sample:
1st to 3rd floor (out 376 l/s + in 371 l/s out)

North

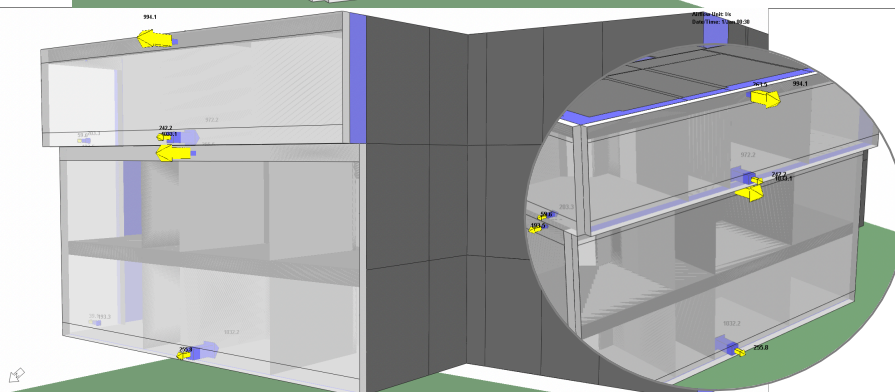


Fig. 88 MaccrFlo-airflow rate (l/s) process within the cavity of Multi-Storey Façade, blue arrows indicate external air inlet, yellow arrows air outlet. Source: (author)- by MacroFlo app.in IES

5.6.5.1 MACROFLO EXTERNAL VENT- VOLUME FLOW RATE SIMULATION

This section represents the final results of the peak *MacroFlow external vent, air flowrate* over the year from (01/Jan to 31/Dec) for selected façade at east orientation of all DSF types at 0.30m width cavity. The graphs results show the max Macro-flow external vent annual from (Jan to Dec) and during April which represents the greatest airflow rate in Al Ain city for 4 DSF types at east selected cavity fig. (89) experienced that the multi-story cavity about 1/s represents greatest volume flow rate, followed by Corridor 1/s,

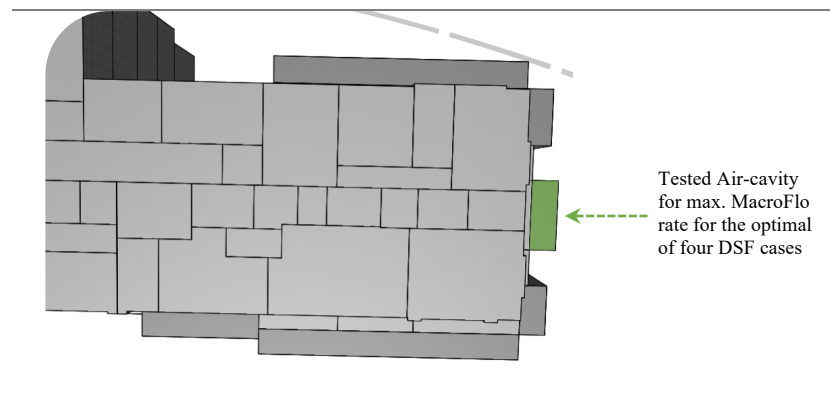


Fig. 89 selected test cavity for Max. MacroFlo rate external vent of DSF cases.

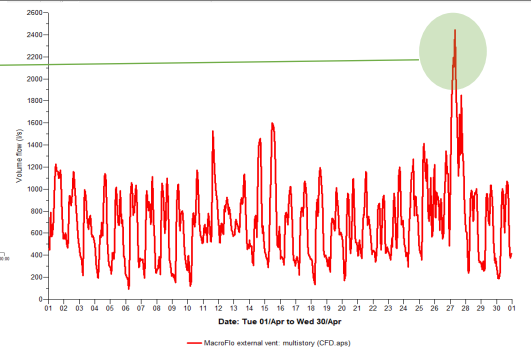
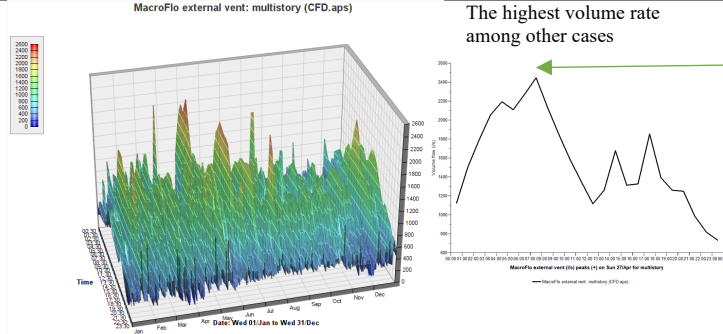
The study shows that wind force plays a dominant role in driving airstreams in and through the DSF, which highly impacts the overall thermal performance of the buildings. air gap between the main enclosure and exterior shell creates a chimney effect stack effect. The study indicated that the air flow within air cavity have major impact on the performance of the DSF.

The charts in fig. (90) illustrates the macroflo external vent for the four DSF optimal cases at east façade as pointed above in fig. (89). The final results indicate that Multi-Storey achieved the greatest volume flow rate about 2600l/s at 27/April

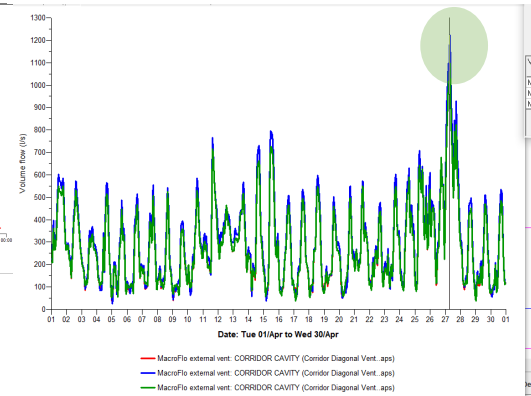
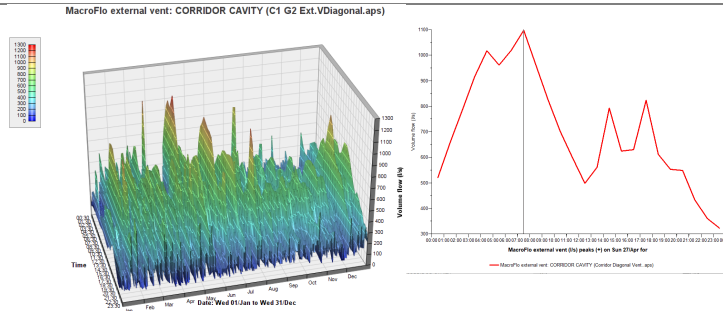
MacroFlo external vent-CFD from Jan to Dec/volume flow rate (l/s)

Airflow rate (l/s) in April

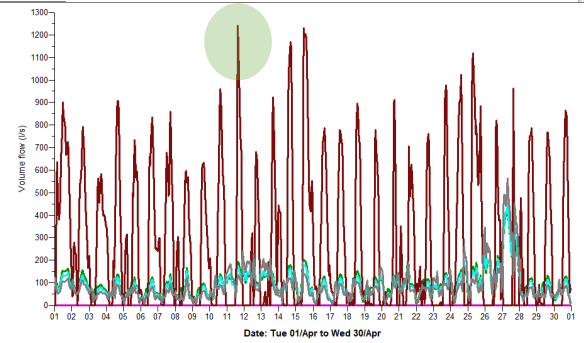
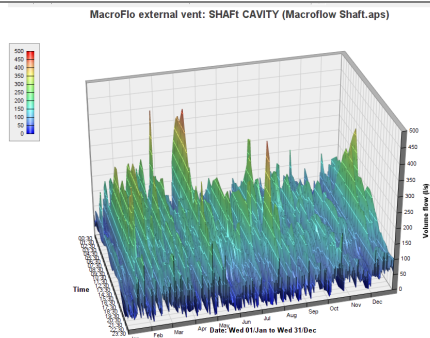
Multi-Story Facade



Corridor Facade



Shaft-Box Facade



Box-Window

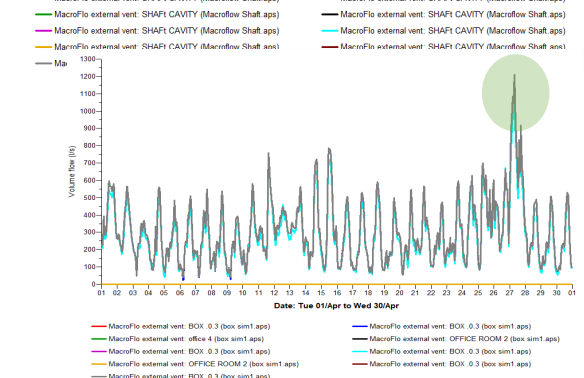
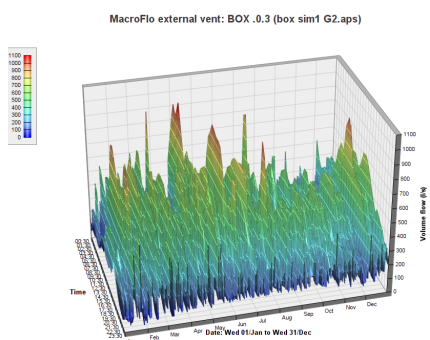


Fig. 90 MacroFlo external vent of four DSF types at 0.30m cavity width shown air volume rate (l/s) all the year and comparison the maximum volume for each type, (right) the total volume flow rate l/s during April for each DSF case at selected east cavity

5.6.5.2 SUMMARIZED THE AIRFLOW ANALYSIS

The Airflow results obtained from Macro-Flow calculations with arrows and values on each opening. In hot climate conditions, natural ventilation is essential to prevent having a heat sink in the air cavity. Overall, the conclusions drawn from the graphs in fig. (90) are the following:

- Increase the height cavity, the air flow rate will increase, (Increase the level height of outlet vents, the efficiency of DSF increase). The taller cavity produces a stronger buoyancy force, creating a greater airflow rate.
- The vent openings type at external skin influenced the bulk air flow rate, the vent openings area increased, the volume air flowrate is also increase. (More important in high-rise buildings). the building with large size area of external vents increased the efficiency performance of the DSF.
- The highest airflow rate within the cavities at the North facing as the wind predominant force on these façades is the strongest. On other hand, South oriented DSFs, with a peak flow rate where the sun radiation is highest and strongest, will cause improve/increase in the stack effect within the facade. This largest stack effect in turn evolve greater air flows which thus limit the temperature achieved within the façade. (BBRI. et al. 2005). In contrast, the lowest DSF air velocity depicted in the east oriented DSFs, due to the minimum solar radiation and exterior wind speed velocity exposed in these façad.
- Thermal buoyancy is the main driving force due to the great difference between the external temperature and the average temperature in cavity
- Cavity is thermal barrier against hot. Vertical buoyancy flow or stack effect happens between lower air inlet and upper outlet as natural ventilation movement.
- Outside ventilated mode driven by natural buoyancy and forced convection to exhaust air through the cavity to the outlet

**Note:* In these cases, insert fans as *Saelens* pointed in previous LR can remove internal heat by enhancing air ventilation, prevent increasing temperature inside the building and enhancing thermal performance of the building.

5.7 CFD ANALYSIS -MICROFLO

A further analysis is conducted the air movement velocity within the cavity, in relation to the cooling loads and conclusions are drawn over numerous parameters via using the MicroFlo- CFD analysis assess the thermal performance of DSF types in differ aspects. The air movement behavior and air velocity within the cavity can build a comparison between the four DSF types.

CFD could be useful tool for study and optimization of DSF performance:

The main features of Microflow; using CFD application (a numerical approach) to predict internal air flow temperature, direction and velocity inside the cavity space. MicroFlo calculated the heat transfer coefficient from the surface based on the local conditions of temperature and velocity around the surface (User Guide IES VE 2016), CFD technique provides details about the airflow system within the air cavity, to performance evaluation of air flow cavities, the technique depends on specific boundary conditions (inputs) based on ApacheSim simulation such as (air surface temperature, air mass flow, gains etc.) This study using MicroFlo (CFD) application in IES software to render a defined zonal bulk air flow occurring by wind pressure and buoyancy force. The results plotted as graphical views of 2D slices at X, Y, and Z-grid line integrated range colors of contours and vectors.

CFD analysis was conducted on four types of DSF models to assess the air velocity, direction and air temperature distribution of each DSF type by using CFD application. The South and East cavity facing façade were selected to save simulation running time as shown in fig. (91), assigned the max peak MacroFlo external vent on (27 April at 7:30) at all DSF cases, each rendering model used a standard (k-ε turbulence) with hybrid discretization available in Microflo settings and used for DSF study, it evaluates the relative ratio between the convection

and diffusion to apply upwind and provided suitable solutions. CFD rendering procedure for more explicitly the cavity of each type was modeled as (void) as separated zone to ensure airflow dynamic without obstructive with no internal heat gains and mechanical conditions, Airflow and temperature characters inside the cavity based on the ambient air temp conducted in weather conditions

Selected study area for analysis the air velocity MicroFlo CFD of DSF includes 3 floors facing south façade for each DSF type individually

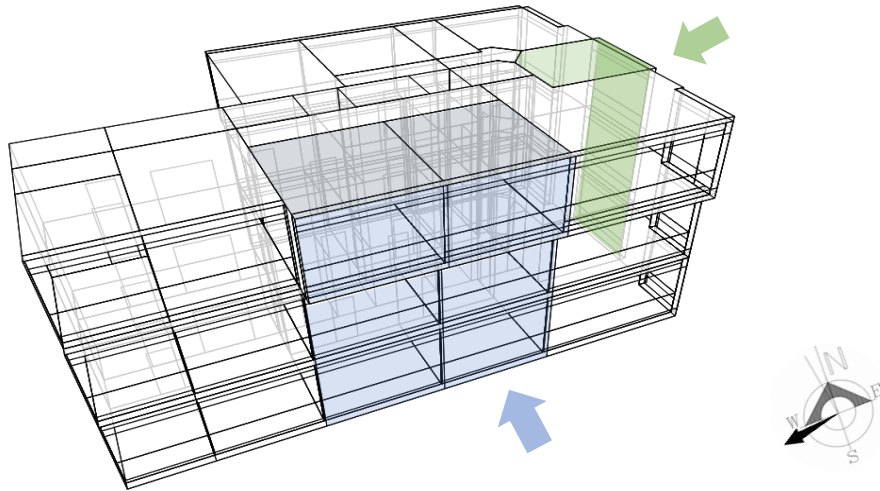


Fig. 91 The selected zonal study for air velocity CFD analysis. Source:(author)

Different scenarios of air flow and velocity occurring inside the air cavity due to pressure difference of the four types of DSF as illustrated in the fig. (92-96). The air flows from the bottom vents (inlet) to the upper openings (outlet) due to pressure difference and wind force around the building facade result air movement within air cavity. The CFD microflow analysis show different temperature levels along the air cavity assist in driving airflow out of the cavity. While, the external wind pressure reduced the amount out flow rate resulting in accumulation heat in the top. (Johnny 2018) a similar condition occurs at each floor with different scale based on wind direction, air velocity, geometric DSF and vents characteristics. It is clearly observed that the higher levels achieved more heat thanks to heat transfer coefficient increase at the higher levels due to the flow gets warmer at rises toward the top of air cavity that proved the

findings by (Radhi, Sharples & Fikiry 2013) The ventilated cavity EAC DSF plays an importance role in reduction overheating through exhaust the hot air trapped to the external vent.

