CFD Optimization Of Building Glazed Cladding In Order To Achieve Thermal Comfort And Achieve Energy Saving

by

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22340

Dissertation submitted in partial fulfilment of

the requirements for the

Bachelor of Mechanical Engineering

with Honours

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Universiti Teknologi PETRONAS

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Approved by,

(ASSOCIATE PROFESSOR DR MOHAMMAD SHAKIR NASIF)

UNIVERSITI TEKNOLOGI PETRONAS
SERI ISKANDAR, PERAK
JANUARY 2020

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

FLORIVALDO DANIEL ARMANDO MACUACUA

ABSTRACT

Double skin façade (DSF) have been widely implemented by new and existing buildings in the market to improve thermal comfort at expense of very low energy demands. DSF has proved to reduce the cooling loads of 30% in buildings that were not conceived with DSF and about 50 % in new buildings. This project aimed to study the Space size between the two façade which has not been optimized and use the structural support as fins to increase heat exchange rate of between the cavity air and outer skin. A building of 2 floors with glazed external façade is used to simulate the impact of sun in DSF. Using Ansys Computer Fluid Dynamics (CFD) analyses the impact of varying the cavity size while using two design of fins.

Six designs were used in this CFD simulation where square shape fins were used due to its drag high coefficient. The cavity depth was varied between 0.25 m, 0.4 m and 0.8 m while having fins on one side of the external façade and for the other design having fins staggered between the inner and external façade. The validation of this experiment is done by simulating a 0.25m cavity depth façade with no fins and the behaviour of this façade will be compared with other glazed DSF. The results show that the one-sided fins design is effective in reducing the inner façade temperature and there is no need to use higher cavity depth façades for such purpose.

ACKNOWLEDGEMENT

I am profoundly grateful to this project supervisor Associate Professor Dr. Mohammad Shakir Nasif for his assistance, advice and continuing supervision in providing the required information in the Final Year Project to be carried on. I would also wish express deep appreciation for the Mechanical engineering department of Universiti Teknologi PETRONAS.

Finally, I honour my family and friends for the support and encouragement throughout the FYP period. I would also like to thank those who has helped to contribute by giving guidance and assistance directly or indirectly throughout the duration of the project.

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CHAPTER 1

INTRODUCTION

1.1. Background

Nowadays, a demand for thermal comfort at expense of very less energy is rising. Rational and efficient use of energy is a topic of major concern. According to Radhi (2009) residential cooling systems, at UAE, are responsible for most part of energy consumption, thus, with global warming the energy consumption is expected to increase by 23.5%. In Europe, buildings consume about 40 % of energy in the block says European Directive 2013/31/EU. Thus, sustainable principles in the environment have been encouraging researchers to have their research time spent on efficient building. However, the design of efficient building highly considers the rational use of energy, where the temperature within its environment is regulated by its structure and design, known as passive buildings (Nicol et al. 2012).

To overcome the issue of high energy demand to achieve thermal comfort, Double Skin Façade (DSF) is widely used in Europe and Asia. Façades have proven to have a crucial role in keeping indoor temperatures and controlling its interactions regarding heat exchange with outdoor. Conventional facades, made of opaque materials, can perform badly regarding ventilation and daylighting leading to discomfort and high energy consumptions (Ghaffarianhoseini et al. 2016)

DSF is normally defined as some type of envelope, an extra layer, is placed in front of a building wall creating therefore an airgap in between. This type of envelope is well known for controlling the heat gain forced by differences between temperature from inside and outside of a building. DSF is a system known for consisting three main elements: two layers (one outer other inner) and the cavity airflow. The implementation of DSF as show to increase thermal comfort using much less energy from the Heat ventilation and Air Conditioning systems, about 30 % of reduction in old building and about 50 % in new buildings (C. O. Souza, A. Souza et al. 2018, Qahtan 2019). Normally, a building with good DSF shows the outer layer temperature high thus the heat is transferred to the interior surface by conduction, by convection is transferred to the cavity. The inner skin is definitely heated by the air heated by the air.

Inside the cavity, the heat transfer phenomenon naturally promotes a difference in the air density. This difference makes the heated air to be risen until the upper opening of the DSF and the fresh air enters the cavity through the lower opening. Based on this temperature inside the building can be reduced. However, the effectiveness of this cavity sizes has not been investigated.

This project aims to understand the design of naturally ventilated DSF with different size of the cavity depth while using structural support of glass as fins to determine its effect on buildings indoor temperature achieve highest energy saving in Malaysia.

1.2. Problem statement

Double-skin façade cavity size change was proved to give to a 10% energy demand reduction (Alberto et al. 2017). The performance of the glazed cladding is directly affected by the cavity space sizing. The previous studies conducted by Alberto show that increasing the size of the air cavity leads to lower energy consumption by the building, in other words, increasing the cavity depth leads to lower temperature of the inner façade. With the high usage of DSF there is a constant need to study thoroughly where the cavity size is reduced with the usage of fins. The fins can be used to slow down the air consequently allow the air to stay longer time in the air cavity therefore increasing the heat exchange between the air and the external façade. Very few studies have been done to reduce the cavity space with the usage of fins in order to have the temperature of the inner wall reduced.

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1.3. Objectives

This project focuses its studies in the analysis of the effect of fins in the DSF in order to increase the thermal comfort. By performing Computational Fluid Dynamics (CFD) simulation to predict the performance of the double cladding. According to the main objective, other objectives have to be considered:

- Analyse the design the DSF design with different cavity depth while using fins to determine its effect on inner façade temperature to achieve energy saving.
- To evaluate the different designs by varying the distribution of fins.

1.4. Scope of study

This study covers modelling of DSF of a building of 2 floors (7 m x 2m façade) using CFD- fluent Modelling simulator, under Malaysia weather conditions (the solar path data and annual outside air temperature data are assumed to be same as the town Ipoh). Natural ventilation will be used in the air cavity. Multi-storey type of geometry will be used. Size of the opening will be same of the façade. Assumptions for the simulation:

- Cavity thickness is varied between 0.25 m, 0.4 m and 0.8
- Two locations of fins will be used, one time on the external façade another design is staggered between external and internal façade.
- Steady state condition
- Density based.
- Solar loading with date and time of simulation on 21st June , 10am.

CHAPTER 2

LITERATURE REVIEW

2.1. Overview of Double skin façade

The DSF is generally defined as a building with normal façade that has an extra skin that works as a protective layer. DSF is a type of envelope, where a second skin, made of transparent glazing, is placed in front of the building façade (Saffer et al. 2005) Researchers like Cabeza, Qahtan and Rahdi define it as an external skin separated from internal skin by air. The ventilated cavity works as a thermal buffer that prevents from undesired heat gain in when hot or heat loss when cold. DSF can be sued in hot countries as well as cold countries. In hot countries the windows at the top and bottom are opened to allow the flow of air to cool the second skin heated by the sun. while in hot countries the windows at the top and bottom are closed to prevent the heat loss of the building to the surroundings.

AT DSF outer layer (shown in fig 2.1), a fraction of solar radiation is reflected, other is absorbed and other part crosses the wall, just as in a single skin façade. The glass temperature of outer wall will definitely increase and by convection the air inside the cavity will be heated. This air, now heated, naturally will become of less density, as a result it will rise through the façade due to the well-known stack effect. Thewind will cause

The wind blowing on the façade can create a positive pressure at the bottom and a negative at the top, causing a natural circulation. This phenomenon of using the change in density to cool down the temperature in the building is known as naturally ventilated façade. When the air inside the cavity is forced out by any mechanical mechanism is known as mechanically ventilated DSF.

Although some see DSF as a very complex concept, it is classified according to three parameters: ventilation, geometry, and airflow path inside the cavity. There is much more detailed characterisation that can be done according to multiple secondary

factors, for instance the thickness of the cavity, the height of the facade, or air openings (Shameri et al.011).

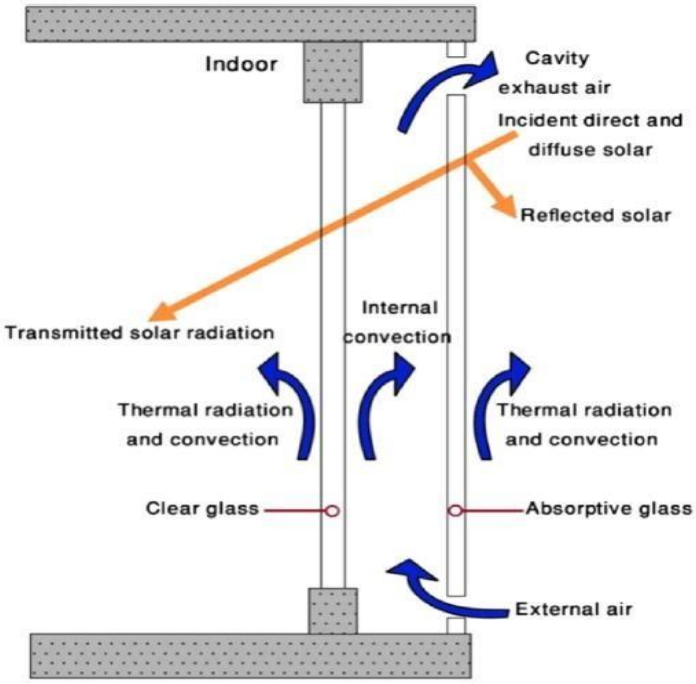

Figure 2.1. DSF retrieved from Barbosa et al. (2014)

2.1.1. Geometry

The geometry refers to the way the glass is placed in the façade. Geometry wise, DSF is classified in box window façade, shaft-box façade, corridor façade and multi-story façade (Kim and Song 2007, Wong 2008). By changing the façade geometry affects the quantity of irradiation that passes from exterior. As a solution, increasing the number of horizontal and vertical parts increases the number of obstacles for solar radiation, making therefore difficult for the sun to pass through the window. Façade geometries are predicted to be responsible for up to 45% of the building's cooling loads says Alberto.

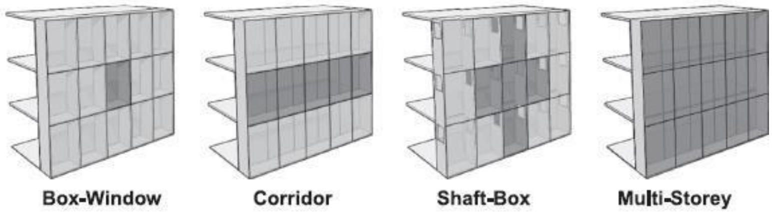

Figure 2. 2. Type of geometries retrieved from Alberto et al. (2017)

2.1.2. Thickness

Thickness is also known as air cavity or cavity depth, refers to the gap between the two layers. The thickness of air layer can vary from 0.8m to 1 m (Ghaffarianhoseini et al. 2016) but in some cases it can go to as low as 0.1 m and as high as 2 m (C. O. Souza, A. Souza et al. 2018). While by changing the thickness from 80 cm to 178 cm Ghaffarianhoseini found that there is a decrease in energy consumption of 5.6 %. The thickness is very dependent on the climate conditions of where the building is located. DSF cavity size change was proved to lead to a 10% reduction of the energy demand (Alberto et al.2017).

