Energy saving by using Double Skin Façade for office buildings in the UAE

توفير الطاقة باستخدام الواجهات المزدوجة فى المبانى المكتبية فى الإمارات العربية المتحدة

By Mohamed Ashour

Student ID 2013117150

Project submitted in partial fulfilment of the requirements for the degree of MSc Sustainable Design of the Built Environment

Faculty of Engineering & IT

Project Supervisor

Professor Bassam Abu-Hijleh

March 2014

PROJECT RELEASE FORM

Student Name	Student ID	Programme	Date
Mohamed Ashour	2013117150	MSc Sustainable Design of the Built Environment	March 2014

Dissertation/Project Report Title
Energy saving by using Double Skin Façade for office buildings in the UAE

I warrant that the content of this Dissertation/Project Report is the direct result of my own work and that any use made in it of published or unpublished copyright material falls within the limits permitted by international copyright conventions.

I understand that one copy of my dissertation/project report will be deposited in the University Library for permanent retention.

I hereby agree that the material mentioned above for which I am author and copyright holder may be copied and distributed by The British University in Dubai for the purposes of research, private study or education and that The British University in Dubai may recover from purchasers the costs incurred in such copying and distribution, where appropriate.

I understand that The British University in Dubai may make that copy available in digital format if appropriate.

I understand that I may apply to the University to retain the right to withhold or to restrict access to my dissertation/project report for a period which shall not normally exceed four calendar years from the congregation at which the degree is conferred, the length of the period to be specified in the application, together with the precise reasons for making that application.

Signature

Executive Summary

There is more demand on glazed façades for high-rise buildings which, increase cooling loads especially in hot and arid climate. Double skin façade is widely used to reduce energy loads and provide visually transparent façades, it has become more popular in cold climates because of the evident ability of the double skin façade to reduce heating loads, on the other hand many studies have shown potential energy savings by using double skin façade in hot climate as well, it is thought to be as a result of ventilating the channel between the external and internal façade. This study attempted to simulate the thermal performance of the double skin façade in high-rise office building in Dubai city, where temperature could reach over 42 ^{o}C in summer. The study examined different parameters that could affect the performance of the double skin façade such as, channel width, glazing type, and natural ventilation mode. Results showed that double skin façade can reduce cooling loads regardless the channel was ventilated or not as result of reduced solar gain by the external façade. The results also showed up to 20% savings in cooling plant sensible annual load and 8% savings in total annual energy consumption, computer simulation were used to estimate thermal performance of the façade and also computational fluid dynamic analysis was used in a partial section of the model to simulate thermal behavior inside the channel. More comprehensive evaluation is recommended for double skin façade system, to balance between cost increase when adding another skin to the building and total running cost savings by reducing annual total energy consumption.

Keywords**:** double skin façade, ventilated double skin façade, solar heat gain, UAE, Dubai, energy saving, hot climate.

ملخص البحث

هناك طلب متزايد على الواجهات الزجاجية للمبانى المرتفعة التى تؤدى لزيادة إستهلاك الطاقة اللازمة للتبريد و خصوصاً فى الأجواء الحارة و الجافة. الواجهات المزدوجة واسعة الإنتشار لقدرتها على توفير الطاقة و توفير الشفافية المطلوبة للواجهات الخارجية للمبانى. لقد اصبحت الواجات المزدوجة أكثر إنتشاراً فى الأجواء الباردة لقدرتها الواضحة على توفير الطاقة المستخدمة فى التدفئة ، من الناحية الاخرى يوجد دراسات عديدة اظهرت إمكانية توفير الطاقة عند إستخدام الواجهات المزدوجة فى الأجواء الحارة أيضاً ،التى يُعتقد انها نتيجة لتهوبة القناة ما بين الواجهة الخارجية و الواجهة الداخلية.فى هذه الدراسة تم محاكاة السلوك الحرارى للواجهات المزدوجة للمبانى المكتبية المرتفعة فى مدينة دبى ، حيث تتعدى درجة الحرارة ٤٢° درجة مؤية فى الصيف. الدراسة إختبرت عدة عوامل متغيرة قد تؤثر على أداء الواجهات المزدوجة ، منها عرض القناة ما بين الواجهة الخارجية و الداخلية و خصائص الزجاج المستخدم و طريقة التهوية الطبيعية للقناة. النتائج أظهرت أن الواجهات المزدوجة يمكن أن توفر الطاقة اللازمة للتبريد سواء تم تهوية القناة أم لا و ذلك نتيجة لخفض الإشعاع الشمسى عن طريق الواجهة الخارجية الإضافية. النتائج أيضاً أظهرت قدرة الواجهات المزدوجة على توفير الطاقة السنوية اللازمة للتبريد بنسب تصل الى ٢٠% و ايضاً توفير استهلاك الطاقة الكلية السنوية بنسبة تصل إلى ٨%. تم إستخدام نظام المحاكاة عن طريق الحاسب الآلى فى هذه الدراسة لتقدير الأداء الحرارى للواجهات المزدوجة ، و أيضاً تم إستخدام نظام ديناميكا السوائل الحسابية فى جزء مصغر للنموذج الثلاثى الأبعاد للمبنى لتقدير السلوك الحرارى داخل القناة. ينصح بتقييم شامل للواجهات المزدوجة لتحقيق التوازن ما بين الزيادة فى التكلفة الكلية للمبنى و إجمالى التوفير لتكلفة التشغيل الناتج عن خفض إستهلاك الطاقة السنوية اللازمة للمبنى.

كلمات البحث: واجهة مزدوجة ، تهوية الواجهة المزدوجة، الحرارة الشمسية المكتسبة، الامارات العربية المتحدة، دبى، توفير الطاقة، المناخ الحار

Table of Contents

Acknowledgment ... vi
List of Figures ... vii
List of Tables ... x
1. Introduction ... 1
2. Literature Review ... 2
2.1. Description of the double skin façade system ... 2
2.2. Performance of double skin façade in hot climate ... 3
2.3. Improving double skin façade performance ... 5
3. Aims and Objectives ... 7
4. Methodology ... 8
3.1. Constructing base model ... 8
3.2. Difficulty in simulating double skin façade ... 8
3.3. Types of double skin façades ... 9
3.4. Simulation models ... 10
5. Climate and Environment ... 11
6. Modelling the Base Case ... 13
7. Analysis ... 16
7.1. Dynamic Simulation modelling tool ... 17
7.2. Operational parameters ... 17
7.3. Model translation to IES VE ... 18
7.4. Full building model simulation ... 20
7.5. Partial model ... 23
8. Results & Discussion ... 25
8.1. Glazing type ... 28
8.2. Ventilation mode ... 31
8.3. Orientation and Height ... 34
8.4. Channel width ... 38
8.5. MicroFlo (CFD) analysis ... 40
9. Conclusion ... 45
10. References ... 46

Acknowledgment

I would like to thank all the staff at the British University in Dubai especially the staff at Faculty of Engineering & IT department for their support. The author would like to thank Professor Bassam Abu-Hijleh for supporting and supervising this project, and I would like to thank my family especially my mother and my wife for encouraging and supporting me all the way.

List of Figures

Figure 1: multi layered façade made of traditional ornaments in Doha tower (right) and Double skin façade in The Shard tower (left) 2

Figure 2: Typical double skin façade system - One Square building, Manchester 3

Figure 3: Different ventilation modes used in the simulation 9

Figure 4: Dubai Electricity Consumption (GWh) in 2012 11

Figure 5: Climate Summary Metrics analyzed by IES VE... 12

Figure 6: CP08 office tower in DIFC, Dubai, United Arab Emirates 13

Figure 7: Typical floor plan for the office tower showing different thermal zones 14

Figure 8: Detailed 3D model for the CP08 tower... 15

Figure 9: Bubble diagram for different parameters used that affects double skin façade performance 16

Figure 10: Simplified translation for the facade 18

Figure 11: Complex translation for the facade.. 18

Figure 12: Model translation to IES VE 19

Figure 13: Model simplified and translated as analytical model to IES VE 19

Figure 14: Typical floor plan showing double skin façade zoning............................ 21

Figure 15: Analytical used for simulating Continuous channel (left) and divided channel (right) 21

Figure 16: Solar shading calculations by SunCast 22

Figure 17: Assigning construction to external walls in Apache 22

Figure 18: Assigning opening types to the model in MacroFlo 22

Figure 19: Partial model for continuous channel showing airflow rates in l/s........... 23

Figure 20: Partial model for continuous channel with horizontal openings showing airflow rates in l/s 24

Figure 21: Partial model for divided channel showing airflow rates in l/s................. 24

Figure 22: MicroFlo (CFD) settings used for the simulation 24

Figure 23: Annual savings for cooling plant sensible load for the full model 25

Figure 24: Annual savings for total annual energy consumption for the full model.. 26

Figure 25: Partial mode results for annual room cooling plant senisible load.......... 26

Figure 26: Partial mode results for annual solar gain 27

Figure 27: Comparison between case DDC-1 and base case in annual cooling plant sensible load 27

Figure 28: Double skin façade monthly savings for the full model........................... 28

Figure 29: Solar gain for office 4 at the 21st of July (Full model) 28

Figure 30: Solar gain for office 4 at the 21st of February (Full model) 29

Figure 31: Air temperature inside channel 4 in July 21st (Full model)..................... 29

Figure 32: Office 4 cooling plant sensible load in July 21st (Full model).................. 30

Figure 33: Office 4 cooling plant sensible load in February 21st (Full model) 30

Figure 34: External vent volume flow at July 21st (Full model) 31

Figure 35: External vent gain - comparison between different ventilation modes (Full model) 32

Figure 36: Air temperature inside the channel with different ventilation modes at July 21st (Full model) 32

Figure 37: Air temperature inside the channel at February 21st - comparison between different ventilation modes (Full model).................................... 33

Figure 38: Volume flow inside channel 4 - comparison between different ventilation modes 33

Figure 39: Solar inside office 4 - comparison between different ventilation modes (Full model) 34

Figure 40: Annual cooling plant sensible load for the 10th floor............................... 35

Figure 41: Annual cooling plant sensible load savings for the 10th floor.................. 35

Figure 42: Comparison between solar gains for different levels.............................. 36

Figure 43: Comparison between cooling loads for different levels 36

Figure 44: Volume flow inside the channel at July 21st (Full model) 37

Figure 45: Building solar energy analysis 38

Figure 46: Volume flow inside the channel by using divided channel (partial model) 39

Figure 47: Volume flow inside the channel by using continuous channel (partial model) 39

Figure 48: Channel temperature - Channel width comparison (partial model) 40

Figure 49: CFD analysis - Temperature contour inside a closed channel at July 21st 41

Figure 50: CFD analysis - Temperature contour inside continuous channel at July 21st 41

Figure 51: CFD analysis - Temperature contour inside a continuous channel with horizontal openings at July 21st 42

Figure 52: CFD analysis - Temperature contour inside divided channel at July 21st42

Figure 53: CFD analysis - velocity contour inside a closed channel at July 21st...... 43

Figure 54: CFD analysis - Velocity contour inside continuous channel at July 21st . 43

Figure 55: CFD analysis - velocity contour inside a continuous channel with horizontal openings at July 21st 44

Figure 56: CFD analysis - Velocity contour inside divided channel at July 21st 44

List of Tables

Table 1: Simulation parameters for primary 15 cases...10

Table 2: CP08 minimum performance for glazing types 14

Table 3: Comparison between energy loads results for levels of translation 18

Table 4: Properties of curtain wall and aluminum composite panels for external walls 20

Table 5: MacroFlo opening types used in the simulation...20

Table 6: Building annual energy consumption 25

1. Introduction

There is more demand for high transparent buildings, as developers and architects are constantly working on providing the best panoramic views for the building's occupants therefore transparent façade is always required especially for office, residential, and hospitality buildings. But providing the best panoramic views for occupants comes with the price of higher energy demand to maintain thermal comfort in hot and arid climates. Many architects explored covering their building's façade with shading screens, fabrics, and ornaments to reduce solar gain which restricts views to the surrounding environment (Figure 1) and reduce natural day lighting inside the buildings, as a result more artificial lighting will be required, but double skin façades can be used to design visually transparent buildings that cannot be achieved by conventional curtain wall systems (Darkwa and D.H.C. Chow 2014) or screened façades. To reduce solar gain, improve daylight quality, and maximise views developers and engineers in moderate and cold climates tend to approach a double skin façade system or using external shading devices (automated or fixed), but in traditional architecture in hot climates it is common to minimise openings and build massive walls that protect the interior of the building from ambient high temperature by absorbing the heat and release the it at night which can be flushed outside the building by natural ventilation.

This paper aims to provide an overview of the efficiency of using double skin façade in office buildings in hot climates. Kambiz *et al.* (2013) study showed that increasing insulation levels for a residential building in Dubai can save 17% of energy use. This study aims to question whether double skin façades can improve insulation levels as well, a study also showed that buildings consume between 60% to 75% of total electricity for cooling (Hassan *et al.* 2013), also building's skin can be responsible for up to 45% of energy required for cooling according to Neveen (2008), which shows the need for developing buildings' skins to act as a moderator between external and internal spaces in order to reduce energy consumption and therefore CO_2 emissions particularly in hot regions such as the UAE.

When cladding a building there are two main systems, single-skin façade (SSF) and multi-skin façade (MSF), Multi-skin façade includes double-skin façade (DSF) and climate interactive façade system (CRFS) (Hassan *et al.* 2013) and single skin façade which is the most conventional cladding system in the middle-east. Although double skin façades is more common in cold climates such as Europe, recently more modern buildings in hotter climate such as China implemented double skin façade claiming that ventilated channel can eject unwanted heat.

Figure 1: multi layered façade made of traditional ornaments in Doha tower (right) and Double skin façade in The Shard tower (left)

2. Literature Review

Traditionally the building's thermal mass was increased by increasing the walls thickness. Today there are different techniques to increase the envelope insulation without increasing the wall thickness, such as ventilated façades where a cavity (channel) is created between the insulated wall and external cladding to remove excess heat by convection. Giancola et al. (2012) monitored the performance of a south facing ventilated façade in Spain, they found that introducing a ventilated cavity removed part of the heat loads while in extreme temperatures more heat gain was observed. As principle the double skin façade acts the same way, except heat is transferred inside the cavity by conduction, radiation, and convection unlike opaque ventilated façades where the channel remains shaded.

2.1. Description of the double skin façade system

Double skin façade is basically an additional skin on the external wall of the building, which can be transparent or opaque (Marko *et al.* 2012). The outer skin can be used as external shading screen, or the system can integrate shading device in-between inner and outer skin (Figure 2). There are several types of double skin façades depending on ventilation mode whether it is ventilated or not and whether the ventilation is naturally or forced (mechanically), or whether the system is indoor (sealed) or outdoor.

Inner and outer layer can be either single or double glazed depending on the main purpose of the double skin façade and climate conditions. Generally double skin façades can be classified in two categories: inaccessible system and accessible system (Sebastian *et al.* 2012). Second layer on the double skin façade doesn't have to be a glass sheets, it could be a metal screen or tensile structure, etc., the second skin can be also designed as responsive system that adapts to weather conditions and can be controlled by BMS. Members at Hascher Jehle Architektur and Behnisch

& Partners together with ARUP engineers proposed a concept for integrated PCM (Phase change material) in the buildings external façade, where the PCM is used as reversed radiator as the PCM at the second skin collects the heat from the ambient air and release it through liquid medium or by using air (Khaled 2013). Baldinelli (2009) designed integrated horizontal louvers and glass, so that the system can be beneficial in both summer and winter seasons, although the model showed considerable cooling loads reduction the louvers had to be entirely closed to provide enough shading which limits visibility and daylight. However in this study the focus will be on glazed ventilated double skin façades.

Figure 2: Typical double skin façade system - One Square building, Manchester

2.2. Performance of double skin façade in hot climate

There is a limited research found in hot arid climates on double skin façade and most of these studies are based on computer simulation results not in actual buildings, but a study by Hassan *et al.* (2013) for multi-façade system in an educational building in Al ain city (approximately 100 km away from Dubai) concluded that 17% to 20% can be saved in cooling energy, Hashemi *et al.* (2010) performed field measurements for a double skin façade in Tehran where temperature could reach 40 ºC in summer, the study showed an increase in temperature inside the channel that could reach 1 ºC to 10 ºC higher than outside temperature when there is direct solar radiation on the façade and when the façade fall in shade the temperature inside the channel could reach 12 ºC less than the outside temperature.

Neveen (2008) suggested that the heat trapped in the channel would encourage natural buoyancy which would reduce heat gain, the author found in a study of an office building in a hot and arid climate equipped with a 6 storey continuous double skin façade, a reduction in annual cooling loads by approximately 30% when using reflective glass in the outer layer of the façade and 12% reduction when using tinted glass, these result where compared with benchmark single skin façade (reflective coated glass), the author also found and increase in cooling loads when using clear glass for the outer layer of the façade.

A study was done by Stelios (2007) suggests that double skin façade can reduce energy consumption between 29% to 35% in Mediterraninan climate and up to 42 % in a hot region such as Riyadh compared to single skin façade, another paper was done by Jan H., Martin B., and Frantisek D. (Michel *et al.* 2007) shows 7-13 % reduction in sensible cooling load for double glazing façade with blinds located inside the channel and the channel is ventilated, the simulation results also showed that ventilation is important to reduce the temperature inside the channel otherwise the temperature will rise 50 ºC above ambient temperature in case the outlet damper is closed. Similar results were found by Aleksandar *et al.* (2012) as they noted that it is necessary to ventilate the channel to reduce the temperature inside it, they also suggested that the double skin façade can have less heat gain than the single skin façade and the reason would be that the outer skin layer can eliminate part of the solar radiation. Most studies on ventilated double skin façade are consistent with studies on ventilated wall covering, as studies on this area have shown reduction in heat gain by ventilating the Channel between the outer skin and the wall (Miguel *et al.* 2013), which makes the double skin façade system highly adaptable with climate conditions by controlling ventilation inside the channel and integrating shading device if required.

Another experiment in an office building in London (Michel *et al.* 2007) also shows that double skin façade performs better in summer than single skin façade due to ventilated Channel and part of solar gain is reflected or absorbed by blinds which is a part of BMS (building management system) that automatically close the shutters when solar gain exceeds 200 W/m^2. The experiment also suggests that using high performance glass in the double skin façade can reduce cooling demand.

On the other hand a comparison between two single skin façades and three single double skin façades for a south façade of an office building with only difference in the type of glazing and channel widths showed that double skin wall with smaller channel width performs slightly better during winter, and during hot months there is no noticeable difference between double skin and single skin façade (Ajla 2013). Overheating inside the channel is proved by many studies, as the main reason behind using double skin façade in European buildings is reducing heating loads, a study by Gratia and De Herde (2004) showed that the temperature inside the channel could reach 42 ºC when outside temperature is 5 ºC, but only when the double skin façade is closed, when it's ventilated the temperature drops to 25 ºC and heating loads increase, the authors also showed that cooling loads increased in summer even when natural ventilation is introduced because of temperature increase inside the channel, however the study included one type of glazing (low-e double glazed for the inner skin and clear single glass for the outer skin). Høseggen *et al.* (2008) also concluded from a study in Norway that double skin façade cannot be justified from economic point of view as heating energy savings from a double skin façade and improved U-value for windows is almost the same, although the author found a slight improvement in cooling loads in summer

2.3. Improving double skin façade performance

Double skin façade performance depends mostly on ventilation modes, whether by buoyancy or mechanically (Wong *et al.* 2008). Hashemi *et al.* (2010) suggested improving ventilation and shading to the double skin façade to reduce temperature inside the channel. Wenting *et al.* (2004) on the other hand tested a prototype building by adding thermal storage wall (solar chimney) at the top of the intermediate space of the double skin façade to improve the stack effect between the building and the double skin façade as the air pressure difference at the top is higher which improves the natural ventilation inside the channel even if the wind is not strong enough. Also of the double skin façades include venetian blinds to control solar radiation and daylight (Nassim *et al.* 2005).

Sebastian *et al.* (2012) study showed that temperature inside the channel between the two layers drops when increasing the channel width, the study also shows that although the glass layers absorbs a lot of heat, the inner skin is always cooler than the outer skin. Selection of the ventilation and glazing type for the double skin façade can affect energy saving considerably, Marko *er al.* (2012) shows in a study for different double skin façades combination that the best settings for reducing cooling loads is using a combination of triple low emission glass and double reflective glass which can reduce up to 42% of cooling loads, these results are consistent with Stelios (2007) as the authors used the best solar protective properties for both inner and outer layer, as well as ventilating the channel naturally or mechanically (better results with mechanical ventilation). Double skin façade's intermediate space (Channel) is usually constructed with openings such as the air flows through it in summer by buoyancy to reduce cooling loads and in winter the openings is closed to warm up the interior space which can be used to reduce heating loads (Wenting *et al.* 2004).

A discussion took place in Arup façade engineering about design parameters that affect façade design (Architectural Research Centers Consortium 2008):

- Hard costs: Building structure, façade construction, and mechanical system
- Soft costs: Energy, operation, and development.
- Human impacts: Thermal comfort, Acoustic benefits, light quality, fresh air, responsiveness to the user, and system control.
- Ecological impacts: Source of materials, fabrication process risk, potential for materials re-use, and carbon equivalent.

If double skin façade system is more optimal than single skin façade, it needs to respond positively to these design parameters. There is no doubt that the double skin façade cost is higher than traditional single skin façade as it could reach 60% to 80% higher, in central Europe where double skin façade is used frequently the cost for a single skin façade is 300 – 500 €/m^2 and for standard double skin façade the cost would reach 600 – 800 €/m^2, but for providing air inlet and outlet or operable louvers the price would be 700 – 1000 €/m^2 and 800 – 1300 €/m^2 respectively (Høseggen *et al.* 2008), therefore it is a question whether double skin façade possible energy savings justify the cost increase for the building's envelope, nevertheless this study aims to focus on the possible energy savings by using double skin façade, and further research is recommended on the possible economical benefits from using double skin facade in hot climates.

3. Aims and Objectives

The aim of this study is not to prove that double skin façade reduces cooling loads, as there are several studies that proved the positive effect of double skin façade in energy consumption, but to investigate how to improve double skin façade performance in reducing cooling loads by altering different parameters which have an impact on thermal behaviour of the system, the objectives summary was:

- Testing the double skin façade on exiting office building that implements the best conventional strategies in reducing solar gain and cooling loads.
- Compare performance of the double skin façade when adjusting the glazing types of both external and internal skins.
- To examine the effect of orientation and height in reducing cooling loads by double skin façade.
- Does the channel width affect the performance of the double skin façade?
- To examine different ventilation modes that could reduce air temperature inside the channel, and therefore heat gain.
- To show how to improve the double skin façade efficiency in hot climate.
- To show the best alternatives that could reduce cooling loads in office buildings.
- To provide a broad view for architects, engineers, and investors on the possible energy savings when choosing double skin façade system.

4. Methodology

The best method to evaluate the performance of a double skin façade is to monitor energy measurements after the building is occupied, as it provides more accurate feedback on the actual energy savings. The second best method is to construct 1:1 scale mock-up for the façade which involves using simulation software for calculations. Since both methods are time consuming and expensive process the method used in the this paper is construction of the double skin façade and calculation for energy performance by software simulation, different compositions for the façade were modelled and tested to assess the efficiency of a double skin façade in a hot climates.