5.7.1 SUMMARIZED THE MICROFLO-CFD ANALYSIS

Analysis the final conclusions drawn from fig. (92 to 96) schematic of CFD-microflow and air velocity contour analysis models simulation for each case indivisually:

For all cases; the air entering the DSF is heated up/cooled down due to the convective heat transfer at the DSF surfaces, then the air raises up/falls down, due to the buoyant forces. The air velocity distribution for all cases is not exactly symmetrical which shows that the temperature distribution has influenced the airflow distribution. the results show air flows inside the cavity and escape nearest to the vent openings at the external skin. Also, the airflow and velocity represented different approach in air distribution between east and south façade, the south facing façade demonstrated greater airflows along the cavity due to higher solar radiation exposed, all cases affected by buoyancy force and stack effect inside the air cavity with different levels.

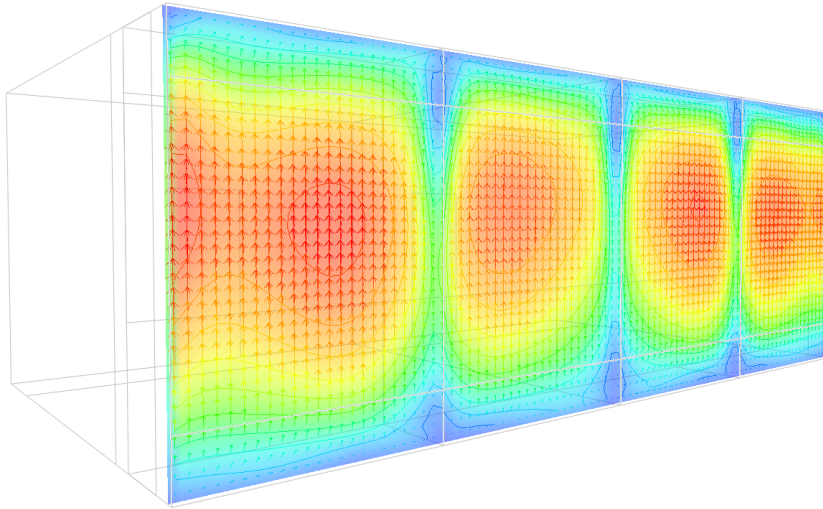
1. **Box-window facade:** at fig. (92) accumulation of hot air concentrated at the upper level of each floor, greenhouse effect clearly noticed at each box unit and trapped heat within cavity, separated ventilation (airflow) for each bay through horizontal and vertical partitioning effects .The air circulation within one façade element.
2. **Shaft-Box facade:** at fig. (93) the airflow is creating in different way; air flows in stratification layers (wavy accumulation in shaft box by side openings, the stack effects in vertical segment draw air from box-window in the whole façade. The air rises in a

vertical shaft alongside the façade and draw the exhaust air from adjacent façade elements within it via shaft box, stack effect. there are side openings in the shaft divisions in the facade intermediate space. The reduction air cavity temperature at lower due to the buoyancy effect moving warm air toward upper levels leading to decrease convective and conductive heat transfer to the inner skin resulting in lower inner surface temperature. the warmer air being channeled upwards using a vertical stack(atrium), as warmer air rises and exits through the top of the stack, cooler air is drawn in at lower level. Stratification (layers) can have appositve effect in spaces in hot climate, the warmer air naturally rises while the cooler air near to occupant, the air allow to stratify, (Anderson 2014)

3. Corridor-facade : at fig. (94) the air-inlet and out-let extract openings in the external façade layer situated near the floor and the ceiling of each storey in diagonal arrangement, the air flow velocity is usually laid out (drawn up) in staggered (overlap) form from bay to bay to prevent vitiated air extracted on one floor entering, Air flows on the diagonal direction to prevent vitiated air from the lower story being sucked in with the air supply of the floor above. Accumulation of hot air in diagonal positions concentrated at the upper level of each floor specially at corners. Not use stack effect as much as Shaft-box Different air pressure at corners due to intertwined effects terminated on each floor.

4. Multi-storey facade: at fig. (95), the air flows in different approach through large openings at the bottom close to the floor and the top of the whole building, it can be noticed that the air cavity space can be ventilated in all directions The air circulation across the entire façade area within the unrestricted cavity between two layers.

Box-Window- south façade



The Box-window units at South façade at 3rd storey, air temperature and velocity closed to the external skin

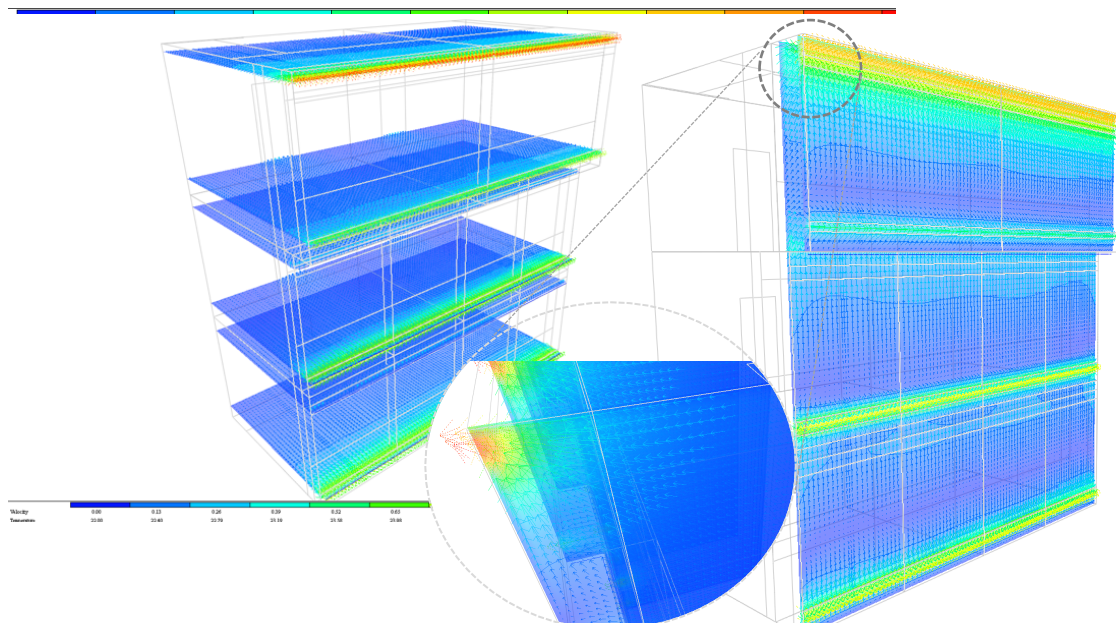
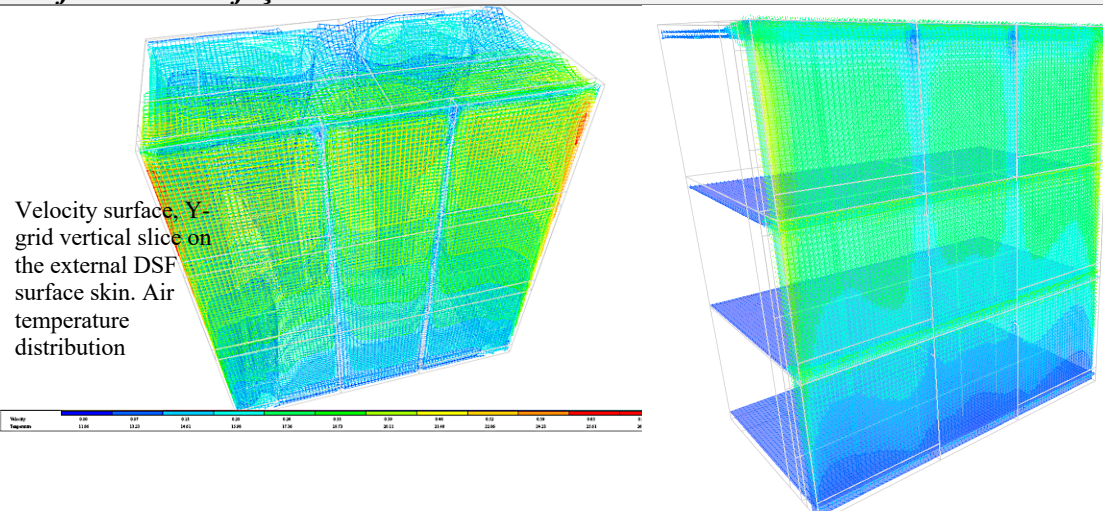


Fig. 92 CFD MicroFlo analysis- velocity contour inside the air cavity of the Box-window at South facing at 27 April, 7:30 (max. MacroFlo external vent). Source: (author)- by MicroFlo app.in IES

Shaft-Box-south façade



Y-grid

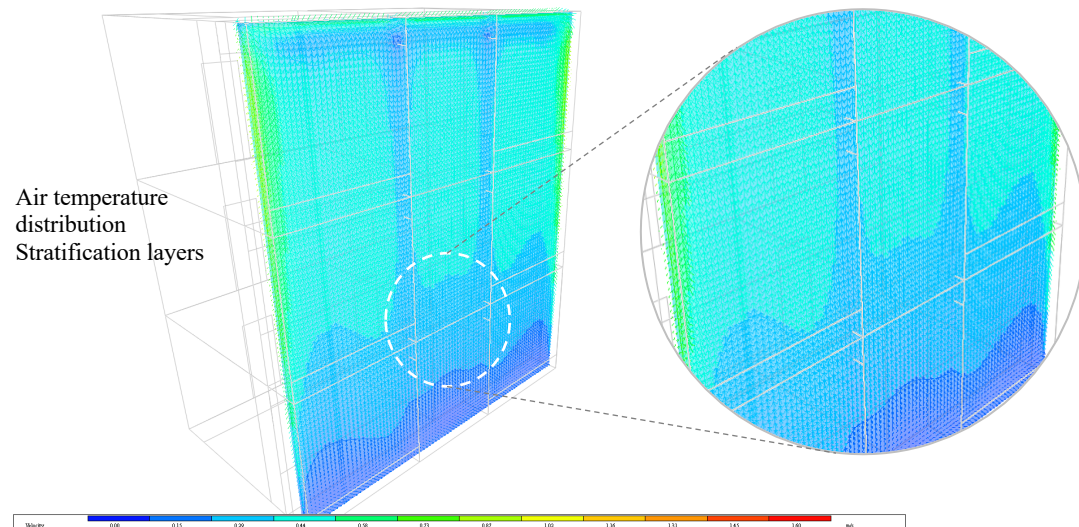


Fig. 93 CFD MicroFlo analysis- velocity contour inside the air cavity of the Shaft-Box Façade at South facing at 27 April, 7:30 (max. MacroFlo external vent). Source: (author)- by MicroFlo app.in IES

Corridor Façade-south facade

Air velocity
surface

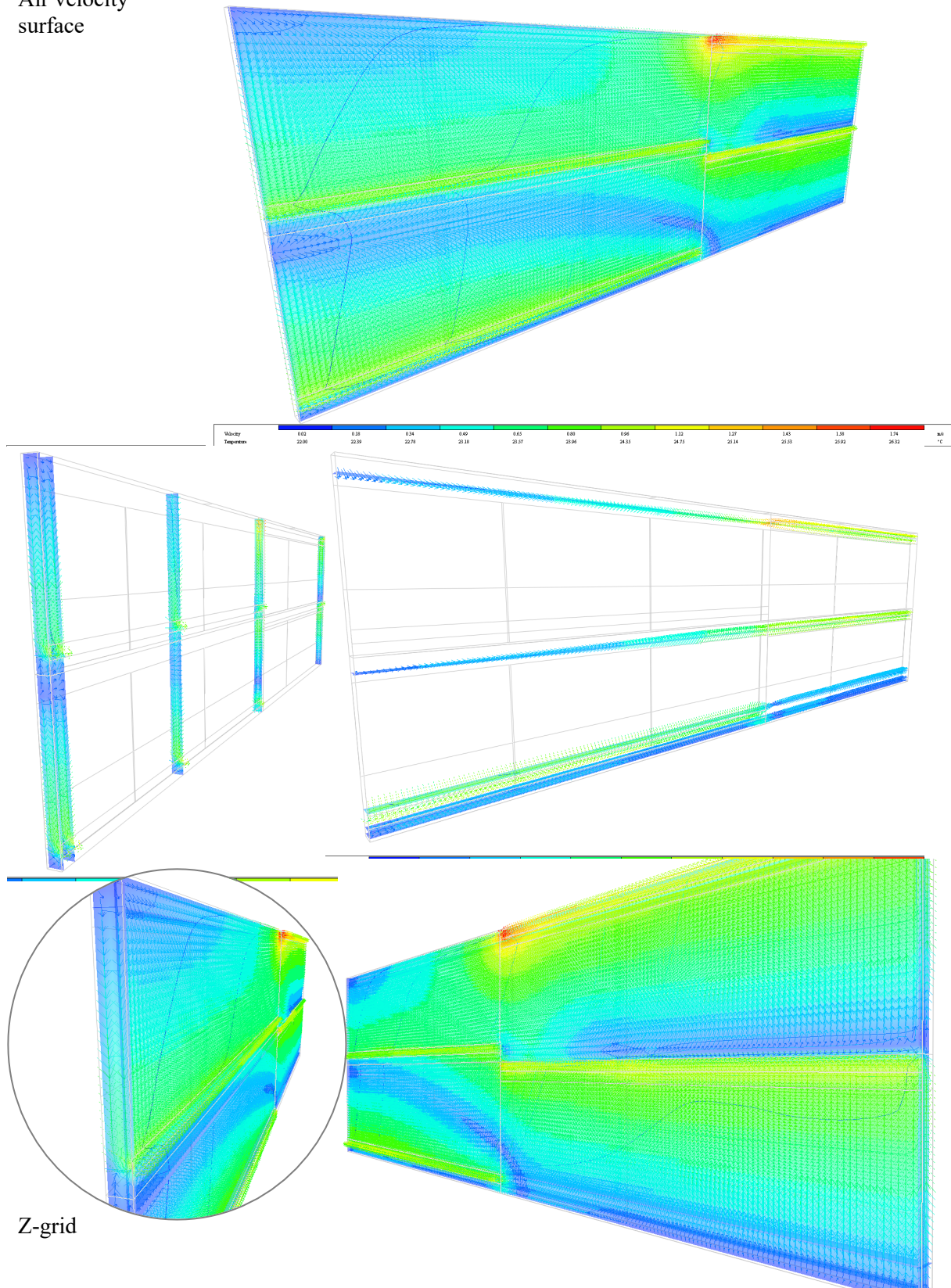
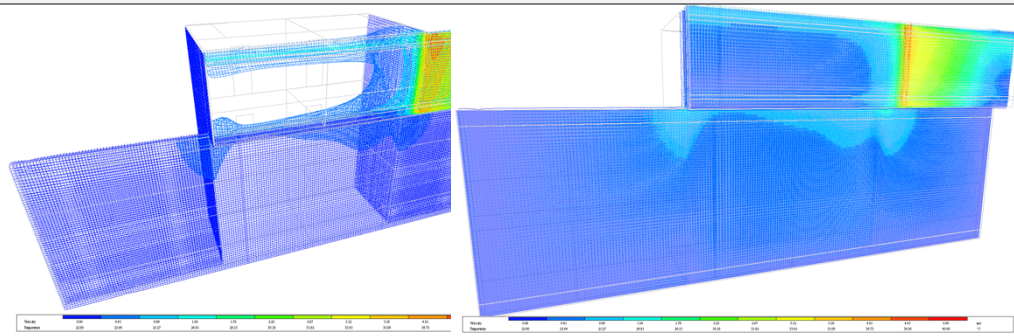


