Courtyards as passive design solution for school buildings in hot areas: UAE as a case study

عمارة الافنيه كحل سلبي في مباني المدارس في المناطق الحاره : الامارات العربية المتحده كحاله دراسية

by

MUNA MAHMOUD SALAMEH

A thesis submitted in fulfilment

of the requirements for the degree of

DOCTOR OF PHILOSOPHY IN ARCHITECTURE AND SUSTAINABLE BUILT ENVIRONMENT

at

The British University in Dubai

Prof. Bassam AbuHijleh

June 2018

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Abstract

The global concentration on green efficient schools is growing as schools represent a considerable sector in the built environment, which consumes a lot of energy to provide a standard level of thermal comfort for students. In the UAE, both private and public-school buildings are assumed to be a high energy consumption sector, in addition to universities, banks and shopping malls. Moreover, the energy consumption in schools seems to be encouraged rather than controlled, thus there is the potential for reducing the sector's energy consumption. Traditional architecture adopted the courtyard design as a distinct form to create the core of houses and moderate the thermal conditions for the surrounding spaces, especially in hot climates. In most of the previous studies on the subject, courtyards were found to be related to houses or buildings in general, rather than educational institutions specifically, such as schools. This research aims to investigate the integration of a well-designed courtyard as a passive design strategy in buildings in the UAE to reduce the energy consumption required for cooling. In addition, the improvements in the thermal comfort conditions within the courtyards should translate to a more comfortable outdoor space for the students.

This research adopted a qualitative approach based on case studies and computer simulations. The case studies were five present public schools' buildings with different plan templates and different courtyard configurations; the schools are models 586, 596, KAT, UPA1 and finally UPA-fin. The computer analysis in this research was based on two software programs: ENVI-met software to evaluate changes in the schools' microclimates due to the presence of courtyards and IESve software to calculate the energy consumption of the school buildings due to the changes of the microclimates affected by the courtyards. The thermal effect of the courtyards on the school buildings was investigated through two stages. The first stage discussed the orientation of the courtyard. The second stage investigated a range of courtyard configurations and designs through five phases, each focused on one of five relevant parameters which are: courtyard's shape factor ratio (W/L ratio), courtyard's area to built-up area (CA/BA ratio), courtyard's outline shape, courtyard's height (number of floors) and finally courtyard's vegetation. There was third stage in this research that investigated the cooling loads for schools (case studies) in relation to the orientation and the design strategies. The cooling plant sensible load was investigated the beginning on specific dates and then it was investigated for the whole academic year.

The outcomes of the research investigations concluded that the design and the properties of the courtyards can affect the indoor temperature of the school building, thus the cooling load. Moreover, the results of the computer simulation revealed that the school UPA-fin was the best school case with the optimum courtyards after adopting the following strategies 1- orientation to the north , 2-CA/BA ratio 20%, 3-square outline for the courtyards, 4-additional third floor on the east mass mainly 5- integrating vegetation in the courtyards, succeeded in reducing the T_{in} to 1.9 ˚C on 21st of September and 1.7 ˚C on 21st of March and that managed to reduce the cooling load by 19% on 21st of September and 27% on 21st of March compared to the basic UPA-fin to the north in phase one .

The investigation of the annual cooling load after adopting only four strategies that included 1-orientation, 2-CA/BA ratio 20%, 3-square outline for the courtyards, 4-additional third floor on the east mass mainly and excluding the integration of vegetation, succeeded in reducing the cooling load by 16.5%compared to phase one UPA-fin basic to the north.

The results showed that the optimum courtyard had the best predicted mean vote (PMV) performance also, as on 21st of September the max PMV reading for the poorest case of stage two equaled 4.35, which covered 48% of the courtyard’s area, while the max PMV reading for the best case of stage two (phase five) equaled 3.15 and covered 1.5% of the courtyard’s area with a reduction of about 1.2 on the PMV scale. On the other hand, on the 21st of March the max PMV reading for the poorest case of stage two equaled 3.0 and covered 48% of the courtyard’s area; while the max PMV reading for the best case equaled 1.9 and covered 1.5% of the courtyard’s area, with a reduction of about 1.1 according to the PMV scale.

The research results revealed that the optimal design of the courtyard can reduce the temperature of the inner spaces of the school, thus it can reduce the cooling load for the school building in general. Moreover, it can improve the thermal comfort for the outdoor areas. The findings of this study will be important for architects, sustainable developers, educational developers, economic consultants and green buildings designers in UAE and in areas with similar climate to help them in designing green schools.