3.1. Constructing base model

It is important to design a base model where conventional façade is used and compare it with double skin façade results, some researchers use fully glazed curtain wall system as the base model others use curtain wall system with external shading device. To provide more balanced comparison it is important to assume the base model is the good-practice façade system otherwise double skin façade will always perform better than a fully glazed façade and worse than a fully shaded façade (Michel *et al.* 2007). It is important to realise when analysing simulation results is the accuracy of the CFD (Computational fluid dynamics) variables. Most of the wind speed and directions profiles might not be valid for the building location within the city, as the wind speed and direction is highly affected by obstacles such as surrounding buildings.

3.2. Difficulty in simulating double skin façade

The difficulty in simulating double skin façade is the complexity of the thermal behaviour inside the double skin façade which depends on the optical, aerodynamic, thermo physical and geometry of the double skin façade components also several physical phenomena such as heat conviction, short and long waves, air movement, and conduction that take place inside the channel. According to Deuk-Woo and Cheol-Soo (2011) experiment, they found considerable difference between measurements from computer simulation and measurements from a physical 1:1 model for a double skin façade. The inaccuracy of computer simulation can be a result of air leakage inside the Channelor from the door, ceiling, floor, and window, it could also be a result of in-accuracy in glazing properties or accuracy in modelling shading devices (models are usually simplified for faster processing), another possible reason could be the difference between the actual heat conviction and estimated one. In the case of adding blinds to the model more complexity is added as well the blinds will affect the velocity of the air inside the channel and the heat conviction (Nassim *et al.* 2005), therefore blinds were excluded in this study.

3.3. Types of double skin façades

As shown in Figure 3 there are three designs for the double skin façades that were examined in this study: continuous double skin façade, continuous double skin façade with horizontal openings, and divided channel or corridor double skin façade. In continuous channel the air flows from the bottom of the façade and exists at the top, the sides were also open similar to Hassan *et al.* (2013) case study, as the external skin is more like a suspended layer from the internal façade .The second design is similar to the continuous design except more horizontal openings added to the façade to allow for more airflow inside the channel. Divided channel has horizontal divisions at each level which forces the air to enter and exit at each level.

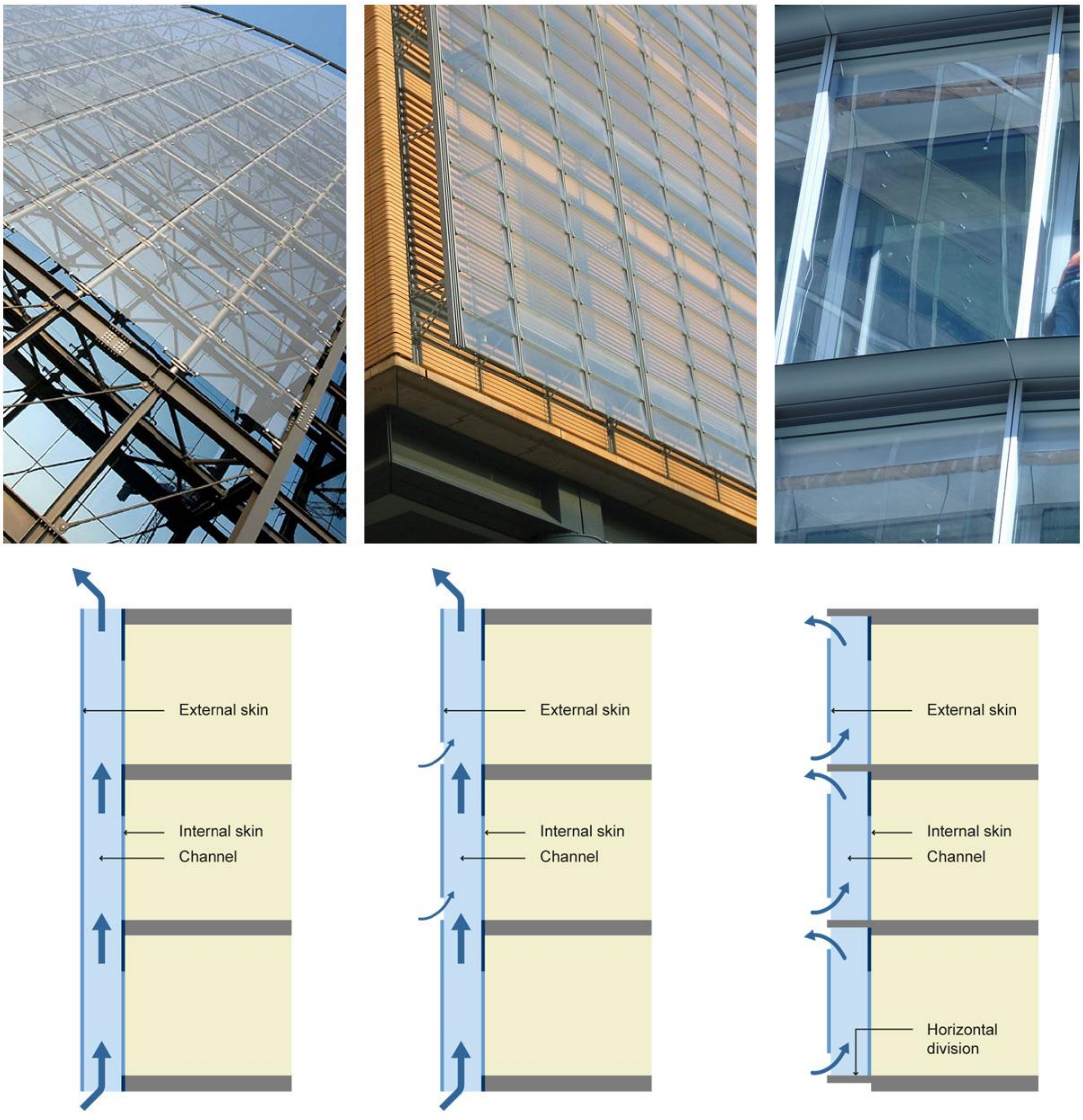

Figure 3: Different ventilation modes used in the simulation

Mediaset Headquarters in Milan, Italy (left), Atrium tower in Berlin, Germany (middle), and Bligh tower in Sidney, Australia (right)

3.4. Simulation models

The results will show the analysis of two analytical models, a full model for the high-rise building under study representing 46 storeys of the office tower and excluding the podium and basements levels, and a simplified model for a 12 m x 13.5 m office space and 5 storey height implementing a double skin façade on the south and east façade. The second model is used to verify the results from the first model as possible errors are expected due to the complex form of the tower, and running a CFD analysis for the full model is time consuming and showed several errors. There are fifteen primary cases presented in the study for both models simulating the thermal performance annually as shown in Table 1, more cases will be presented and discussed to clarify results.

Table 1: Simulation parameters for primary 15 cases

No.	Case	Skin glazing type	Channel width	Ventilation mode
1	Base case	Single skin double glazed	-	-
2	SD-1	Single glazed (external) and double glazed (internal)	1 m	Closed channel
3	DD-1	Double glazed (external) and double glazed (internal)	1 m	Closed channel
4	DS-1	Double glazed (external) and double Single (internal)	1 m	Closed channel
5	SDC-1	Single glazed (external) and double glazed (internal)	1 m	Continuous channel
6	DDC-1	Double glazed (external) and double glazed (internal)	1 m	Continuous channel
7	DSC-1	Double glazed (external) and double Single (internal)	1 m	Continuous channel
8	DDC-0.5	Double glazed (external) and double glazed (internal)	0.5 m	Continuous channel
9	DDC-1.5	Double glazed (external) and double glazed (internal)	1.5 m	Continuous channel
10	SDCH-1	Double glazed (external) and double glazed (internal)	1 m	Continuous channel and horizontal openings
11	SDD-1	Single glazed (external) and double glazed (internal)	1 m	Divided channel
12	DDD-1	Double glazed (external) and double glazed (internal)	1 m	Divided channel
13	DSD-1	Double glazed (external) and single (internal)	1 m	Divided channel
14	DDD-0.5	Double glazed (external) and double Single (internal)	0.5 m	Divided channel
15	DDD-1.5	Double glazed (external) and double Single (internal)	1.5 m	Divided channel

5. Climate and Environment

The case study building is located at Dubai world trade centre district, temperature in Dubai can reach 42 ºC in summer and minimum of 16 ºC in winter, average annual humidity is 60 % and average rainy days between 2009 and 2012 was 14 days (Dubai Statistics Center 2012).The region between 40º N and 40º S is called “solar belt” due to the large amount of solar radiation in that area, Dubai is located at 25.2º N and 55.3º E, the studies have shown that at 25º N daylight happens 4449 h/year and receives 70% sunshine (Islam *et al.* 2010). Dubai’s hot and humid climate requires intensive use of air conditioning to maintain comfortable indoor environment for building’s occupants. Population in Dubai increased more than 230 % between the year 2000 and 2011(862,387 to 2,003,170) as a result CO_2 production increased by 15.1% per capita in the UAE (Kambiz *et al.* 2013).

According to DEWA (Dubai Electricity and Water Authority) the electricity peak demand increased from 3,228 MW in 2004 to 6,637 MW in 2012, and the commercial sector is responsible for 47.33% of the electricity consumption in 2012 as shown in Figure 4 (DEWA 2012), therefore more attention should be paid in developing commercial buildings façades.

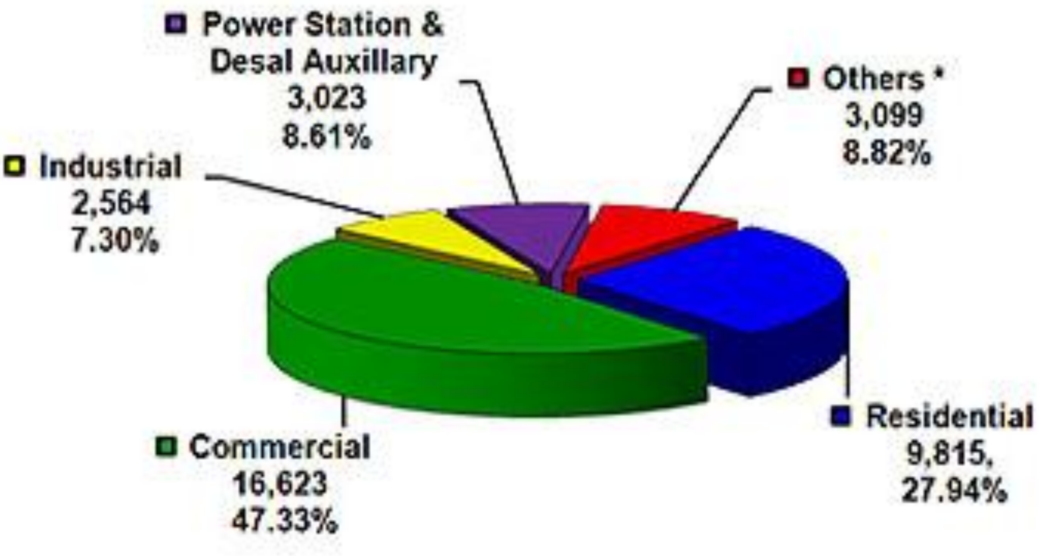

Figure 4: Dubai Electricity Consumption (GWh) in 2012

The location was analysed by (IESVE Version 2013) according to ASHRAE 90.1 classification, the report showed data based on the nearest weather data (Abu Dhabi) and the results shows a very hot dry climate, deficient participation most of the year, and summer season is dominant most of the year.

Summer has large diurnal range (Figure 5) and humidity is mostly above comfort zone and mean daily global radiation is 6001.9Wh/m^2. According to the analysis the month of July has the maximum annual temperature (47 ºC) and the warmest months are May, June, July, August, September, and October, while the coldest month is January. Minimum temperature occurs in February (5 ºC), this information is useful to determine the most critical time to test the efficiency of the double skin façade. Annual mean wind speed is 3.6 m/s and mean direction is east and north -26.5º.

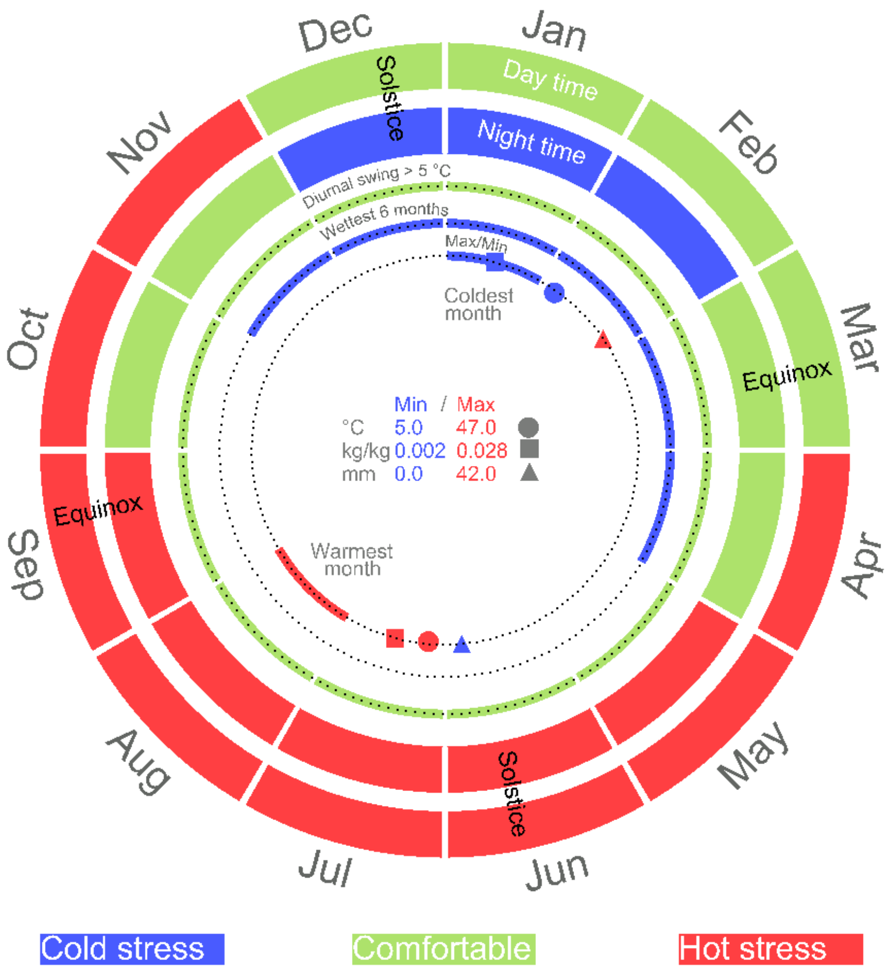

Figure 5: Climate Summary Metrics analyzed by IES VE

6. Modelling the Base Case

The building under study is called CP08 or Central park 08 (Figure 6), it is located at the end of Dubai international financial centre master plan, the building is part of twin towers project one is residential and the other is offices lined on the ground by a podium housing retail and car park. The study will focus on the office tower which is the southern tower in the master plan. The tower's highest point is 293.7 m. The tower consists of three wings, the wings rise in height in a spiral form 146.7 m, 192.9 m, and the highest is 343.3 m. The common typical plan combining the three wings that starts from the 1st floor up to 20th floor will be selected for further analysis to identify the effect of height and orientation on the façade performance.

Figure 6: CP08 office tower in DIFC, Dubai, United Arab Emirates

The plan is a three pointed star shape like, which maximises day lighting for the offices, as the typical plan consist of 12 faces each face has different orientation to the sun. The core is centred in the plan therefore the façade is only covering office spaces. There are 4 types of glazing covering the façade:

- Silver double glazed unit low-emissivity coating and thermally broken fixed on aluminium frame.
- Silver single glazed insulated spandrel panel covering slab and fall ceiling
- Black double glazed unit low-emissivity coating body tinted dark grey and thermally broken fixed on aluminium frame.
- Black single glazed insulated spandrel panel covering slab and fall ceiling

The façade is not fully glazed. A series of insulated composite aluminium panels are spaced in the plan to minimise glazing area. Data on specifications for selected curtain wall and required performance is collected from construction issue drawings provided by the architects. The actual performance of the façade may vary after construction. Minimum performance criteria for glazing types were shown in Table 2.

Table 2: CP08 minimum performance for glazing types

Glazing panel type	*U*-value (W/m^2K)	Light transmission (%)	External light reflectance (%)	Internal light reflectance (%)	Shading co-efficient (SC)
Silver double glazing	1.7	3%	42%	12%	0.10
Silver spandrel panel	0.57	3%	42%	-	0.10
Black double glazing	1.6	6%	4%	-	0.12
Black spandrel panel	0.57	6%	4%	-	0.10
Aluminum Composite panel	0.35	-	-	-	-

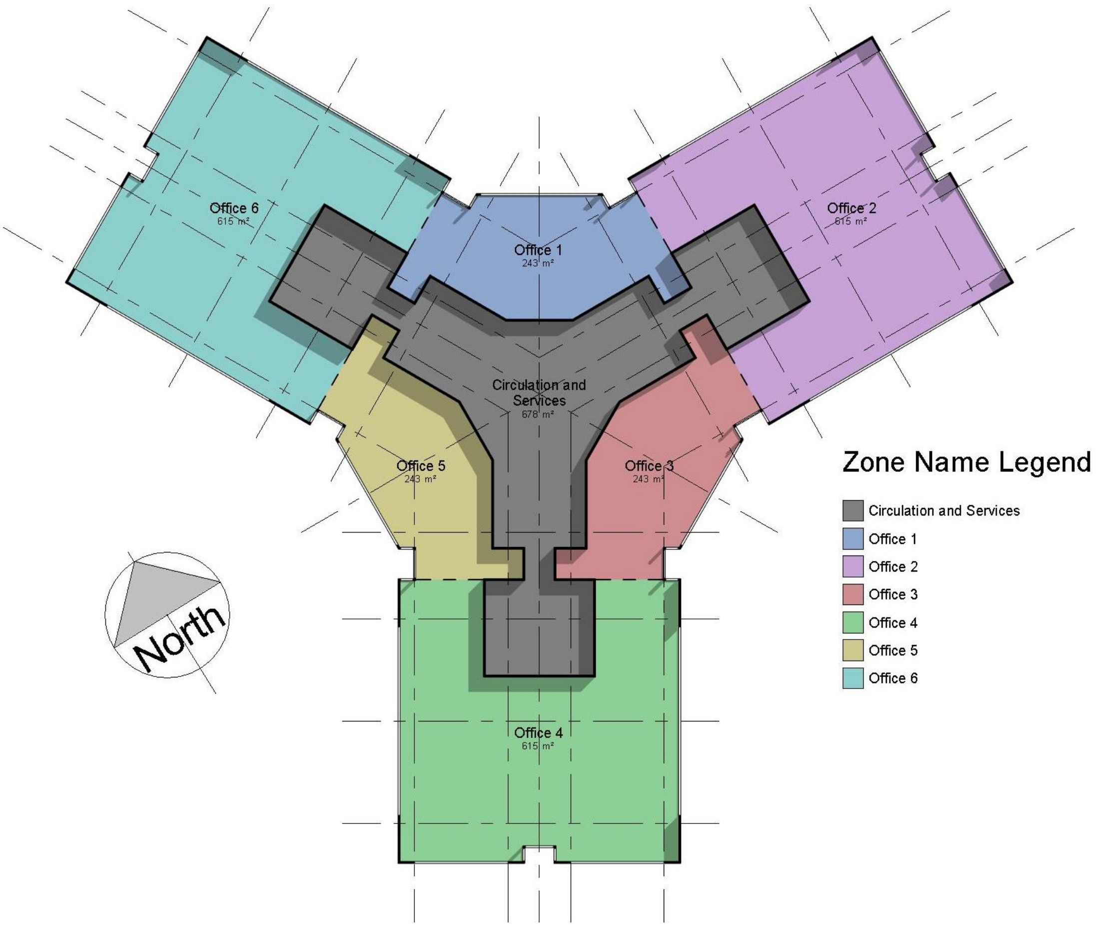

Figure 7: Typical floor plan for the office tower showing different thermal zones

The model has been done by (Autodesk Revit version 2014) as shown in Figure 8 and then transferred to IES VE for analysis due to complexity of the existing façade to insure that accurate glazing percentage is modelled to provide more balanced comparison as mentioned in methodology section, the floor plate was divided into seven thermal zones (Figure 7), six zones to analyse the effect of orientation on thermal behaviour inside the space, considering the complex floor shape of the tower, therefore different façades have no clear orientation to North, East, West, or South, but divisions can provide a picture where improvements to the building's skin are mostly needed, the bigger offices area are 627 m^2 each and the smaller offices are 249 m^2 each . Another zone defines the core of the building, to simplify the model and minimise error all functions within the core are defined as one space, although infiltration is expected to occur from the doors the model is used for a comparison between different façade types not to calculate the actual building energy performance, therefore columns, fall ceilings, and raised floors were not included in the analysis as well. The glazing types were also simplified to one type as double gazed and 1.7 W/m^2K as minimum *U*-value. (Office 4) zone is the tallest tower (46 levels) and (office 6) zone is the middle tower (36 levels) and (office 2) zone is the shortest tower (25 levels) each level is 4.2 m high and the first floor level is +29.1 m.

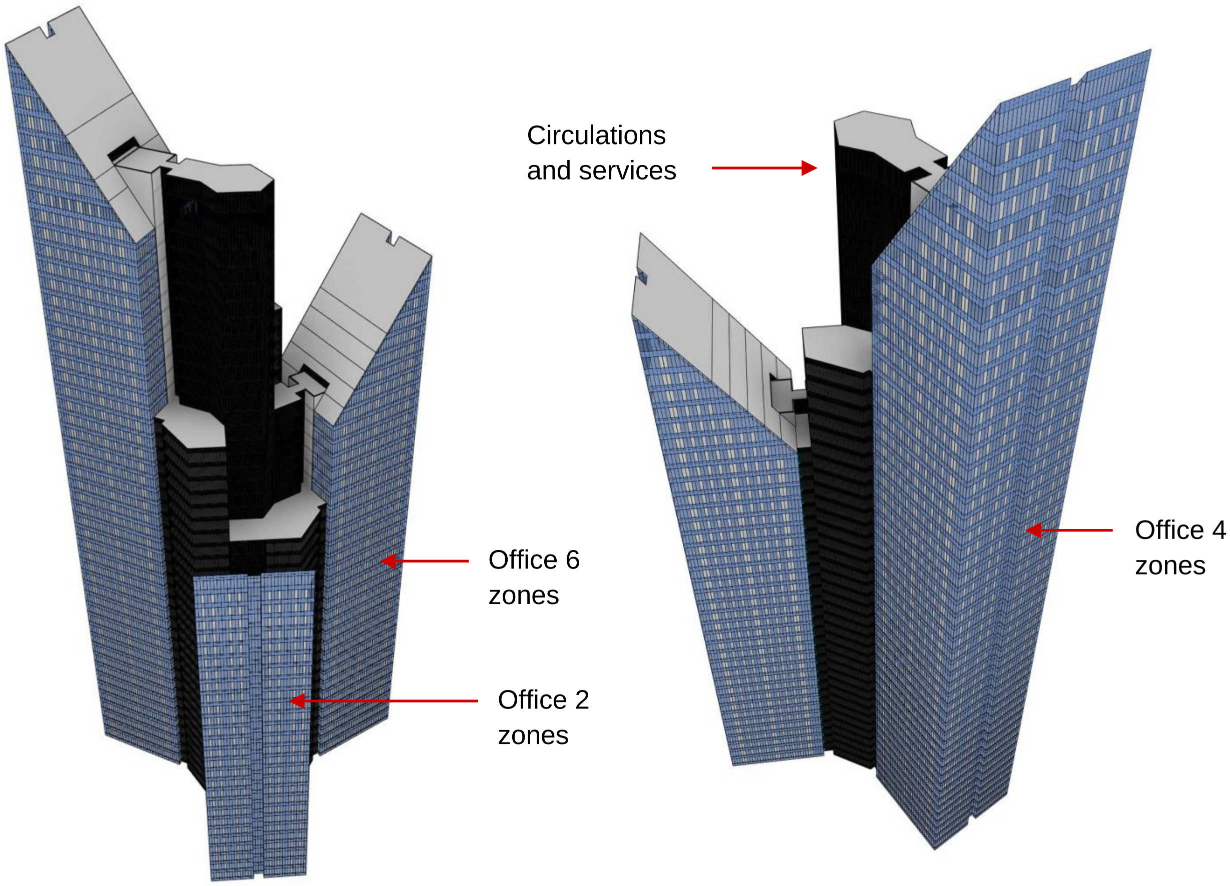

Figure 8: Detailed 3D model for the CP08 tower

7. Analysis

To examine double skin façade impact on solar gain and cooling loads, different model configurations were simulated as shown in the diagram in Figure 9. The glazing properties were tested by selecting different glazing types, the effect of channel width (intermediate space) was also tested by simulating three different options. Direction of the façade was also examined by showing cooling loads for each zone to identify the effect of orientation on energy consumption. A single parameter was modified in each simulation and compared to the bas-case model.