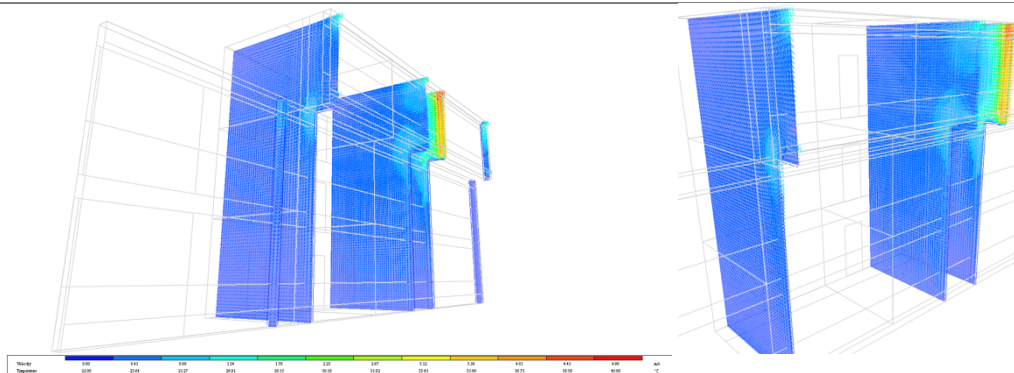
Fig. 94 CFD MicroFlo analysis- velocity contour inside the air cavity of the Corridor façade at south facing at 27 April, 7:30 (max. MacroFlo external vent). Source: (author)- by MicroFlo app.in IES

Multi-Story-South Facade

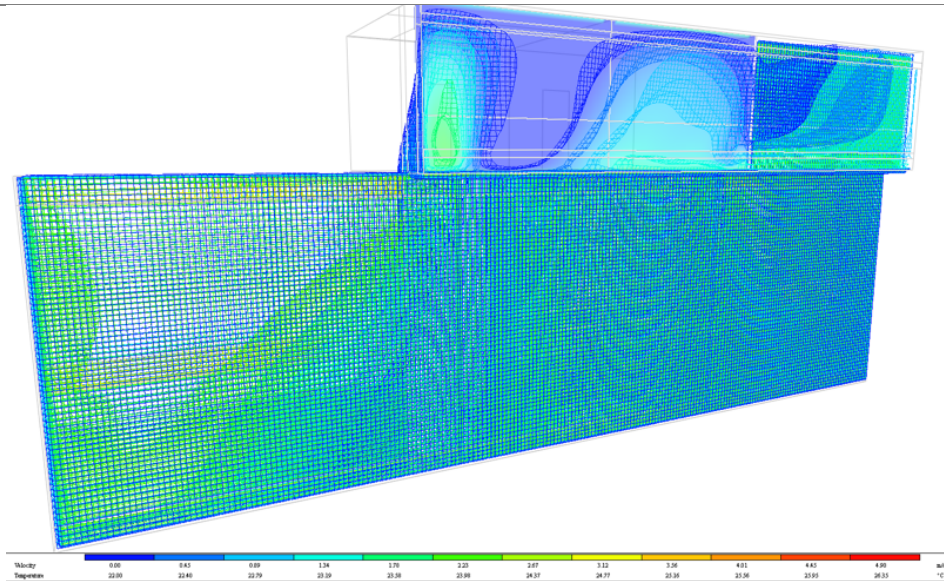
Air velocity
surface



x-grid



Temperature
surface



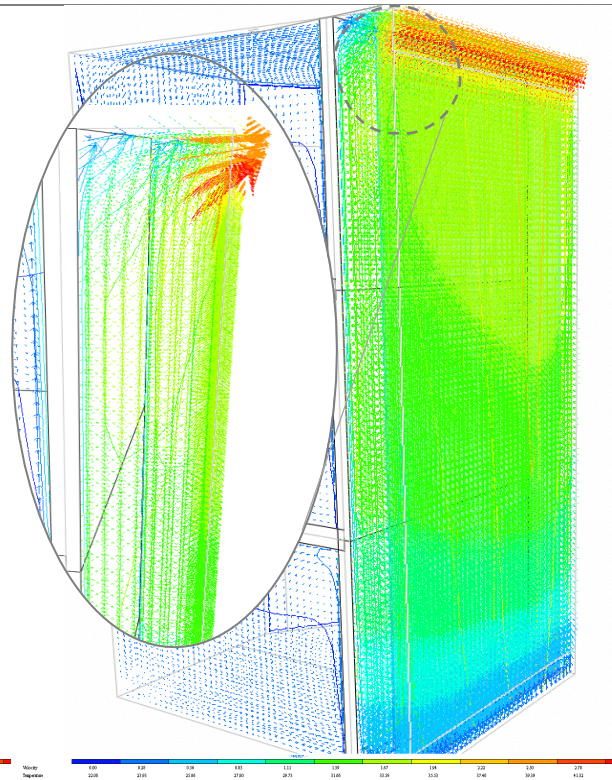
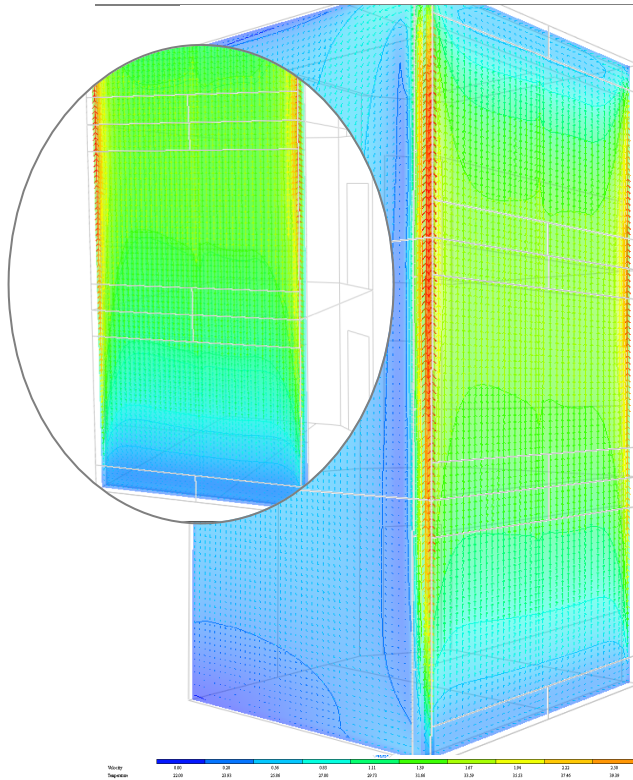
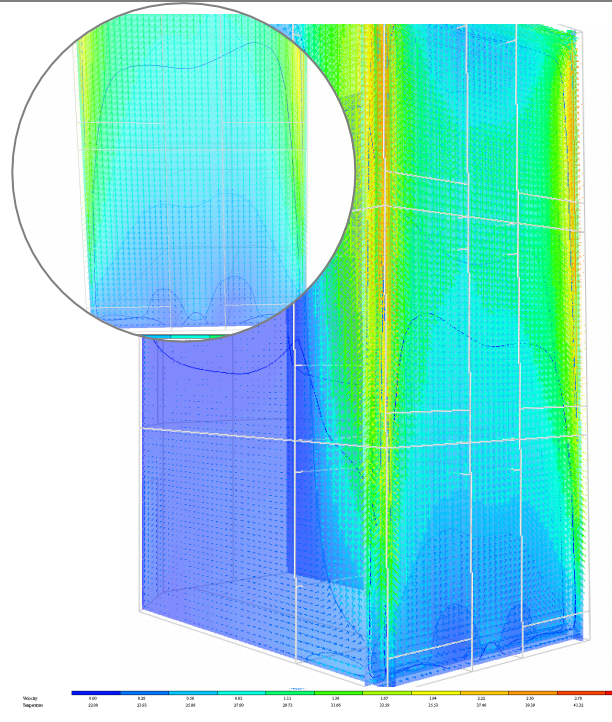
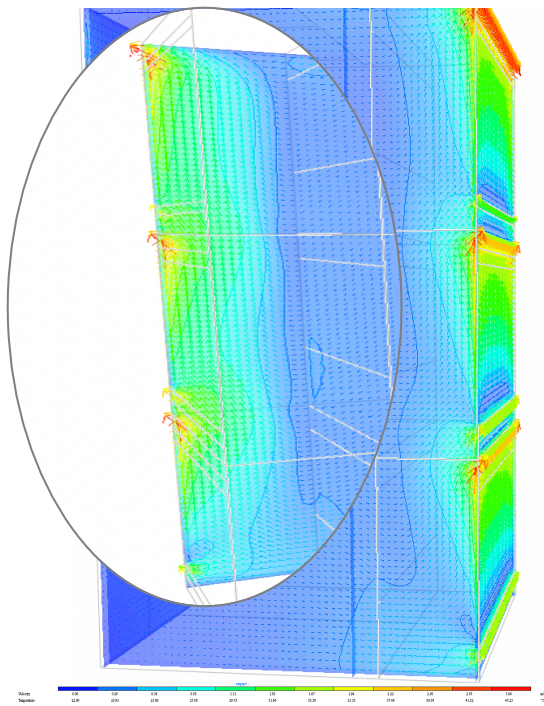
To ensure airflow dynamic unobstructive airflow

Fig. 95 CFD MicroFlo analysis- velocity contour inside the air cavity of the Shaft-Box Façade at South facing at 27 April, 7:30 (max. MacroFlo external vent). Source:(author)- by MicroFlo app.in IES

MicroFlo-CFD (air velocity and air temperature) Analysis of the 4 DSF types at East facade

Box-Window Facade

Shaft-Box Facade



Corridor Facade

Multi-Story Facade

Fig. 96 CFD MicroFlo analysis of the optimal cases of four DSFs types at selected cavity in east facing façade for each model. Source:(author)- by MicroFlo app.in IES

Overall, each cavity type shows different behavior of air movement inside the cavity, analysis airflow-CFD findings; The air velocity and temperature surface are varying within cavity. The highest air velocity in all cases cavities is for South oriented DSFs, with a peak of the sun radiation. While lower DSF air velocity is depicted in the east facing DSFs, due to the minimum solar radiation and exterior wind speed velocity on these façades. Air flow behavior performs differ distributed from façade surface to another depends on the position of air vents, size and area of vents, the height of cavity, wind direction and velocity. In general, The air velocity and vectors direction significantly great at the corner and the top of each cavity for all cases.

There are many criteria can manage the air velocity and temperature inside the cavity and results in different performance of each DSF type:

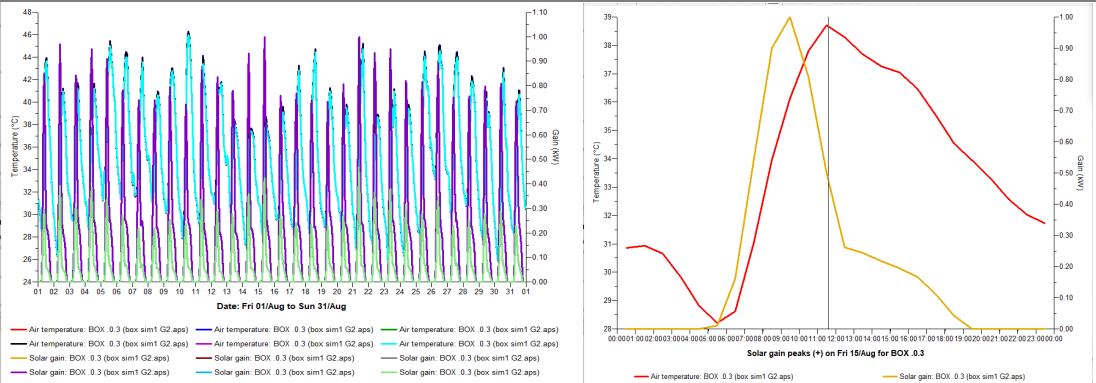
- ***The geometry*** of the façade, thermodynamic in terms of heat transfer process conduction, radiation and convection occurring within air cavity.
- ***The airflow path*** observed from CFD, airflow is created by effects of greenhouse effect and different temperature between internal and external cavity, it can be clearly noticed in fig. (92 to 96) that the air velocity and the air temperature distribution are changing along the height of the cavity of each case, the air flow improves air velocity flow at each openings confirmed with (Radhi, Sharples & Fikiry 2013), the results indicates that airflow affected by a number of parameters, opening size and positions, the cavity width and glazing properties. Incorporating all these within the chosen DSF structure and the optimized opening settings are the key factors that will determine the effectiveness of the DSF in improving the indoor thermal comfort. (Barbosa & Ip 2014)

- ***The air temperature***, is different gradients inside the cavity; the lower part has heated air (lower density) buoyancy turns to improve creating a stack effect, while the hot air lift to upper parts of air cavity hence forcing the outdoor air enter from openings.
(Radhi, Sharples & Fikiry 2013)
- ***Air moving within cavity***; It can be noticed, some closures such as corridor and shaft-box cavity in some façade corners have a great difference in air pressure due to intertwine effects which terminated on each storey. (Hilmarsson 2008)
- ***The strength of the buoyancy***; buoyancy force relied on the air temperature and convective heat transfer at surfaces. The higher temperature, the higher strength of the buoyancy force will result such as multi-story façade and corridor. The wind force is another component of driving forces. The main features of the wind forces is their random and extremely fluctuating nature. where the driving forces (wind and buoyancy) may counteract or act together, determining the mass flow rate in the cavity.
(GhaffarianHoseini et al. 2016)
- The concept of a thermal buffer utilizing **the stack effect** to remove excessive heat within the cavity reduces the cooling loads significantly. The temperature range of the triggered components can be adapted to specific contextual requirements as climate zones, facade orientation and user preferences.(Molter et al. 2017)

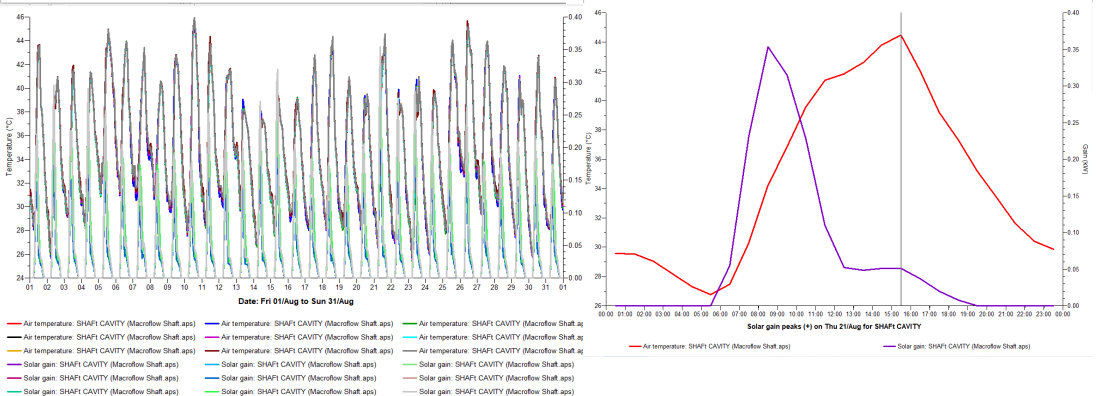
5.8 AIR TEMPERATURE AND SOLAR GAIN ANALYSIS