2.1.3. Airflow

The circulation of air in the cavity can occur naturally or mechanically with the use of fans or when needed even combined.

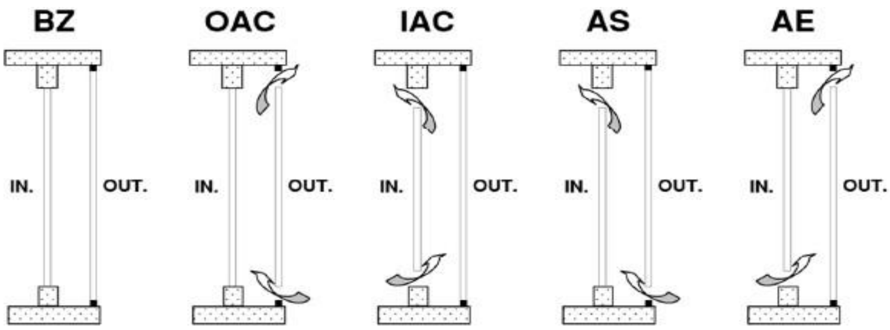

Figure 2.3. different types of airflow in a DSF retrieved from Barbosa and IP (2014)

2.2. Double skin façade

DSF arose in the beginning of the twentieth century as a possible solution to improve the thermal performance of the building. The application of DSFs is considered as an interesting solution, though, at the same time, highly affected by the building location (Shameri et al. 2011, Ghaffarianhoseini et al. 2016). Apart from creating a physical separation between the building to the environment the DSF has a great influence in the heating and cooling energy consumption and its efficiency directly associated with its ability of reducing energy costs, while assuring the desired thermal comfort to the occupants.

There is not much variation on the temperature measured on the same surface (C. O. Souza, A. Souza et al. 2018), showing little or no standard deviation. When the temperatures rise the DSF contributes in reduction of the temperature inside a room. Results show that the air velocity is increased between the lower and upper opening due to the heat being transferred from the second skin to the air. This phenomenon is expected due to the stack effect though the values are small they should not be neglected. DSF has shown effective regarding temperature reduction. However optimum air gap size is a crucial in achieving such reduction.

DSF is a passive design that should be integrated at conceptual phase. Key parameters namely air gap size, type and material of geometry and outdoor temperature. By changing the thickness from 80 cm to 178 cm Ghaffarianhoseini found that there is a decrease in enrgy consuption of 5.6 %. Alberto et al. (2017) varyed the size of the air gap between 25 cm, 50 com and 100 cm where he found that the icrease in air gap size causes a reduction on the cooling loads. For instance, when reducing the thicness from 0.25m to 1m the cooling load was reduced by 4.6%. The increase in air thickness causes an increase in ventilation rate at expenxe of the air velocity. From a CFD analysis Alberto concluded that increasing the air gap changes the airflow from laminar to turbulent.

Narrow cavity sizes demand less enery from the building due to high stack phenomenon in the cavity (Barbosa & Ip, 2014). While The change in thickness size can influence directly the convection heat transfer coeficient with then results in change in air velocity change resulting in heat exchange (Alberto et al. 2017). Barbosa tried to compesate the low heat exchange by circulating more air while Alberto preffers to have more heat exchange.

Barbosa and Ip (2014) analysing the impact of dsf in a building in Brazil found out that the air flow decreases as you go up in the façade, meaning, the temperature difference is little that causes the air flow to reduce not having therefore high exchange of heat. In figure 2.4., It is possible to see that the airflow in a 10 story building decreases as the air is moving up, causing very less heat exchange.

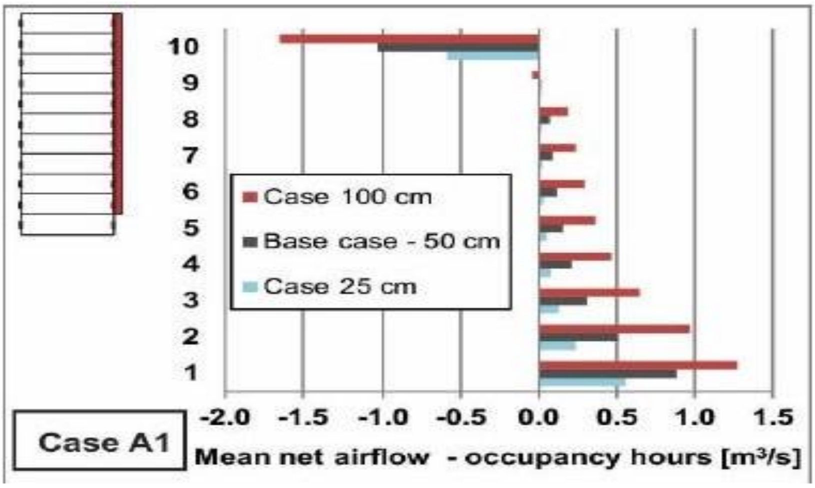

Figure 2. 4. Annual mean of the net airflow for each floor retrieved from Barbosa and IP (2014)

2.3. Malaysia conditions

In Malaysia there is high incidence of solar radiation on the east to west façades. Therefore, the nearby surfaces will definitely become overheated. Qahtan (2019) investigated the effect of DSF oriented to west, at Securities Commission (SCB) Bukit Kiara in Kuala Lumpur. The cavity gap in the SCB DSF is 1.2 m. The outer layer of SBC building is 12 mm thick low-e tinted green glass and the inner is 8 mm thick green glass.

In this experiment Qahtan found that it is feasible to install the DSF in the wall that there is most radiation, in other words, the climate has major influence on DSF performance. According to Qahtan Malaysia receives, in average, a total radiation of 4.31kWh/m^2. In February, there is the highest solar radiation of 4.6 kWh/m^2. The maximum radiation from the sun varies from 250 Wh/m^2 to 300 Wh/m^2 (Zain-Ahmed, 2009). During work days the wind velocity can reach up to 0.11 m/s due to usage of air-conditioners Qahntan says. However, on weekends the wind velocity can be neglected. Using a low e-glass he found out that the solar radiation intensity can reach to 945 W/m^2.

Qahtan in his experiment concluded the air temperature does not contribute to the heat gain in the bulding. However, the direct solar radiation has significant impact on building temperature but the usage of DSF has a big play in reducing the temperature inside the building.

2.4. Research gap

Table 2.1. Summary of research gap

Authors	Title	Objectives	Methodology	Findings	Limitations
Qhanta, 2019	Thermal performance of a double-skin façade exposed to direct solar radiation in the tropical climate of Malaysia: A case study	Aims to investigate the effectiveness of the DSF in controlling the heat gain under the direct solar radiation of the West orientation in the tropics, Malaysia.	1.The numerical simulation is done through ANSYS ®CFX 2. The heat transfer between surfaces and air flow more reliably, the analysis of CFD	1.Installation of an external façade, configuring a DSF, is effective with regard to temperature reduction of the outer face. 2. The addition of heat gains to the building is through direct radiation.	1.Analises the facades exposed to direct solar radiation from the west
C.O. Souza, 2018	Experimental and numerical	To investigate the	1.The numerical simulation is	1.Direct solar radiation	1.Does not study the effect of

	analysis of a naturally ventilated double-skin façade	efficiency of a naturally ventilated double-skin façade (DSF) built in a test cell focusing on the airflow and heat convection of the cavity formed by DSF.	done through ANSYS ®CFD 2. Built a test cell in Brazil	and the double-glazing surfaces temperature have a clear impact in indoor air temperature.	multiple parameters that affect the performance of DSF.
Alberto et all, 2017	Parametric study of double-skin facades performance in mild climate countries	Systematically assess the impact, in the building performance, of geometry, airflow path, cavity depth, openings area and type of glazing.	Performed a CFD analysis, varying the geometry and cavity size.	1.Airflow in multi-story presented, in average, 30% less HVAC related energy demands. 2. Air cavity leads to a decrease in the energy demand of up to 9.5% in Indoor Air Curtain facades. 3. DSFs can lead to Heat gains	1.His studies are limited to mild Southern European Countries
Ghaffarianhosein et all, 2016	Exploring the advantages and challenges of double-skin façades (DSFs)	Study of the current design of DSFs and their technical aspects	Performed an analysis on multi-storey building in South-Korea	1.DSFs are very useful to reduce energy demand	1. The cavity depth was only varied between 2 cases 0.8 m and 1 m only. 2. This study is limited to some conditions

CHAPTER 3

METHODOLOGY

3.1. Research methodology

In this research Computer Fluid Dynamics (CFD) in ANSYS will be used to perform the study. Start by designing of the 3 types façades with air cavity of 0.25m, 0.50m and 0.8m of distance of air cavity see its impact using CFD. Then will move, Design the façades with the fins to analyse its impact on the temperature inside to see its impact using CFD simulation. The velocity of the cavity air for both inlet and outlet, and also the temperature outlet of cavity air will be recorded and used for further evaluation. All the designed DSFs and the base case model will be compared side by side in order to evaluate their outcome.

3.1.1. Design of Double skin Façade

The double skin façade in this simulation will consist of two layers (one outer and other inner) of single glazed skin of the same material properties of thickness of 1.2 cm with no shading devices. The air gap size will be of 0.25 m, 0.50 m and 0.80 m having the base model of thickness of 50 cm. According to Victor (2018) “the optimum fins’ height to cavity thickness ratio is at around 35% for all type of Design DSF” this is because the heat transfer ability is the highest from the inner DSF wall to the cavity air and hindering effect is not high enough to stop the flow of cavity air effect from stack effect. The fins will be installed 1 m away from both inlet and outlet, will be square in order to have the highest drag coefficient, will be of 0.1m both width and thickness seen in figure 3.1 and 3.2. The fins are installed on the side of the external façade for one design (figure 3.1) and staggered for another design type (figure 3.2.). Aluminium will be sued to insulate the sidewalls to not allow direct sun radiation to penetrate the interior of the façade. Table 3.1. gives the details of each design used in this simulation, as well as the number of fins used.