ملخص البحث

يتزايد التركيز العالمي على المدارس ذات الكفاءة الخضراء ، حيث تمثل المدارس قطاعًا كبيرًا من المباني التي تستهلك الكثير من الطاقة لتوفير مستوى بيئي و حراري مناسب للطلاب . في الإمارات العربية المتحدة ، يعتبر قطاع مباني المدارس الخاصة والعامة مرتفع في استهلاك الطاقة، خاصة الضرورية لتبريد الفراغات الكبيره للانشطة المضافه على المدارس الحديثه، بناء على ذلك ، هناك حاجه ملحه لتقليل استهلاك الطاقة في المدارس بشكل لا يؤثر سلبيا على البيئه الحرارية الداخلية للمباني . تتبنى العمارة التقليدية فكرة الفناء الداخلي كمركز محوري للبيوت والمباني الاخرى. تعمل الافنية الداخليه على تحسين الظروف الحراريه الداخليه للمباني خاصة في المناطق الحاره مثل الامارات العربية المتحده. في معظم الدراسات السابقة ، كانت الافنية الداخلية مرتبطة بالمنازل أو المباني بشكل عام أكثر من المباني التعليميه مثل المدارس . يهدف هذا البحث إلى دمج تصميم الافنية الداخلية كاستراتيجية تصميم سلبية في مباني المدارس في دولة الإمارات العربية المتحدة للحد من استهلاك الطاقة اللازمة للتبريد للمباني . بالإضافة إلى ذلك ، هذه الافنية ممكن ان تشكل مساحات خارجية ممتعة ومريحة لنشاطات الطلاب الخارجية.

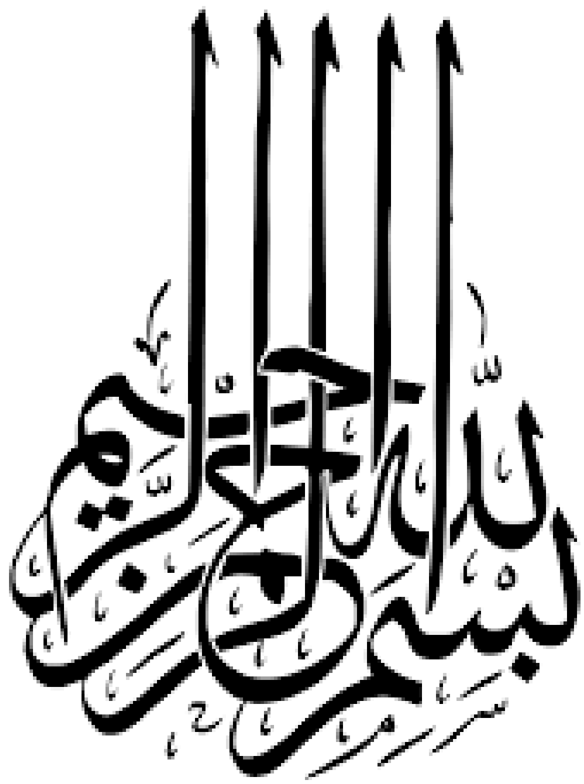
استخدمت هذه الدراسة نهجًا نوعيًا (Qualitative) يعتمد على مباني قائمة كنماذج دراسيه بالاضافة الى برامج كمبيوتر قادره على تحليل الظروف البيئيه للمباني . كانت النماذج الدراسيه عبارة عن خمسة مبانٍ للمدارس العامة تحتوي على تصاميم مباني متعدده وتكوينات أفنية مختلفة ؛ و تشمل هذه النماذج المدارس التالية: 586 و 596 و KAT و UPA1 وأخيراً UPA-fin . اعتمد تحليل الكمبيوتر في هذا البحث على برنامجين: برنامج ENVI-met لتقييم التغييرات في المناخ الخارجي للمدارس نظرًا لوجود الافنية . وبرنامج IESve لحساب استهلاك الطاقة الازمة للتبريد لمباني المدارس الناتجه عن اعتماد تصاميم مختلفة للمدارس. تم البحث في التأثير الحراري للافنية على المباني المدرسية من خلال ثلاث مراحل : المرحلة الأولى ناقشت توجه الفناء حسب الاتجاهات الرئيسية الاربعة. بينما ركزت المرحلة الثانية على التحقق من تأثير مجموعة متنوعة من تصاميم الافنية على الاداء الحراري للمباني . و قد تم بحث هذه التصاميم من خلال خمس خطوات ركزت كل واحدة منها على متغير واحد ذا صلة بتصميم الافنية : نسبة طول الفناء الى عرضه (W / L)، نسبة مساحة الافنية الى مساحة المبنى (CA / BA) ، شكل مخطط الفناء مربع او مستطيل ، ارتفاع الفناء (عدد الطوابق) وأخيراً استخدام نباتات مختلفه داخل الافنية. اما المرحلة الثالثة فقد شملت حسابات استهلاك الطاقة بناء على استراتيجيات التصميم للافنية. وقد أظهرت نتائج المحاكاة الحاسوبية في هذا البحث ان تصممم الأفنية