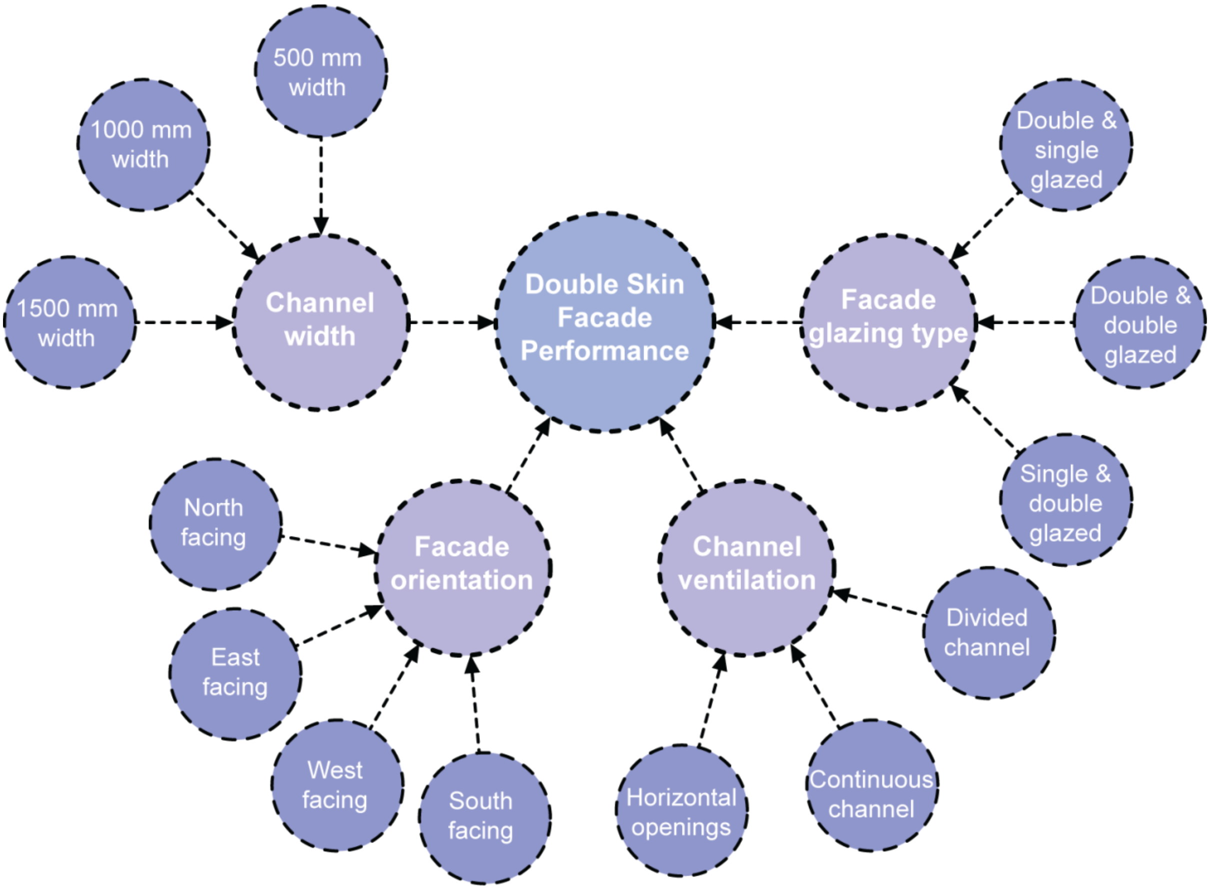

Figure 9: Bubble diagram for different parameters used that affects double skin façade performance

7.1. Dynamic Simulation modelling tool

Simulation was performed by dynamic thermal modelling computer software (IESVE Version 2013) to provide quantitative analytical data on the performance of double skin façade. Apache Simulation is used for thermal performance, SunCast for solar shading and penetration, ApacheHVAC for air conditioning system, and MicroFlo is used for CFD analysis. Weather profile for Dubai is linked to the software simulation IESVE which is based on typical meteorological year that includes direct solar radiation, diffuse radiation, wet and dry bulb hourly temperatures, wind speed, cloud cover, cloud cover, and sunshine hours. It was not possible to assess the accuracy of the software predictions due to the difficulty in collecting data for the actual performance of the building, an alternative would be validating the software accuracy by previous researchers on the same field of study, an example would be a study done by Neveen (2008) on double skin façades using the same simulation tool and the author found a goof agreement between IESVE prediction and the actual data collected on a building in Cairo, an error between 1% and 2% was found for most of the year in predicting energy loads and in the month of May and August the error was 8% which can be neglected as an overall estimation, the author suggested that the difference could be as a result of the between actual and predicted weather condition or could be as a result of different occupancy patterns and also the actual heat transfer through individual components might differ.

7.2. Operational parameters

Certain parameters were set as constant in all simulations which represent operational profile of the building:

- Location is Dubai Intl Airport, United Arab Emirates 25.27 N and 55.31 E
- Abu Dhabi weather data was used (nearest city).
- Cooling set point 23.9 ºC.
- Boilers are used for heating and VAV single duct for cooling system.
- Flow rate 180.2356 l/s and extract flow rate is 199.4309 l/s
- Fluorescent is used as lighting fixtures.
- 11.613 m^2/person is defined as occupancy density for the building
- Infiltration and air tightness is 48.5697 l/s
- Cooling plant operate between 8 am to 6 pm.
- The simulation included office floors only, Podium and basements levels are not included in the analysis
- Core including services, shafts, and circulation are considered as one zone
- Channel space is defined as unoccupiable space where cooling and heating is turned off and zero occupancy density

7.3. Model translation to IES VE

The model has been simplified as shown in Figure 13 and translated from (Autodesk Revit version 2014) to IES VE by defining office zones as open office plan and circulation and services zone was defined as unoccupiable, VAV single duct was selected as the building conditioning system (Figure 12). Translating the façade in IES VE can be done be five levels of complexity, Simple, Simple with shading surfaces, Complex, Complex with shading surfaces, and Complex with mullions and shading surfaces, two levels were tested to validate whether there is a need to use a complex level or not, the third floor cooling loads was simulated by SunCast and Apache engines, the results showed that cooling loads in the “Simple with shading surfaces” (Figure 10) model was lower slightly than “Complex with shading surfaces” (Figure 11) by a negligible amount (less than 1%) as shown in Table 3, to minimise computational time and resources the “Simple with shading surfaces” model will be used. The simple translation for the façade represents glazing as one single window and solid areas in the curtain wall such as mullions, aluminium panels, and spandrels are represented as solid walls, on the contrary complex translation represents glazing as several windows.

Table 3: Comparison between energy loads results for levels of translation

Complexity	Mean room cooling plant sens. load (*kW*)	Max. room cooling plant sens. load (*kW*)	Mean chillers load (*kW*)	Max. chillers load (*kW*)
Simple with shading surfaces	60.5026	308.9016	68.3350	496.1501
Complex with shading surfaces	60.9008	309.9458	68.8890	499.9241

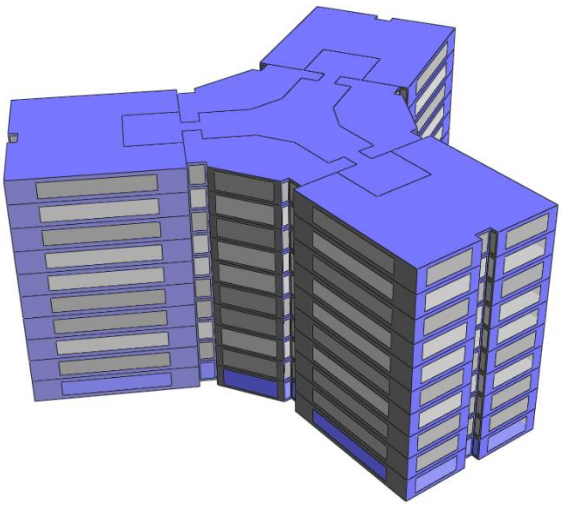

Figure 10: Simplified translation for the facade

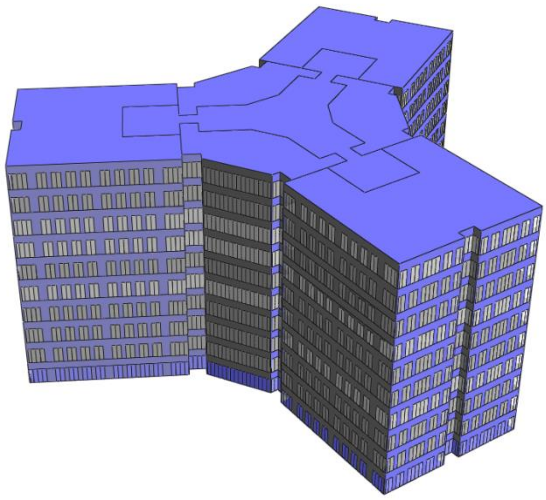

Figure 11: Complex translation for the facade

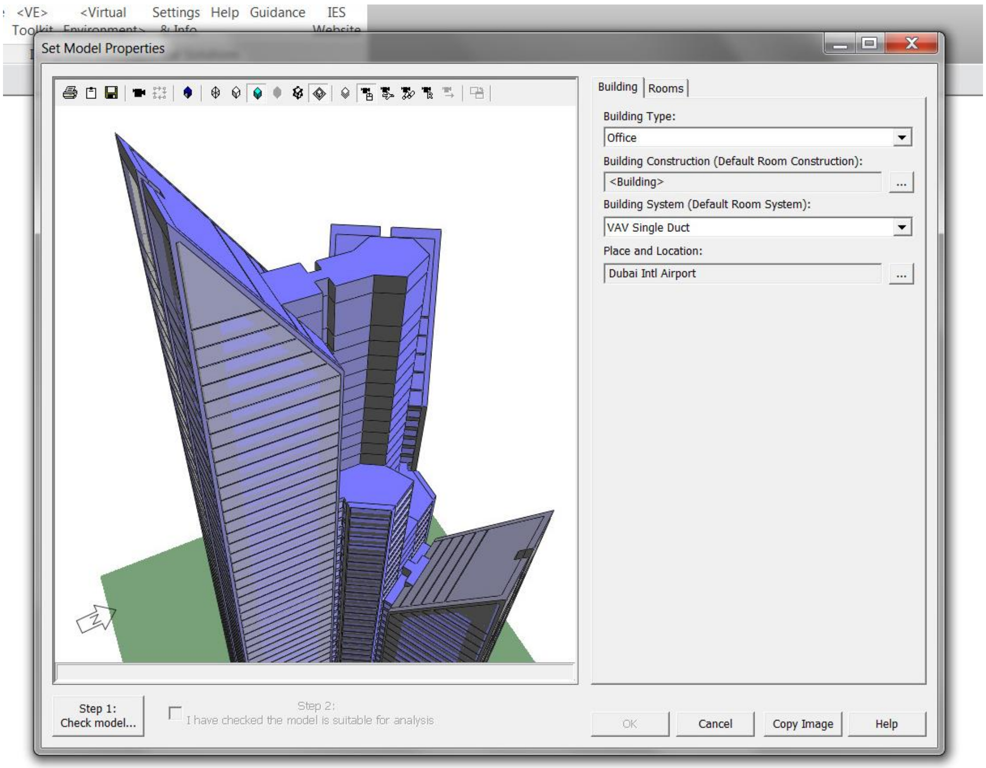

Figure 12: Model translation to IES VE

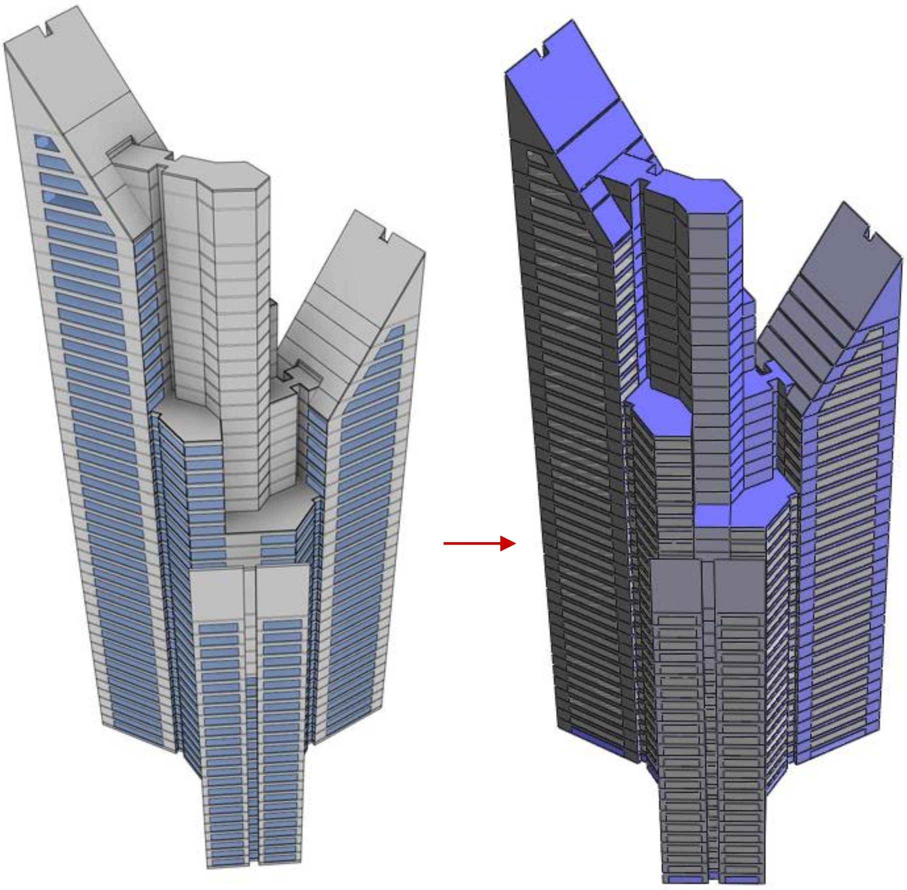

Figure 13: Model simplified and translated as analytical model to IES VE

7.4. Full building model simulation

The double skin façade was assigned for all sides of the buildings excluding the recessed area in the plan (Figure 14) the double skin façade starts form the 1st floor up to the end, as It is recommended by some researchers to introduce air intake higher from the ground to minimise dust and particles entering the channel and improve air quality inside the double skin façade (Neveen 2008), the model double skin façade was adjusted in (Autodesk Revit version 2014) and translated to analytical model in IES VE (Figure 15). Shading calculation analysis was done for each case from January to December, diffuse shading factors were also calculated as shown in Figure 16. The properties of external glazing and walls were assigned by Apache (Figure 17) and floors and ceilings properties were constant in each simulation. There are three constructions assigned for external walls, and glass construction was modified according to specifications provided by a manufacturer (Dxb.emiratesglass.com, 2014), the properties of external walls listed in Table 4 are: double glazed panels, single glazed panels, and Metal cladding for opaque walls. Openings that allow for airflow inside the channel were assigned in MacroFlo as defined in Table 5 and shown in Figure 18, the wind pressure coefficient was also considered which was derived from wind tunnel experiments (Iesve.com 2013), and each opening type was modified according to each surface exposure, however in divided channel simulation the openings were assigned as window centre hung with 30% opening from bottom and tope to simplify the model and to reduce computation time which showed similar results to the partial detailed model which will be explained in the next sections.

Table 4: Properties of curtain wall and aluminum composite panels for external walls

Material	Description	*U*-value (W/m^{2}K)	SHGC	g-value
Low-e double glazed	24 mm (6+16+6 mm) insulating glass unit	1.6723	0.4105	0.4182
Single glazed	Uncoated 6 mm single glass	6.2742	0.8116	0.8199
Metal cladding	Light weight metal clad fixed on 100 mm insulation board	0.3293	-	-

Table 5: MacroFlo opening types used in the simulation

Opening type	Exposure Type	Opening category	Openable area (%)	Max opening angle (^{o})
Divided channel openings	High-rise semi-exposed wall h/H = 0.8	Window centre hung	30	30
Wall openings & slanted roof	High-rise semi-exposed wall h/H = 0.8	Window - sash	90	-
Flat roof opening	High-rise semi-exposed flat roof h/H = 0.8	Window - sash	90	-
Bottom opening	High-rise semi-exposed flat roof h/H = 00	Window - sash	90	-

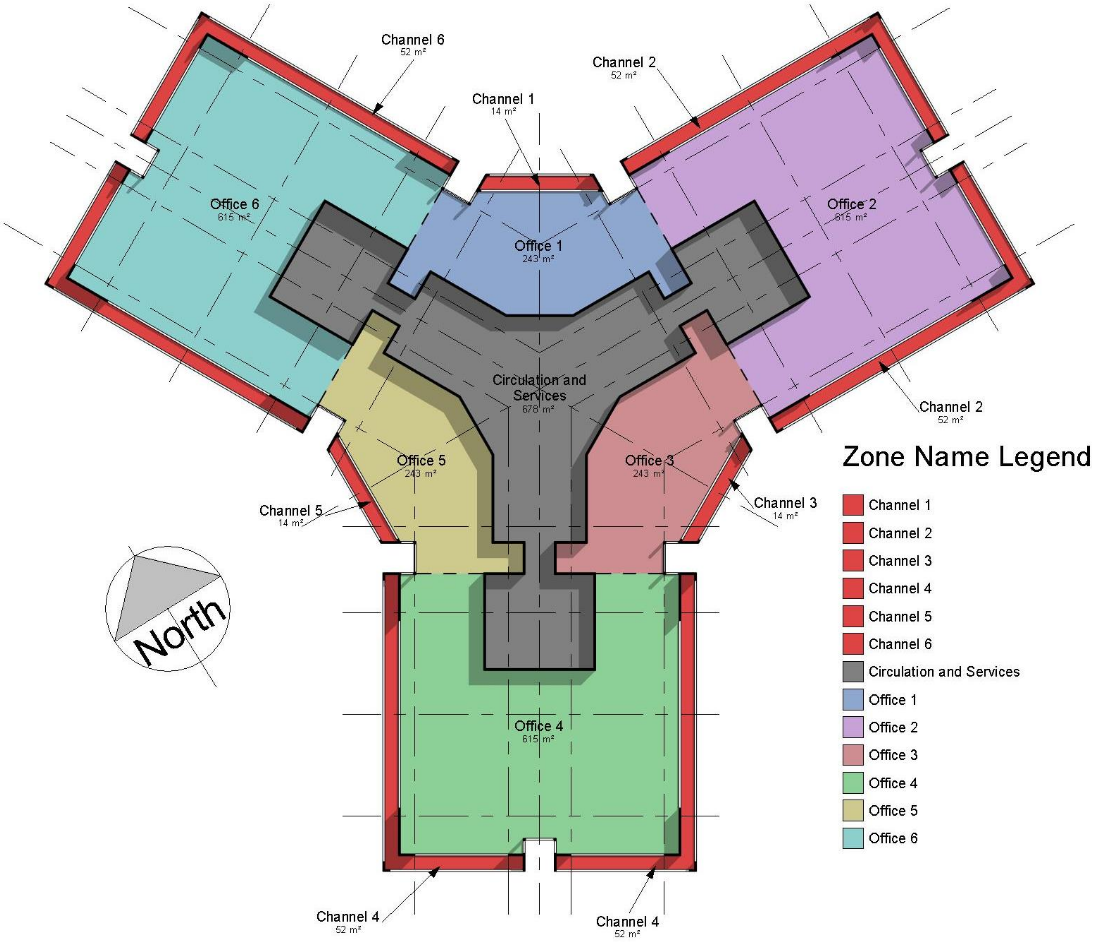

Figure 14: Typical floor plan showing double skin façade zoning

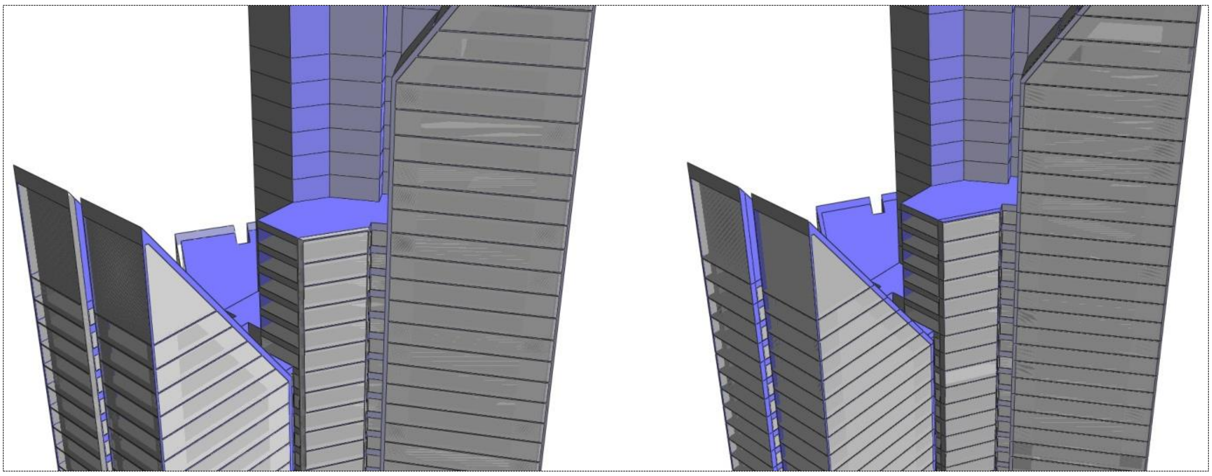

Figure 15: Analytical used for simulating Continuous channel (left) and divided channel (right)