Table 24: Air temperature and solar gain at east facing façade cavity of the 4 optimal DSF cases in August

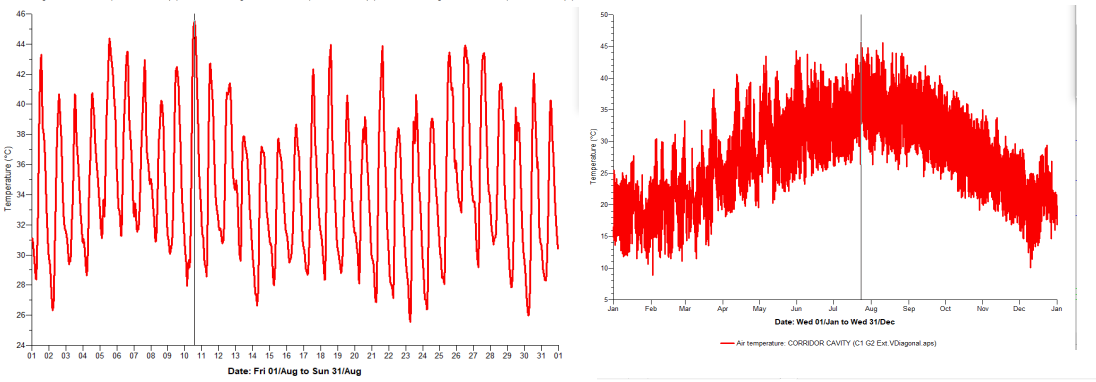
Box-window facade



Shaft-box facade



Corridor facade



Multi-Storey facade

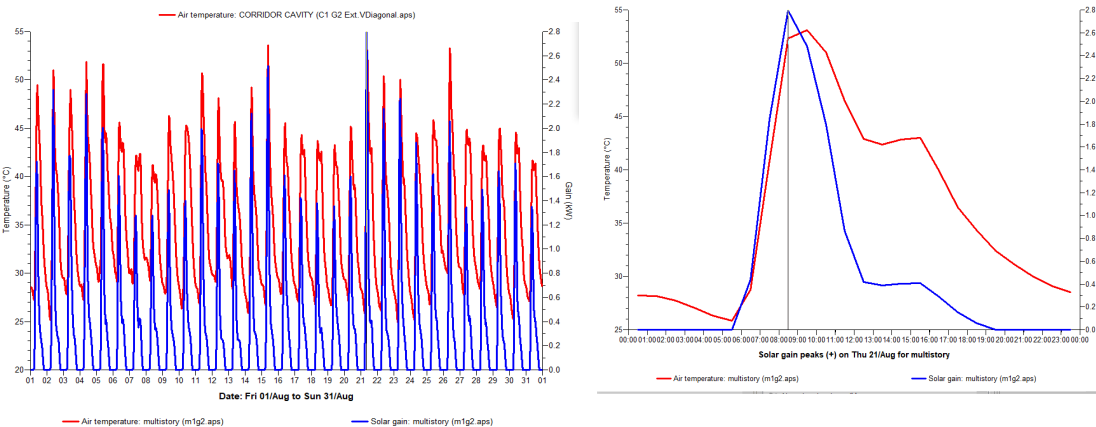
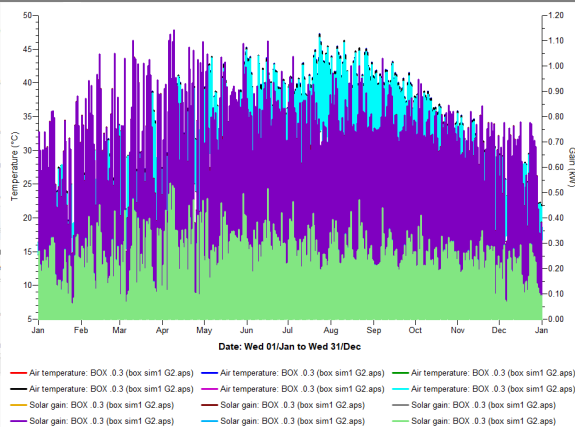


Table 25 Annual air temperature and solar gain at east facing façade cavity of the 4 optimal DSF cases

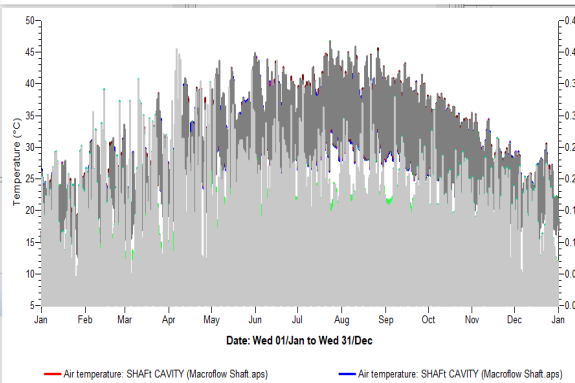
**Box-
Window**



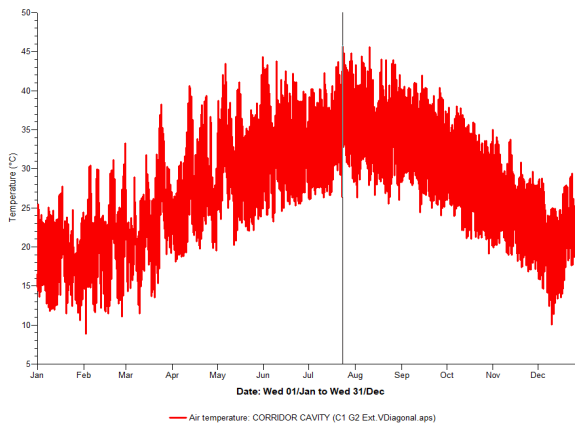
The following charts show that the annual air temperature and solar gain of four DSF cases, the results derived from dynamic thermal simulation in only east façade for each optimal case @ (sim1=0.30 m cavity depth with G2 glazing system), the peak air temp. results recorded at August with different levels.

The higher temperature, the higher strength of the buoyancy force will result such as multi-story façade and corridor

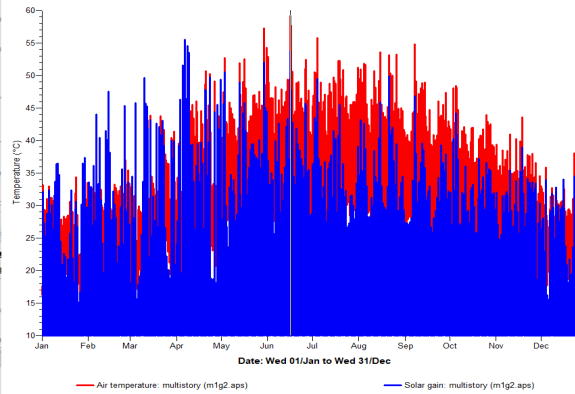
Shaft-Box



Corridor



**Multi-
Storey**



CHAPTER SIX

CONCLUSION

6. CHAPTER 6 CONCLUSION

DSFs refer to the building envelope system includes multi-layer skins (external and internal skins) with buffer air space to manage ventilation and solar protection. This work confirmed DSF potential to achieve annual cooling saving loads in commercial buildings in extreme hot climate such as Al Ain -UAE. The study based in a numerical investigation by using IES-VE simulation software, and shown thorough comparison between case studies theoretical and simulation results. The basic target of this study was to assess and investigate the DSF performance in multi-used building in hot climate, and predicting the optimal characteristics. After analyzing the final results of all simulation strategies, the DSF system proved more energy efficient than conventional façade of refence base.

The simulation approach of this paper focused on the comparison of four types of proposed natural ventilated DSFs being constructed to three facades (south, east and north) of three-storeys typical building (reference base) with 10.50 m height. This comparison based on calculation energy consumption (the total annual cooling loads (MWh) and the total annual electricity consumption (MWh)) and tested the behavior of airflow within the cavity (MacroFlow) and air velocity analysis (Microflo) for each type. this work made up of different strategies focusing on modifying DSF parametric to provide the optimal solutions for enhancing energy performance of the building façade. Final Findings verified that significant benefits result from applying DSFs, it provides savings in annual cooling demands range from (6.70% to 10.30%) relative to the reference base in hot climate.

6.1 SUMMARY OF THE RESEARCH

from simulation strategies results, the study concluded that:

- a. **the 1st strategy** involves 4 DSF types, each case of DSF with 3 altering cavity depths (0.30m, 0.90m and 1.50m) associated with 3-glazing combination (G1, G2, G3) through integration each sim. of cavity depth, the results achieved energy efficient by reduce cooling loads to (223.55 MWh) by 9.20% of Multi-storey façade comparing with reference base which consumed (246.21MWh) annual cooling loads, followed by Corridor, Shaf-box and Box-window façade with (224.5 MWh, 224.9 MWh, and 231.5 MWh respectively) with reduction cooling loads by (8.80%, 8.6%, and 5.9% respectively). In regarding with altering **optical properties**, all cases with G2 (double pane outer, doble pane inner) achieved the highest energy saving, followed by G3 (single pane outer, triple pane inner), G1 (single pane outer, double pane inner) in sequence.
- b. The 2nd strategy based on selected the optimal case of 4 DSF types, after that changing SDs-vertical louvers positions through the cavity was applied to improve DSF thermal performance, results found that adapting external positions of SDs with DSF is most efficient resulting in saving greatest amount of energy saving for all cases, but didn't show significant benefits in saving the total annual energy consumption is only slightly more than 1st strategy. the results with SDs show that Multi-Storey façade provide the best performance in saving energy consumption about (220.91MWh) total annual cooling loads by (10.30 %) reduction cooling loads in comparison with reference base, followed by Corridor façade, Shaft-box, and Box-window record (222.27 MWh and 223.10 MWh, and 229.7 MWh respectively) by (9.72% and 9.39%, and 6.6% respectively) in saving cooling loads. Integration middle SDs with G2 glazing and 0.30 cavity depth reduced the

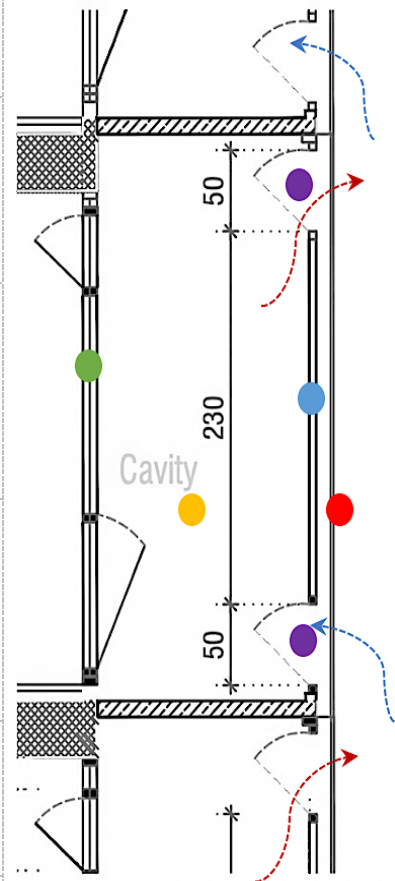
efficiency of energy saving consumption, followed by the inner positions which show the lowest reduction amount in comparison with other alternatives.

The optimal design of this work can't be employed to all the buildings, since optimization and applying of such this system may vary according to the climate conditions, different criteria and the building location, the findings highlight the importance of the need for careful consideration when designing the dimensional parameters of DSFs construction. All parameters are coupling affect each other play significant role with air flow performance, heat transfer process and energy performance of DSFs. Another purpose of this research to Investigate the influence of key parametric design through analyzing the relationship between them and to over the whole system. The study concluded that there are different parameters influenced on the efficiency of DSF design performance, the findings were derived from dynamic thermal simulation results. According to the final findings, this work led to set of guidelines for design of energy efficient DSFs in hot climates.

The final results analysis showed that the optimal DSF in hot climate resulted in higher saving cooling loads by decreasing the air cavity depth, choosing the ideal glazing properties focusing on the external glazing layer with lowest SHGC an U-value, installing the shading devices at the external layer of DSF could the efficient positions in such this case, as well as improving the openings vents increasing the efficiency of DSF system by increasing the airflow rate within the natural ventilated cavity contributed in decreasing the heat air accumulation, resulting saving cooling loads.

The following table (26) summarized the overall findings related to the optimal key DSF design parameters for enhancing thermal performance of DSF system

parameter		State of art review findings
DSF typologies-Geometry	Box-Window	reduction cooling loads with SDs by 6.68%, the results be affected by green-house effect.
	Shaft-Box	Reduction cooling loads with SDs by 9.39 %, the results are influenced by Stack-effect
	Corridor	9.72% reduction cooling loads, the results have influenced by Diagonal vent openings.
	Multi-Story	Fully open vents along the facade, the most optimal type, reduction cooling loads by 10.30% relative to the reference case, the highest ventilation flow rate about 2600 l/s max. volume flow-rate
● Cavity depth		Thinner air cavity depth, lower energy consumption, 0.30 m width is preferred. Increasing stack-effect, heat towards the interior room minimized. Cavity depth caused difference in heat transfer coefficient
Glazing properties	● External skin	Double glazing with Lower SHGC & U-value Higher insulated, better thermal performance, reduced solar transmittance (w/m^2), minimizing heat gain. Most part of heat blocked before reaching air cavity. G2 is recommended for external DSF skin
	● Internal skin	Double glazing with Lower SHGC & U-value Higher insulated, better thermal. Optical glazing properties caused variation in temperature and solar gain.
● Solar shading devices SDs		External SDs-Vertical louvers position the most efficient performance. Inner and middle positions increase heat transfer to indoor
● Vents opening		Larger area and size, better performance. decreases the flow-resistance, leading to greater amount of air flow through the cavity
● Hight of the façade		The Higher cavity facade, better performance. The taller cavity formed a greater(stronger) buoyancy force, leading in a larger airflow-rate. Hight of floor level cavity and distance between vent openings caused difference in temperature



cross section of DSF cavity system integrated natural ventilated external air curtain mode EAC

Table 26 Parametric study key design for enhancing DSF system. Source:(author)

The DSF performance act as one unit system is highly dependent on the *geometry of the façade*, the physics of *heat transfer* processes occurring inside the cavity, *the airflow path*, *the air velocity* and *the air temperature* change along the *height of the cavity*, which are affected by a number of parameters such as the *shading device SDs configurations*, *the cavity width* and *glazing properties*. In conclusion, **Airflow analysis** is considered significant process for energy modelling represent; measuring temperature within different heights inside the air cavity to show thermal transfer by convection within DSFs cavity, the natural airflow cross-ventilation through vents openings, and affecting using stack-effect in cooling loads. The airflow simulations required a geometric boundary, local site and weather profile conditions in early design stage. The final results represent compatible rate with previous studies under the same conditions.