يستطيع التأثير على الوضع الحراري واستهلاك الطاقه اللازمة للتبريد للمبنى، بالأضافة الى ذلك أظهرت النتائج أن أفضل مبنى مدرسة يشمل تصميم مثالي للفناء وبأقل معدل لاستهلاك الطاقة كان مدرسة UPA-finالذي يشمل فنائين ، مع نسبة مساحة الافنية الى مساحة المبنى 20٪ ، ومع شكل مربع لمحيط الفناء. علاوة على ذلك ، كان أفضل مبنى ذا ثلاثة طوابق ، يحتوي على مزيج من الأشجار والعشب داخل الأفنية.

لقد اظهرت نتائج البحث ان استراتيجيات التصميم لمدرسة UPA-fin ذات الافنية المثالية قد نجحت في تقليل الحرارة الداخلية للمبنى بمقدار 1.9 درجة مئوية في 21 ايلول و 1.7 درجة مئوية في 21 اذار وذلك ادى الى تقليل طاقة التبريد بنسبة 19 ٪ في 21 ايلول و 27 ٪ في 21 اذار.

عند دراسة استهلاك طاقة التبريد السنوية لمدرسة UPA-fin تبين ان اول اربع استراتيجيات جيده لتصمصم الافنية التي تشمل توجيه المبنى للشمال مع نسبة مساحة الافنية الى مساحة المبنى 20٪ ، ومع شكل مربع لمحيط الفناء و ثلاثة طوابق للمبنى قد نجحت في خفض طاقة التبريد بنسبة 16.5٪ .

أظهرت نتائج البحث أن التصميم الأمثل للافنية في المدارس يمكن أن يقلل من درجة حرارة الفراغات الداخلية لها ، وبالتالي يمكن أن يقلل من طاقة التبريد اللازمة لهذه المدارس بشكل عام. وعلاوة على ذلك ، يمكن أن تخلق هذه الافنية داخلها ظروف حرارية محسنه ومناسبه لاستخدام الطلبه للانشطة المختلفة. يتوقع ان تكون نتائج هذه الدراسة مهمة للمهندسين المعماريين ، والمطورين المستدامين ، ومطوري التعليم ، والمستشارين الاقتصاديين بجانب مصممي المباني الخضراء.



In the name of Allah, the most merciful the compassionate

Dedicated with love

To

The soul of my father Mr. Mahmoud Yousef Salameh

A brave, generous and caring man, who believed in me and taught me to be strong, passionate for knowledge and search always for the best

My mother Mrs. Huda Jazar

A strong and gentle soul who gave unconditioned love and taught me to trust in Allah, to believe in myself and to work hard to achieve the best always. Whose loving spirit sustain me still as a rock of stability throughout my life. Whose prayers day and night made me able to get this success and honor

My wonderful children,

Daughter Ayda and sons Hashim, Ahmed, Mahmoud and Kareem

Who gave me inspiration, support and encouragement to go on in this long journey. You have made me stronger, better and more fulfilled than I could have ever imagined. God gave me a huge blessing to have you. I love you to the moon and back.

My Husband Mr. Basim Touqan

A gentle man. Thank you for your love, patience, support, faith and friendship

My brothers and sisters

Thank you for a lifetime of unfailing love, loyalty, encouragement and support.

Thank you all for everything that you do and have done for me to make life more enjoyable. I pray God will bless you all always and give you a nice long life

Acknowledgment

I would like to thank my caring sister May Salameh who gave me endless support through this journey. Thank you for your infinite encouragement , continual care, and attention. Thanks for being a person who always stands beside me.