Table 3.1. Design data for double skin façade

Design	**Cavity depth (m)**	**Number of fins**	**Location of fins**
Design 1	0.25	15	One sided
Design 2	0.25	30	Staggered
Design 3	0.40	15	One sided
Design 4	0.40	30	Staggered
Design 5	0.80	15	One sided
Design 6	0.80	30	Staggered

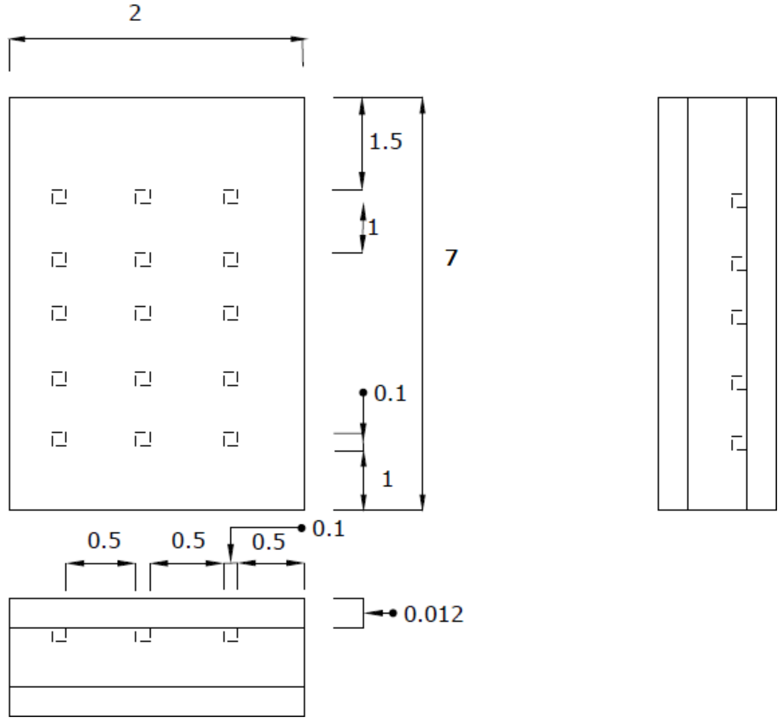

Figure 3. 1. Double skin façade for fins on one side design

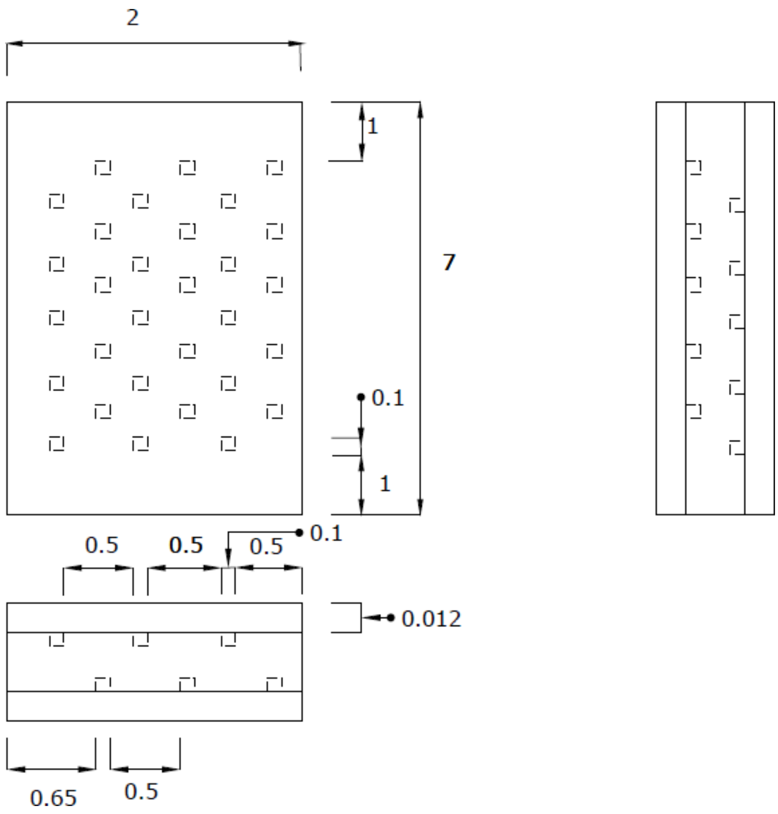

Figure 3.2. Double skin facade design for staggered

3.1.2. DSF Simulation Conditions

Adam (2018) says that “During the meshing process of the geometry, structured Quad mesh is more preferred the unstructured Tri mesh. Structured mesh is known to provide more accurate results in terms of flow direction compared to unstructured mesh”. Therefore, In this geometry hexahedral elements will be generated in the pre-processor stage. The aspect ratio is 10.1 and the skewness factor is 0.5. In the Computer Fluid Dynamics (CFD) density-based type of solver will be used, with steady state time and acceleration -9.81 m/s^2 in y direction. The Energy Equation Model and viscous model of standard K-epsilon with standard wall functions have to be switched on. The radiation model is also used by solar tracing for both direct and diffuse solar radiation.

This simulation is performed under Malaysia weather conditions where there is high solar radiation from the west. The façade will be simulated as being in Ipoh in a latitude of 4. 5975˚ East and latitude of 101.0901˚ North at 10am in the morning.

Table 3.2. Material properties

Properties	Material		
	Aluminium	**Glass**	**Air**
Specific mass [kg/m3]	2719	2800	1.225
Specific heat [J/kg.K]	871	750	1006.43
Thermal conductivity [W/m.K]	202.4	1.07	0.0242
Transmissivity	N/A	0.7	N/A
Absorvity	N/A	0.3	N/A
Viscosity [Kg/m-s]	N/A	N/A	1.7894 e -5

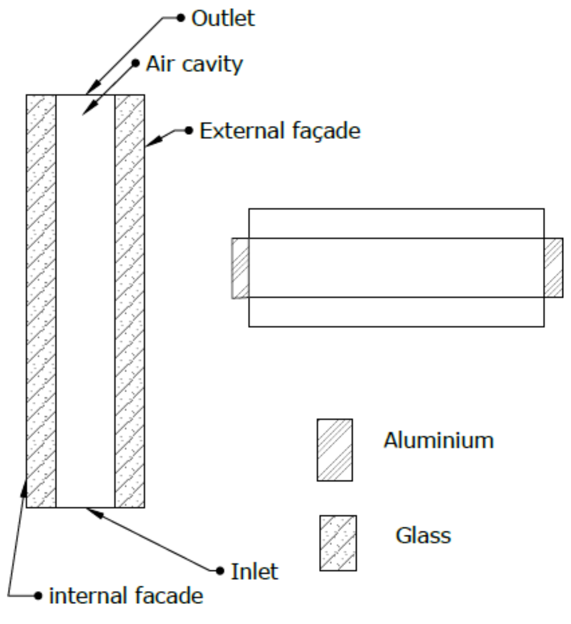

Figure 3.3. Double skin façade material location

Note: The figure 3.3. is just to show the location of the materials used in this simulation. Aluminium was assigned to the side walls of the air cavity.

3.1.3. Boundary conditions

Table 3.3. shows the approximate initial boundary conditions values based on estimated local conditions in Malaysia.

Table 3.3. Boundary conditions

Boundary conditions	**Value**
External Façade radiation temperature (˚C)	25
External Façade wall thickness (m)	0.005
External Façade external emissivity	0.85
External Façade BC Type	Semi-Transparent
External Façade Heat generation rate (w/m^3)	0
External Façade	Participates in the tracing
Inner façade Temperature (˚C)	Not set
Inner façade BC Type	Semi-Transparent
Inlet velocity	0
Air temperature (˚C)	22
Inlet	Participates in the tracing
Outlet	Outflow type

3.1.4. Post-processor stage

This simulation is accomplished with absolute converging criteria of 0.000001. The contour from velocity and temperature can be visualised in the CFD post processor. The average velocity magnitude and static temperature at the outlet of the model may also be calculated by area weighted average. The solution is set to run 500 iterations where at about 245 the solution converges in almost all the designs (seen in Appendix A).

3.2. Gantt chart

3.2.1. For Final Year Project 1:

Table 3.4. Gantt chart for Final Year Project 1

Week / Activity	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Understand DSF														
Define the flow of work														
Literature review														
Define the scope of problem														
Define Methodology														
Learn about ANSYS CFD														
Create the model														
Writing of the interim report														
Improvements on the work														

Milestones-

3.2.2. For Final Year Project 2

Table 3.5. Gantt chart for Final Year Project 2

Week / Activity	1	2	3	4	5	6	7	8	9	10	11	12	13	14
DSF model Development	■	☒												
Literature review	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Perform mesh sensitivity		■	■											
Varying the number of fins and its layout			■	☒										
Analyse the results										■	■	☒		
Writing The dissertation												■	■	■
												■	■	■

Milestones- ☒

3.3. Flow chart for Final Year Project

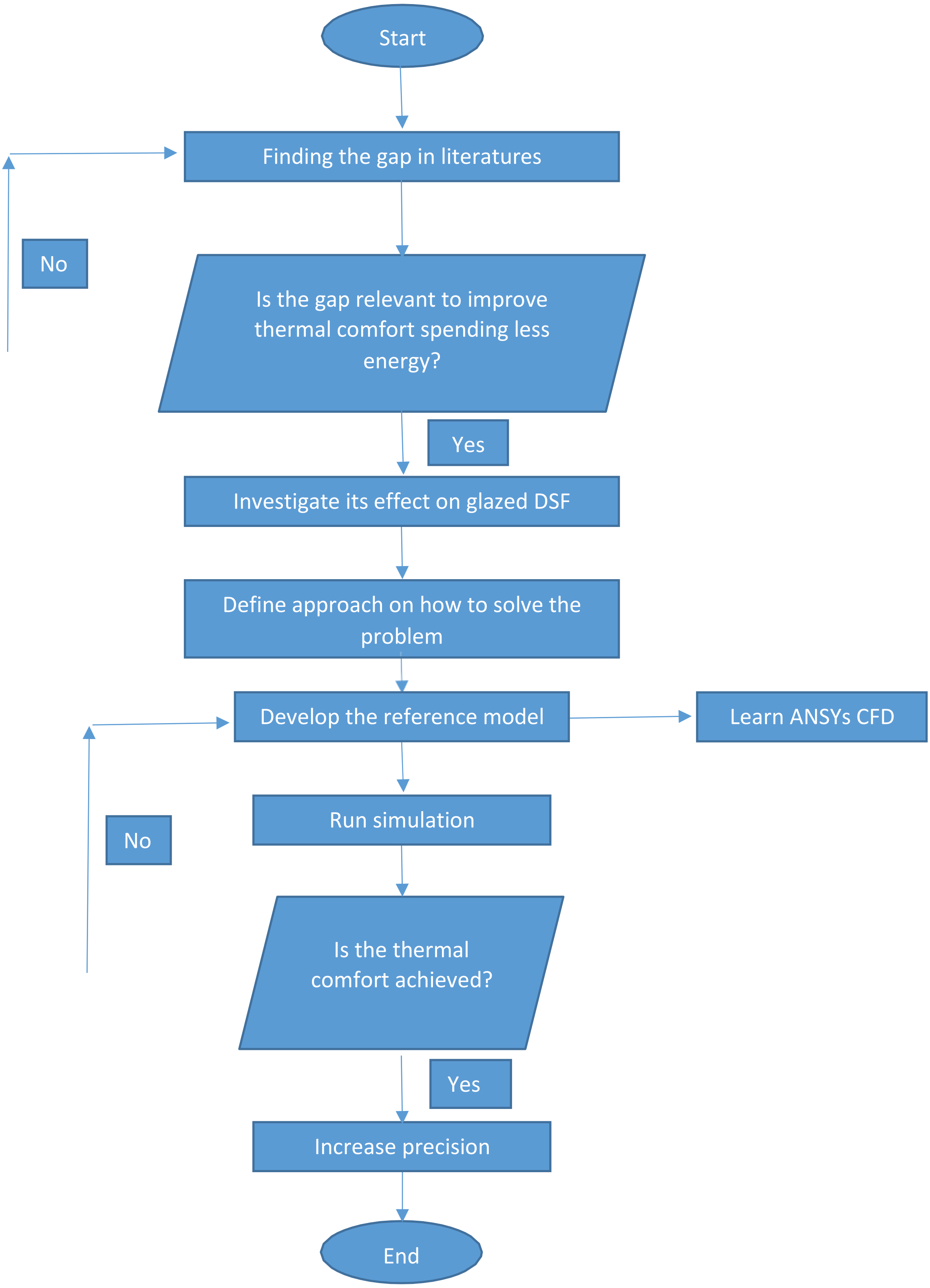

Figure 3.4. Flow chart of the project

CHAPTER 4

RESULTS AND DISCUSSION

4.1. Results

In this analysis two types of fins design where used in different cavity sizes were tested and compared. For All the Double Skin Façade (DSF) models the side view of the temperature and velocity contours are at the middle of the side view. The area-weighted average from the CFD simulation is taken to get the readings of velocity and temperature.