The study summarized the main findings with influenced factors of each parameter were assessed in this work, so the final outcomes of this work can be reviewed in regarding with followings:

- a. Flowrate;** there are strong relationship between air flow rate and design opening vents. The results were revealed by using CFD analysis to predict the air flowrate in the cavities. The findings found that optimum DSF cavity depend on buoyancy force. So, for increasing the buoyancy induced flow-rate was Multi-Storey Façade illustrated the ideal case due to larger size and area of openings vents along the façade with highest distance between inlet and outlet vent openings in compare with other cases. the optimum performance of DSF based on **opening vents size**, that larger openings area in the cavity decreases the flow-resistance, leading to greater amount of air flow through the cavity. The greatest airflow volume rate is measured in multi-story type at south façade (highest solar radiation) and north façade (predominant wind). Improving natural ventilation avoid heat sinking inside the air cavity. The study found that the air flow within air cavity have major impact on the performance of the DSF.

- b. **CFD analysis results:** that the most DSF cases show accumulation heat air at upper levels, and corners edge where the air under different pressure due to intertwined effects terminated on each floor. Thus, results indicate to more investigation in opening criteria such as, size, design and positions of inlet and outlet along the external skin of DSF.

- c. **The heat transfer;** the final results of simulation DSF cases verified with the heat transfer process in the cavity was clearly observed at CFD analysis in this study for each case, the heat transfer represents by the potential of air space itself by draw off some of incident direct solar radiation within the cavity space, then heated air are carried by convection currents upwards and after that extracted to the outdoor by opening vents at the top of cavity. (Boake et al. 2003) when warm air rising up by convection resulting in minimizing heat transfer to the user room, hence reducing cooling loads.

- d. the importance of **stack effect** is clearly noticed in all DSF cases with various levels. The stack effect within the cavity resulting in less energy demand for cooling the building. thinner profile cavity is preferable and optimized the efficient of stack effect in this work. In general, DSF system based on buoyancy force effect, when the external layer of DSF is warmed up by absorbing solar radiation, the air within the cavity turns to rise up, resulting in decreasing heat transfer inside the building.

- e. **Orientation** is important issue for optimization performance of DSF design, the results obviously showed different performance among 3 facades, the south and north facing façade was more efficient in amount airflow than east façade. The DSF has to be well ventilated specifically at south faced where solar radiation is the highest, to prevent overheating.

- f. **The cavity depth;** play a significant role in reduction energy performance. As DSF cavity depth increases, the saving of the total energy consumption decreases. The end results might be debatable, and relative to their specific design (model), seasonal variations, and climatic conditions. Inter-relationship between the openings dimensions, air temperature and airflow rate were observed by Gratia and De Herde, and Oesterle et al., (2001)

presented an extensive description of the function and the air flow of the cavity in relation with constructional parameters. The authors mention that only when the cavity between the façade skins is relatively shallow (less than 40 cm) significant pressure losses are likely to occur. Otherwise, the air cavity space offers no major resistance to the air flow. So, thinner profile is recommended and preferred at regions meet same conditions.

- g.** Investigation influenced location of the **solar shading devices SDs** in reduction the air temperature and reducing direct solar gains into the building rooms is importance parameter for enhancing DSF building performance. In contrast, the heat absorbed by shading device can also increase the air temperature and the stack effect inside the cavity. If placed SDs close to the inner layer, there is the risk of great heat transfer to the occupant rooms by convection. (Barbosa & Ip 2014) The energy demand analysis demonstrates that the energy performance strongly depends on the setting of SDs positions through the cavity. take into account the position arranged in DSFs under hot-arid climate with extreme solar heat. So, in this work the external SDs position is the ideal solution among others.
- h.** The choice of adequate **glazing optical thermal properties** is one of the most important decision that architect should take into consideration during the design stage. so, this decision effects on final design results and improving energy efficiency. Energy savings attributed to DSFs are achieved by minimizing solar loading at the perimeter of buildings by providing a low solar factor and lower U-value minimizes cooling load of adjacent spaces. Selected **G2** glazing (double pane in external skin-double pane in internal skin) in this work show the optimal glazing properties with lowest SHGC (0.1247) and (2.4773 U-value) among other configurations, due to the higher value of thermal resistance and lower heat transfer coefficient. The results also indicate that the external skin of DSF is the most sufficient in enhancing energy performance of the building in comparison with internal skin.

The analysis results of this study could be used in making early decisions regarding enhancing energy efficiency of DSF performance to save cooling energy consumption in the UAE- hot climate regions. Overall, the research context proves efficient implantation of DSFs in hot

climate under several criteria. The study may contribute in architectural and engineering development in terms of structural and construction of building façade process by transferring the current view design through replacing the conventional (typical) wall structure to a new trend in light-weight structure and enhancing energy efficiency performance of the building envelope.

6.2 RESEARCH LIMITATIONS AND CHALLENGES

Thorough analysis and studies of the current DSFs construction characteristics, and technical aspects have been reported in many papers, the most studies are limited/focused on cold and temperate climates mostly in Europe and North America. But the impact of DSF on thermal performance and energy efficiency in hot-arid climate are little, not sufficient enough. So, this work address looking at simulated performance of different types of DSF applications and observed their capabilities in enhancing energy performance of building façade under hot-arid climate conditions.

A little knowledge and experience of DSFs performance. Although there are several studies have conducted to-date, there are no certain/clear and standard guidelines of modelling(designing), performance predict and assessing DSF system. (Wang et al. 2021). The most study cases of DSF are designed by referring to the previous design and studies. Joe et al. (2014). The BESTFACADS mentioned some limitation/obstacles in achieving measured data analysis of DSFs cavity energy demand and temperature (not much available), because the building owners are not allow easily taking such sensible data. (Streicher et al. 2004)The complicated of design DSFs due to interaction different design components of natural ventilation and thermal performance is required cautiously understanding structural design. In naturally ventilated buildings, the airflow behavior inside the cavity still needs investigation to account for the effect of different configurations of the openings to the air flow at different

floor levels. the finale results might be debatable, and relative to their specific design, seasonal variations, and climatic conditions. The decision to construct building with DSF can trigger motivation for engineers and architects.

The cost-efficient investment higher comparing to the typical façade possible disadvantages of DSFs. There is lack/little published work and data related to operation energy benefits of DSF construction, achieving data in terms of energy use may generalized or fails getting a specific credit for system. implementation of DSF systems in the budlings in the case of hot climates are limited. The findings result from several studies illustrated diversity of consequence DSF performance, that is indicate the DSF strongly relied on climate conditions, components of DSF design and building location.

6.3FUTURE WORK

Investigation in DSF application in hot-climate needs further investigation, more anlaysis and studies for effective thermal management. also, more studies need to be done regarding changing the other parameters. Adaptive sustainable strategies and passive energy design of DSFs system, afford potential solutions to the glazed buildings. To meet the sustainability targets, there is a need for continuing the improvement of new building concept, technologies that can enhance the energy efficiency of buildings, synchronized improving the indoor environmental comfort of building occupants. Designing a DSF according to climate is still in-progress, mainly due to the complicated nature of airflow and heat transfer that occur within the cavity. There is growing tendency to use DSF system, it could provide an efficient and sustainable solution to overcome the heat gains to maximize the efficiency of the DSF performance. On other perspective, the application of DSF not only to the existing building but also could be for new design building, Overall, the results of this research created the opportunity to discuss the strengths and weaknesses of using DSFs.

This study draw plans to conduct the following future research, designing an optimal type of the DSFs according to the energy performance and improving thermal comfort of the building. Based on cavity depth as a thermal buffer insulation (reducing thermal heat transfer to the inner space), the size of an opening vents, the effects of thermal properties (insulation) of glazing system and shading devices positions (configurations). Improving air flow operating process within the air cavity. Study the effects of DSF on the daylighting performance. Future works should be focused in geometry design of each DSF types in according these parametrs, improving air flow operating rates by inlet and outlet external openings which enhancing thermal insulation.

DSF system and current applications led to inspired on the future of building façade architecture. Future projects should intend to transition from typical wall to ventilated façade by enhancing air space, in order to optimize building environment, well-being, thermal comfort and energy. Therefore, this work purposed to extend the behavior of DSF and analysis different applications in specific climate and Al-Ain City -UAE was selected as the sample reference city. The optimization parameters have some characteristics, could offer some inspirations for designing DSFs in hot climates. Adapted in SDs system configurations such as, mesh pattern shading, *Mashrabiya* system, louvers provide significantly confidence in ventilated DSF performance in hot climate. Investigation in hybrid and mechanical ventilation of DSF in hot climate could be offer efficient performance.

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APPENDIX

Appendix 1: IES Virtual Environment user interface

“Natural ventilated DSFs were tested and investigated by using dynamic thermal simulation Apache in IES VE software”.

The simulation analysis in this work used the IES-Virtual Environment software which is divided into many applications including certain informative functions belonging to thermal performance, solar shading etc. The dynamic thermal modelling analysis of the multi-used building used the following applications:

- ModelIT (building modeller)
- SunCast
- Apache (Thermal calculation and simulation)
- MacroFlo (multi-zone air movement)
- VistaPro (Advanced analysis)
- MicroFlo (CFD)

After modeling a 3D building in sketch-up software and editing the model via IES-ve modelIT application. For saving time running and for more accuracy, the study selected a specific zone of the whole building to run dynamic thermal simulation and analysis. The selected model made up of 3 stories (room and adjacent building) as shown in table (27). The next stage defined the room parameters through assigned space via building template manger such as (constructions, thermal conditions, opening types, etc.)

The building conditions based on the local climate data to simulate dynamic thermal performance. It also considers assigned construction materials with thermal properties, energy demand for annual heating and cooling loads, internal gain, air ventilation. The paper focused on observiation thermal performance of the building.(Hindman & Hindman 2020)

Applications & Navigators

- ModelIT (building modeller)
- SunCast
- Apache (Thermal calculation and simulation)
- MacroFlo (multi-zone air movement)
- VistaPro (Advanced analysis)
- MicroFlo (CFD)

1

Model browser

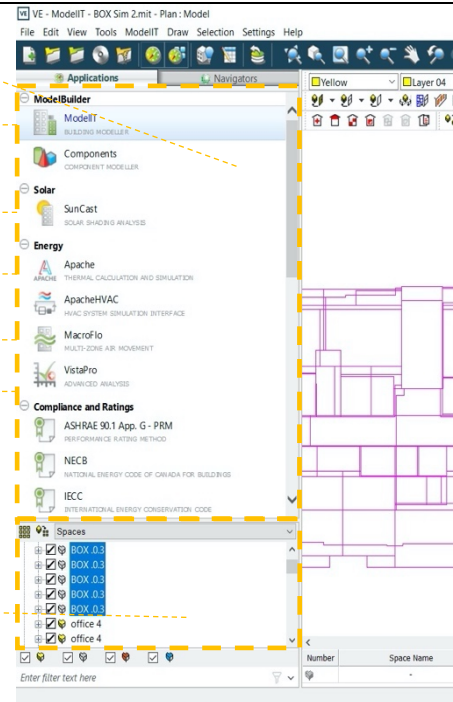
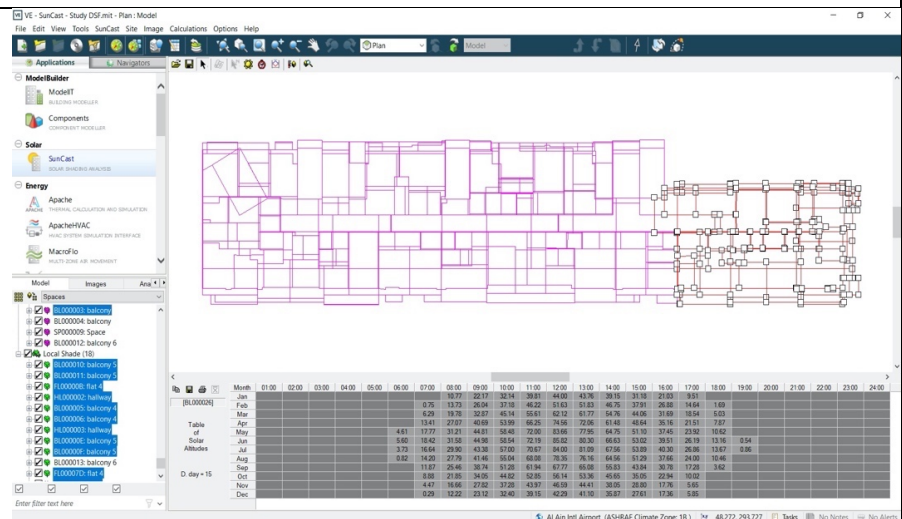


Table 27 IES-VE modelling process and simulation energy performance

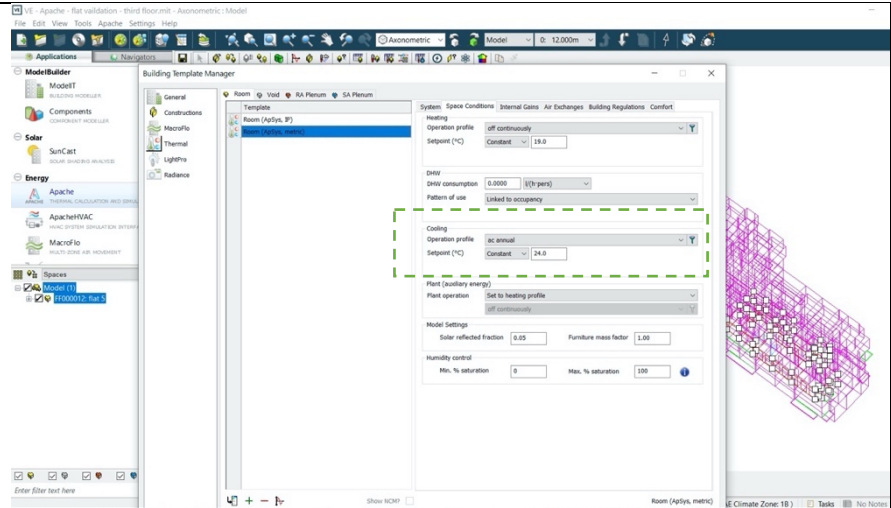
SunCast analysis, the selected area of whole building model for analysis, in pink is the adjacent building

2



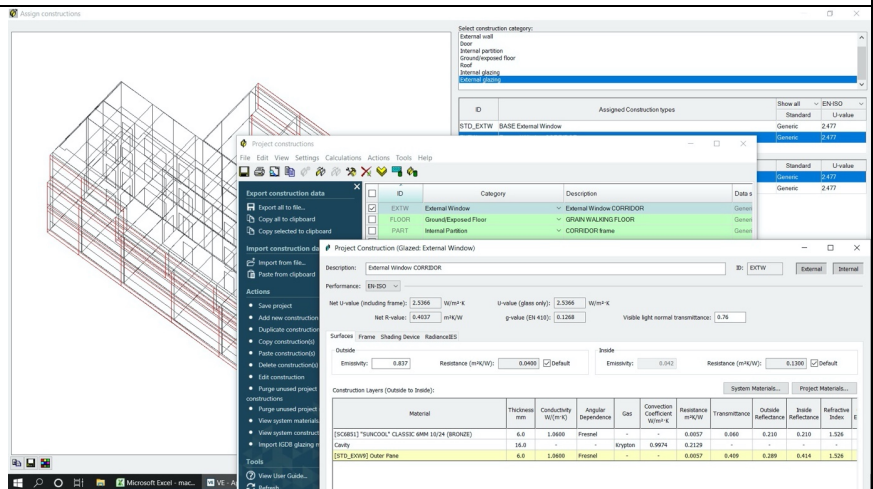
Building template manger, identifying thermal- space conditions