I would like to express my deepest gratitude to my supervisor
Prof. Bassam AbuHijleh
for his unwavering support, collegiality, patience and mentorship throughout this research.
I would like to express my thanks to Dr Hanan Taleb for her support.

I would like to extend my thanks to everyone who offered collegial guidance and support over the years and helped me in my struggle to achieve my dream

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Abbreviations:

Symbol	*Meaning*
W/L	Shape factor width to length
WO	Worst orientation
BO	Best orientation
T_{in}	Indoor air temperature without air condition
CA/BA	Courtyards to built up are ratio
CA/PA	Courtyard area to the plot area
PMV	Predicted Mean Vote
SVF	sky view factor
W/H	Width to height ratio
SSD	Solar Shadow Index

Chapter 1: Introduction

1.1 Overview

The world is focusing on sustainability within all aspects of life, including buildings, to reduce energy consumption (Paorez-Lombard, Ortiz and Pout 2008). Governments have set targets to control the energy intake of buildings and the CO_2 emissions to mitigate climate change. Desideri and Proietti (2003) and Dias Pereira et al. (2014) stated that the global interest and encouragement for energy efficiency in schools is increasing because schools represent a considerable sector in the built environment which consume a lot of energy to provide a standard level of thermal comfort for students.

In the UAE, school buildings for both private and public (governmental institutions) are the second highest sector in terms of energy consumption after the residential sector. Energy consumption in schools seemed to be encouraged rather than controlled (Qader 2009), beside the fact that schools represent the largest section among public buildings (Zhang et al. 2017). Thus, there is significant potential for decreasing energy consumption in this sector, and this is the main concern of this study, which explores how to decrease the energy consumption in the school buildings in hot and humid environments. The UAE has set a target to reduce CO_2 emissions by producing about 24% of the required energy from green sources by the year 2021 (Mittal 2015). The UAE target is related to the use of renewable energy, more than implementing passive design solutions in buildings which are inexpensive in general, such as courtyards, thermal insulation, wind towers. Passive design solutions are used in buildings to improve the internal thermal settings with the least energy intake (Anderson & Michal 1978; Clair 2009; Drach & Karam-Filho 2014). Traditional architecture in some cultures adopted the courtyard as a special form to create the core of the traditional house, especially in hot and warm areas (Muhaisen & Gadi 2005). The courtyard can moderate the thermal conditions for the surrounding spaces and improve the lighting levels (Safarzadeh & Bahadori 2005; Vaisman & Horvat 2015).

This research will adopt the courtyard as a passive design solution for educational buildings in hot climates, such as the UAE. As in most previous research, the courtyard was related to houses or buildings in general more than educational structures, such as schools. This research will investigate and highlight the courtyard's role and ability in enhancing the thermal performance for school buildings toward creating green schools with less energy intake and reduced CO_2 emissions. Moreover, the research will study the outdoor thermal comfort (PMV) for the courtyard, to investigate its ability to provide a pleasant outdoor space that can positively affect students' satisfaction by improving their social interaction. In addition, the courtyard structure will be assessed for its impact on the mental and physical wellbeing of students, especially during break time. This study will use a computer simulation methodology, by adopting Envi-met software to evaluate the outdoor and the indoor thermal effects of the school courtyard, and IESve software to calculate the energy consumption of the buildings with courtyards for comparative analysis. The findings of this study will be important for architects, sustainable developers, educational developers, and economic consultants beside green buildings designers.

1.2 Research problem, motivations, significance, questions and aims

1.2.1 Research problem

Energy consumption in buildings accounts for 40% of all energy consumption in the UAE (Dubai Municipality 2015; Unep.org 2016). Hejase and Assi (2013) stated that electricity consumption increased more than twelve times, from 5.87 billion kWh in 1980 to around 79.54 billion kWh in 2009 (11,463.63 kWh per capita in 2009). This is an indicator for the high annual consumption rate which is nearly 10% compared to a world rate which is around 3%. The energy capacity in the UAE is around 24.9GW, most of it consumed by buildings (Jime.ieej.or.jp 2016). The footprint in the UAE is 10.7 gha/cap (global hectares per person) (Uae.panda.org 2018; Ewing et al 2010) as shown in figure 1.1. This significantly exceeds the world average per person footprint (Afshari, Nikolopoulou and Martin, 2014) which is 2.1 hectares. Moreover, the residential commercial buildings in the UAE consume 225% electricity than their European counterparts (Khawaja 2012). Therefore, energy efficiency in buildings is a major concern in the UAE (Afshari, Nikolopoulou and Martin 2014).