4.1.1. Validation

Double skin façade consists in two layers placed in a way that an intermediate cavity is created to allow the air to flow in the cavity. To verify the CFD simulation the results of a reference model is used to compare with general engineering performance of double skin façade. Figure 4.1. shows that the there is an increase in temperature from the left to the right which is caused by the solar radiation. The external façade on the left can reach temperatures of about 27 ˚C. The air inside the cavity leaves at 38 ˚C. Sabrina Barbosa says that it is normal on a multi-story building with façade to need a little bit more of a cooling load in the lower levels due to temperature difference being low consequently the velocity is low causing low. The velocity throughout the cavity increases due to stack effect caused by temperature difference(Sánchez, Giancola et al. 2017), where at the inlet there is lower velocity because the air has not been exposed to a different temperature. When going up in the cavity there is an increase in the velocity cased by the difference in temperature (the colder air goes down and the hotter goes up due to change in density forced by temperature differences). The velocity in figure 4.2. reaches its peak at the outlet with a value of 0.0498m/s. The velocity from left to right does not change due to temperature differences but only due to friction on both walls.

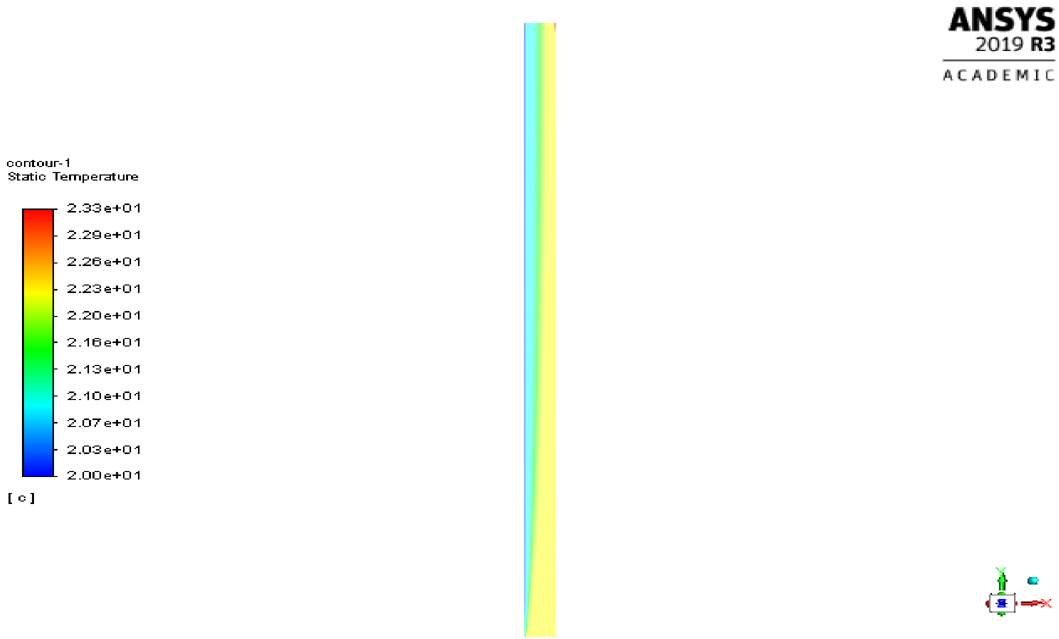

Figure 4.1. Temperature contour of the reference model

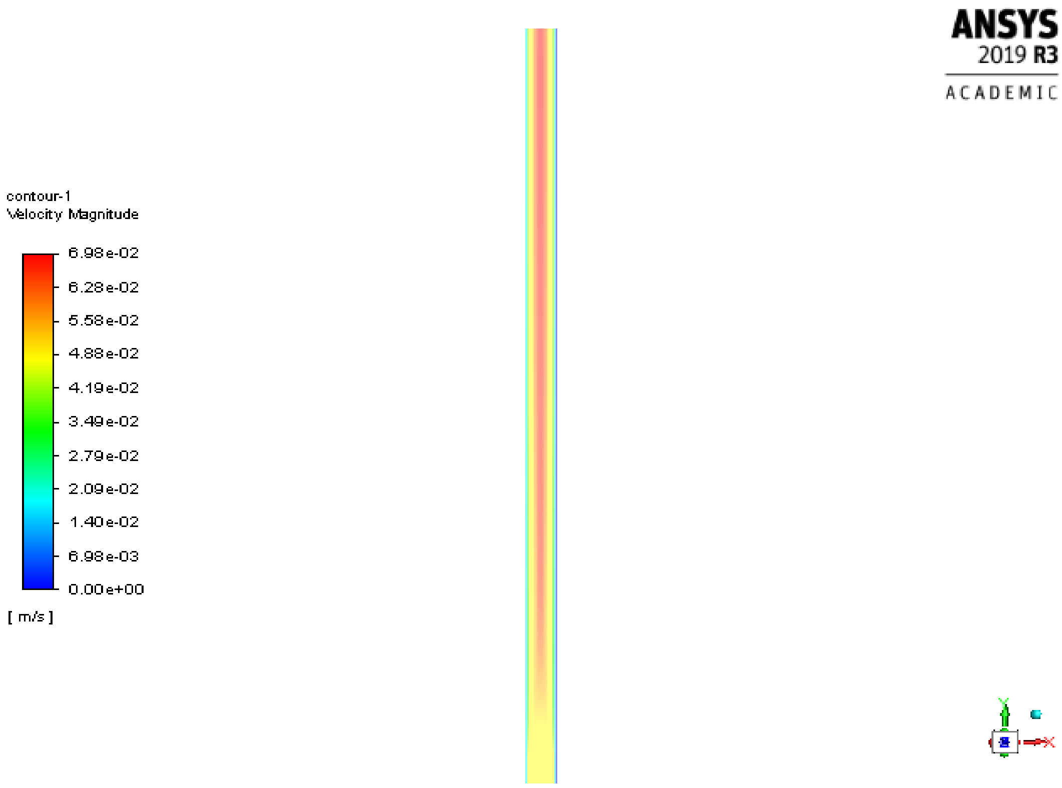

Figure 4.2. Velocity profile of reference model

4.1.2. Mesh sensitivity

To further validate the results Mesh sensitivity analysis was done in order to get more accurate results, to see if the output is dependent on the number of elements. After conducting a series of 11 different sets of mesh elements it is possible to see in figure 4.3. that the seventh (7th) configuration can be taken for temperature out of the cavity but for the velocity the solutions stabilizes on the ninth (9th) configuration of about 130000 elements.