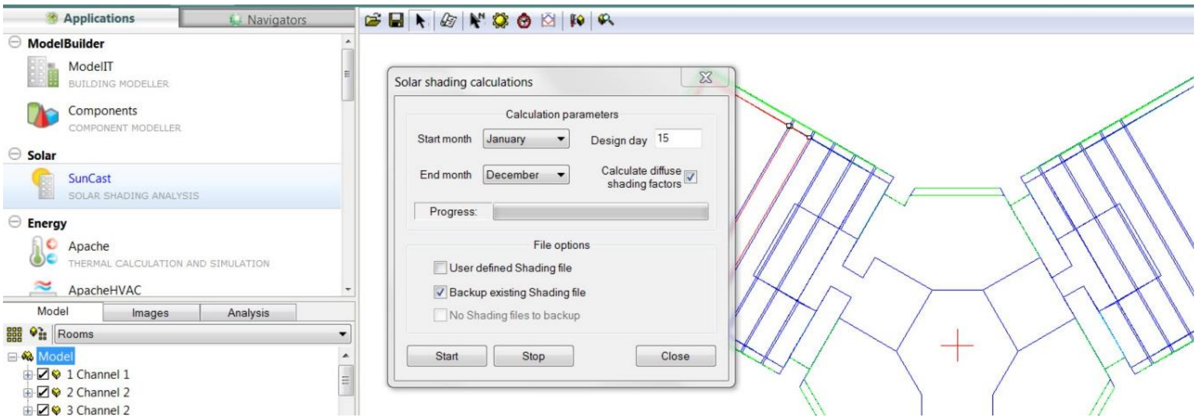

Figure 16: Solar shading calculations by SunCast

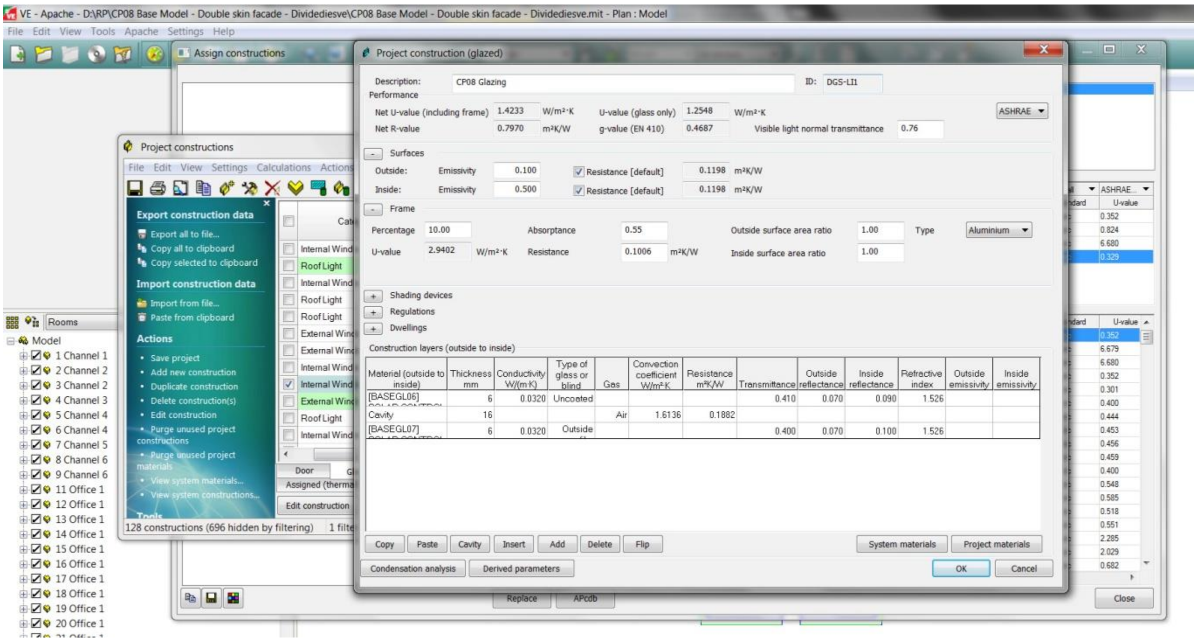

Figure 17: Assigning construction to external walls in Apache

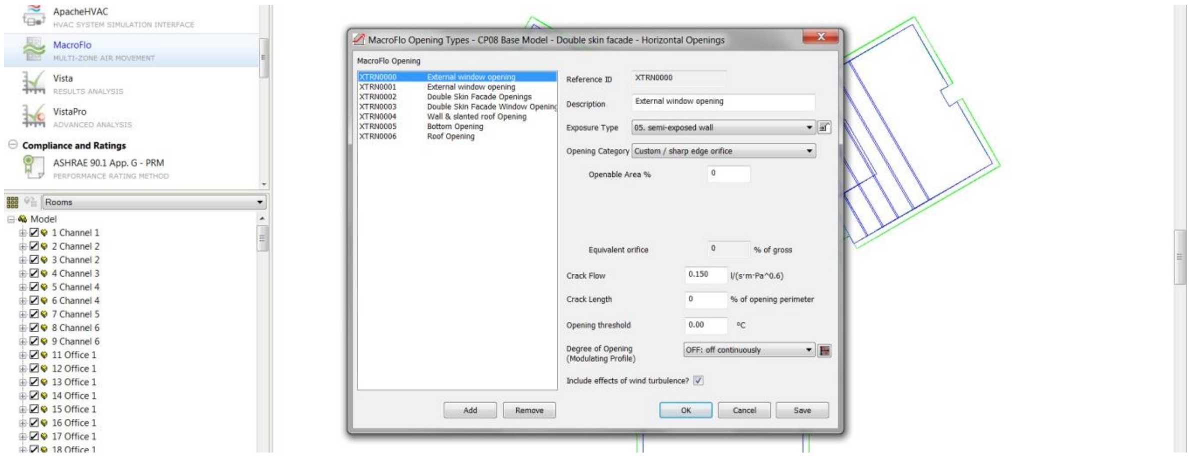

Figure 18: Assigning opening types to the model in MacroFlo

7.5. Partial model

The partial model is used to validate results from the full building model and save computational resources as well as minimising errors that could be a result from over complexity and to avoid higher calculation time and excessive memory use in CFD analysis. The partial model is a 12 m x 13.5 m office space (162 m^2), 5 storey high and 8.4 m high from the ground. The double glazing is assigned to the south and east façade and the same glazing ratio were used to the external skin and external skin. Opening types and material properties were used as per the full model, except the openings on the external skin were more detailed and 90% openable area was selected (to allow for frame and structure).

The model was used for MicroFlo (CFD) analysis to simulate airflow inside the channel for three scenarios (continuous, horizontal openings, and divided channel). July 21st was selected for the simulation date starting from 12 pm and 0.3 m grid spacing is assigned to the model. The supplied air temperature was set to 34.4 ºC (minimum dry bulb for the month), the airflow in and out was entered manually by referring to data provided by VistaPro on the same date at 12 pm as shown in Figures 19, 20, and 21, the airflow in was set as general supply diffuser and the airflow out was set as extract, the CFD simulation used 500 outer iterations (Figure 22) and surfaces temperatures were imported from thermal simulation data (Apache) of the same date.

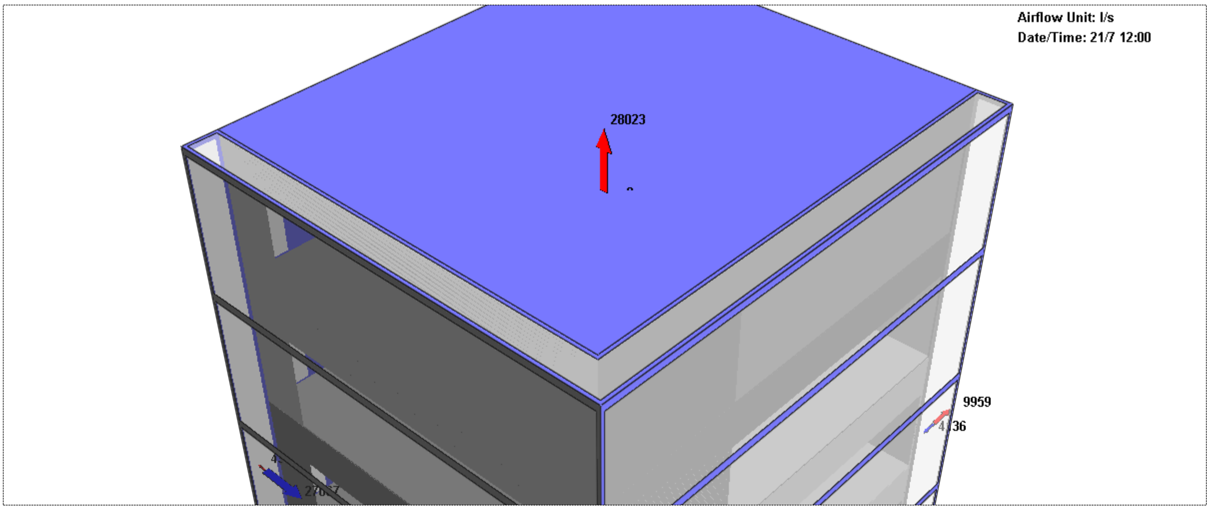

Figure 19: Partial model for continuous channel showing airflow rates in l/s

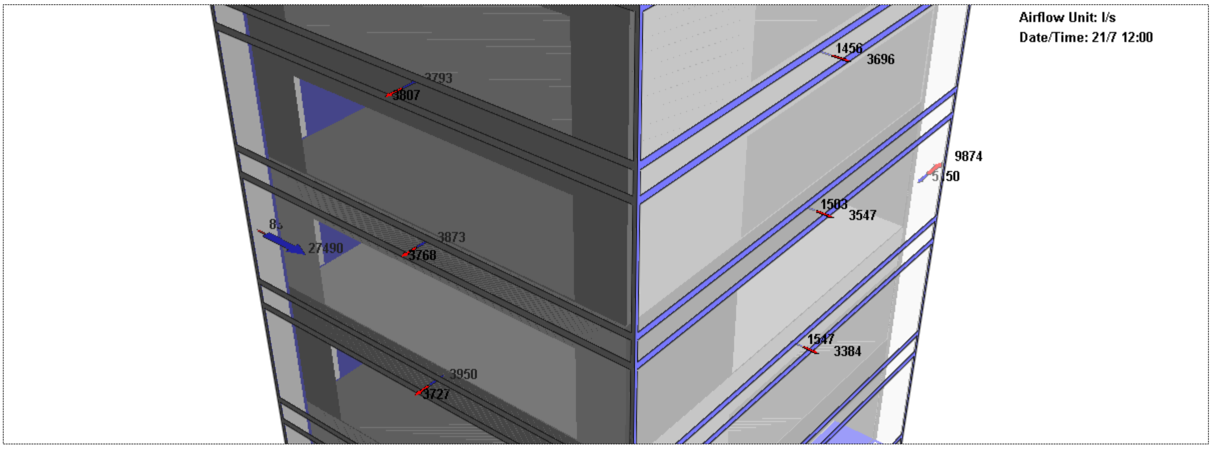

Figure 20: Partial model for continuous channel with horizontal openings showing airflow rates in l/s

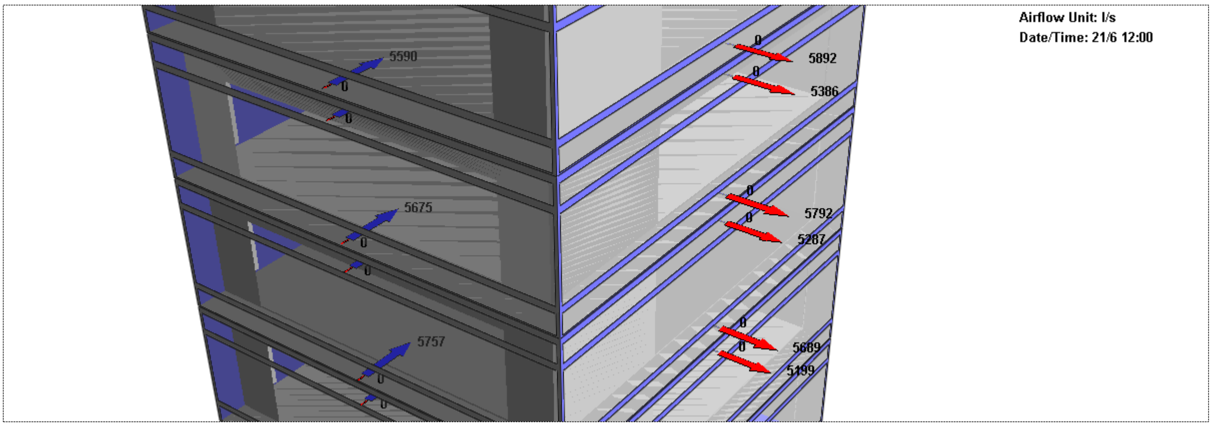

Figure 21: Partial model for divided channel showing airflow rates in l/s

Blue arrows represent flow in and the red arrows represent flow out

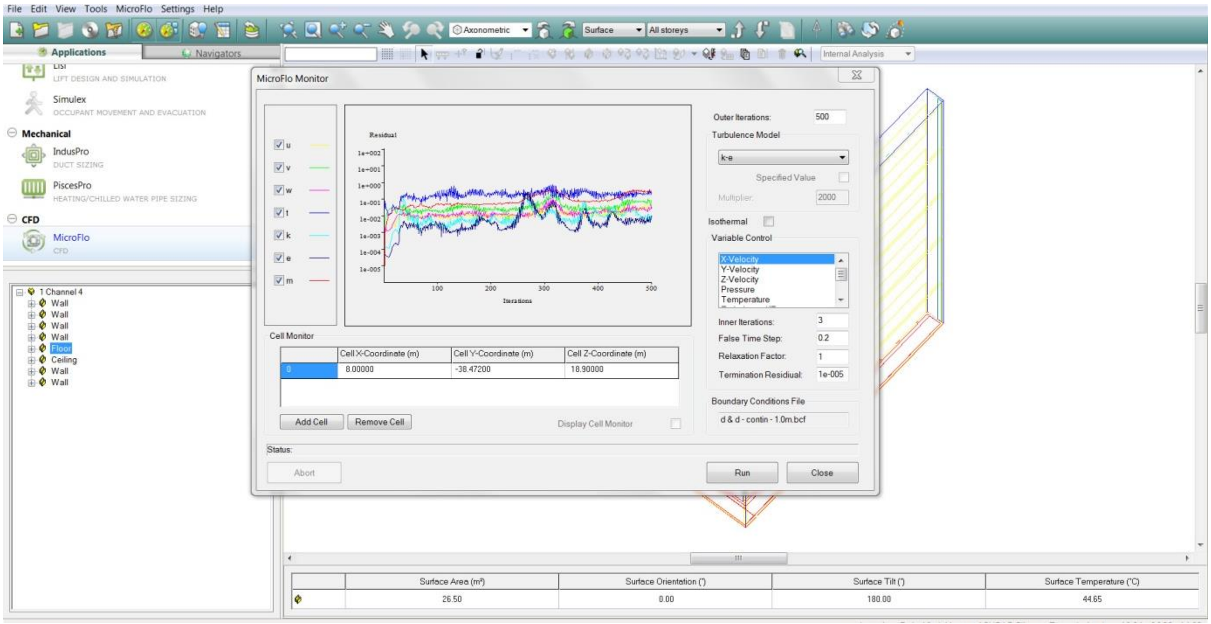

Figure 22: MicroFlo (CFD) settings used for the simulation

8. Results & Discussion

The results were consistent with (Hashemi *et al.* 2010), (Neveen 2008), and (Hassan *et al.* 2013), the double skin façade can reduce cooling loads by 20.37% (Figure 23 and Table 6) and reduce total annual energy consumption by 8.32% (Figure 24 and Table 6). The results also showed that sealed double skin façade reduced total energy consumption by almost 4% and cooling loads by approximately 8%, Similar results were found by He *et al.* (2011) in a study for a double skin façade in Hangzhou, they found energy savings even when the cavity was closed, on the other hand they also found less than 8% energy savings when the channel was ventilated, they argued that part of the solar radiation is transmitted by the vent opening therefore more hot air is entering the channel. The difference between total energy savings and cooling loads savings was the fixed variables in all the simulation such boilers, lighting, and occupancy density.

Table 6: Building annual energy consumption

Energy load	Base case	SD-1	DD-1	DS-1	SDC-1	DDC-1	DSC-1	DDC-0.5	DDC-1.5	SDCH-1	SDD-1	DDD-1	DSD-1
Total yearly energy consumption (MWh)	24,864	24,274	23,615	24,794	23,964	22,875	23,754	22,841	22,848	22,794	23,755	22,803	23,614
Total room cooling plant sensible load (MWh)	21,847	20,544	19,124	21,666	19,863	17,501	19,291	17,557	17,536	17,455	19,460	17,398	19,056

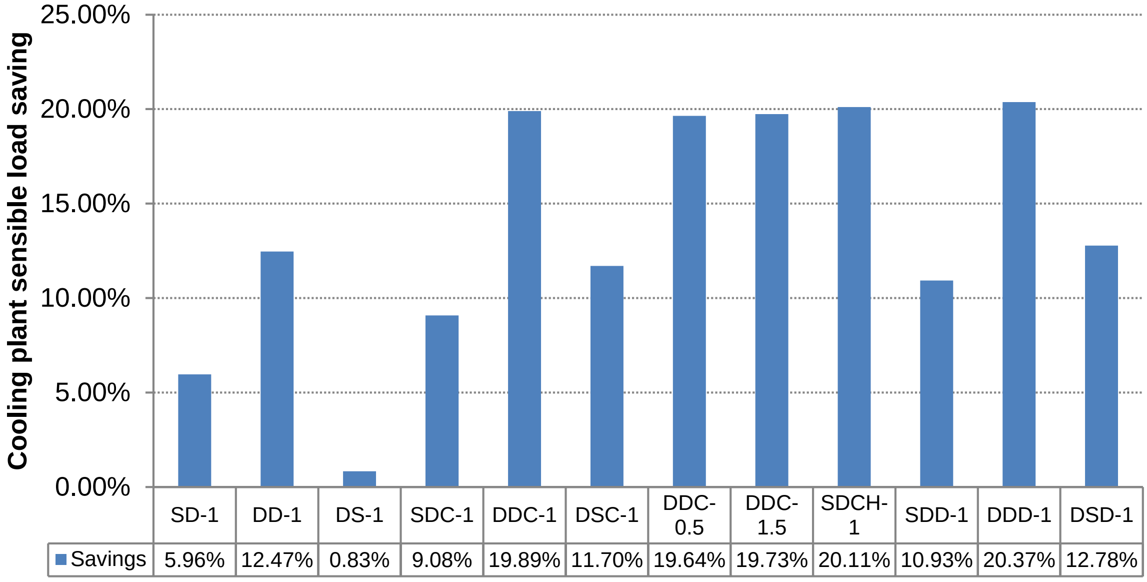

Figure 23: Annual savings for cooling plant sensible load for the full model

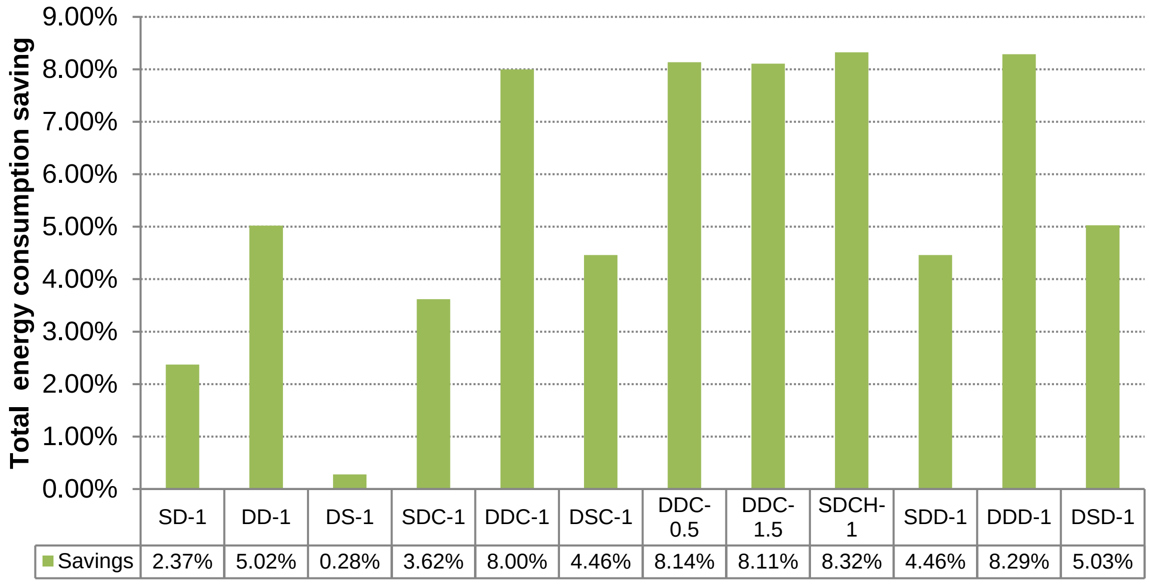

Figure 24: Annual savings for total annual energy consumption for the full model

Partial model showed consistent results as case: DDC-1, DDCH-1, and DDD-1 (where double glazing is used for both inner and outer skins) showed the best cooling load savings (Figure 25), the graph on Figure 26 shows that cooling load reduction by the double skin façade is not the same ratio as the reduction in solar gain, in the case of DDC-1 more than 30% reduction in cooling loads and 80% reduction in solar gain, this could be explained by the hot air inside the channel which contributed to heat gain inside the building. The results also show more cooling load savings in the partial model (30%) as the full model was not fully glazed and some areas in the full model were not covered by the double skin façade which could have reduced the double skin façade efficiency, also large areas of exposed envelope where the façade didn't change, such as exposed core and recessed areas on the upper floors could have reduced the double skin façade efficiency as well.