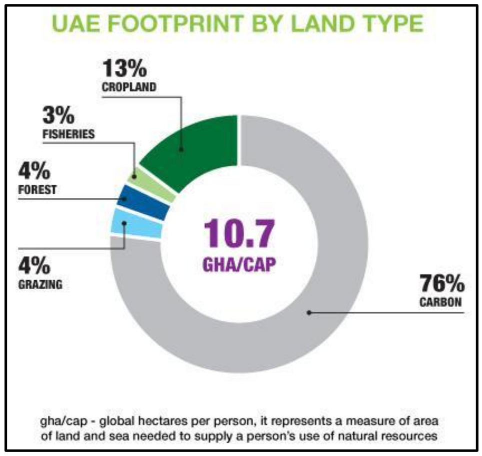


Figure 1. 1: UAE footprint by land use (Uae.panda.org 2018).

The demand of buildings in both the private and public sectors in the UAE is increasing in order to handle the growing population, consequently a huge amount of energy from fossil fuels is required for cooling and dehumidifying these buildings, amounting to about 170 to 240 kWh/m2 (Hausladen, Liedl & De Saldanha 2012). Thus, cooling in buildings (residential, public, services and so on) consume around 70% of the energy in the UAE, and that increases the pollution in urban areas (Clair 2009; Perdikis 2015) and restricts economic growth (Afshari, Nikolopoulou & Martin 2014). Katanbafnasab and Abu-Hijleh (2013) stated that the dependence on fossil fuel to maintain the luxury lifestyle in the UAE was not a clever practical solution, as the high energy consumption required for buildings increases the CO_2 emissions and accelerates climate change. Cantón et al. (2014) indicated that building designs and concepts should be developed as a response to the location and climate conditions of a given structure. In the case of the UAE, architects have focused on imported designs with specific function or form more than designs that can cope with the harsh desert conditions (Clair 2009). This can likely be explained as the preference of people in the UAE for modern style buildings with large areas of glass on the elevations, which required significant amounts of energy for cooling (Al-Masri & Abu-Hijleh 2012; Beriatos 2003). Afshari, Nikolopoulou and Martin (2014) stated that the chillers in the UAE consume around 57.5% of the total building energy consumption (figure 1.2).

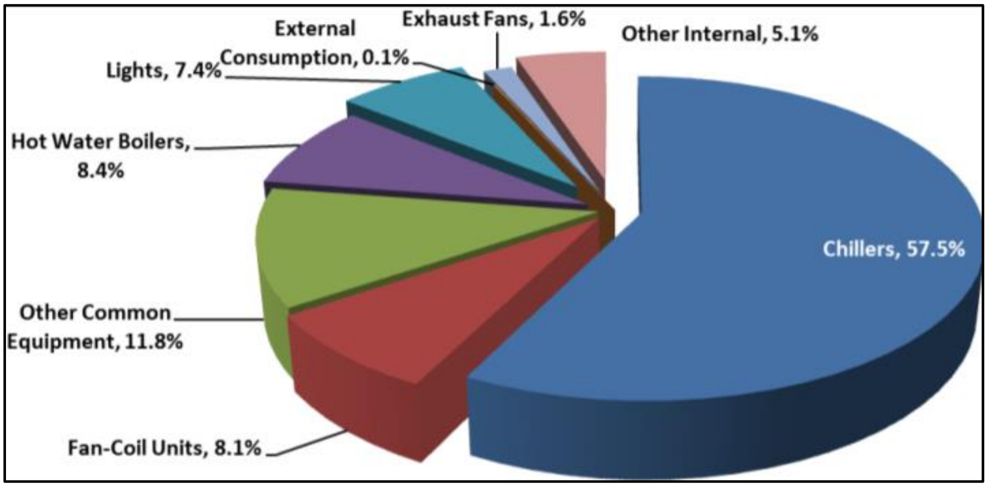


Figure 1. 2 : Electrical energy consumption according to end use (Afshari, Nikolopoulou & Martin 2014).

Schools, as part of the built environment, consume a lot of energy to provide comfortable conditions for students that have to meet high standards for education (Desideri & Proietti 2003; Al-Khatatbeh & Ma'bdeh 2017; Zhang et al. 2017), such as adequate lighting, appropriate thermal levels especially in the hot weather of the UAE. This is exacerbated as schools are occupied in the day time, mostly from morning until afternoon when the temperature is in its peak.