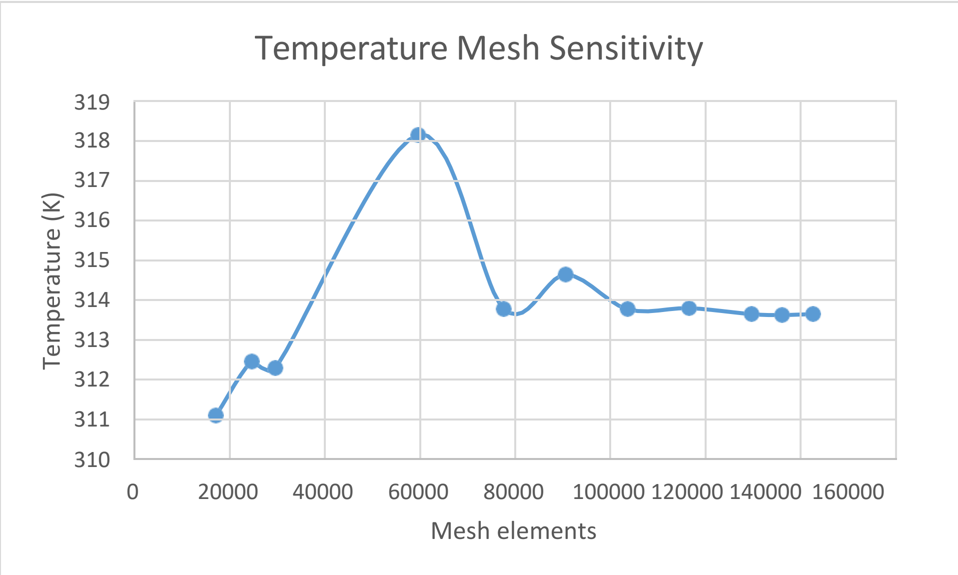

Figure 4.3. Mesh sensitivity for Temperature out

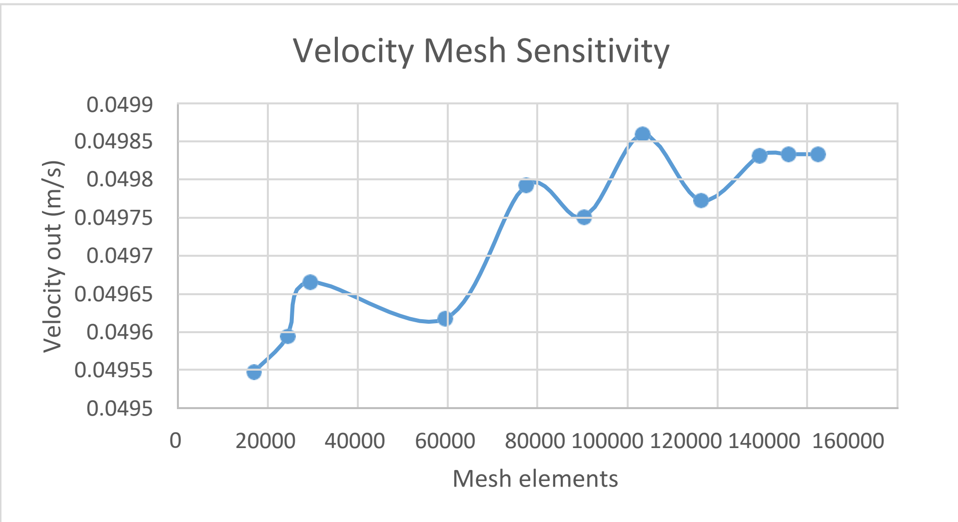

Figure 4.4. Mesh sensitivity for velocity

4.1.3. CFD Simulation Temperature

In this simulation no scale will be used to reduce the computational power of the CFD because the scaling might affect the results. The figure 4.7. shows the temperature profile in the different DSFs designs. The one-sided fins show a slight increase in temperature at the outlet (figure 4.4.) having a maximum of 57˚C at the biggest cavity depth. For the 0.25 m cavity depth there is a big increase of outlet temperature from 38 ˚C to 47 ˚C when comparing the temperatures of reference model with the one with fins. When comparing the design that has fins on one side with staggered generally there is not much difference in temperature. In the 0.25 m there is a big difference between the one sided and staggered temperature at the outlet of 7 ˚C, the staggered has the highest temperature of 54 ˚C. While the other designs have little difference for instance the 0.8 m cavity depth where at the staggered the air leaves with 57 ˚C while the one sided 59 ˚C. One interesting fact is that for cases above 0.25 m the outlet temperature for staggered cases are lower than the one sided which is the opposite of the 0.25 m case. The temperature increases as the air inside the cavity is blocked partially by the fins, forcing therefore the air to stay more time in the façade causing its temperature to rise. In figure 4.7 although the air is heated to higher temperatures compared to the reference model, it is possible to see that the temperature does not affect the temperature of the inner wall for all the one-sided cases, whereas at the staggered the heat affects the inner wall.

For one sided fins cases the rise in temperature at lower part of the façade caused by low temperature difference it is not seen. At the one-sided fins at the case the air temperature increases at the first two fins then rapidly decreases and on the next three the air temperature almost remains heated and constant. On the other side for the one-sided case b and c the fluctuations on the air temperature is only seen on the first fin, from the second onwards the air temperature remains constant.

For staggered fins cases the rise in temperature at lower part of the façade caused by low temperature difference it is not seen but at the higher part of the façade the heated air heats the upper part of the inner skin. The temperature at the outlet, in all of the staggered design increases with the increase of cavity depth (figure 4.5 and 4.6).

For the temperature profile in the staggered designs for designs d and e the air gets heated not to highest temperature then gets cold in the first 2 to 3 fins on both sides and only in the 4th the air gets a constant temperature while on the design d the temperature of the air is the same with the previous designs of staggered category but only on the heated wall (on the right figure 4.7). On the design f the temperature in the middle of the air cavity is not the same as in the side walls, it is smaller until the last fin of the inner wall. While in other two staggered designs the temperature gets uniform throughout the air cavity after the 3rd fin of both walls. Generally, the staggered design affects the inner wall temperature (mostly at the top) while the one sided does not. The temperature of the inner wall at the one-sided designs are independent of the size of the cavity this might be due to the size of the fins which are 35% of the cavity depth.

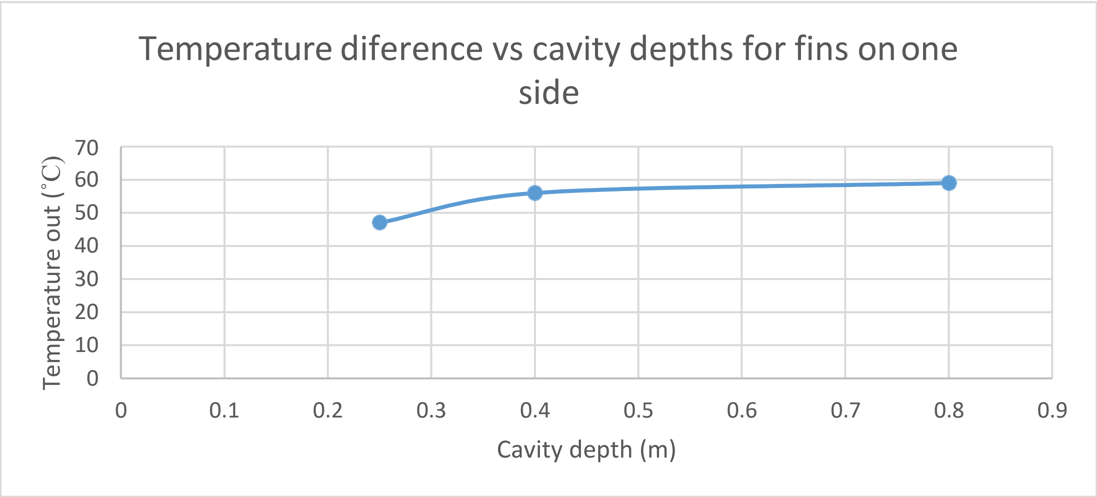

Figure 4.5. Temperature out vs cavity depth for fins on one side

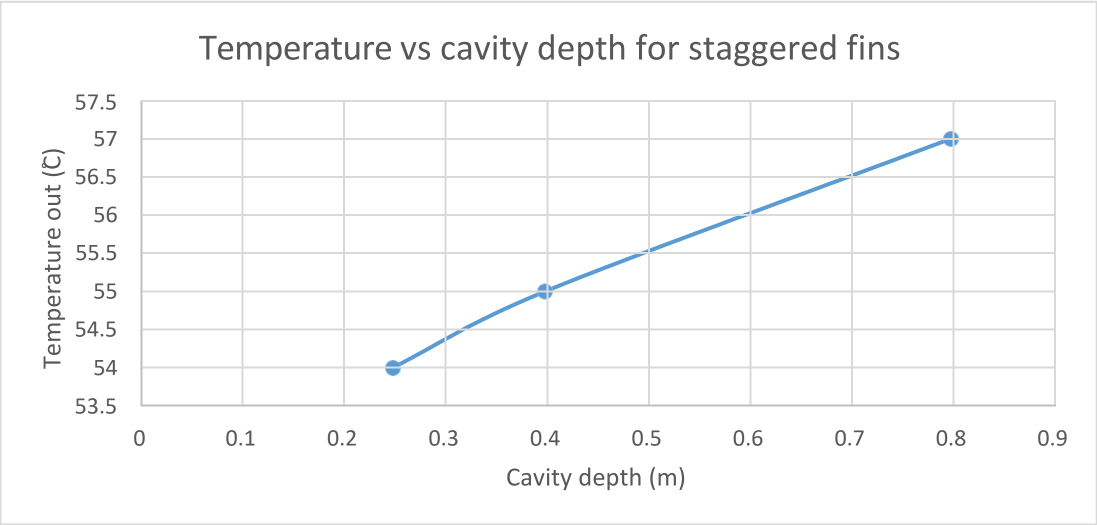

Figure 4.6. Temperature out vs cavity depth for staggered fins

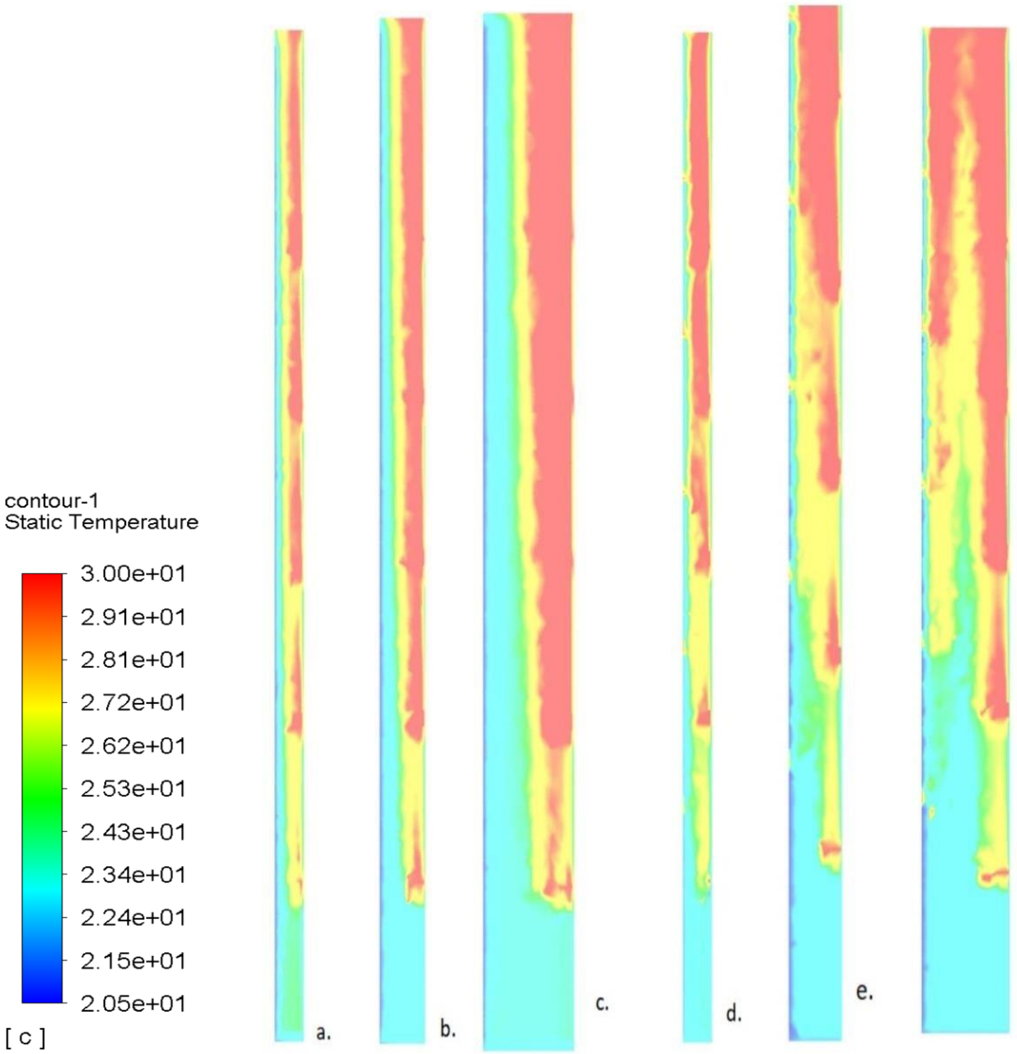

Figure 4.7. Temperature profile of double skin façade for a. design 1, b. design 3, c. design 5, d design 2, e. design 4, f. design 6 respectively.