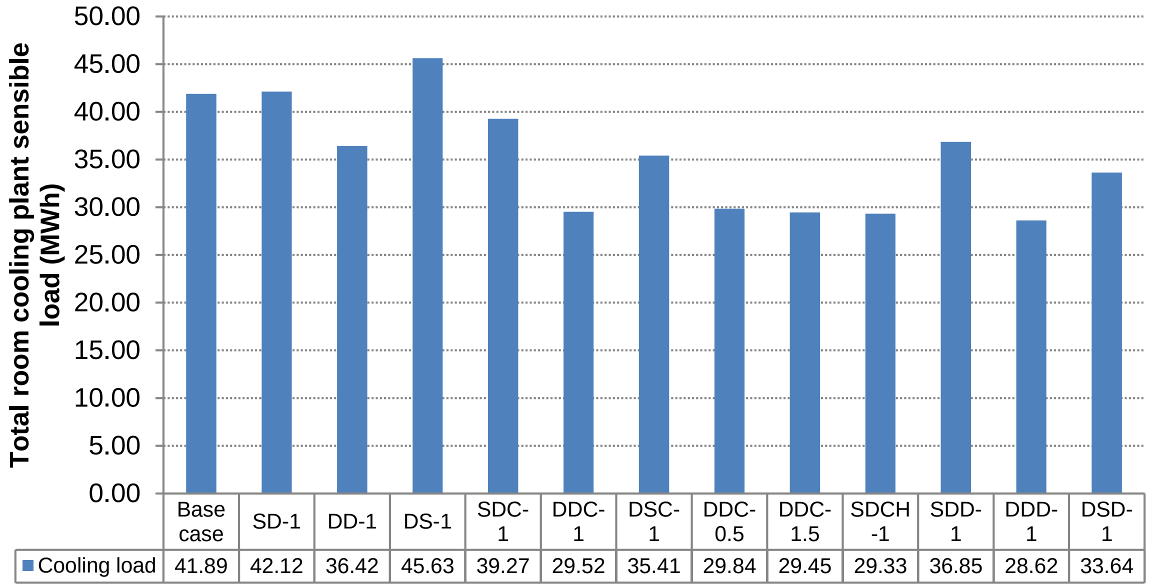

Figure 25: Partial mode results for annual room cooling plant senisible load

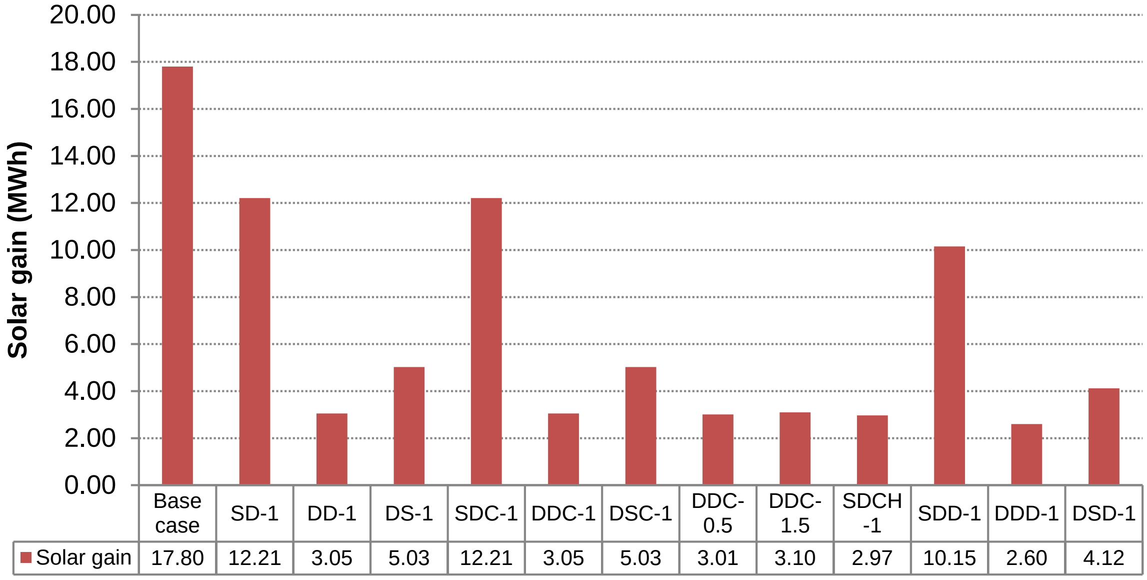

Figure 26: Partial mode results for annual solar gain

Figure 27 and 28 shows more cooling load savings can be measured in colder months, and the least savings can be found in July and August which are the hottest months in the year, which could be explained by He *et al.* (2011) results, as it is more difficult for the heat to be flushed to the outside when higher external temperature is measured, as a result more heat is entering the channel and then transmitted inside the building.

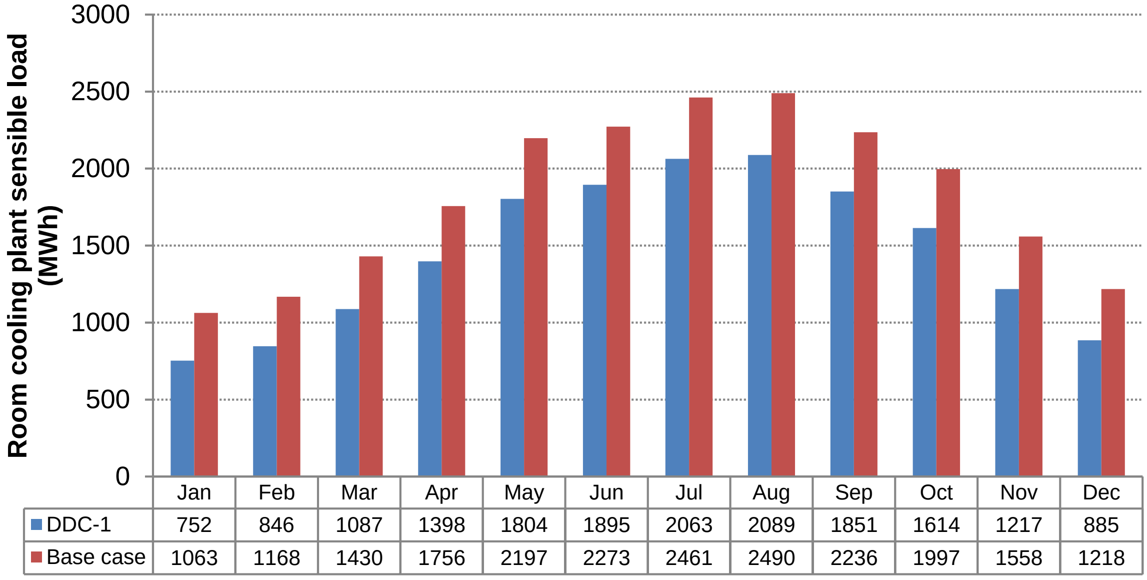

Figure 27: Comparison between case DDC-1 and base case in annual cooling plant sensible load

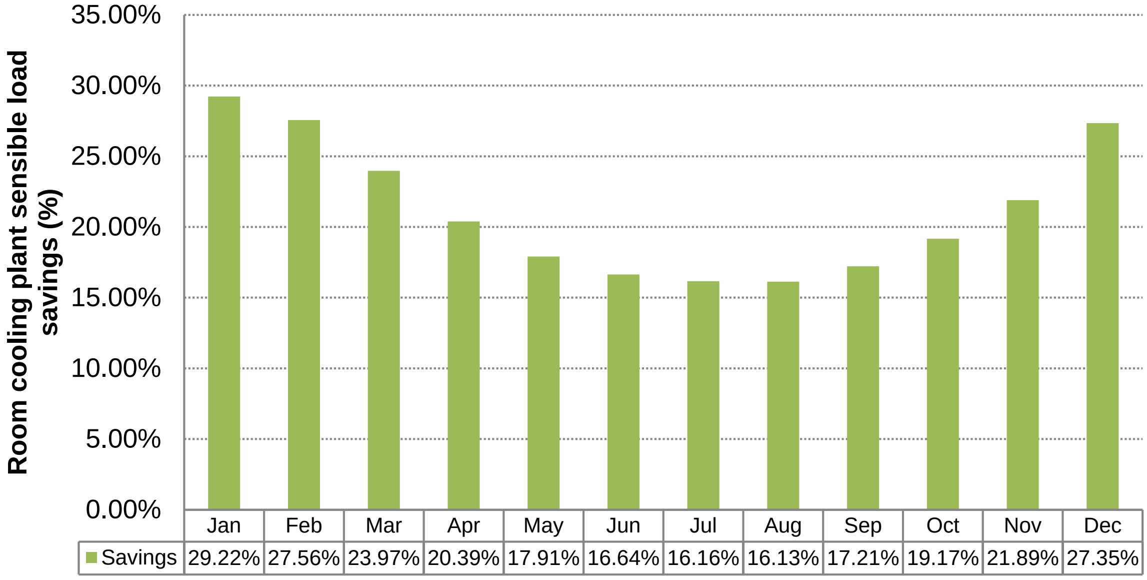

Figure 28: Double skin façade monthly savings for the full model

8.1. Glazing type

All simulations showed better cooling load savings in the case of using double glazing for the internal façade, Stelios (2007) also found reduced cooling loads by using the best solar protective properties for both inner and outer layer. The results were expected as many studies showed similar findings because of reduced solar gain by using double glazing for both layers as shown in Figure 29 and 30. It is also noted that when using double glazing for the external façade and single glazing for the internal façade the double skin façade performed better than using single glazing in the outer skin, as the single glazing will transmit more heat inside the channel.

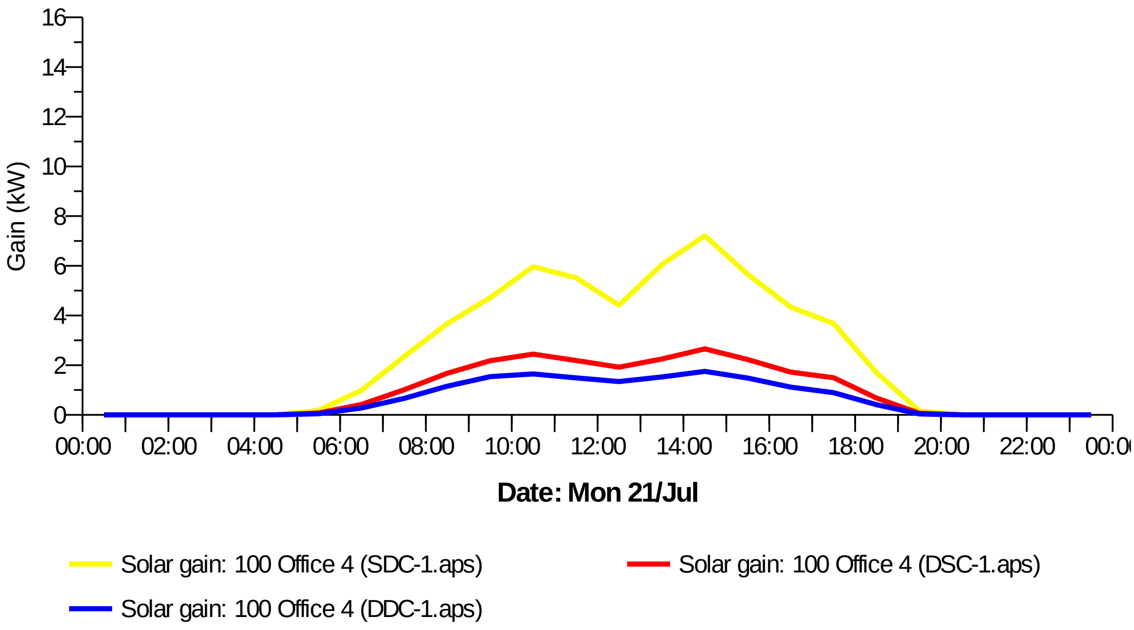

Figure 29: Solar gain for office 4 at the 21st of July (Full model)

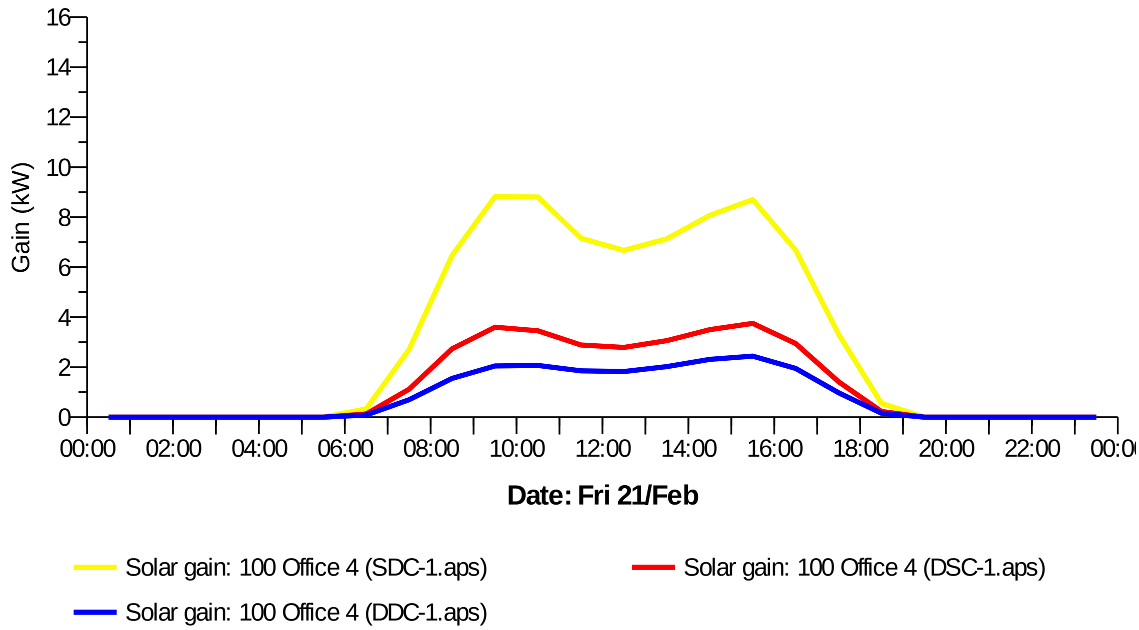

Figure 30: Solar gain for office 4 at the 21st of February (Full model)

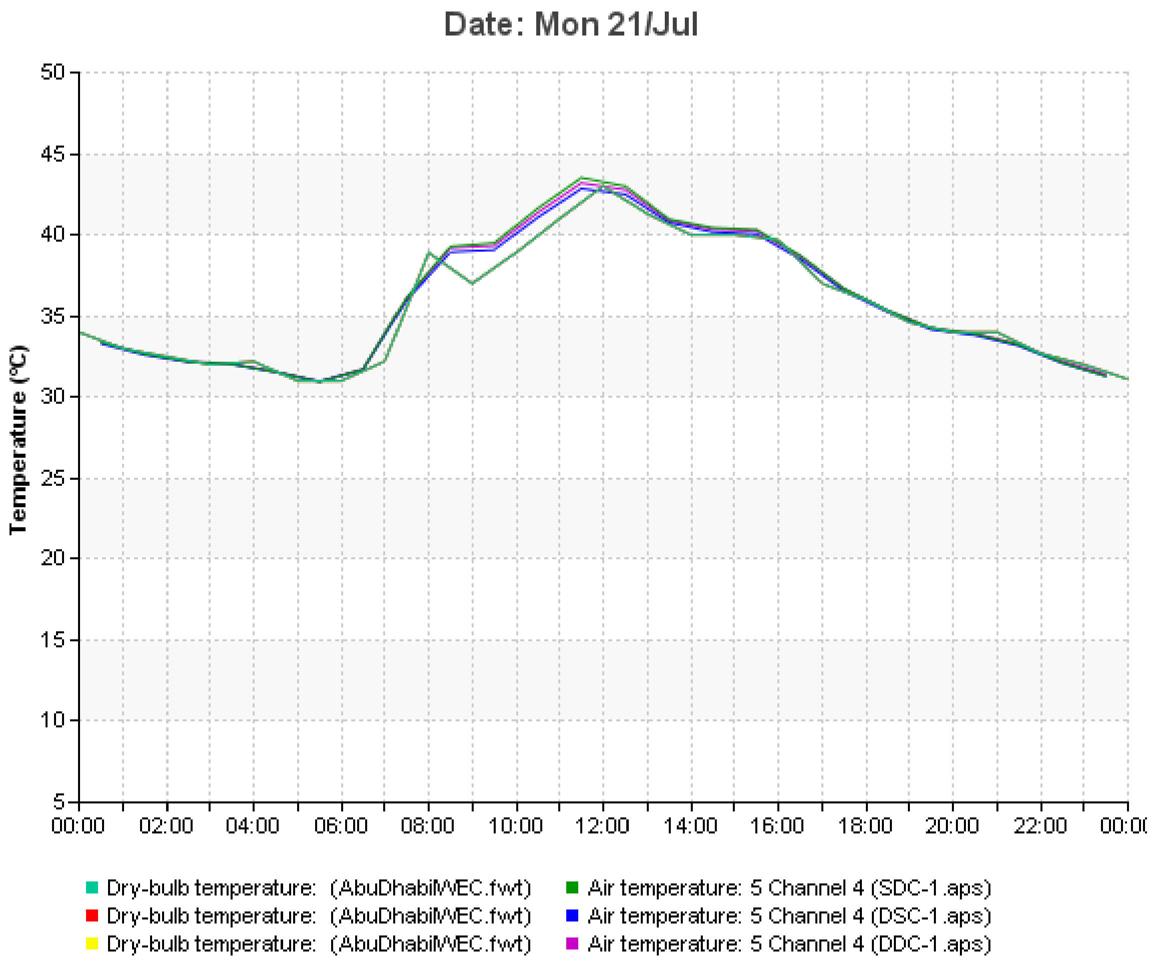

Figure 31: Air temperature inside channel 4 in July 21st (Full model)

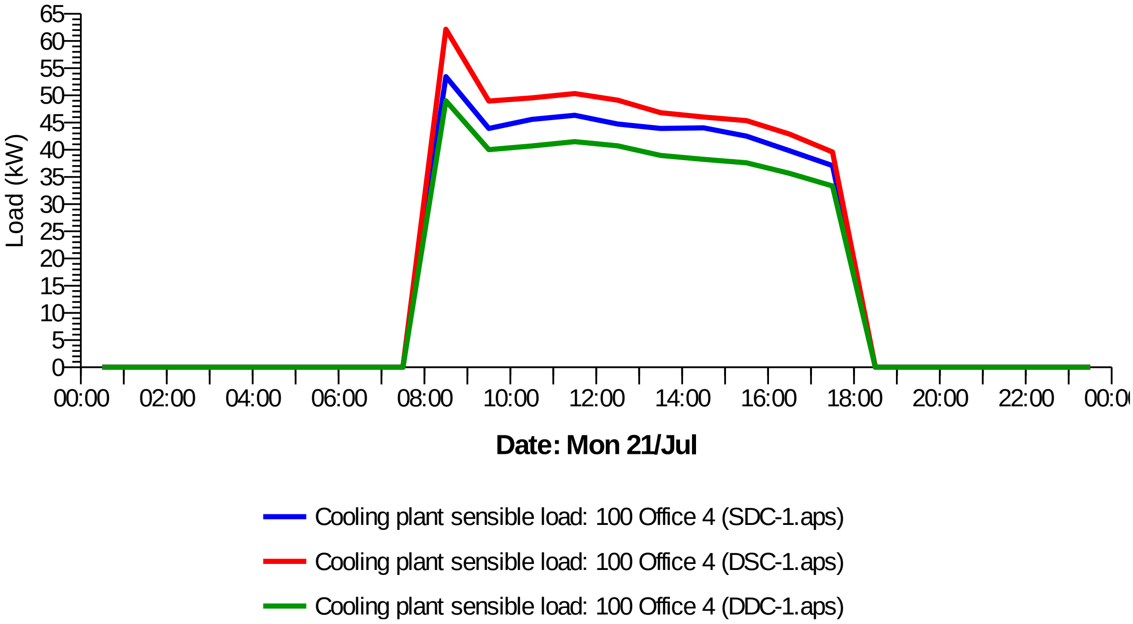

Figure 32: Office 4 cooling plant sensible load in July 21st (Full model)

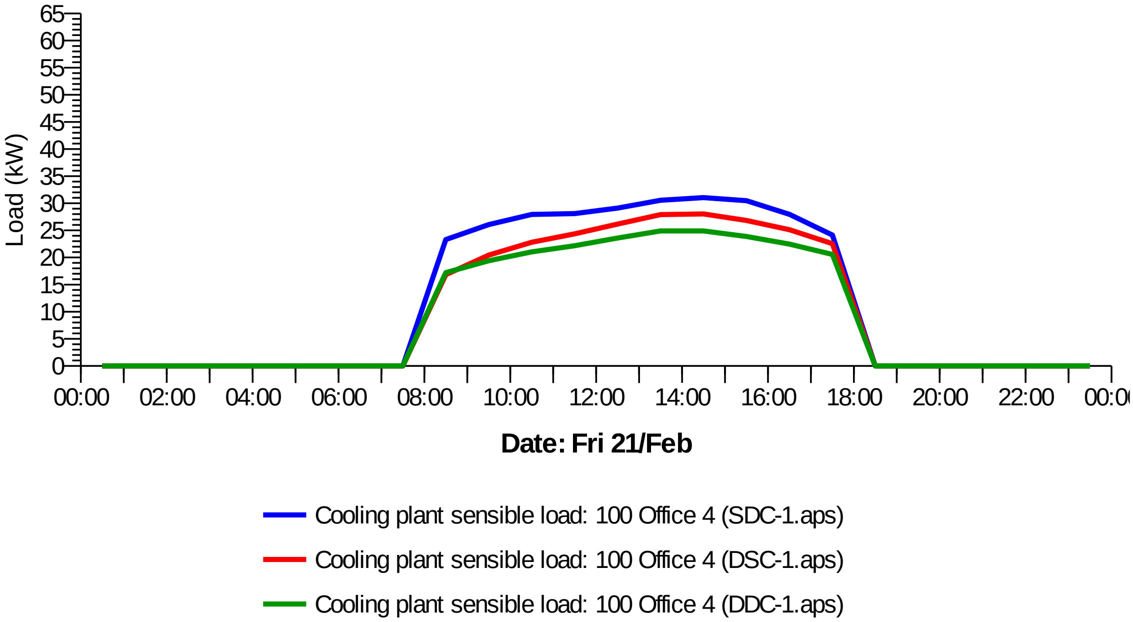

Figure 33: Office 4 cooling plant sensible load in February 21st (Full model)

Figure 33 and 32 shows that using single glazing for the external skin and double glazing for the internal skin performed better than the opposite in hot season, this could be explained by the buoyancy effect that flushes the hot air from the channel, but when using double glazing on the external skin less temperature deferential is measured between inside and outside the channel, Figure 34 also shows less air flow inside the channel when using double glazing for the external skin, on the other hand using double glazing for both skins performed the best. Same results were also found by Hassan *et al.* (2013) as they found that using single glass as outer layer reduces the system efficiency by 26% but lower solar heat gain coefficient (SHGC) is more effective in reducing direct gain and green house effect inside the channel.

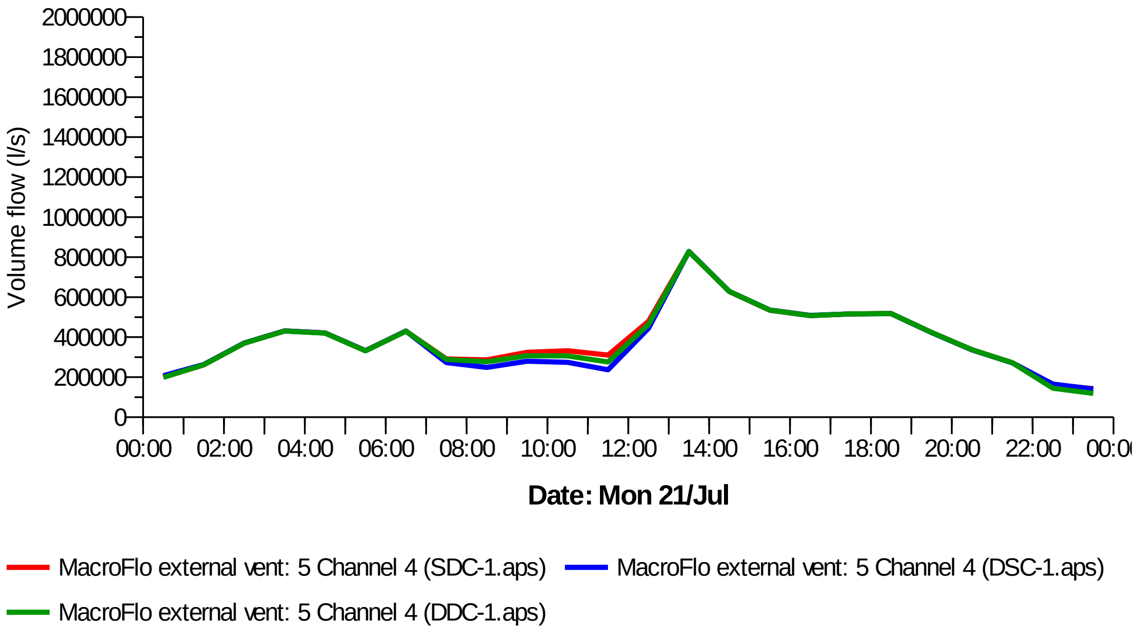

Figure 34: External vent volume flow at July 21st (Full model)

8.2. Ventilation mode

Total energy savings and total cooling loads reduction for all ventilation modes were similar when using double glazing for both internal and external skins, on the other hand more improvement in energy savings observed when using divided channel type with single glazing on the internal or the external façade as shown in Figure 23 and 24, although Figure 36 and 37 shows higher air temperature inside the channel when using divided channel. This could be explained by Figure 38 and 39, as less solar gain is observed when using divided channel and more volume flow inside the channel, also the horizontal divisions in the case of using divided channel provides more shading to the façade which reduces solar gain inside the building, on the other hand more airflow inside the channel causes more hot air supplied and therefore more heat gain inside the building as shown in Figure 35 external vent gain graph. Nassim *et al.* (2005) also found that air velocity is higher next to external façade in the case of positioning the inlet and outlet openings at the bottom and top of the façade, which could explain the low air temperature inside the continuous channel. The results also show that using single glazing for the internal skin with divided channel can still reduce 12% of cooling loads (Figure 23), this result worth considering when comparing the price of using double glazing for both skins with using single skin for the internal skin while reducing solar gain with shading or possibly ventilating the channel mechanically.