3



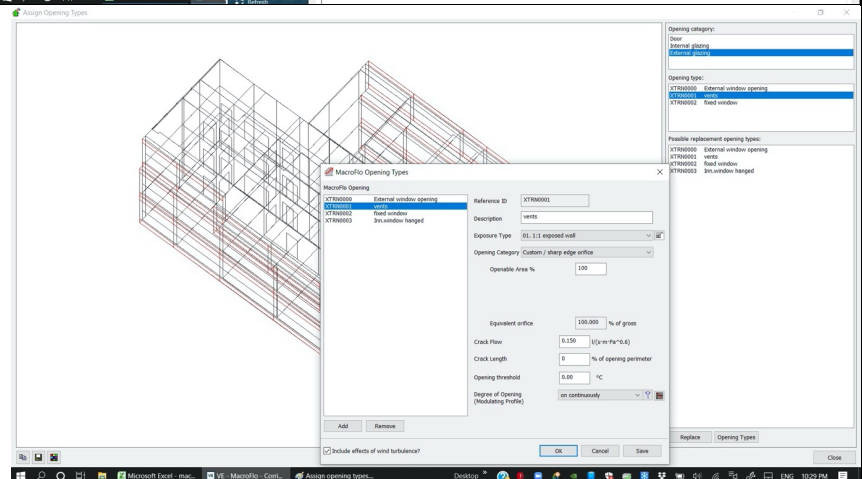
Assign construction materials for proposed skin

4



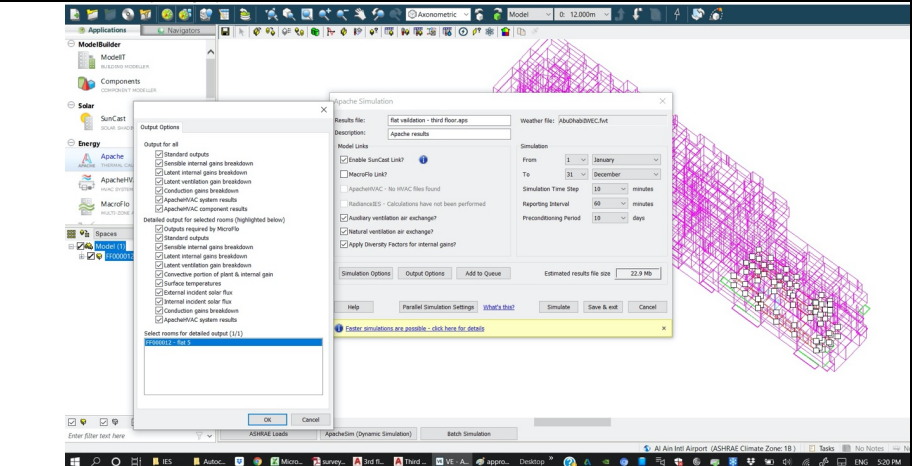
Macroflo opening types, assign the configurations of vents at external layer

5



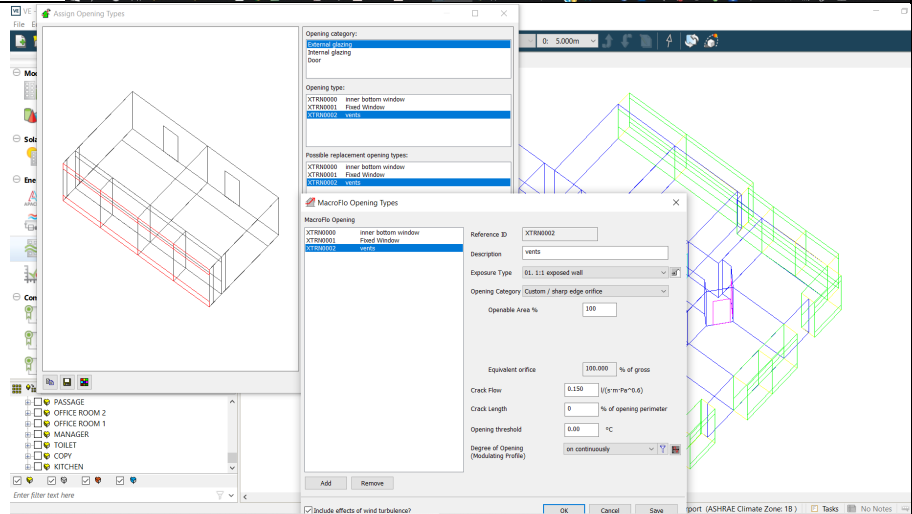
Apache results, for dynamic thermal simulation of flat area validation by Apache

6



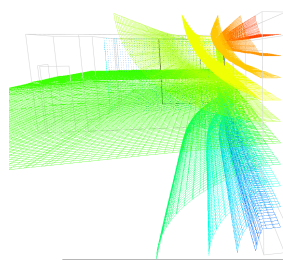
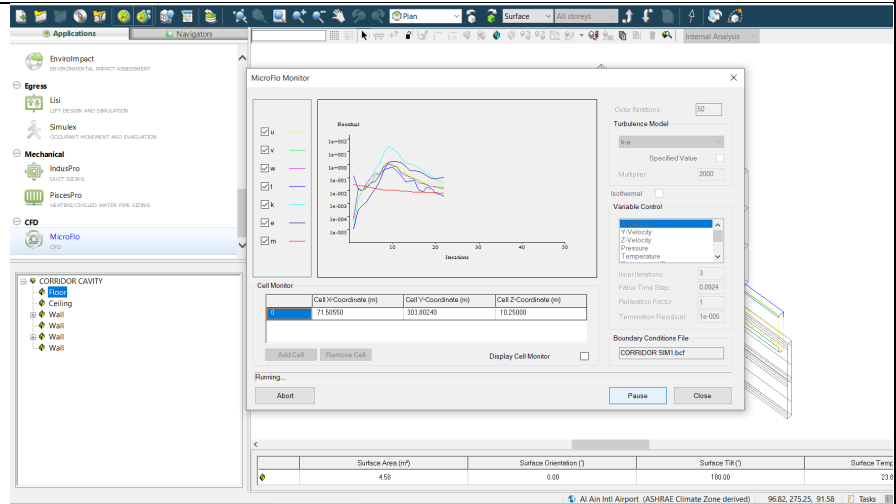
Assign openings vents configurations top and bottom vents at external layer skin

7



MicroFlo monitor during simulation running after importing the **boundary condition** file includes the name of file was used to import the data for internal simulation

8



pressure surface CFD -microflow in the air cavity of multi-storey DSF

DSFs Cavity Type	Scenarios based on cavity depth (0.3, 0.9,1.5 m)	Scenarios based on Glazing Properties	Room cooling plant sens. load (MWh)	Total electricity (MWh)	Saving cooling load reduction %
BOX WINDOW	Sim1 (0.30 m cavity width)	G1	236.15	118.07	4.09
		G2	231.52	115.76	5.96
		G3	233.65	116.82	5.10
	Sim 2 (0.90 m cavity width)	G1	242.25	121.13	1.61
		G2	237.31	118.65	3.62
		G3	238.24	119.12	3.24
	Sim 3 (1.5 m cavity width)	G1	242.65	121.32	1.45
		G2	238.12	119.06	3.29
		G3	238.54	119.27	3.11
Shaft Box-Window	Sim1 (0.30 m cavity width)	G1	228.00	114.00	7.40
		G2	224.90	112.45	8.66
		G3	227.50	113.75	7.60
	Sim 2 (0.90 m cavity width)	G1	229.89	114.95	6.63
		G2	228.30	114.15	7.27
		G3	230.25	115.13	6.48
	Sim 3 (1.5 m cavity width)	G1	230.97	115.49	6.19
		G2	230.17	115.08	6.52
		G3	231.22	115.61	6.09
Corridor	Sim1 (0.30 m cavity width)	G1	239.82	119.91	2.59
		G2	224.54	112.27	8.80
		G3	228.55	114.28	7.17
	Sim 2 (0.90 m cavity width)	G1	237.76	118.88	3.43
		G2	227.10	113.55	7.76
		G3	230.51	115.25	6.38
	Sim 3 (1.5 m cavity width)	G1	236.93	118.47	3.77
		G2	226.31	113.15	8.08
		G3	228.73	114.36	7.10
Multi-Story	Sim1 (0.30 m cavity width)	G1	235.14	117.57	4.49
		G2	223.55	111.78	9.20
		G3	227.25	113.63	7.70
	Sim 2 (0.90 m cavity width)	G1	236.36	118.18	4.00
		G2	224.77	112.38	8.71
		G3	228.11	114.06	7.35
	Sim 3 (1.5 m cavity width)	G1	236.81	118.40	3.82
		G2	225.23	112.61	8.52
		G3	228.09	114.05	7.36

Appendix 2: Electricity Bills

The followings are monthly consumption of electricity (electricity bill) of tenet's owner flat, from meter readings of Al Ain distribution company. For private purposes, the owner did not allow access to his own information except relative electricity consumption data, I blocked out by blue shaded to confirm his request.



Bill Date
Apr 12, 2020
Premise Number
1646757004
Premise Type
Commercial Building
Account Class
Residential (Residential Expat)

Previous Billing Details

Previous balance	AED 199.23
Payment received since last bill	AED -199.23
Last Payment Date	Mar 14, 2020
Balance Forwarded	AED 0.00

Consumption Charges

✓ 872.00 kWh @ AED 0.268 /kWh	AED 233.70
Total	AED 233.70
Other Charges	AED 0.00
Adjustments/Corrections	AED 0.00

TAXES ON ELECTRICITY USAGE

VAT 5% on consumption charges 233.70	AED 11.69
VAT 5% on Other Charges	AED 0.00

Total Cost of Electricity	AED 245.39
----------------------------------	-------------------

Total subsidy for the year 2020	AED 32.26
Actual Cost 0.305 AED/unit	AED 265.96



Total To Pay
AED 245.39
Pay by or before Apr 22, 2020

Meter Reading Information

Meter Number 200021395266	
Start read Mar 07, 2020	11395
End read Apr 06, 2020	12267
Total consumed units	872

872 kWh used over 30 days

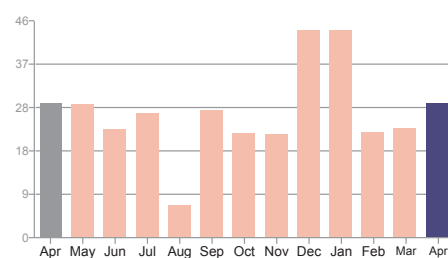
Your electricity usage over time

↑ 0%

Increase of 0.01 kWh per day in electricity used compared to the same period last year.

AED 7.79

Average daily cost of electricity in the current period without VAT



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Al Ain Distribution Company

AADC TRN:100264873900003

Total To Pay

AED 218.37

Pay by or before Aug 16, 2020

Meter Reading Information

Meter Number 200021395266

Start read Jul 07, 2020 14537

End read Aug 06, 2020 15313

Total consumed units 776

776 kWh used over 30 days

Bill Date

Aug 06, 2020

Premise Number

1646757004

Premise Type

Commercial Building

Account Class

Residential (Residential Expat)

Previous Billing Details

Previous balance AED 237.78

Payment received since last bill AED -237.78

Last Payment Date Jul 15, 2020

Balance Forwarded AED 0.00

Consumption Charges

✓ 776.00 kWh @ AED 0.268 /kWh AED 207.97

Total AED 207.97

Other Charges AED 0.00

Adjustments/Corrections AED 0.00

TAXES ON ELECTRICITY USAGE

VAT 5% on consumption charges 207.97 AED 10.40

VAT 5% on Other Charges AED 0.00

Total Cost of Electricity AED 218.37

Total subsidy for the year 2020 AED 28.71

Actual Cost 0.305 AED/unit AED 236.68

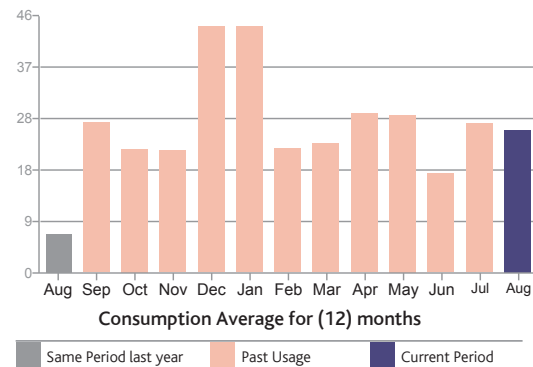
Your electricity usage over time

>100%

Increase of 18.92 kWh per day in electricity used compared to the same period last year.

AED 6.93

Average daily cost of electricity in the current period without VAT



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شركة العين للتوزيع

Al Ain Distribution Company

AADC TRN:100264873900003

Total To Pay

AED 191.35

Pay by or before Feb 16, 2020

Meter Reading Information

Meter Number 200021395266

Start read Jan 07, 2020 10007

End read Feb 06, 2020 10687

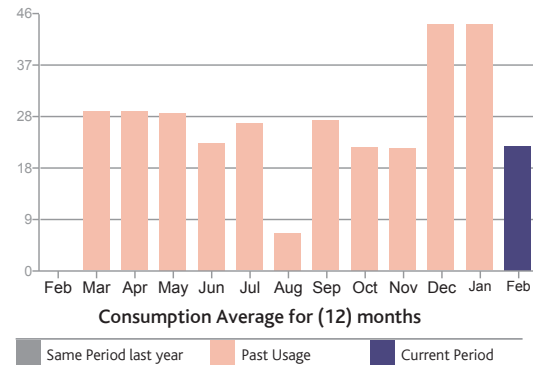
Total consumed units 680

680 kWh used over 30 days

Your electricity usage over time

AED 6.07

Average daily cost of electricity in the current period without VAT



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Bill Date

Feb 06, 2020

Premise Number

1646757004

Premise Type

Commercial Building

Account Class

Residential (Residential Expat)

Previous Billing Details

Previous balance AED 391.43

Payment received since last bill AED -391.43

Last Payment Date Jan 12, 2020

Balance Forwarded AED 0.00

Consumption Charges

✓ 680.00 kWh @ AED 0.268 /kWh AED 182.24

Total AED 182.24

Other Charges AED 0.00

Adjustments/Corrections AED 0.00

TAXES ON ELECTRICITY USAGE

VAT 5% on consumption charges 182.24 AED 9.11

VAT 5% on Other Charges AED 0.00

Total Cost of Electricity AED 191.35

Total subsidy for the year 2020 AED 25.16

Actual Cost 0.305 AED/unit AED 207.40

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AADC TRN:100264873900003

Total To Pay

AED 237.78

Pay by or before Jul 19, 2020

Meter Reading Information

Meter Number 200021395266

Start read Jun 06, 2020 13692

End read Jul 07, 2020 14537

Total consumed units 845

845 kWh used over 31 days

Bill Date

Jul 08, 2020

Premise Number

1646757004

Premise Type

Commercial Building

Account Class

Residential (Residential Expat)

Previous Billing Details

Previous balance AED 158.15

Payment received since last bill AED -158.15

Last Payment Date Jun 13, 2020

Balance Forwarded AED 0.00

Consumption Charges

✓ 845.00 kWh @ AED 0.268 /kWh AED 226.46

Total AED 226.46

Other Charges AED 0.00

Adjustments/Corrections AED 0.00

TAXES ON ELECTRICITY USAGE

VAT 5% on consumption charges 226.46 AED 11.32

VAT 5% on Other Charges AED 0.00

Total Cost of Electricity AED 237.78

Total subsidy for the year 2020 AED 31.27

Actual Cost 0.305 AED/unit AED 257.73

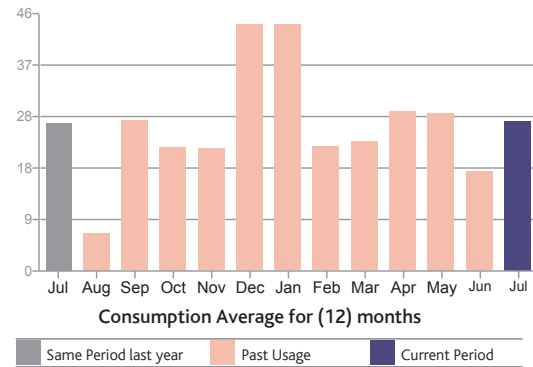
Your electricity usage over time

↑1%

Increase of 0.37 kWh per day in electricity used compared to the same period last year.