4.1.4. CFD Simulation velocity

In this simulation no scale will be used to reduce the computational power of the CFD because the scaling might affect the results. From figure 4.8. analysing the fins on the heated wall (one side) although the velocity change is not much different it should not be neglected. The least velocity is seen on the smaller cavity depth then slowly increases at cavity is 0.4 m then it increases linearly with the cavity depth to the 0.8 m cavity size. These facts might be due to the fact that the air is being heated to higher temperatures making therefore, the speed of the air faster. Similarly, to the one-sided fins design, the staggered fins design on figure 4.9 clearly there is not much difference in the velocity out among each other. The velocity out increases with cavity depth but this time the leap is from the 0.25 m to 0.4 m cavity depth where the speed leaps from 0.046 m/s to 0.05 m/s then at 0.8 m cavity depth the velocity does not increase much, due to temperature difference among both cases 0.4 m and 0.8 m . Amazingly at both cases although of 0.8 m cavity the maximum speed is registered of 0.051m/s.

In figure 4.10. there is the velocity profile throughout the cavity for the multiple designs. At cases a, b and c are for fins on one side of the wall, it is possible to see that the speed of air is lower at the external skin (on the right) due to the presence of fins on that wall and also the size of the fins which are 35% of the cavity size. At one sided fins it is possible to see that the speed reaches its maximum of roughly 0.0587 m/s near the inner wall. The speed then reduces because the fins at one sided are 1.5 m of the outlet. Whereas for the staggered design d, e and f the speed of the air is low at both skins which is expected due to the presence of fins where 15 fins are on each side. The highest speed is seen in the middle of all double skin façades where its maximum can go up to 0.06 m/s.

The velocity profile at 0.25m cavity depth is irregular throughout the façade in both staggered and one-sided designs. Although the velocity on the staggered is smaller compared to the one sided, the staggered has some flakes of high velocity in some parts of the cavity. For the 0.4m cavity the velocity profile (figure 4.10) and velocity out (figure 4.8 and 4.9) are almost the same but the velocity profile of the staggered has some flakes of velocity that are higher than the one sided. One peculiarity about the 0.4 m staggered design has some flakes, in the middle of the high velocity stream, where the velocity gets as small as near the external façade.

For the speed of 0.8 m cavity in the velocity profile picture (figure 4.10) they do not reach the same highest speed, one sided has higher compared to the staggered. The velocity starts getting high at roughly one to two meters of the 0.8 m cavity while in other cavities it gets high earlier, but the earliest is 0.25 m cavity among the other two. One effect seen in both figures 4.8. and 4.9. is a fact that changing the cavity depth size influences the air velocity inside it (Alberto, Ramos et al. 2017). Alberto also states that "The variation of the air gap thickness(s) changes the values of the heat transfer coefficient by convection within the cavity, leading to different results regarding the air temperature in its interior and, consequently, the heat exchanges with the occupied Zone".

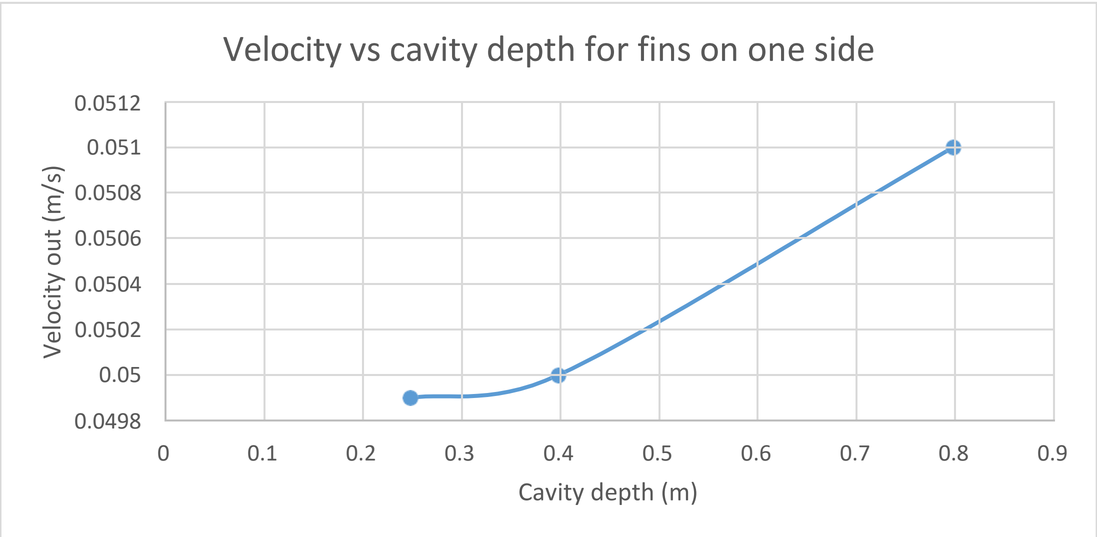

Figure 4.8. velocity vs cavity depth for one sided fins design

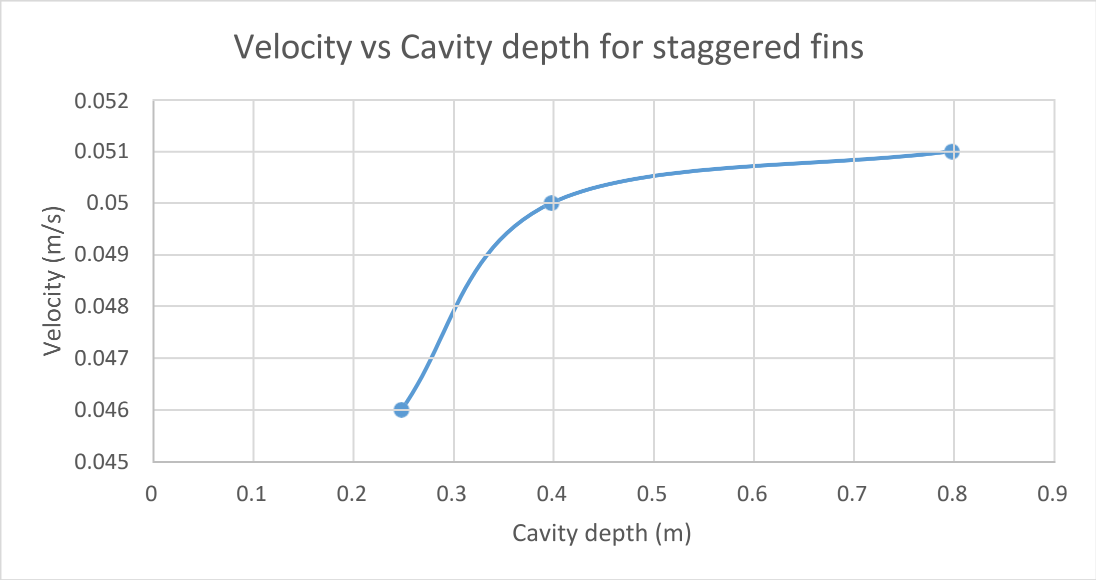

Figure 4.9. Velocity vs Cavity depth for staggered fins

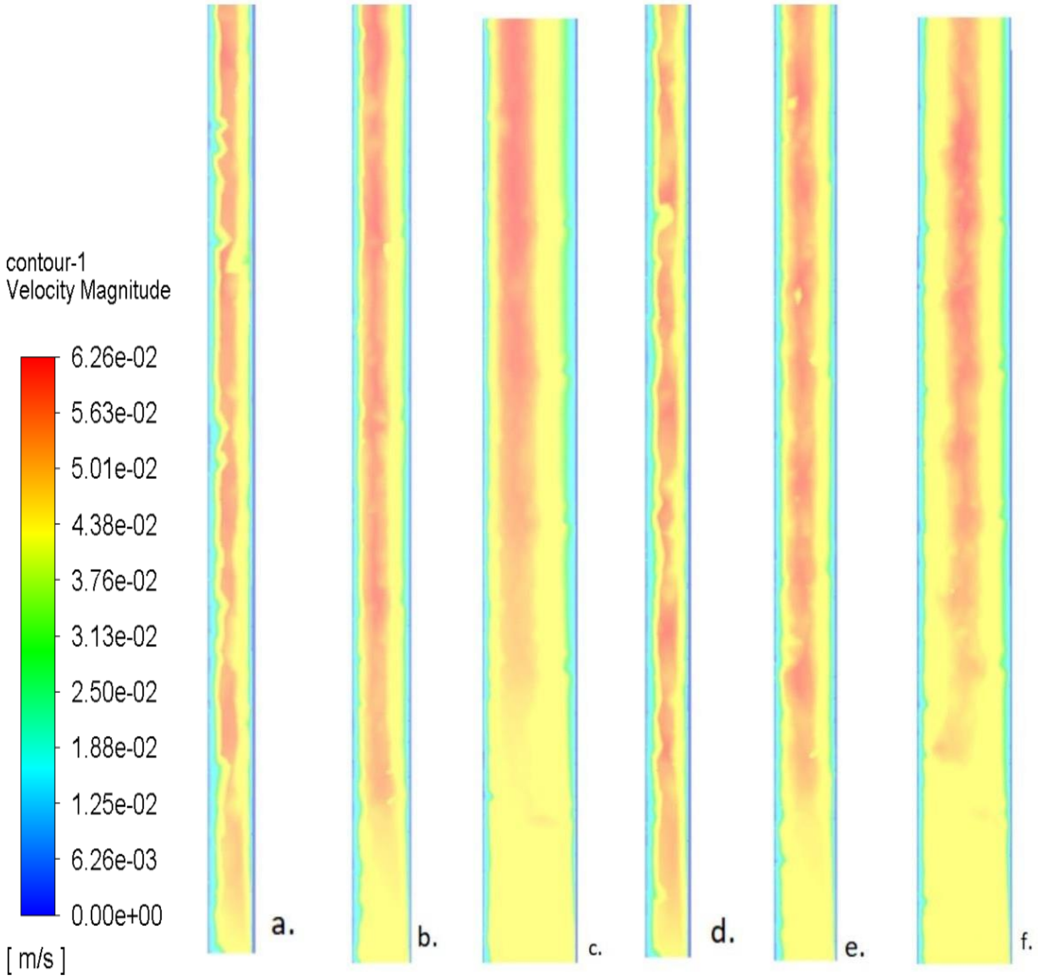

Figure 4.10. Velocity profile of double skin façade for a. design 1, b. design 3, c. design 5, d. design 2, e. design 4, f. design 6 respectively.

4.2. Discussion

When discussing the effects of temperature and velocity inside the façade is due to the fact that the fins are blocking the air from flowing inside the cavity as they should, causing therefore the air to rise in temperature at the place of the fins. For the one sided design with fins at the external façade, there are layers of hot temperature, near the external façade, and relatively cold temperature near internal façade, due to the fins being an obstacle for the air causing it to reduce its velocity at the region of the fins. Whereas at the zone where there is no fins the velocity will be higher as the result the façade has lower temperature. For the staggered fins, the blockage of the fins is on both facades with fins height of 35 % of the cavity depth making 70% of the cavity blocked and only 30% of the cavity of free flow of air. As a result, the high speed region is in the middle showing high effect on the internal façade temperature causing it to rise. Between the two designs the one sided fins is the best for hot countries for it proves to be very effective in reducing the temperature of inner façade.