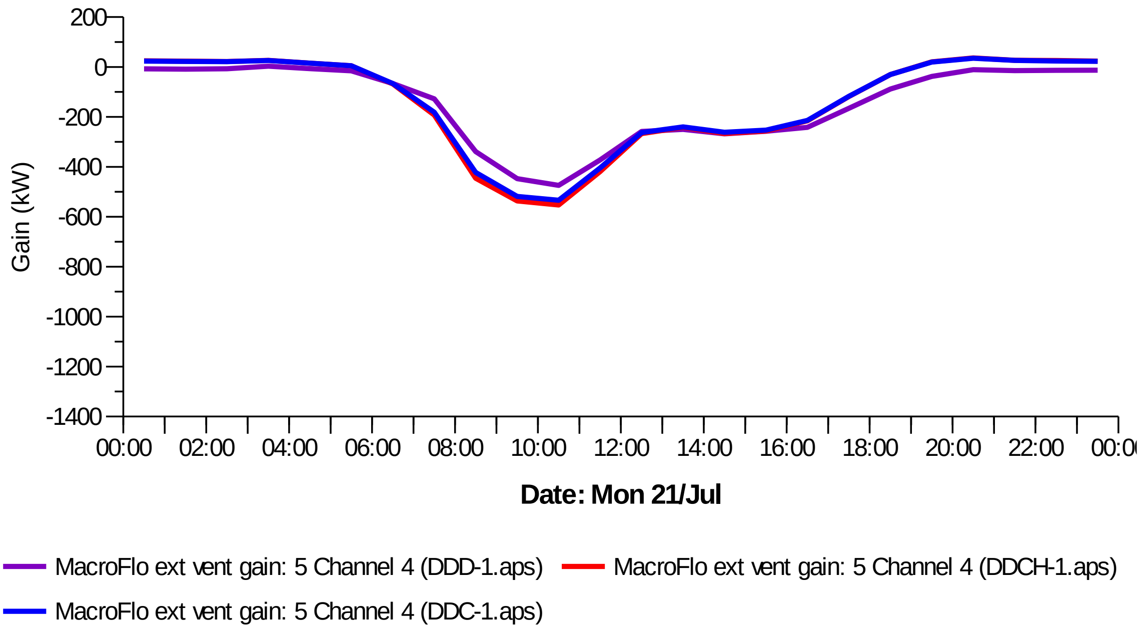

Figure 35: External vent gain - comparison between different ventilation modes (Full model)

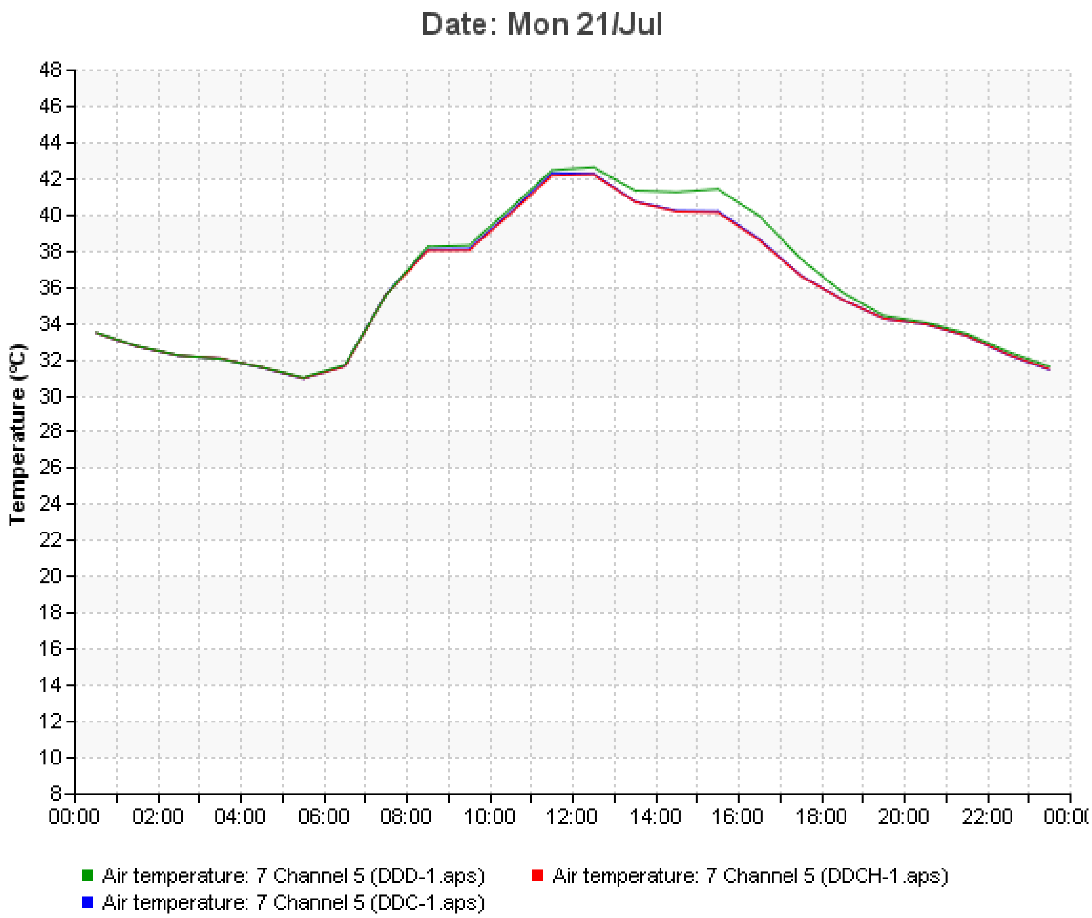

Figure 36: Air temperature inside the channel with different ventilation modes at July 21st (Full model)

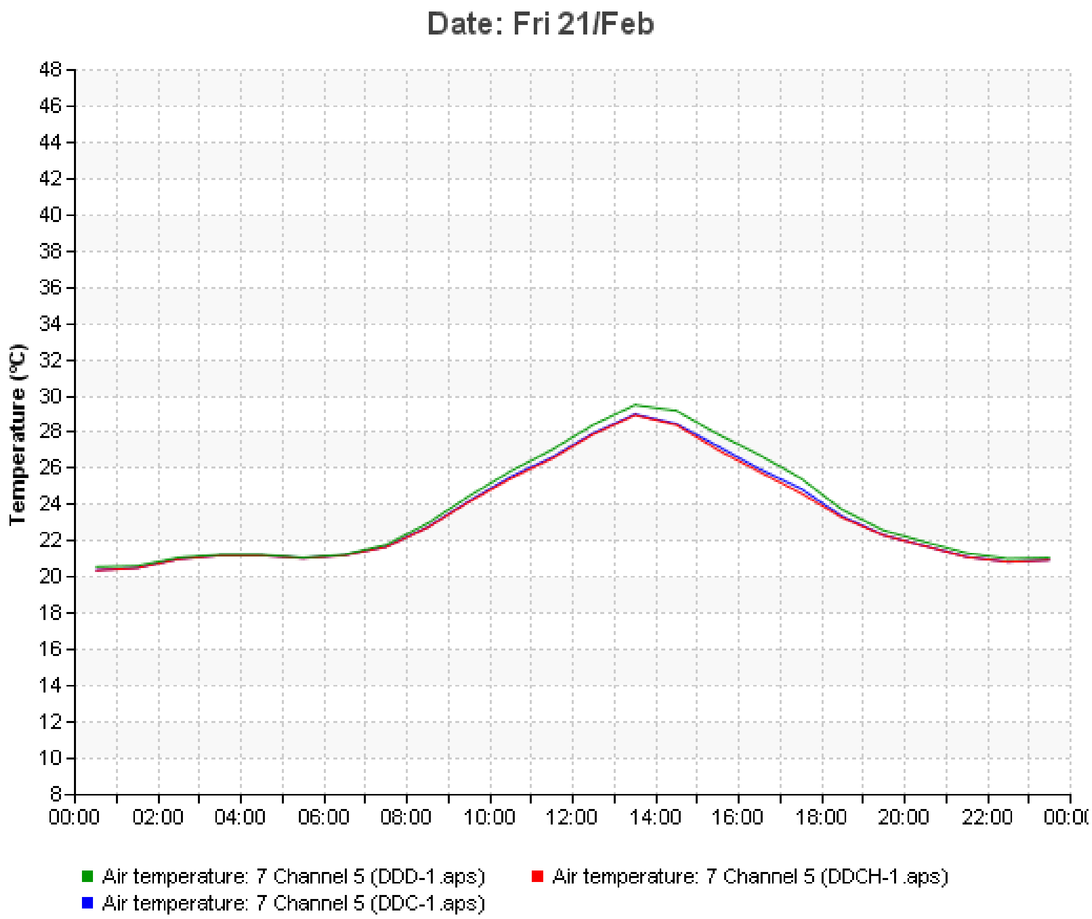

Figure 37: Air temperature inside the channel at February 21st - comparison between different ventilation modes (Full model)

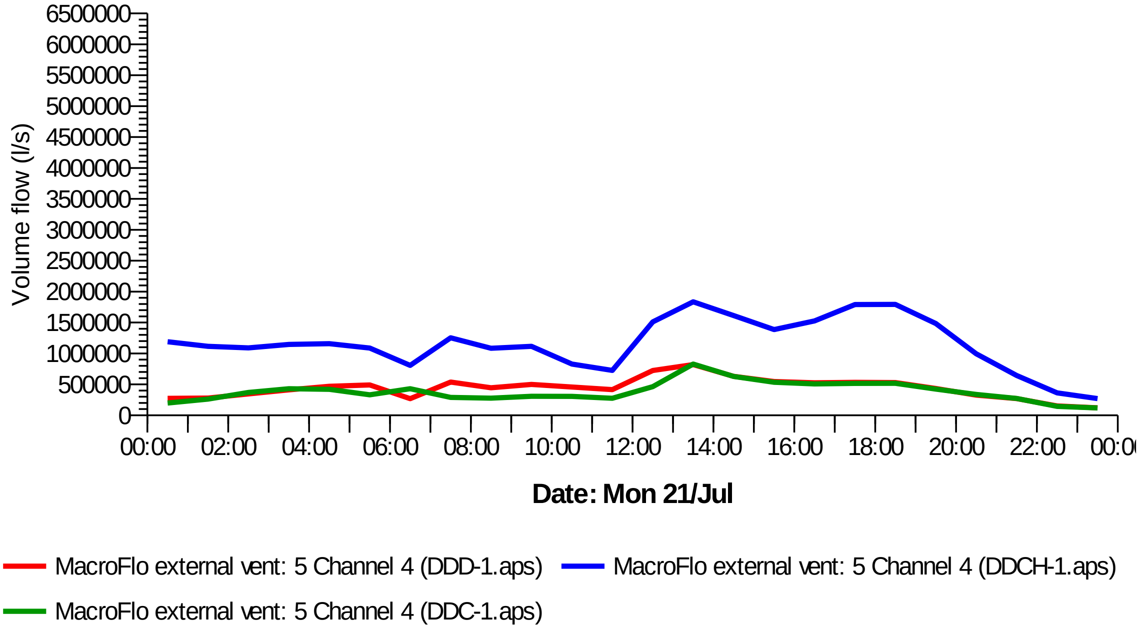

Figure 38: Volume flow inside channel 4 - comparison between different ventilation modes

(Full model)

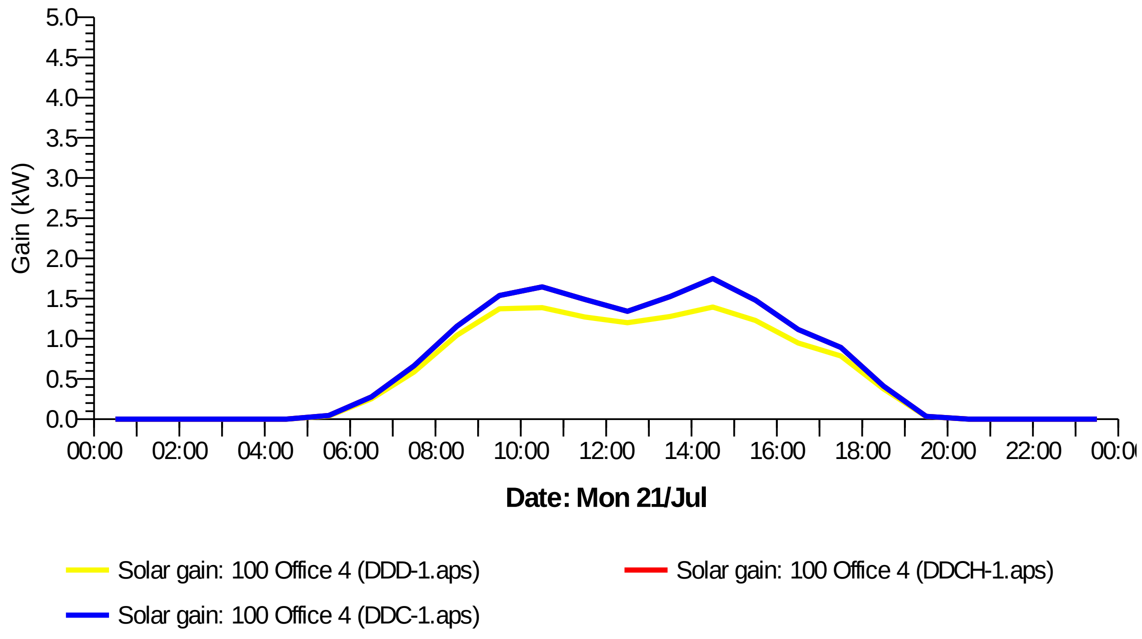

Figure 39: Solar inside office 4 - comparison between different ventilation modes (Full model)

8.3. Orientation and Height

Ventilation inside the channel is affected by temperature thermal force and wind pressure force (Lou *et al.* 2012) which depends on thermal deferential between inside and outside the channel as well as the height of the channel. Figure 41 shows more cooling load plant sensible load savings for south and east facing offices than the north and west facing ones, Figure 44 graph can explain the results as more volume flow is measured inside channel 4 (south east facing) which shows that more solar radiation improves buoyancy effect inside the channel, in another words increasing temperature differential inside and outside the channel. As shown in Figure 45 the façade that receives more solar radiation performs better when using double glazing for both skins. Graph at Figure 40 also shows that double skin façade reduced cooling loads differential for different orientations to the sun inside the building when compared to base case. Figure 42 and 43 show more solar gain and hence more cooling load at the bottom and the top of the building and less solar gain at the middle level, these results are not completely consistent with (Hassan *et al.* 2013) and (Darkwa and D.H.C. Chow 2014), as Hassan *et al.* (2013) found that the heat coefficient is higher at the upper levels as the air gets warmer at the top and Darkwa and D.H.C. Chow (2014) also found an increase in the temperature in upper floors of the building. This could be explained by extreme air temperature that supplies the channel in this region, nevertheless higher temperature is also measured at the higher level when compared to middle one.

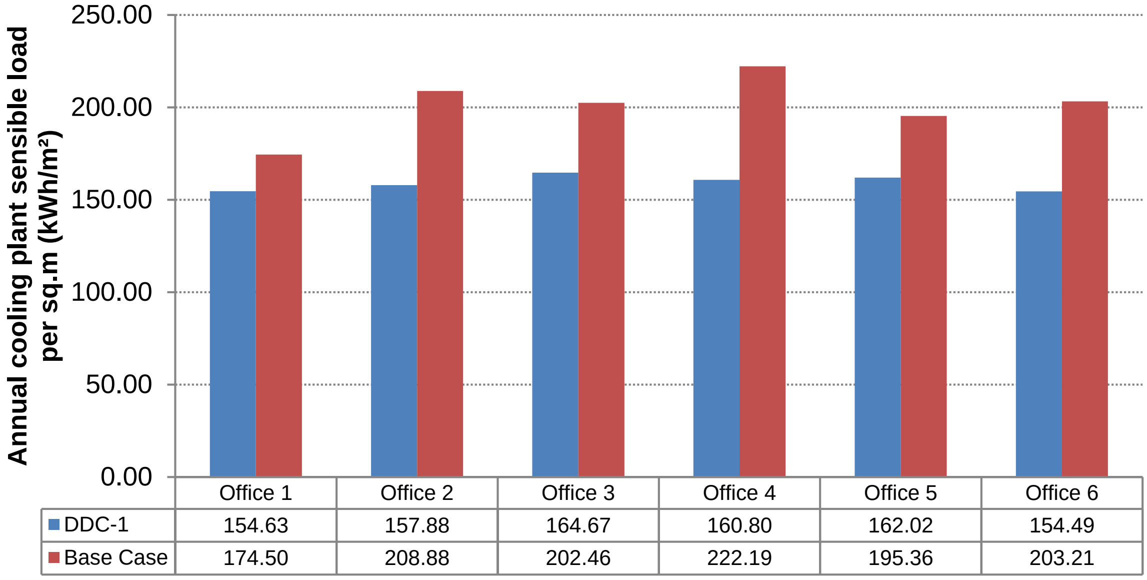

Figure 40: Annual cooling plant sensible load for the 10th floor

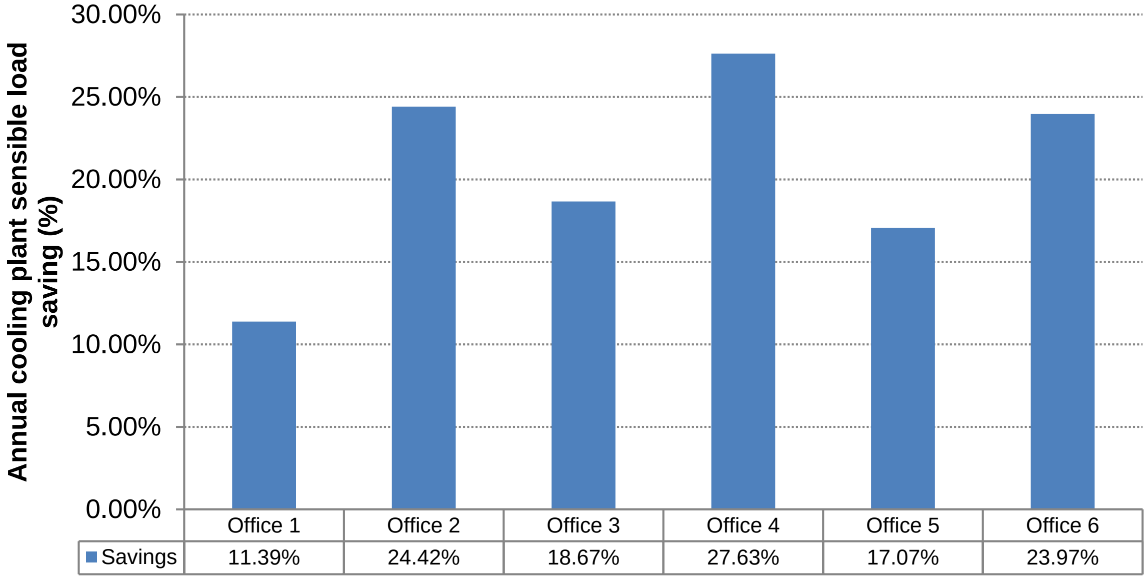

Figure 41: Annual cooling plant sensible load savings for the 10th floor

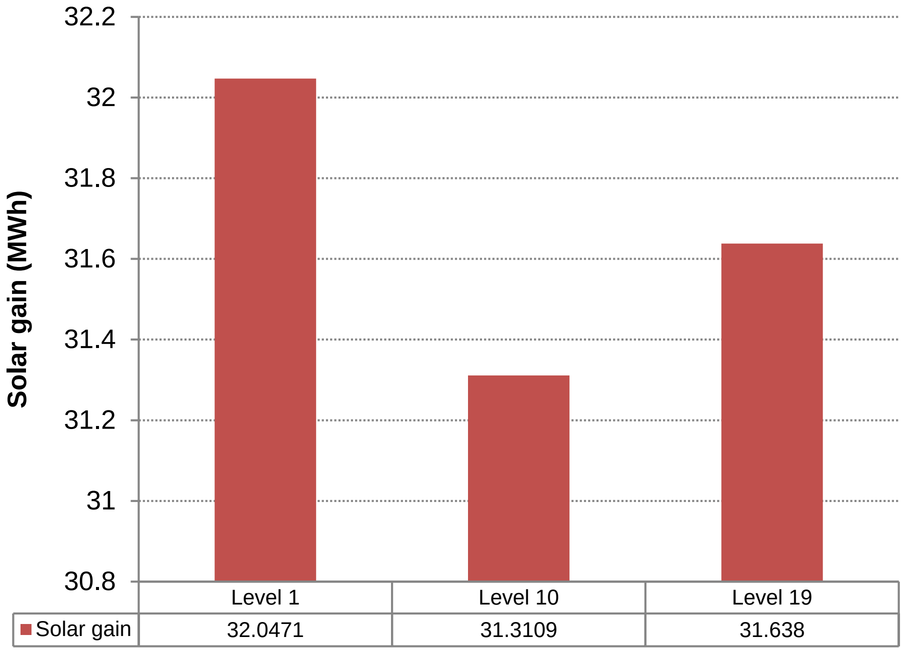

Figure 42: Comparison between solar gains for different levels

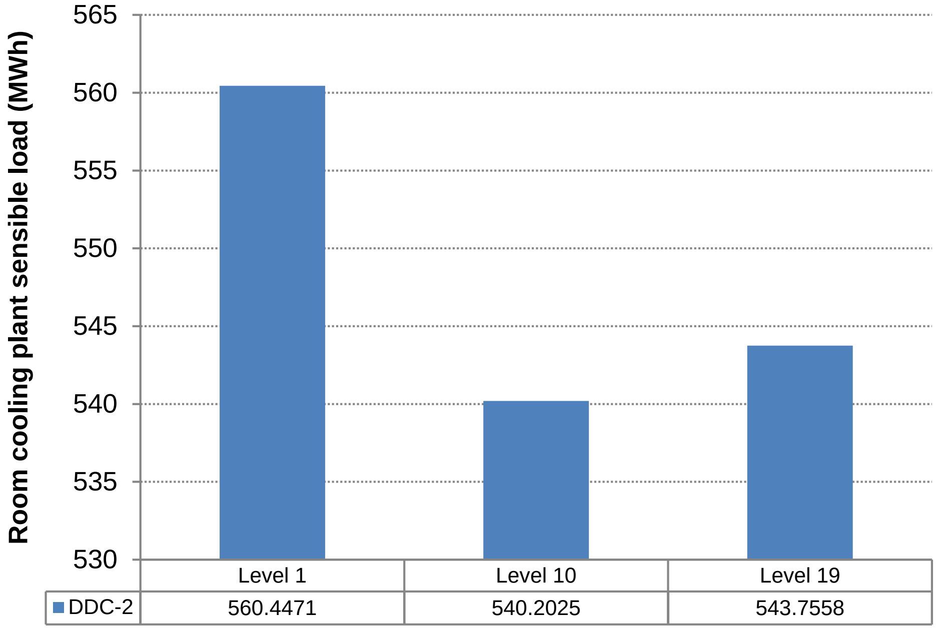

Figure 43: Comparison between cooling loads for different levels

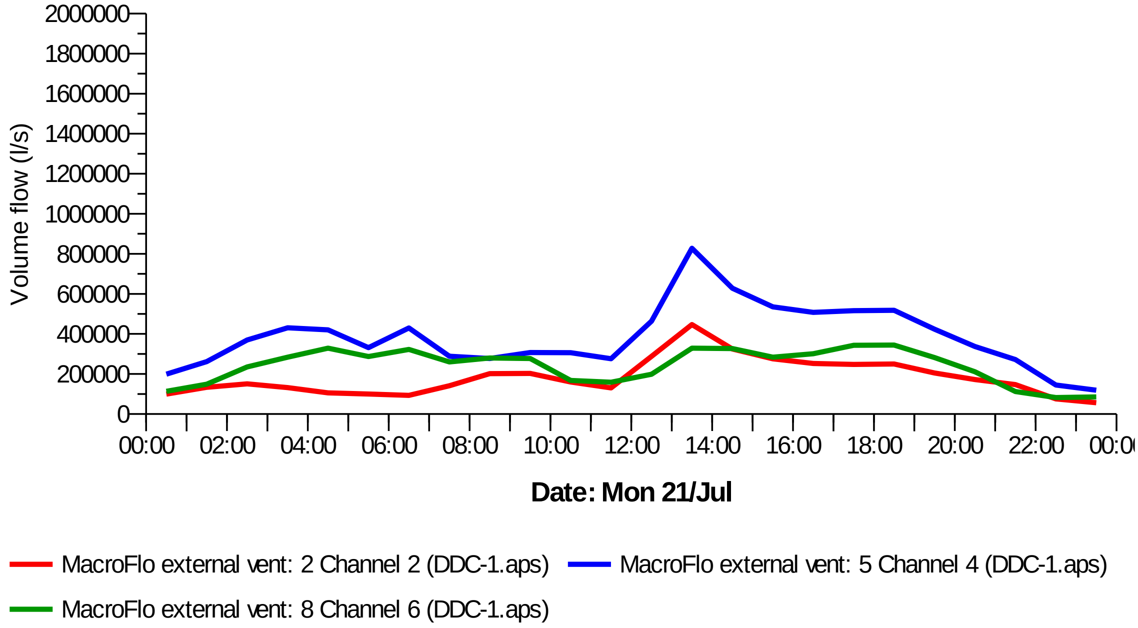

Figure 44: Volume flow inside the channel at July 21st (Full model)