AED 7.31

Average daily cost of electricity in the current period without VAT



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AADC TRN:100264873900003

Total To Pay

AED 158.15

Pay by or before Jun 16, 2020

Meter Reading Information

Meter Number 200021395266

Start read May 06, 2020 13130

End read Jun 06, 2020 13692

Total consumed units 562

562 kWh used over 31 days

Bill Date

Jun 06, 2020

Premise Number

1646757004

Premise Type

Commercial Building

Account Class

Residential (Residential Expat)

Previous Billing Details

Previous balance AED 242.84

Payment received since last bill AED -242.84

Last Payment Date May 13, 2020

Balance Forwarded AED 0.00

Consumption Charges

✓ 562.00 kWh @ AED 0.268 /kWh AED 150.62

Total AED 150.62

Other Charges AED 0.00

Adjustments/Corrections AED 0.00

TAXES ON ELECTRICITY USAGE

VAT 5% on consumption charges 150.62 AED 7.53

VAT 5% on Other Charges AED 0.00

Total Cost of Electricity AED 158.15

Total subsidy for the year 2020 AED 20.79

Actual Cost 0.305 AED/unit AED 171.41

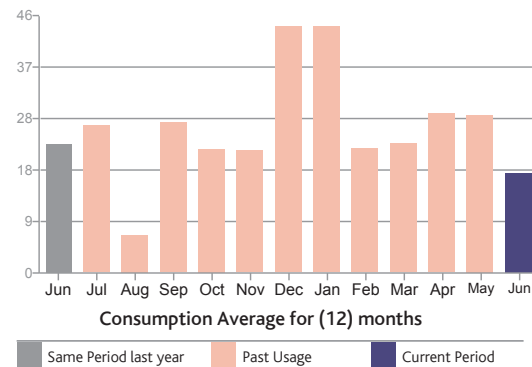
Your electricity usage over time

22%

Decrease of 5.20 kWh per day in electricity used compared to the same period last year

AED 4.86

Average daily cost of electricity in the current period without VAT



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Total To Pay

AED 199.23

Pay by or before Mar 17, 2020

Meter Reading Information

Meter Number 200021395266

Start read Feb 06, 2020 10687

End read Mar 07, 2020 11395

Total consumed units 708

708 kWh used over 30 days

Bill Date

Mar 07, 2020

Premise Number

1646757004

Premise Type

Commercial Building

Account Class

Residential (Residential Expat)

Previous Billing Details

Previous balance AED 191.35

Payment received since last bill AED -191.35

Last Payment Date Feb 13, 2020

Balance Forwarded AED 0.00

Consumption Charges

✓ 708.00 kWh @ AED 0.268 /kWh AED 189.74

Total AED 189.74

Other Charges AED 0.00

Adjustments/Corrections AED 0.00

TAXES ON ELECTRICITY USAGE

VAT 5% on consumption charges 189.74 AED 9.49

VAT 5% on Other Charges AED 0.00

Total Cost of Electricity AED 199.23

Total subsidy for the year 2020 AED 26.20

Actual Cost 0.305 AED/unit AED 215.94

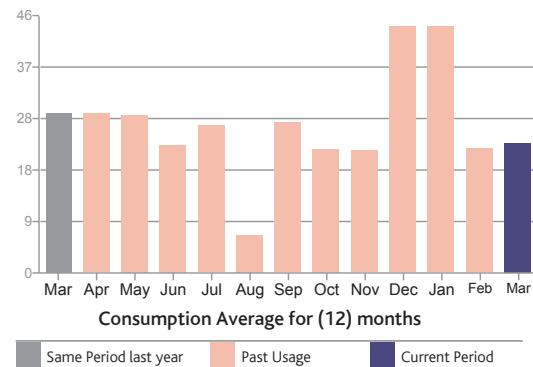
Your electricity usage over time

18%

Decrease of 5.45 kWh per day in electricity used compared to the same period last year

AED 6.32

Average daily cost of electricity in the current period without VAT



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شركة العين للتوزيع

Al Ain Distribution Company

AADC TRN:100264873900003

Total To Pay

AED 242.84

Pay by or before May 24, 2020

Meter Reading Information

Meter Number 200021395266

Start read Apr 06, 2020 12267

End read May 06, 2020 13130

Total consumed units 863

863 kWh used over 30 days

Bill Date

May 12, 2020

Premise Number

1646757004

Premise Type

Commercial Building

Account Class

Residential (Residential Expat)

Previous Billing Details

Previous balance AED 245.39

Payment received since last bill AED -245.39

Last Payment Date Apr 15, 2020

Balance Forwarded AED 0.00

Consumption Charges

✓ 863.00 kWh @ AED 0.268 /kWh AED 231.28

Total AED 231.28

Other Charges AED 0.00

Adjustments/Corrections AED 0.00

TAXES ON ELECTRICITY USAGE

VAT 5% on consumption charges 231.28 AED 11.56

VAT 5% on Other Charges AED 0.00

Total Cost of Electricity AED 242.84

Total subsidy for the year 2020 AED 31.94

Actual Cost 0.305 AED/unit AED 263.22

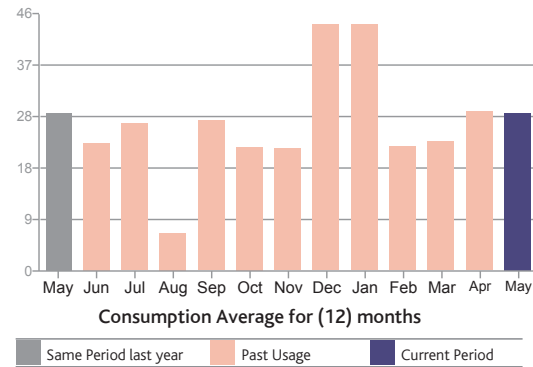
Your electricity usage over time

↑0%

Increase of 0.01 kWh per day in electricity used compared to the same period last year.

AED 7.71

Average daily cost of electricity in the current period without VAT



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Total To Pay

AED 238.07

Pay by or before Oct 18, 2020

Meter Reading Information

Meter Number 200021395266

Start read Sep 06, 2020 16143

End read Oct 06, 2020 16989

Total consumed units 846

846 kWh used over 30 days

Bill Date

Oct 06, 2020

Premise Number

1646757004

Premise Type

Commercial Building

Account Class

Residential (Residential Expat)

Previous Billing Details

Previous balance AED 233.56

Payment received since last bill AED -233.56

Last Payment Date Sep 14, 2020

Balance Forwarded AED 0.00

Consumption Charges

✓ 846.00 kWh @ AED 0.268 /kWh AED 226.73

Total AED 226.73

Other Charges AED 0.00

Adjustments/Corrections AED 0.00

TAXES ON ELECTRICITY USAGE

VAT 5% on consumption charges 226.73 AED 11.34

VAT 5% on Other Charges AED 0.00

Total Cost of Electricity AED 238.07

Total subsidy for the year 2020 AED 31.30

Actual Cost 0.305 AED/unit AED 258.03

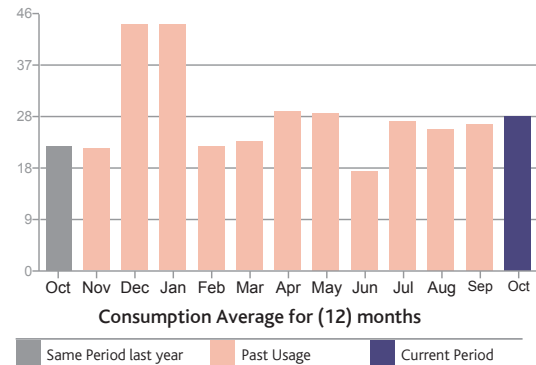
Your electricity usage over time

24%

Increase of 5.57 kWh per day in electricity used compared to the same period last year.

AED 7.56

Average daily cost of electricity in the current period without VAT



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AADC TRN:100264873900003

Total To Pay

AED 233.56

Pay by or before Sep 16, 2020

Meter Reading Information

Meter Number 200021395266

Start read Aug 06, 2020 15313

End read Sep 06, 2020 16143

Total consumed units 830

830 kWh used over 31 days

Bill Date

Sep 06, 2020

Premise Number

1646757004

Premise Type

Commercial Building

Account Class

Residential (Residential Expat)

Previous Billing Details

Previous balance AED 218.37

Payment received since last bill AED -218.37

Last Payment Date Aug 13, 2020

Balance Forwarded AED 0.00

Consumption Charges

✓ 830.00 kWh @ AED 0.268 /kWh AED 222.44

Total AED 222.44

Other Charges AED 0.00

Adjustments/Corrections AED 0.00

TAXES ON ELECTRICITY USAGE

VAT 5% on consumption charges 222.44 AED 11.12

VAT 5% on Other Charges AED 0.00

Total Cost of Electricity AED 233.56

Total subsidy for the year 2020 AED 30.71

Actual Cost 0.305 AED/unit AED 253.15

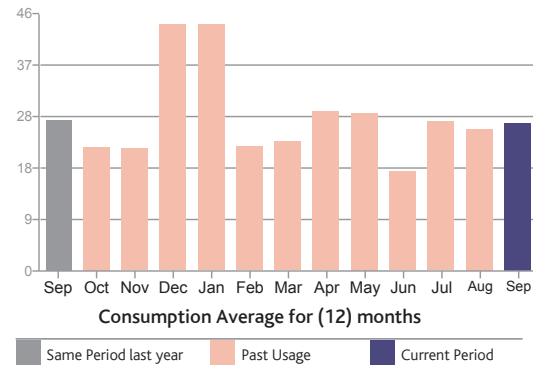
Your electricity usage over time

2%

Decrease of 0.61 kWh per day in electricity used compared to the same period last year

AED 7.18

Average daily cost of electricity in the current period without VAT



Pay a fixed monthly amount for your Water and Electricity Bill by registering in Istmrar Service and activating "Bill Smoothing" option .For more information, please call our toll free number 8009008

 contact centre
800 9008

 by post
P.O.Box 1065, Al Ain

 visit our website
www.aadc.ae

 SMS
3200

 AD Government Contact Centre
800555

00313/04081444

Survey Questioner; related to measurement the annual energy (Electricity) consumption of the Air Condition (AC) in the residential flat for thesis study:

1. How many persons are living in the flat (the capacity)?

Four

2. How many Air condition units (AC) are turning on (working) on daily basis?

Two

3. What is the Setpoint Temperature of the AC?

24°C

4. Do you operate the AC in all rooms every day? How many hours are working?

No 8 to 12 hours

5. How many times do you turn off the AC during the day and the night?

Two times

6. How many equipment (devices) you have in each room? And how much are working all time?

One to three

7. How many hours do you turn on the TV?

3 hours

8. Does the setting point at night different from the day time? If yes how much?

No

9. If run the AC at lower degree temperature, then When and How many people in the space?

No

10. Do you keep the AC temperature degree at the room in Winter same as during the Summer? If No How much the setting point?

AC is switched off in winter during daytime

11. Which is temperature in AC cool more in room?

26°C

12. Do you change the temperature setting point every day? If yes, When?

No

13. Do you leave the AC unit working continuously while the room is empty?

No

14. Do you turn ON the AC during the sleep time? If yes What is the setting point?

24°C

15. How many hours turn on the AC during day time and night time?

None. AC works continuously

8. Does the setting point at night different from the day time? If yes how much?

No

9. If run the AC at lower degree temperature, then When and How many people in the space?

No

10. Do you keep the AC temperature degree at the room in Winter same as during the Summer? If No How much the setting point?