Schools consume around 100 kWh/m2/year in the UAE (Swiss International Scientific School Dubai 2015) while in Greece, for instance, it is only 57 kWh /m2/year as it has a cooler Mediterranean climate (Hernandez, Burke and Lewis 2008; Dias Pereira et al. 2014). Consequently, schools and other private buildings in particular are candidates with significant potential to reduce energy consumption (Santamouris et al. 2007; Dias Pereira et al. 2014; Thewes et al. 2014; Sekki, Airaksinen and Saari 2015; Gov.uk 2016). The large number of schools, in addition to their high energy consumption, have led to an urgent intervention in school building design for energetic efficiency and savings (Desideri & Proietti 2003; Al-Khatatbeh & Ma'bdeh 2017), which is the main focus of the research. Schools can be designed according to passive design solutions to reduce energy consumption. The traditional passive design solution, such as courtyards and Badgir, were dominant in traditional UAE architecture and used to maintain comfortable indoor environs in the hot local climate (Clair 2009). However, unluckily these solutions were ignored after the discovery of oil, and the usage of chillers (Katanbafnasab & Abu-Hijleh 2013).

The UAE government responded to the world's requests to reduce CO_2 emissions, and established a target to reduce energy consumption from fossil fuels by using renewable energy to create more stable sustainable environment and mitigate climate change (Masdar & IRENA 2015; Hejase and Assi 2013). The UAE target is to produce about 24% of the required energy from green sources by the year 2021 to mitigate climate change (Mittal 2015). This target mainly depends on the production of renewable energy which is expensive in cost compared to the passive design concepts in buildings which are supposed to be cheaper solutions and can decrease the energy intake of buildings with less cost. Building Bulletin 101 (2016) and Drach and Karam-Filho (2014) indicated the prominence of passive design solutions and their role in adjusting the energy consumption of buildings.

Passive design concepts do not integrate electrical and mechanical devices, on the contrary they act as reaction to the climatic effect (sun and wind), available materials, location and many other factors. Clair (2009) stated that the traditional architecture in the UAE was created as a result of the harsh hot climate as it functioned as a passive design technique and it has the potential to be employed in the future. The courtyard is one of the passive design concepts that was ignored and can be readopted as a practical solution for cooling, lighting, ventilation and social interaction for many types of buildings in the UAE. The courtyard as a traditional basic cell of the building (private or public) (Amiriparyan & Kiani 2016) was established many centuries ago in the Middle East, especially in hot and warm areas (Muhaisen & Gadi 2005), because of its ability to improve the thermal conditions and the lighting in the adjoining masses (Manioğlu & Oral 2015). The courtyard retains the cold air at night and offers shading in the daytime hours (Safarzadeh & Bahadori 2005; Gidlöf-Gunnarsson & Öhrström 2010).

Many studies investigated the building form on the energy consumption mainly for office buildings but school building geometry was less investigated (Zhang et al. 2017). Moreover, many studies were conducted to explore the courtyard's role in increasing the thermal efficiency of buildings, but unfortunately most of them focused on the courtyard as a passive design solution for houses or buildings in general. Accordingly, there was a gap in the literature about courtyards in schools, which has contemporary special criteria according to its large area, type of occupancy and time of occupancy. Abanomi and Jones (2005) and Al-Khatatbeh and Ma'bdeh (2017) mentioned that the high occupancy of the classrooms in school buildings is the direct reason for the high energy consumption, which is required to provide suitable indoor thermal, air and lighting conditions. Abanomi and Jones (2005) added that a student produces in a representative school around 70-100 w/h according to his activity. Zomorodian,and Nasrollahi (2013) argued that in spite of the high energy intake, appropriate thermal conditions are not regularly provided in classrooms.