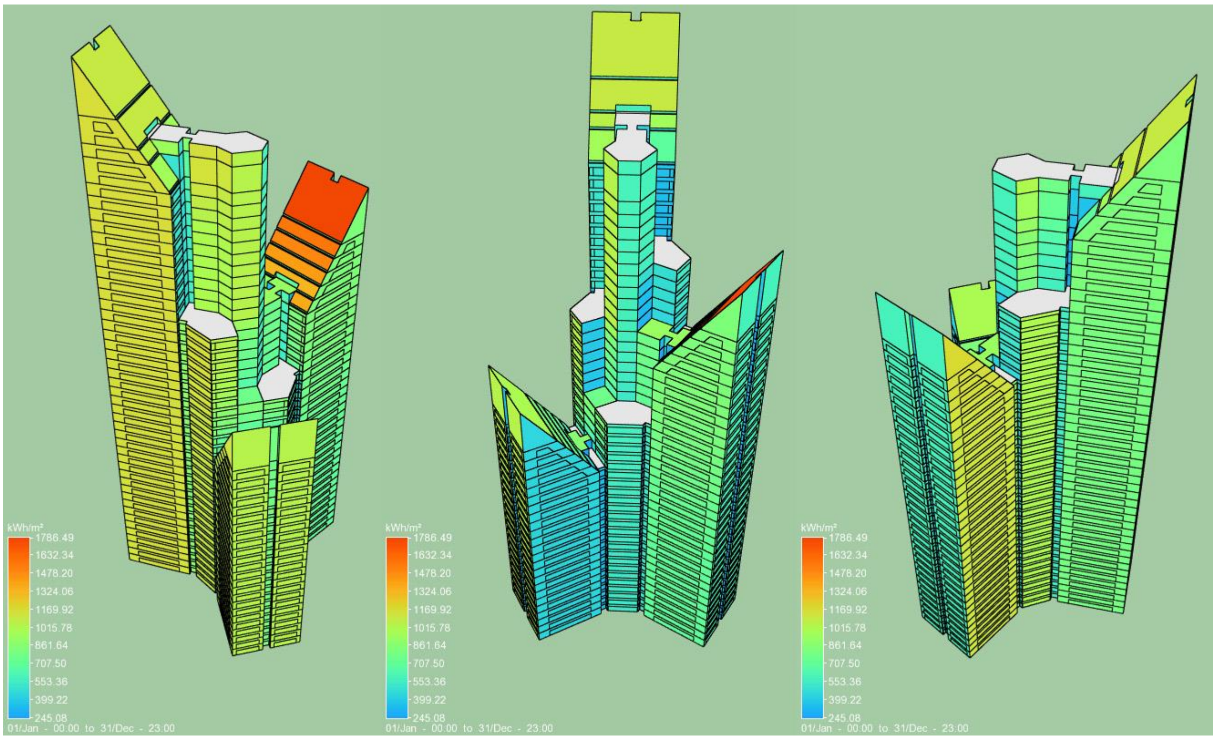

Figure 45: Building solar energy analysis

8.4. Channel width

Total energy consumption and cooling load savings as shown in Figure 23 and 24 shows very slight difference when changing the channel width (less than 1%). Figure 48 showed lea air temperature inside the channel when increasing the channel width, the results are consistent with Sebastian et al. (2012) study as they found that temperature drops inside the channel when increasing the channel width. Wong *et al.* (2008) found that the 300 mm width for the channel had the best results in ventilating the façade, similar results were found as shown in Figure 23 but only slight improvement was observed. Figures 46 and 47 show that volume flow increased when channel width was increased, and the effect was higher in continuous channel. The results is also consistent with previous observations as the increased channel temperature doesn’t necessarily mean increased cooling loads as thermal differential could induce buoyancy effect to flush the heated air away from the channel and therefore avoiding greenhouse effect inside the channel. Hassan *et al.* (2013) also found that decreasing the channel width reduced the air flow and therefore flushing the heat was affected as well, which is consistent with this study results.

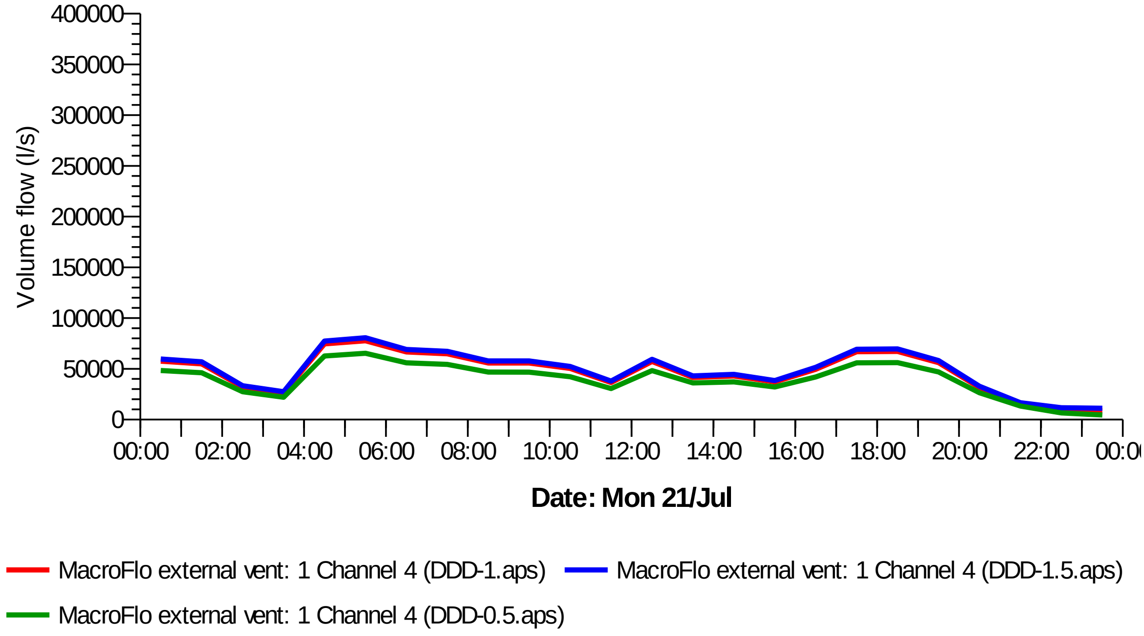

Figure 46: Volume flow inside the channel by using divided channel (partial model)

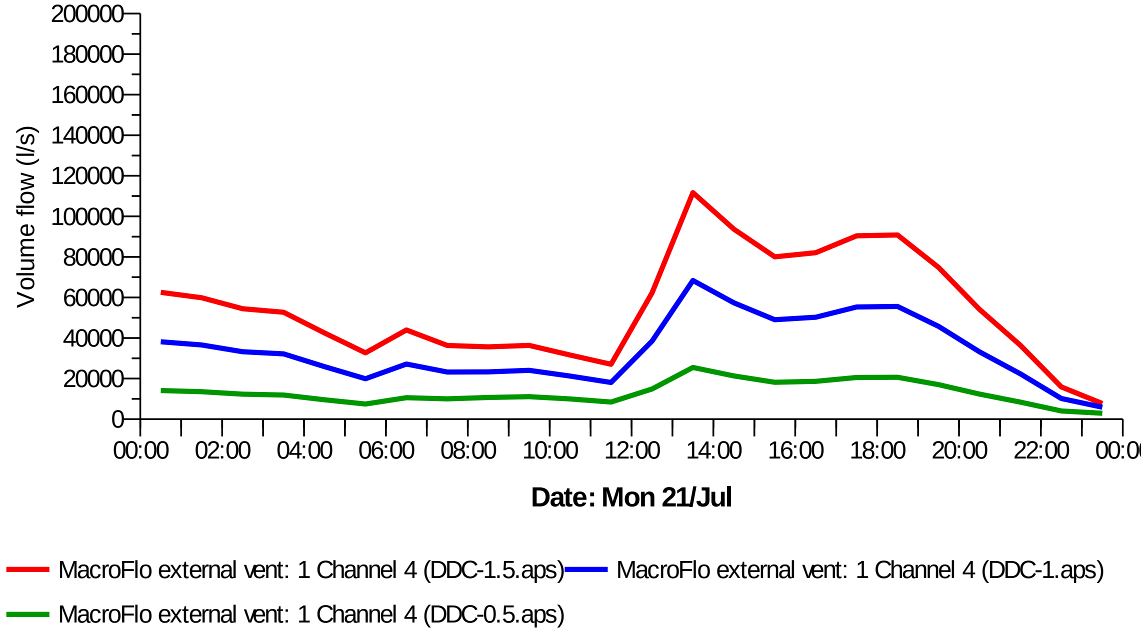

Figure 47: Volume flow inside the channel by using continuous channel (partial model)

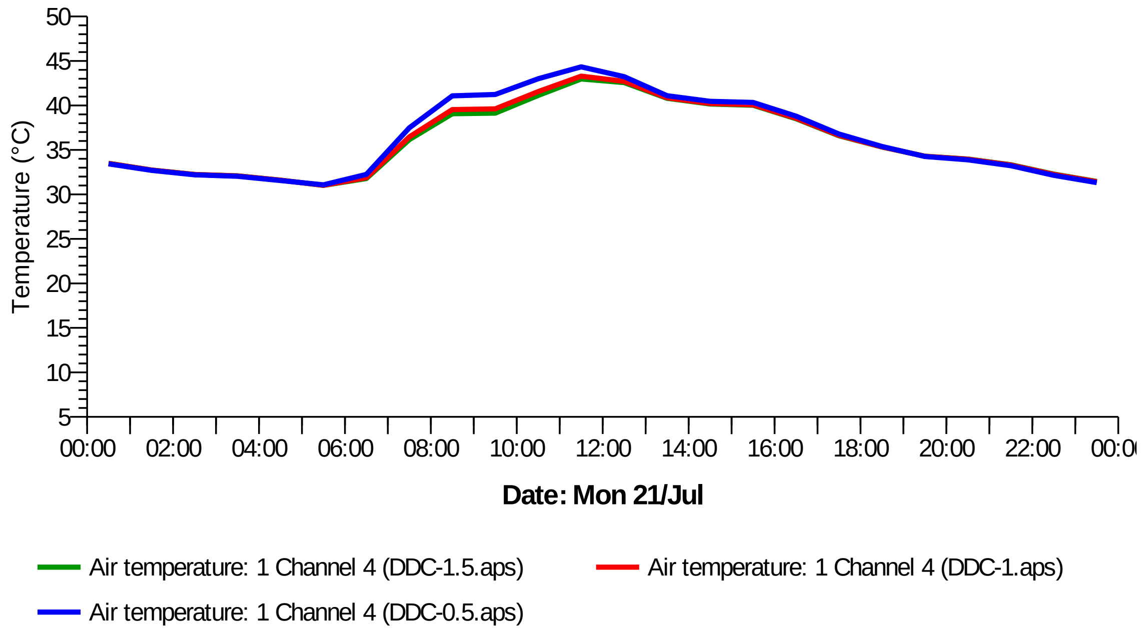

Figure 48: Channel temperature - Channel width comparison (partial model)

8.5. MicroFlo (CFD) analysis

IES VE has limitation as MacroFlo is designed to simulate bulk air movement by buoyancy and wind pressures using zonal airflow, however to simulate the effect of momentum, turbulence or mass continuity MicroFlo (CFD) is required (Iesve.com 2013) on the other hand to simulate the wind forces accurately by CFD airflow values for each opening in the building has to be adjusted manually which was extremely time consuming for simulating a 46 storey building, therefore a simplified model was needed to perform the CFD analysis on different ventilation modes, also CFD simulation requires a lot of computation power therefore many studies are based on a simplified model for the façade which is restricted to steady-state case (Michel *et al.* 2007). CFD results as shown in Figures 49 to 56 show better flow inside ventilated façade and heated air is not trapped inside the channel and flow to the nearest exist, the figures also show that the air velocity is always higher near the exist and at the corner, which is similar to Lou *et al.* (2012) findings, they tested a model for a high-rise building in the wind tunnel wrapped with corridor type double skin façade tower and found that pressure equalization for the shorter double skin façade is easier than the wider one. They also found that pressure equalization is disturbed at the corner of an L-shaped double skin façade. Figure 49 also shows that patches of hot air are evident for trapped heat which can be explained by Figure 53 as well. CFD analysis also shows that ventilated channel didn’t cool the channel but reduced overheating by allowing the trapped air to exit.

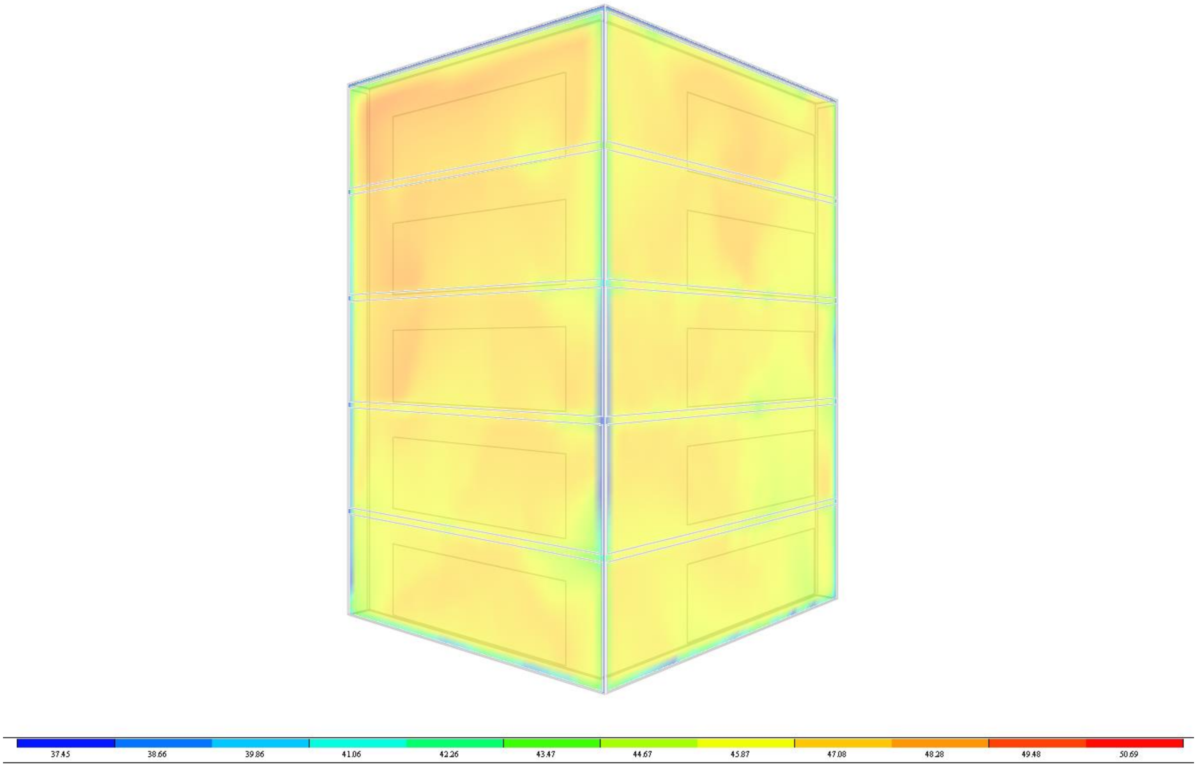

Figure 49: CFD analysis - Temperature contour inside a closed channel at July 21st

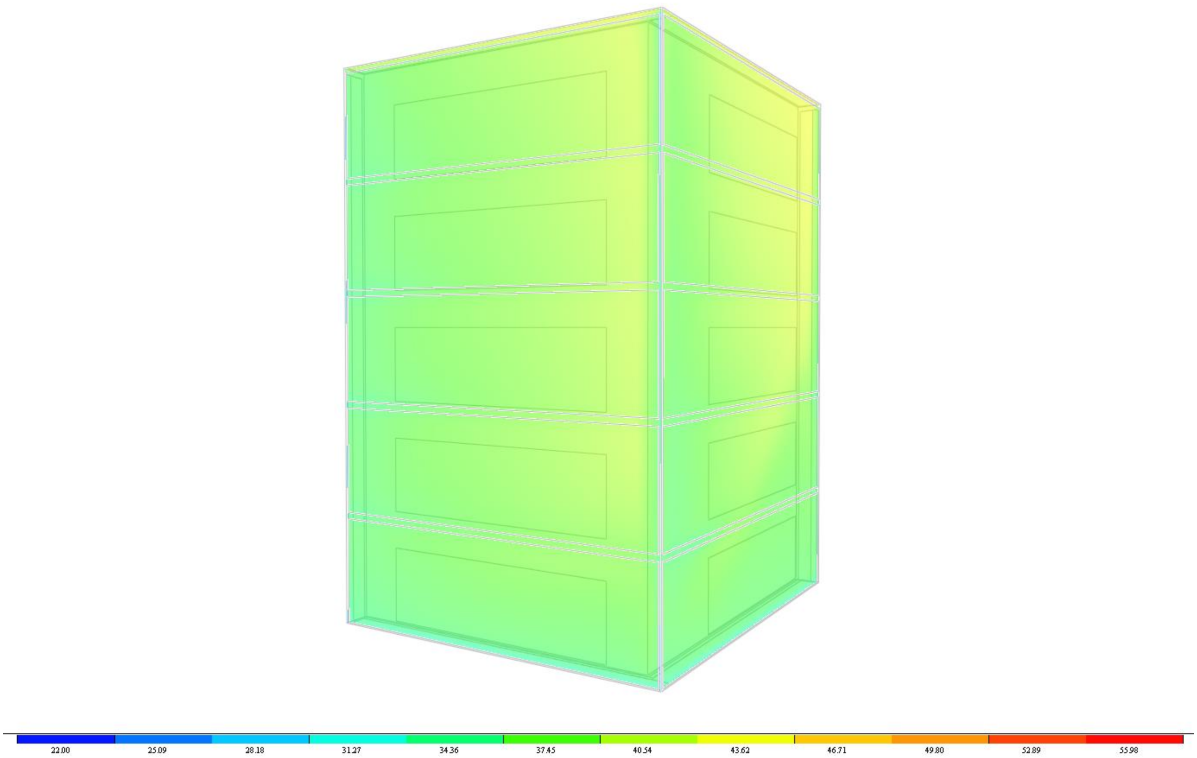

Figure 50: CFD analysis - Temperature contour inside continuous channel at July 21st

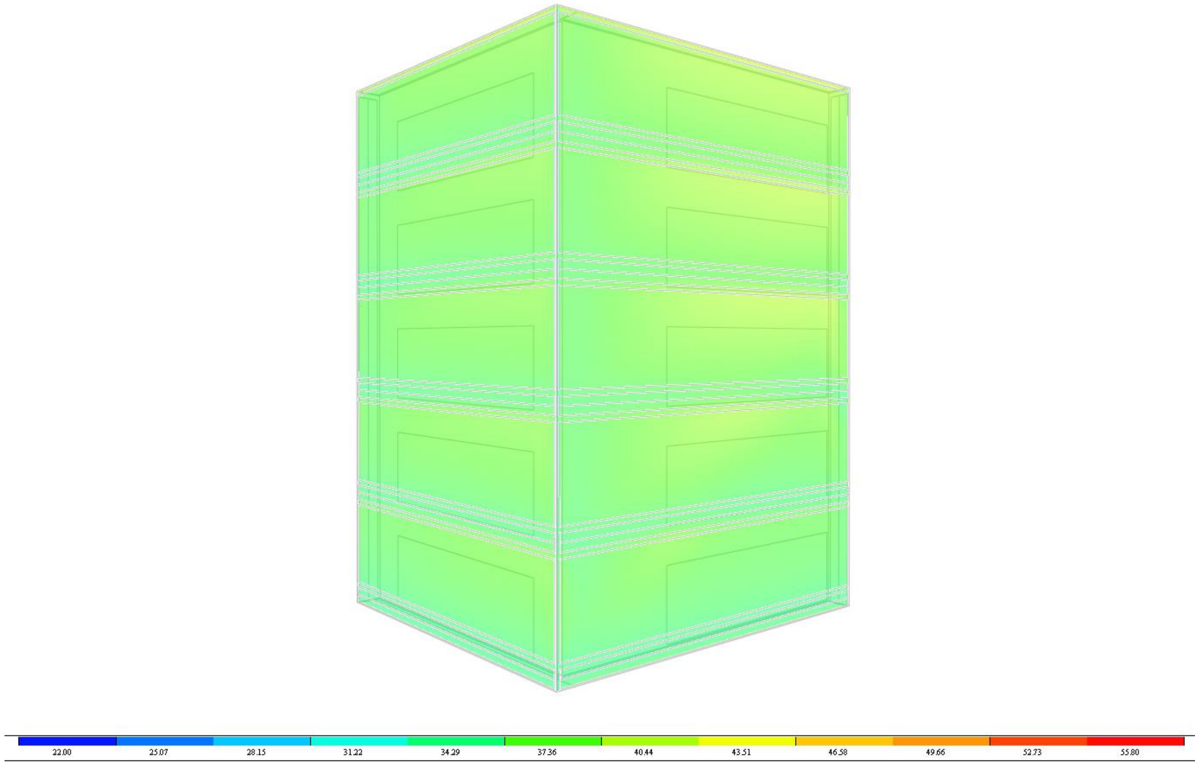

Figure 51: CFD analysis - Temperature contour inside a continuous channel with horizontal openings at July 21st