The relation between temperature and velocity is not directly proportional, higher the velocity lower the temperature. The fins are used to slow down the velocity causing the temperature to rise.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1. CONCLUSION

This project aimed to investigate the effect of increasing the cavity depth using fins to block the air with two design of fins (one side and staggered) using Computer Fluid Dynamics. Under constant boundary conditions and solar radiation of Ipoh-Malaysia a total of six designs were simulated. The use of fins while increasing the size of the air cavity had effects on the air velocity and temperature of both external and inner façade. This project aimed to study these effects. Another aim of this project is to reduce the size of the air cavity while having the compared results as the larger air cavities. The study was done using steady-state assumptions during peak solar loadings in Malaysia at 10:00 A.M.

The increase in thickness of the air gap normally leads to a decrease in in HVAC energy demand in the building(Alberto, et al. 2017) but with this experiment it was noted that with the use of fins (with height of 35 % of cavity thickness) on the external façade leads to a decrease in temperature of the inner facade. The one-sided fins design shown to be very effective in reducing the temperature in the inner façade. The staggered fins design increase a lot the internal façade temperature especially at the top of the façade which can lead to thermal discomfort. To conclude the usage of fins on external façade offers significantly better results having smaller cavity depth. Overall, the results of this research created the opportunity to discuss the strengths and weaknesses of using modified traditional double-skin facades.

5.2. RECOMMENDATION

It is recommended for this simulation to be done in transient state as the solar loading differs from time to time, also, it would be good to have a more comprehensive study of the same design in different places (states or towns) of Malaysia.

Moreover, the staggered condition can be furthered studied where low drag coefficient fin type can be used on the inner façade, mixing of various types of fins to increase the speed in the inner façade. The staggered condition can be furthered studied on its effect on hot countries.

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APPENDICES

APPENDIX A: Convergence of the simulation

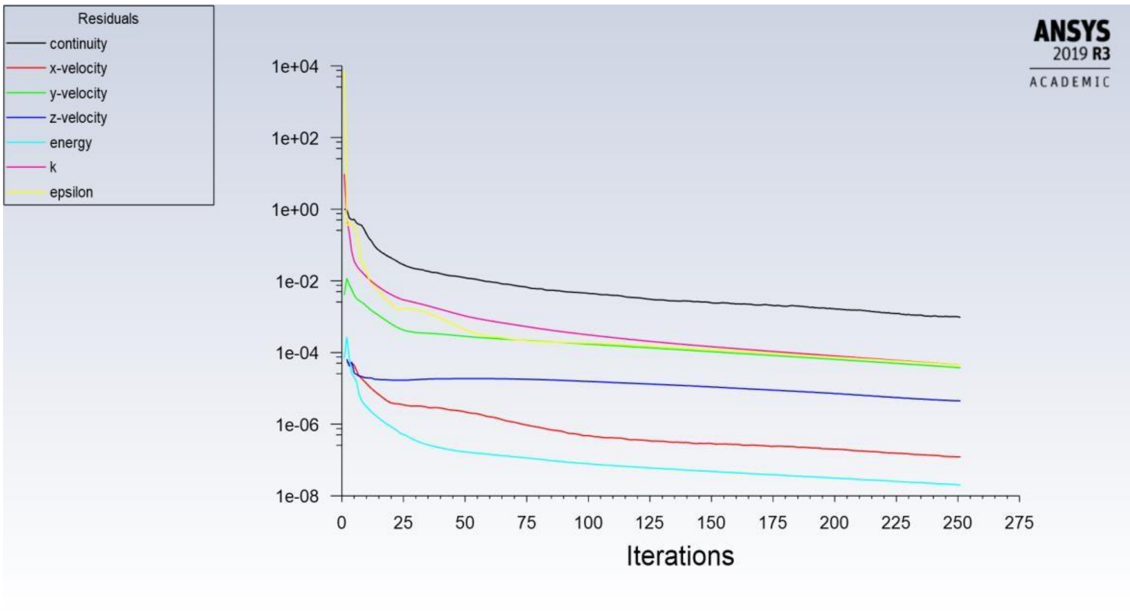

Figure A.1. Scaled residuals for reference model without fins.

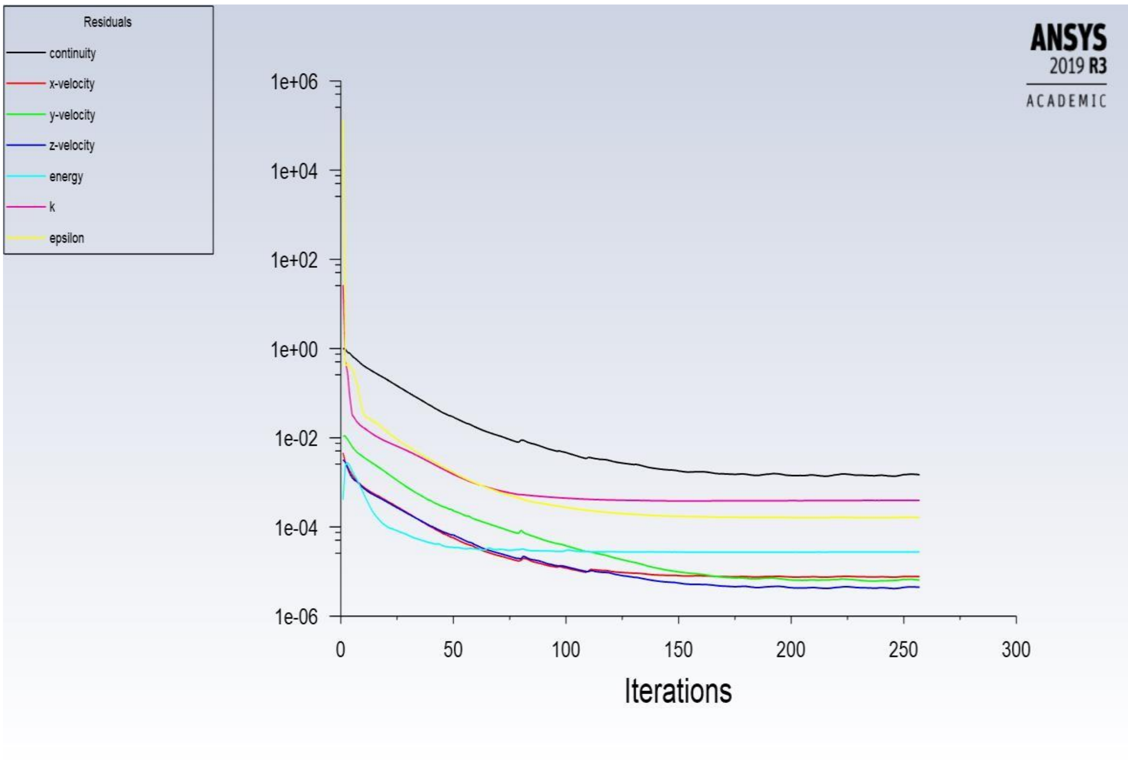

Figure A.2. Scaled residuals for 25 cm cavity depth with fins on one side (Design 1).

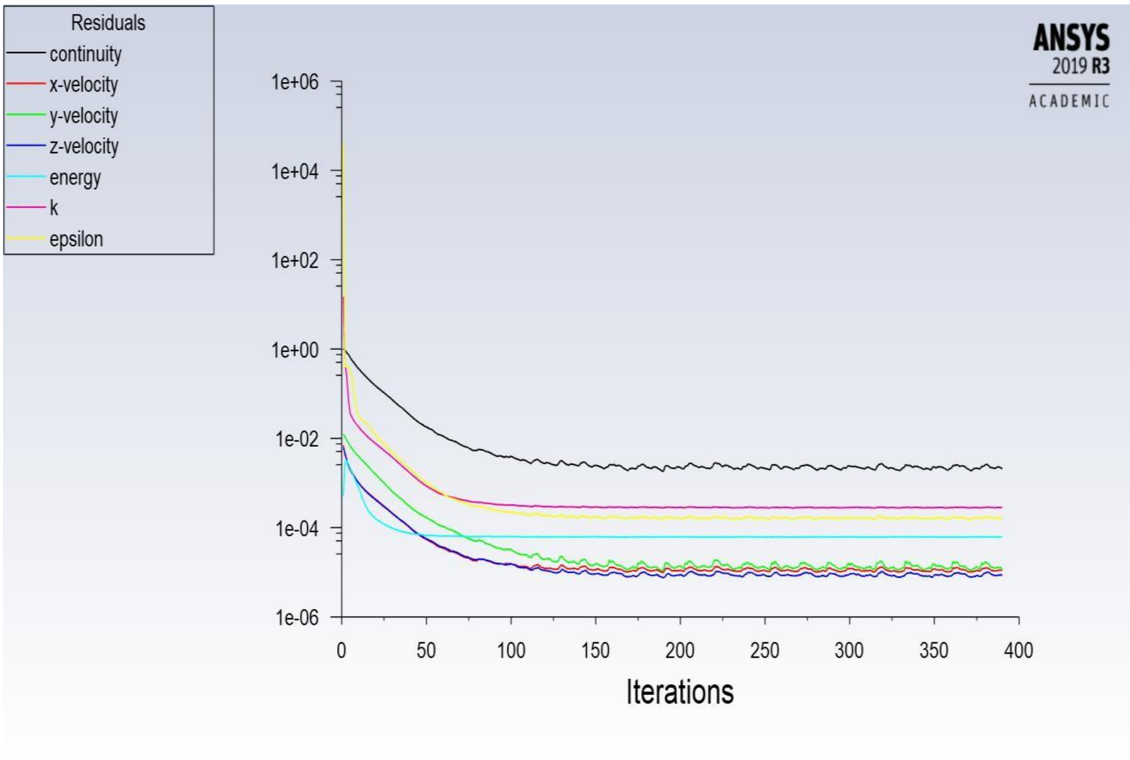

Figure A.3. Scaled residuals for 25 cm cavity depth with fins staggered (Design 2).