Soltanzadeh (2011) stated that the courtyard's role in the traditional old schools is similar to the house courtyard's role because of the green areas and private atmosphere. Hyde (2000) and Edwards (2006) stated that the courtyard was a tactic for house design. Furthermore, there are other previous studies that investigate the courtyard's effects on buildings in general, which focused on the environmental field, including thermal performance, ventilation, courtyard landscape role, adjusting the noise,amongst other factors.(Fardeheb 2008; Bagneid 2010; Tablada 2013; Acosta, Navarro & Sendra 2014; Kim, Yang & Kang 2014; Jamaludin et al. 2014; Zhang et al. 2014; Martinelli and Matzarakis 2017). Despite the fact that Aldawoud and Clark (2008) stated that courtyards can be efficient in low height buildings, Zhang et al. (2017) insisted that courtyards were lightly investigated in school buildings which are low rise in general. As a result, courtyards can have the ability to offer a rational passive design solution for educational buildings, which have low rise structures, such as schools. This research will inspect facts related to the courtyards as passive design solutions for school buildings in hot and humid climates,; the field of the research will be in the context of the UAE.

1.2.2 Research motivations:

The research motivations of this study were mainly to mitigate the climate change and decrease the CO_2 emissions, in addition to creating healthier cities according to Roberts' (2008) statement, that building design should be counted as one of the methods of mitigation and reducing CO_2 emissions, while providing and preserving comfortable internal conditions. Accordingly, this research focuses on means to decreasing the energy consumption in buildings, mainly schools, for cooling. The main idea was how to design sustainable green schools with proper courtyard ratios as passive design solutions for sustainable schools, because schools in the UAE are designed in a way that increases the solar gain for the internal spaces and that require a lot of energy for cooling

(Al-Sallal 2010). Based on that, de Santoli et al. (2014) argued that the main criteria of all classrooms is the high energy consumption.

Schools, as part of the built environment, consume a lot of energy to provide comfortable conditions for students that have to meet high standards for education (Hong, Koo & Jeong 2012; Dias Pereira et al. 2014; Sekki 2015), such as adequate lighting and appropriate thermal levels (Al-Khatatbeh & Ma'bdeh 2017), especially in the hot weather of the UAE. More motivations came from the lack of studies related to the geometry of school buildings to improve their thermal performance (Zhang et al. 2017), such as using courtyards as passive design solutions to modify the thermal performance of school buildings.

1.2.3 Significance of the research

This research is expected to deliver high value and critically defined outcomes. The research will evaluate the courtyard concept in a comprehensive way under the pillars of sustainability within environmental, economic and social contexts. Moreover, the research will highlight the courtyard's role in improving the thermal behavior and the natural lighting levels in school buildings, and consequently reducing the CO_2 emissions and mitigating the climate change. There was a gap in the literature related to the thermal effects of courtyards combined with school buildings directly, as this was seldom discussed in the previous body of literature (Zhang et al. 2017).

Courtyards were mainly related to houses as passive design solutions to improve the thermal behavior and the ventilation of the houses and building in general (Al-Hemiddi & Megren Al-Saud 2001). There is a difference between house building and school building in terms of the number of occupants, time of occupancy, type of equipment, design of the building and so on. For example, Manioğlu and Oral (2015) investigated a courtyard's thermal performance for buildings with ground areas that ranged between 100-200m^2, Ghaffarianhoseini, Berardi & Ghaffarianhoseini (2015) examined another building with a courtyard that had an area of about 576m^2, while one of the schools which will be investigated in this study named 596 (governmental school) has an area of about 1458m^2. It is important to mention here that Cantón et al. (2014) evaluated the thermal performance of a courtyard in a school building in Argentina, however, this was an assessment process for refurbished pre-elementary school with an area around 300m^2 only. Moreover, the occupancy of schools is high compared to the occupancy of houses, as Al-Khatatbeh & Ma'bdeh (2017) declared, the high occupancy of the classrooms in the schools is one of the reasons for the high energy consumption required to deliver appropriate thermal settings. Abanomi and Jones (2005) added that a student produces, in a representative school, around 70-100 w/h according to his activity. In addition, the occupancy time for a school is limited to schooling time, unlike for houses.

A limited number of studies have discussed the school courtyard, and most of them focused on the ventilation and landscaping, more than on the thermal effect. Soltanzadeh (2011) argued the importance of the presence of trees in old traditional school courtyards to provide a more relaxing atmosphere and more shaded areas for studying, and he did not discuss the thermal and the lighting effects of the courtyard on the school building. Banerjee and Annesi-Maesano (2012) used measurements form school courtyards to evaluate the outdoor and indoor rates of air pollution in schools and classrooms without any further discussion for thermal effects. Grün and Urlaub (2015) pointed to the importance of providing pleasant outside natural views for the students in schools and they nominated courtyards as a proper design frame for that purpose. Khodabakhshi, Foroutan and Samiei (2016) mentioned that the courtyard was as a basic element in traditional school buildings, but in some modern schools the basic courtyard has disappeared and been replaced by a linear design.