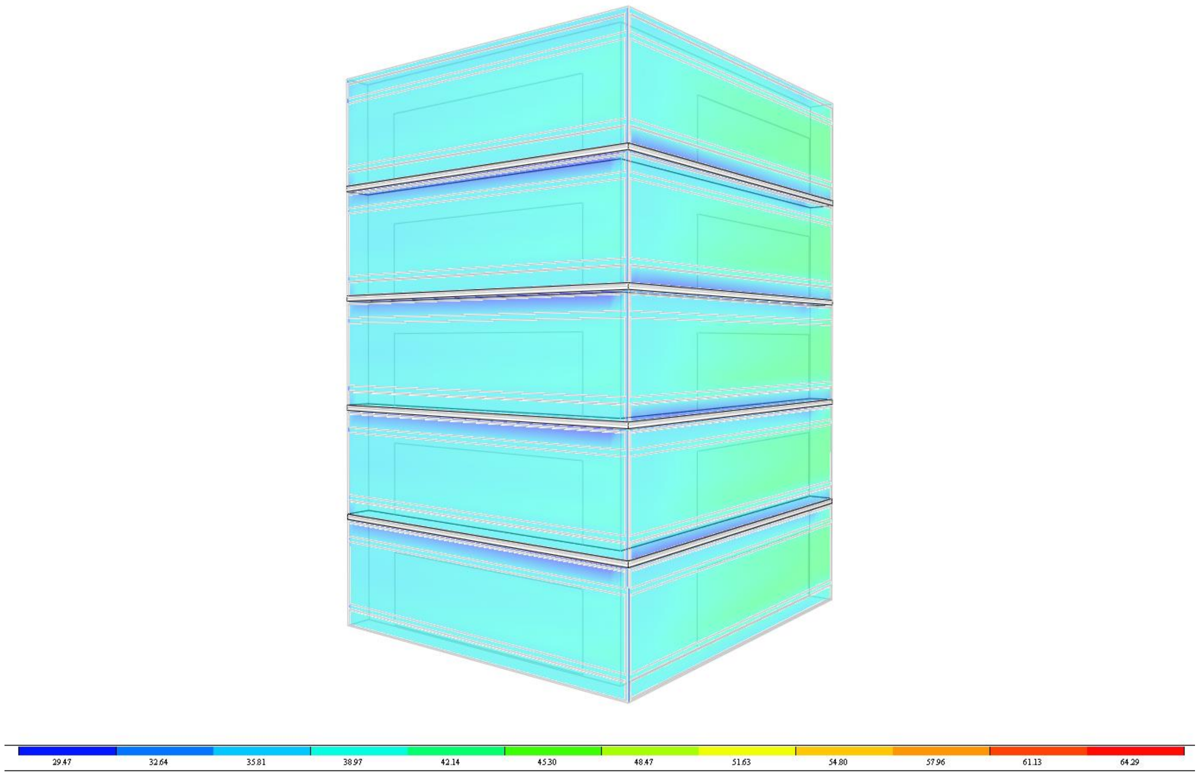

Figure 52: CFD analysis - Temperature contour inside divided channel at July 21st

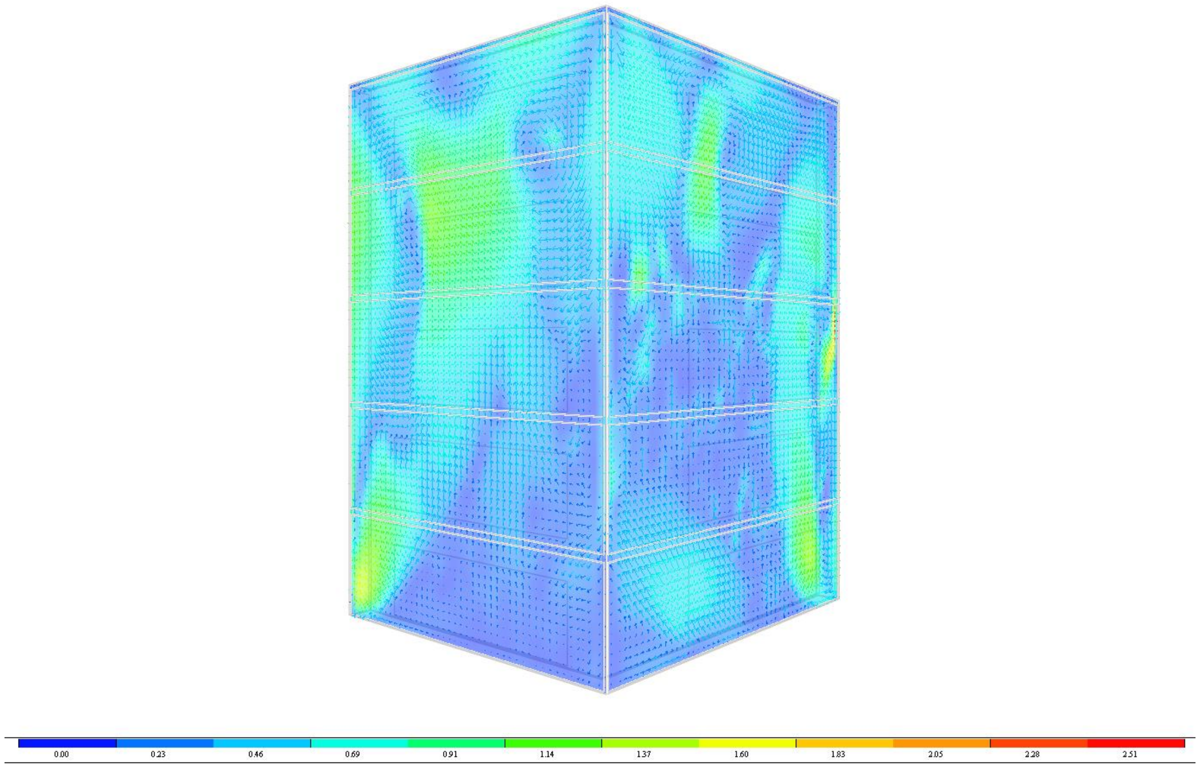

Figure 53: CFD analysis - velocity contour inside a closed channel at July 21st

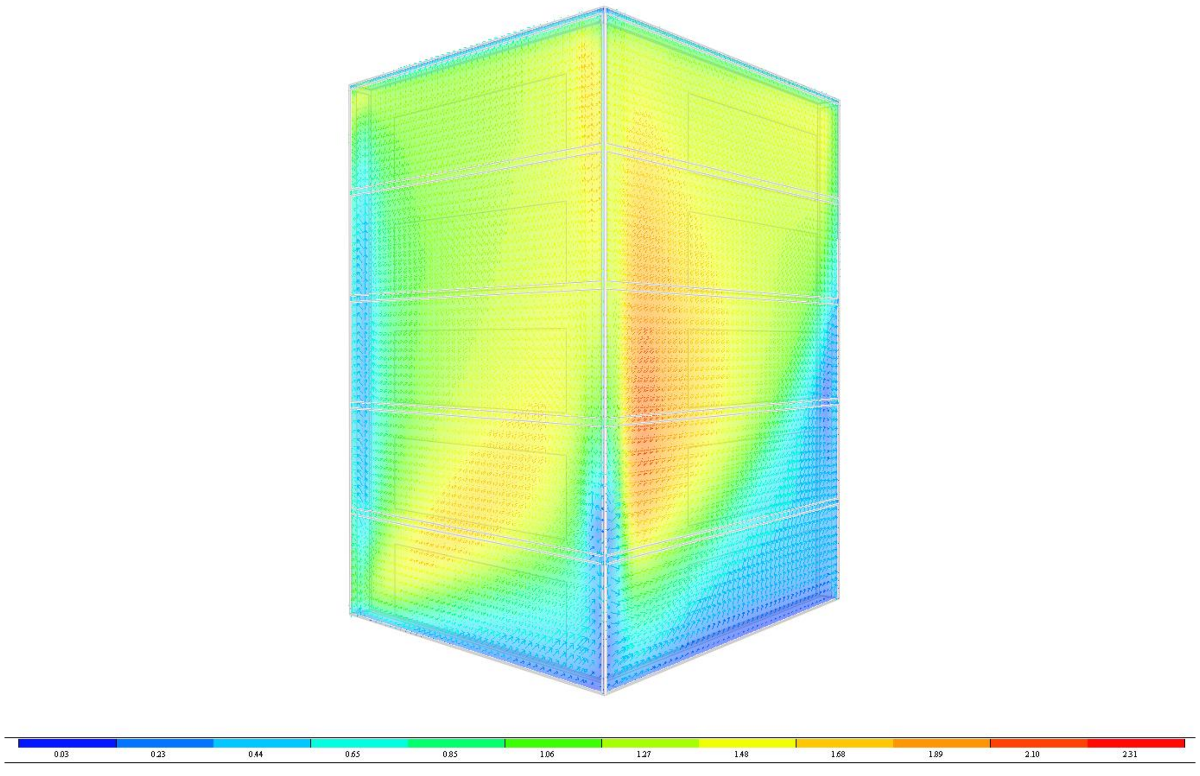

Figure 54: CFD analysis - Velocity contour inside continuous channel at July 21st

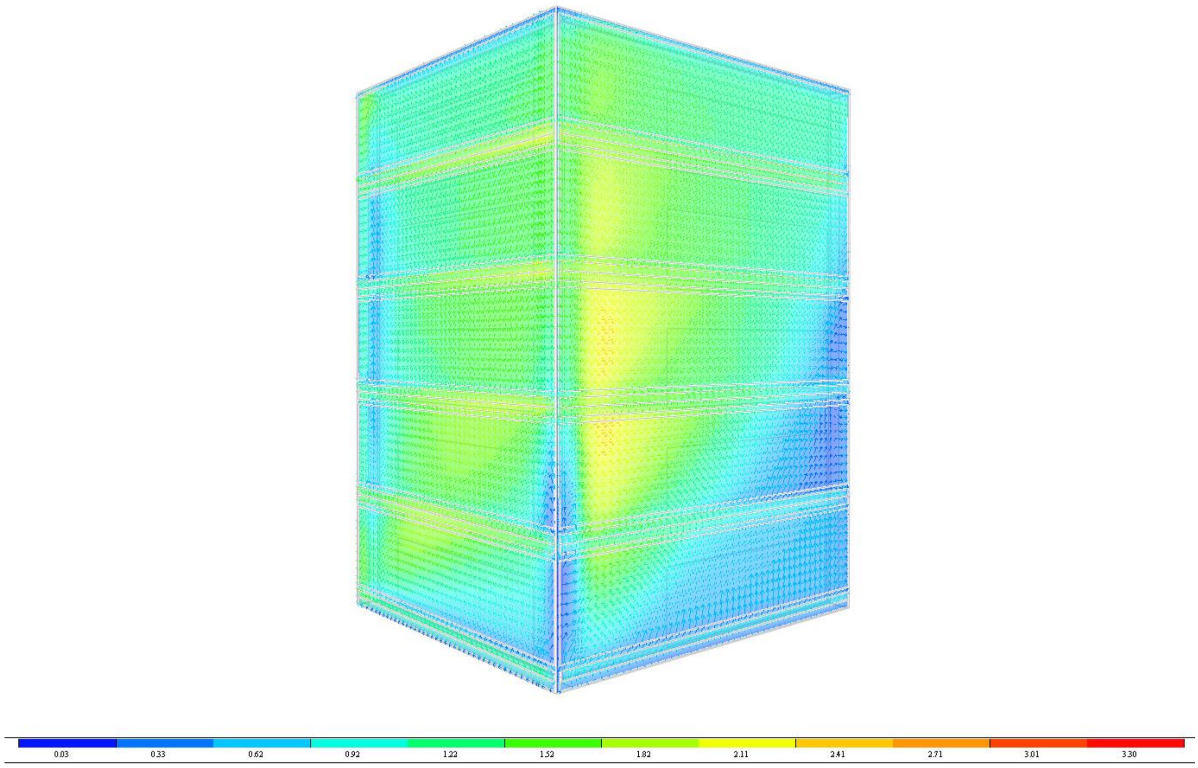

Figure 55: CFD analysis - velocity contour inside a continuous channel with horizontal openings at July 21st

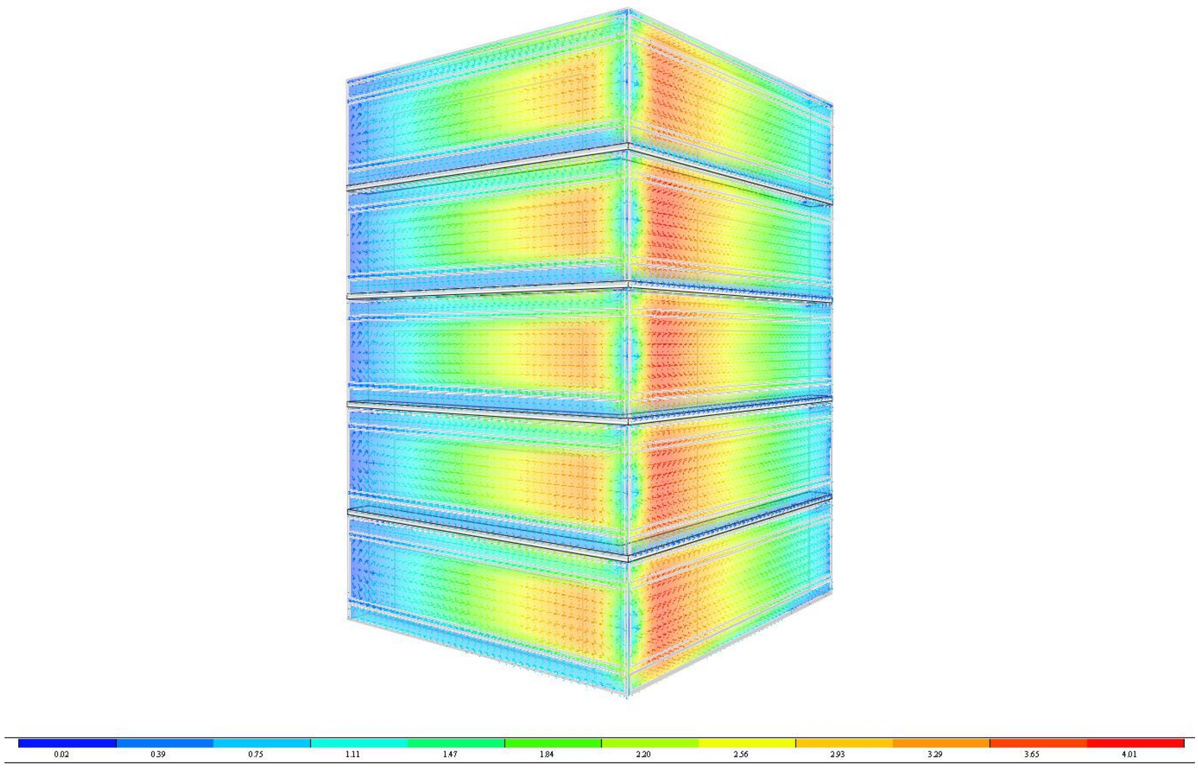

Figure 56: CFD analysis - Velocity contour inside divided channel at July 21st

9. Conclusion

Double skin façade can save annual cooling plant sensible loads up to 20% and total annual energy consumption by 8%, in general terms the thermal performance of the double skin façade depends on buoyancy effect, as the external layer of the façade is heated up therefore the air inside the channel starts to ascend while reducing heat transferred inside the building. The effect of different parameters were analysed in this study, the results showed that using the best solar protective properties to the glass for both internal and external skin will achieve the best performance, which was expected and consistent with several studies presented in the literature review section. Altering the channel width and ventilation mode didn’t show significant energy savings. The results also showed that the double skin façade was more efficient on the south and East orientation than the North and West one. As a conclusion divided channel with double glazing used for both external and internal façade showed the best alternative for reducing cooling loads.

Double skin façades are very expensive systems and complex to build which is why simple curtain wall systems with double glazing panels are a conventional system nowadays. Therefore more research on improving double skin façade ventilation specially when using single glazing for internal or external skin to reduce more cooling loads and energy consumption, which could cost less than using double glazing for both skins, also more studies are suggested for using natural ventilation of the double skin façade in colder seasons as some results showed that the air temperature inside the channel falls within the comfort zone.

It is also recommended to investigate different approaches and tools in simulating the performance of double skin façade, as the thermal behaviour of the double skin façade is very complex, several aspects were not included in the simulation such as outer skin structure, the use of grating in the continuous channel, or the use of shading device between the façade layers. It was not possible to accurately predict the exact performance of the system for the full building, using partial model was more time efficient, but simulating the full model gave a better understanding on where the double skin façade was more efficient and where it needs more improvement, more techniques on simulating full building models is also recommended for the future.

10. References

2007 ARCC Spring Research Conference (2008). *Green Challenges in Research, Practice, and Design Education*. Oregon: Architectural Research Centers Consortium.

Aleksandar, S., Tanja, B., Damir, D., and Ivan, H. (2012). Development of simple calculation model for energy performance of double skin façades, *Thermal Science*, vol. 16, issue 1, pp. S251-S267.

Ajla, A. (2013). *Sustainable Façades : Design Methods for High-performance Building Envelopes*. New York : Wiley.

Baldinelli, G. (2009). Double versus single skin façades in hot arid areas Double skin façades for warm climate regions: Analysis of a solution with an integrated movable shading system, *Building and Environment,* vol. 44, issue 6, pp. 1107–1118.

Central Park District District 08, Dubai International Finance Centre. *Projects* [online]. Hopkins Architects. [Accessed 19 February 2014]. Available at: http://www.hopkins.co.uk/projects/10/130/.

Darkwa, J. and D.H.C. Chow, Y. Li. (2014). Heat transfer and air movement behaviour in a double-skin façade, *Sustainable Cities and Society*, vol. 10, pp. 130–139.

Deuk-Woo, K. and Cheol-Soo, P. (2011). Difficulties and limitations in performance simulation of a double skin façade with EnergyPlus, *Energy and Buildings*, vol. 43, issue 12, pp. 3635–3645.

DEWA. *Electricity Statistics 2012* [online]. Government of Dubai. [Accessed 02 February 2014]. Available at: http://www.dewa.gov.ae/aboutus/electStats2012.aspx.

Dubai Statistics Center. *Climate and Environment Reports 2012* [online]. Government of Dubai. [Accessed 02 February 2014]. Available at: http://dsc.gov.ae/En/Pages/Home.aspx.

Dxb.emiratesglass.com. 2014. *Emirates Glass*. [online] Available at: http://dxb.emiratesglass.com:90/eglweb/products.html [Accessed: 10 Feb 2014].

Giancola, E., Sanjuan, C., Blanco, E. and Heras, M. (2012). Experimental assessment and modelling of the performance of an open joint ventilated façade during actual operating conditions in Mediterranean climate. *Energy and Buildings*, vol. 54, pp. 363-375.

Gratia, E. and De Herde, A. (2004). Optimal operation of a south double-skin façade. *Energy and Buildings*, vol. 36, issue 1, pp. 41-60.

Hashemi, N., Fayaz, R., and Sarshar, M. (2010). Thermal behaviour of a ventilated double skin façade in hot arid climate, *Energy and Buildings*, volume 42, issue 10, pp. 1823–1832.

Hassan, H., Stephen, S., and Fayze, F. (2013). Will multi-façade systems reduce cooling energy in fully glazed buildings? A scoping study of UAE buildings, *Energy and Buildings*, vol. 56, pp. 179–188.

He, G., Shu, L. and Zhang, S. (2011). Double skin façades in the hot summer and cold winter zone in China: Cavity open or closed?. Vol. 4, issue 4, pp. 283-291.

Høseggen, R., Wachenfeldt, B.J., and Hanssen, S.O. (2008). Building simulation as an assisting tool in decision making: Case study: With or without a double-skin façade?, *Energy and Buildings*, volume 40, issue 5, pp. 821–827.

Iesve.com. 2014. *IES User Guides*. [online] Available at: http://www.iesve.com/support/userguides [Accessed: 25 Dec 2013].

Islam, M., Alili, A., Kubo, I., and P. Ohadi, M. (2010). Measurement of solar-energy (direct beam radiation) in Abu Dhabi, UAE, *Renewable Energy*, vol. 35, issue 2, pp. 515-519.

Kambiz, R., Wilhelm, F., and Sahand, T. (2013). Evaluating the sustainability impact of improved building insulation: A case study in the Dubai residential built environment, *Building and Environment*, volume 67, pp. 105-110.

Khaled, P. (2013). The use of Phase-Change-Material as cooling-strategy for buildings in the Chilean climate, *International Journal of Low Carbon Technologies*, vol. 3, issue 2, pp.101-109.

Lou, W., Huang, M., Zhang, M. and Lin, N. (2012). Experimental and zonal modeling for wind pressures on double-skin façades of a tall building. *Energy and Buildings*, vol. 54, pp. 179-191.

Marko, G., Bratislav, D., Branislav, V., and Mladen, M. (2012). Influence of glazing types and ventilation principles in double skin façades on delivered heating and cooling energy during heating season in an office building, *Thermal Science*, vol. 16, pp. S461-S469.

Michel, C., Mick, E., Matthias, H., and Ronald, V. (2007). *EU COST C13 Glass and Interactive Building Envelopes - Final Report: Volume 1*. Amsterdam: IOS Press.

Miguel, M., Gonzalo, L., and Amparo, L. (2013). CFD model of air movement in ventilated façade: comparison between natural and forced air flow, *Energy and Environment*, vol. 4, issue 3, pp. 357-368.

Nassim, S., Monika, W., and Jean, R. (2005). Three-dimensional simulation with a CFD tool of the airflow phenomena in single floor double-skin façade equipped with a venetian blind, *Solar Energy*, vol. 79, issue 2, pp. 193-203.

Neveen, H. (2008). Double versus single skin façades in hot arid areas, *Solar Energy and Buildings,* vol. 40, issue 3, pp. 240–248.

Sebastian, H., Nelu-Cristian, C., and Monica, C. (2012). Numerical modeling of solar radiation inside ventilated double-skin façades, *Mathematical Modelling in Civil Engineering*, issue 4, pp. 96-101.

Stelios, C. (2007). On the performance of double skin façades in different environmental conditions, *International Journal of Sustainable Energy*, vol. 26, issue 4, pp. 221-229.

Wenting, D., Yuji, H., and Tokiyoshi, Y. (2005). Natural ventilation performance of a double-skin façade with a solar chimney, *Energy and Buildings*, volume 37, issue 4, pp. 411-418.

Wong, P., Prasad, D. and Behnia, M. (2008). A new type of double-skin façade configuration for the hot and humid climate. *Energy and Buildings*, vol. 40, issue 10, pp. 1941-1945.