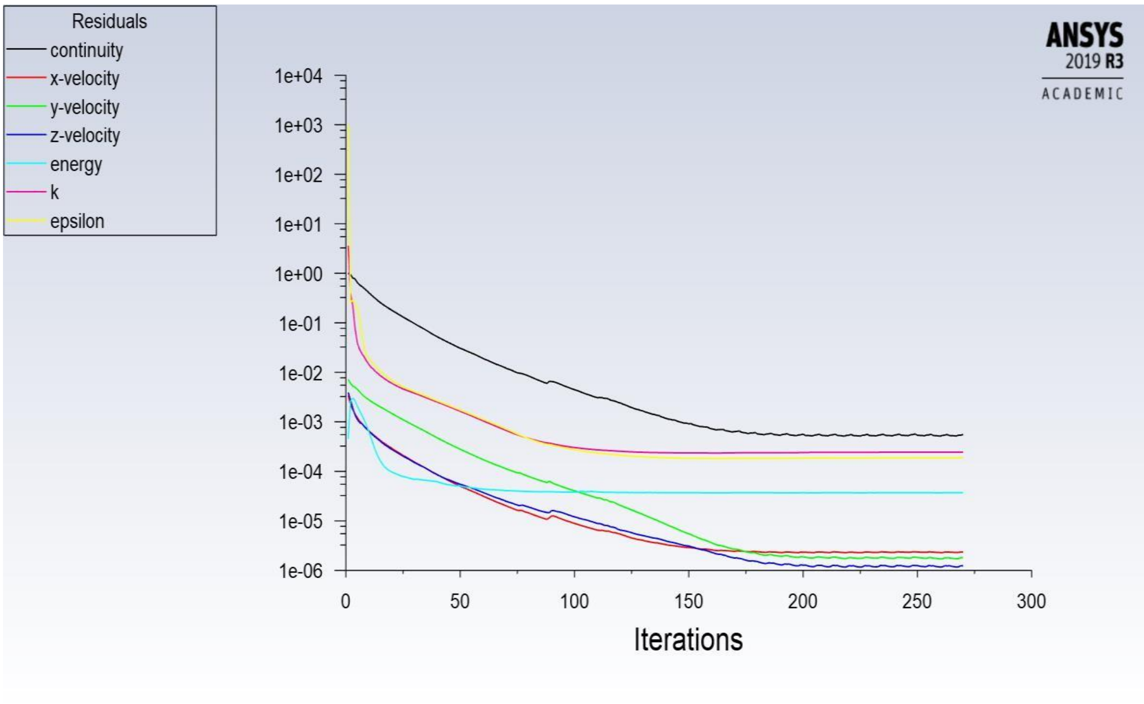

Figure A.4. Scaled residuals for 40 cm cavity depth with fins on one side (Design 3).

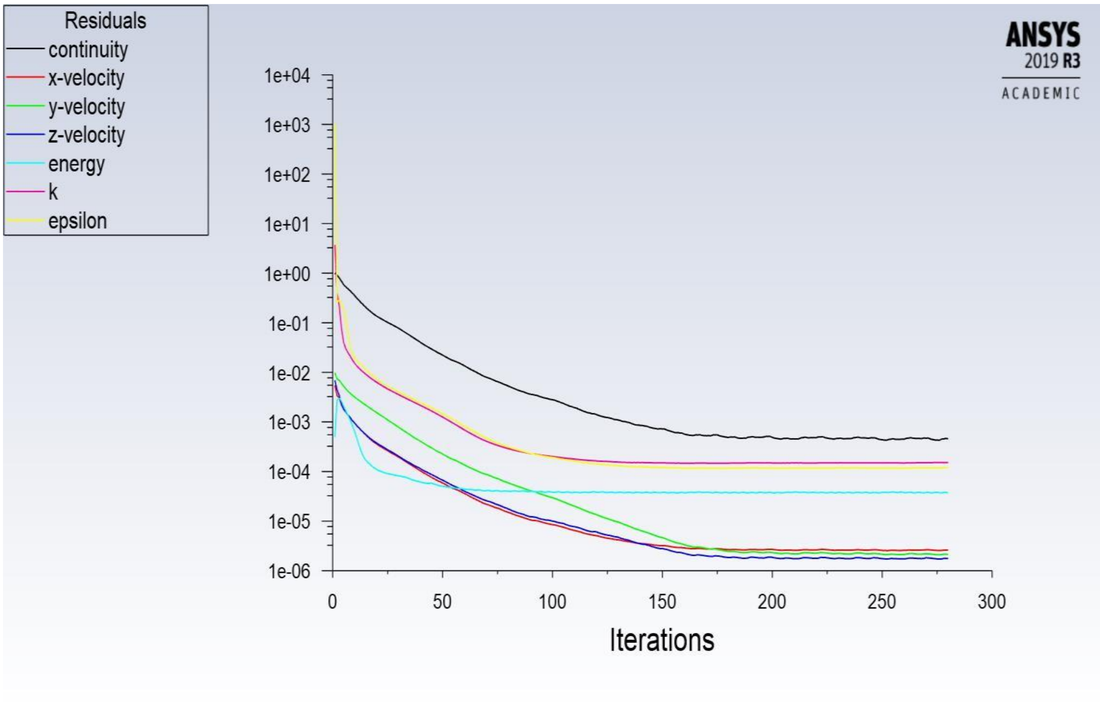

Figure A.5. Scaled residuals for 40 cm cavity depth with fins staggered (Design 4).

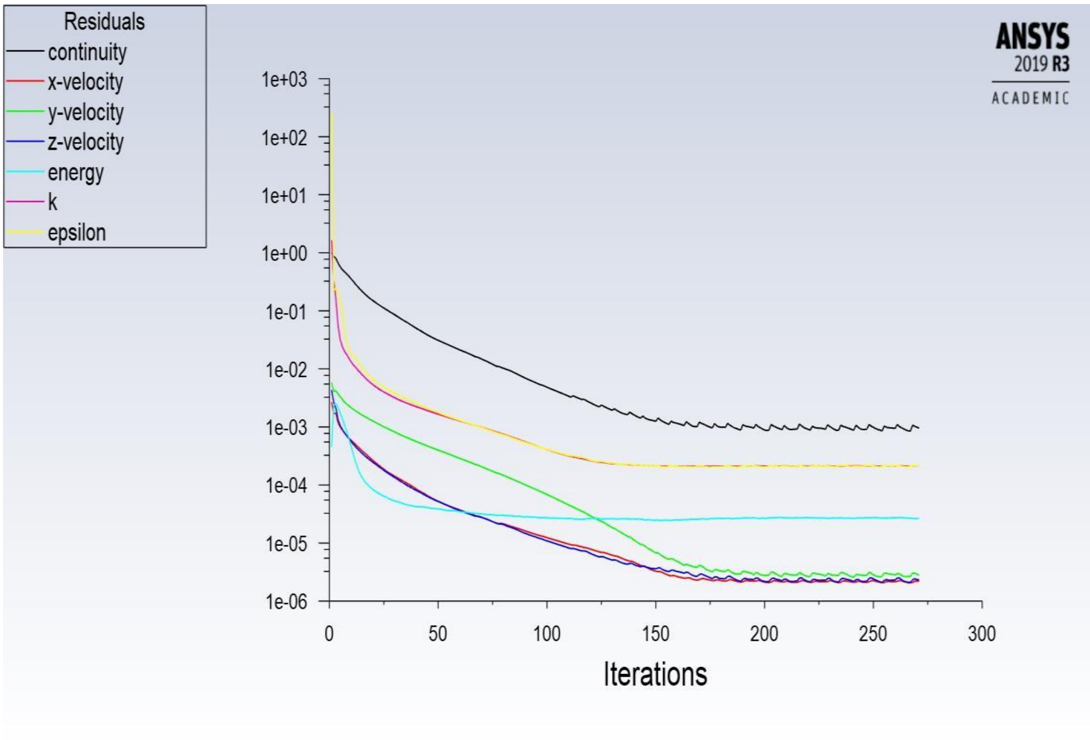

Figure A.6. Scaled residuals for 80 cm cavity depth for fins on one sided (Design 5).

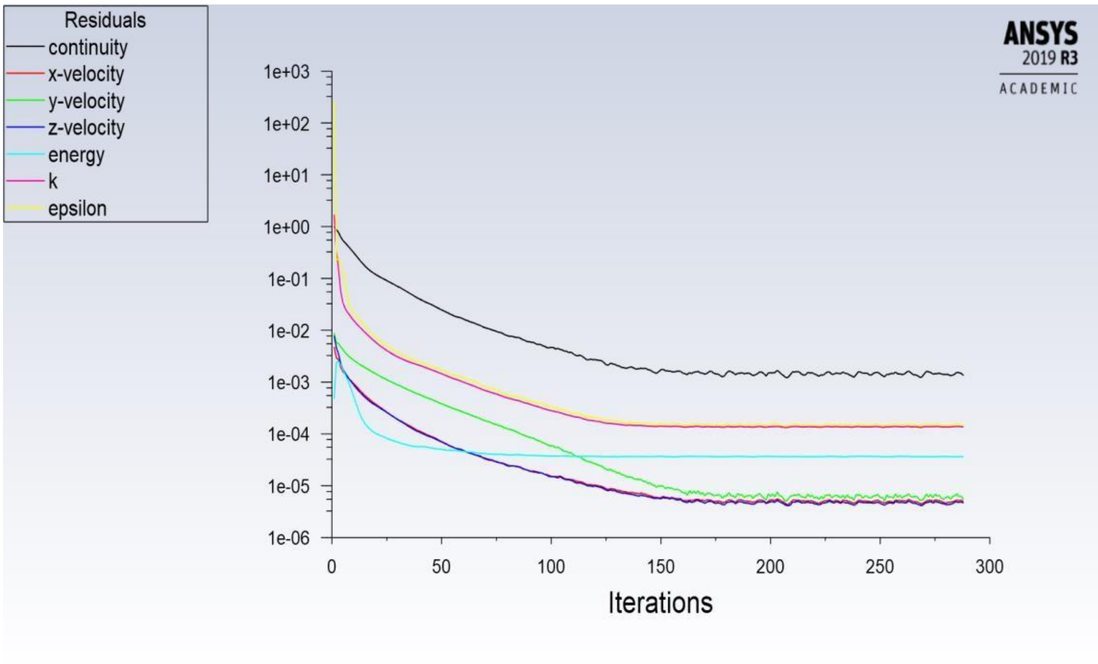

Figure A.7. Scaled residuals for 80 cm cavity depth with fins staggered (Design 6).

APPENDIX B: Outputs of the simulation

Table B.1. Temperature of the inner and outer façade

Model	Fin type	Internal façade temperature (˚C)	External façade temperature (˚C)
Reference model	Non existing	21.05	27
Design 1	1 sided	21.78	36
Design 2	Staggered	25	36.8
Design 3	1 sided	21.0	39
Design 4	Staggered	23.8	38
Design 5	1 sided	20	39.5
Design 6	Staggered	27.0	39.5

Table B.2. Inlet and outlet velocity

Model	Fin type	Inlet Velocity (m/s)	Outlet velocity (m/s)
Reference model	Non existing	0.03	0.0499
Design 1	1 sided	0.035	0.0499
Design 2	Staggered	0.035	0.046
Design 3	1 sided	0.038	0.05
Design 4	Staggered	0.038	0.05
Design 5	1 sided	0.035	0.051
Design 6	Staggered	0.035	0.051

Table B.3. Temperature at outlet

Model	Fin type	Outlet Temperature (˚C)
Reference model	Non existing	38
Design 1	1 sided	47
Design 2	Staggered	54
Design 3	1 sided	56
Design 4	Staggered	55
Design 5	1 sided	59
Design 6	Staggered	57