AC is switched off in winter during daytime

11. Which is temperature in AC cool more in room?

26°C

12. Do you change the temperature setting point every day? If yes, When?

No

13. Do you leave the AC unit working continuously while the room is empty?

No

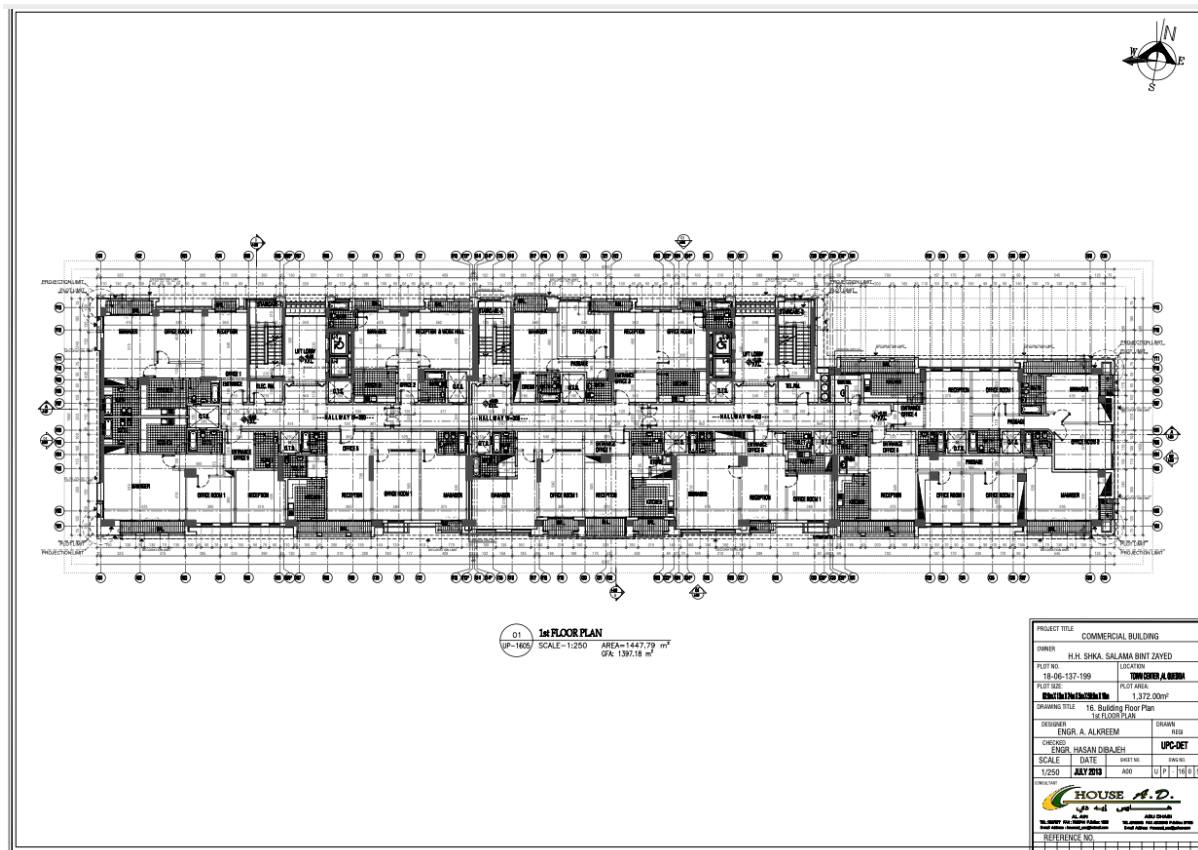
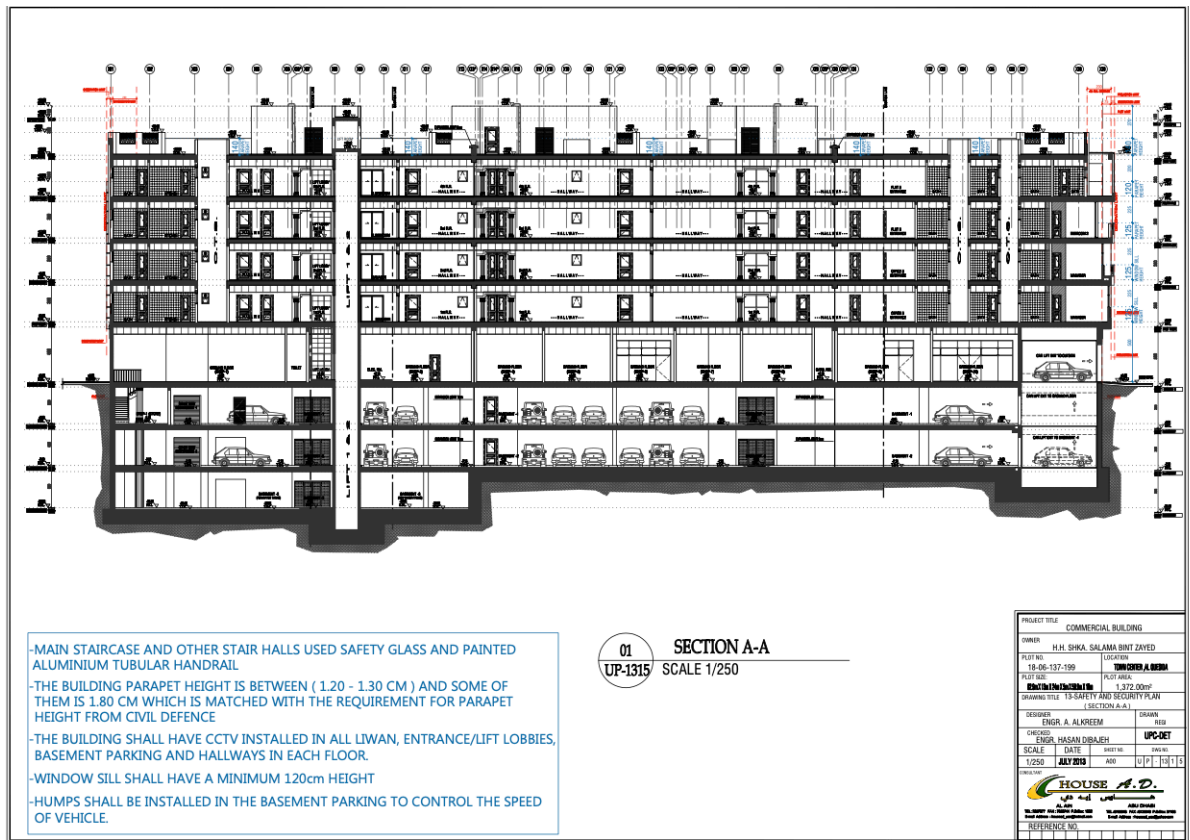
14. Do you turn ON the AC during the sleep time? If yes What is the setting point?

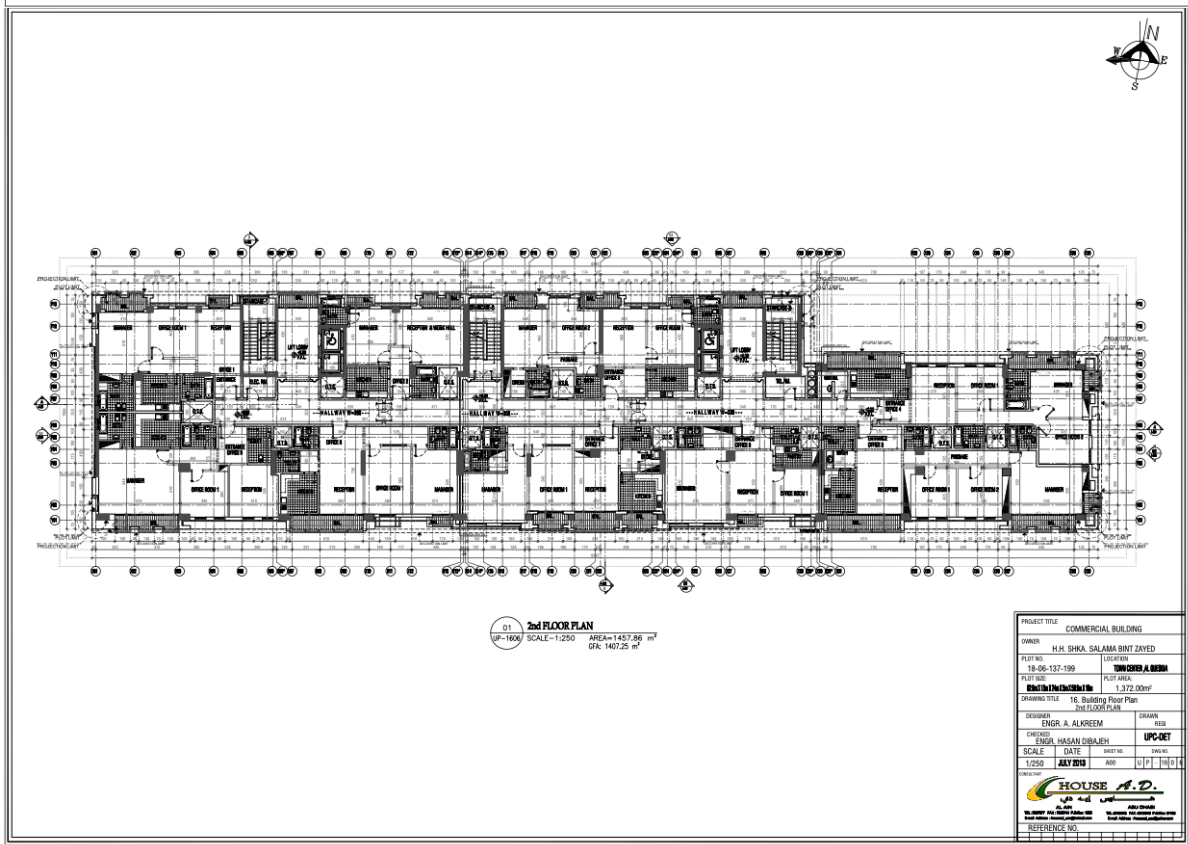
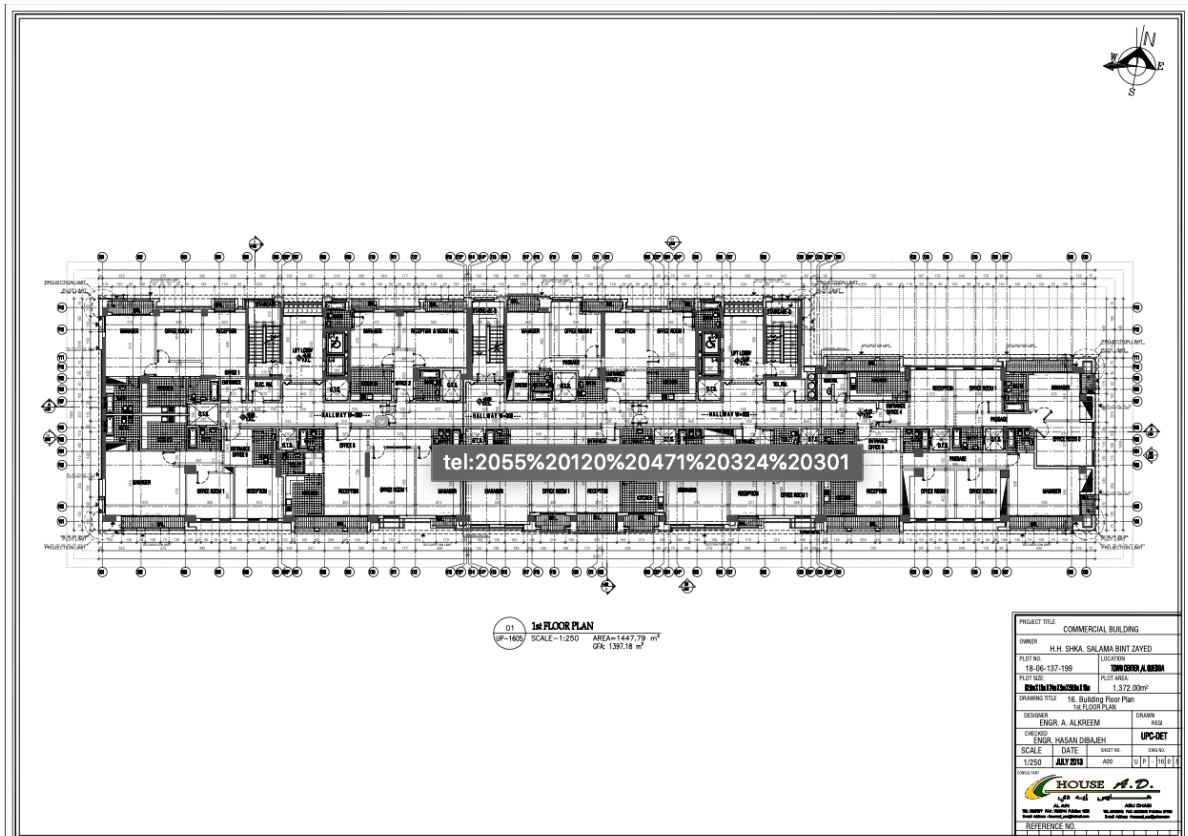
24°C

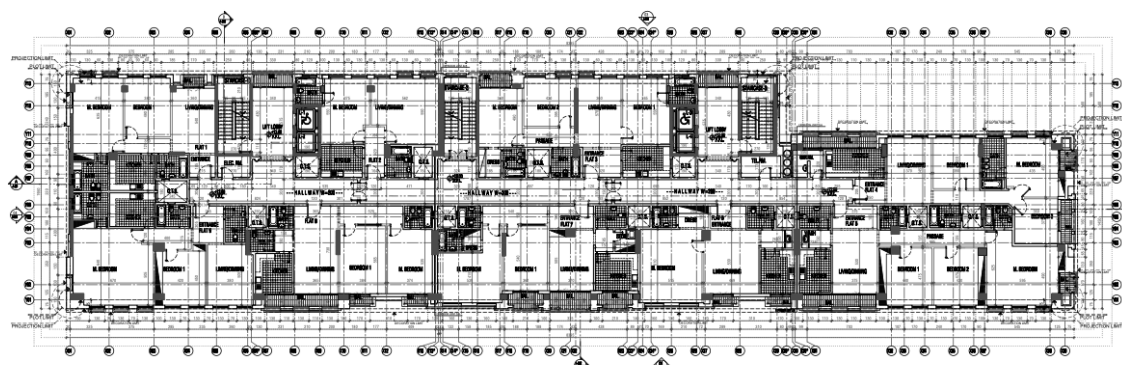
15. How many hours turn on the AC during day time and night time?

None AC works continuously

Appendix 3 Original workshop drawings of the project

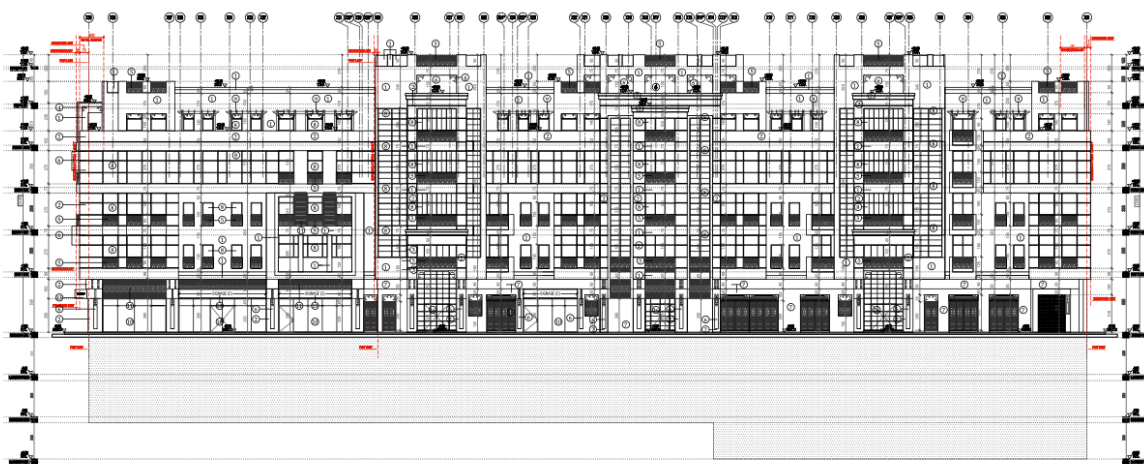






01 **THIRD FLOOR PLAN**
UP-1607 SCALE-1:250 AREA=1491.32 m²
GFA: 1440.71 m²

PROJECT TITLE		COMMERCIAL BUILDING	
OWNER H.H. SHKA, SALAMA BINT ZAYED			
PLOT NO.	H-18-06-137-199	LOCATION	TOWN CENTER AL REEMAH
PLOT SIZE	1,372.00m ²	PLOT AREA	
DRAWING TITLE 16. Building Floor Plan THIRD FLOOR PLAN			
DESIGNER ENGR. A. ALKREEM		DATE	1/250
CHECKED ENGR. HASAN DIBAJEH	SCALE	DATE	ADD
SCALE	DATE	DATE	DATE
1/250	JAN 1999	ADD	U P - 168
CONSULTANT			
			
Mr. Ali Al-Kreem Head office - House A.D. Building Email: ali@housead.com		Mr. Hassan Dibajeh Head office - House A.D. Building Email: hassan@housead.com	
REFERENCE NO.			



01
UP-1403

REAR ELEVATION 3
SCALE-1:250

[illegible]



REVISIONS:		PROJECT TITLE: COMMERCIAL BUILDING	
(1) C.A. (OWNER REQUEST)		OWNER:	H.H. SHAKA, SALAMA BINT ZAYED
(2) C.A. (OWNER REQUEST)		PROJECT LOCATION:	SALAMA
(3) C.A. (OWNER REQUEST)		DATE:	18-03-17-199
(4) C.A. (OWNER REQUEST)		DATE:	18-03-17-199
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