El-Bardisy, Fahmy and El-Gohary (2016) insisted on the importance of courtyards in schools as space for activities and relaxation;, they added that a courtyard within a school building should have proper landscaping and shading devices to improve the thermal conditions of the school. Kang, Lee and Jung (2016) mentioned that the school courtyard helped in the school experimental learning. Thus, this study will be of great importance as it will define the proper ratios for the ideal courtyards with the suitable thermal performance for contemporary and future school buildings in hot humid areas, by investigating case studies of school buildings (public governmental schools) with different proportions, heights and configurations of courtyards, and then it will point to the optimum ratios for those courtyards. Additionally, this study will estimate the influence of the micro-climate conditions for school buildings which was created according to the courtyard improvements before calculating the energy consumption for the schools. Using the new estimated microclimates for calculating the energy consumption is expected to give more accurate results about the energy consumption than the general climate of the country; this approach has rarely been used in the previous studies as in Sharmin and Steemers (2015) research which was about buildings in general. Moreover, this study will define the traditional method to enhance the thermal efficiency of the courtyards, which is landscaping. Finally, this study will investigate the thermal comfort (PMV) for the courtyard of the school to evaluate its ability to provide suitable, pleasant and social outdoor space, specially at the break time. The results of this study can provide the architects and designers with a framework for designing sustainable green school buildings based on passive design concepts for a better future in the UAE and areas with a similar climate.

Based on the previous studies, the courtyards can be of great value for schools due to the following reasons:

First: The courtyard environmental effect:

a- The courtyard can mitigate the influence of the hot climate and improve the thermal performance, the cooling and the ventilation for the internal spaces around it with the least energy intake.

Second: The courtyard economic effect, which can be clear on more than one level:

a- The school level: as courtyards can decrease the energy consumption for schools, consequently the electricity bill, moreover the courtyard strategy can decrease the capital cost of the school buildings as less equipment for cooling is used. In return, courtyards in school buildings with the proper proportions and sizes can save a lot from the government budget every year, as the public school buildings in the UAE consumed around 18.5% from the education budget, which was around 16.43% of the total budget of the country on the year 2010 (Ministry of Education – UAE 2013).

b- The UAE level: as improving the energy efficiency by courtyard will reduce the cost for mitigating the climate and future carbon costs.

Third: The improved PMV levels of the courtyards can support the social life of the students. As courtyards can improve social interaction and the satisfaction of the students toward the school building, that will advance their ability to study and their educational achievement. Despite the limited time that students spend in the courtyard, but that time is suitable for social interaction among them, especially if it is in the break, lunch or sport activities times and even in some science classes, if the courtyard contains plants, sand, and so on.

Thus, courtyard designs can be developed and integrated with contemporary concepts of design for green schools.

1.2.4 Questions of the research

Most of the publications about courtyards in many studies, projects and theories highlighted the importance of the courtyard in houses as an environmental tool design without focusing on the associated economic and social effects. Moreover, few studies implemented the concept of a courtyard in school buildings because of their thermal effects, raising many important questions:

1. What role can the traditional courtyard concept play in modern school buildings in order to minimize the energy consumption for cooling (environmental wise), thus reducing the electricity bill and the capital cost (economical wise) in hot arid areas?
2. Can the suitable orientations, configurations, ratios and height of the school courtyard beside the green areas, increase its efficiency?
3. Can the optimum school courtyard (less energy consumption for the indoor spaces) produce better outdoor thermal comfort (PMV), which can affect positively the students satisfaction by improving social interaction, the pleasant outdoor space and mental and physical wellbeing?

1.2.5 Aims of the research

Schools are educational buildings that consume a lot of energy to maintain comfortable climatic conditions for the interior spaces according to high levels and standards. As a result of the large number of schools in the UAE on the one hand and because of the high energy consumption in schools on the other hand, an urgent intervention is required to minimise the energy consumption in schools without affecting negatively the wellbeing of the interior spaces. The research aims to integrate a well-designed courtyard as successful passive design strategy in the school buildings in the UAE to reduce the energy consumption for cooling, which will have positive environmental and economic effects, as courtyards have proved, over time, their positive interaction with the hot climate. On the other hand, the study aims to highlight the thermal comfort improvement for the optimum school courtyard (PMV), which is expected to affect positively student satisfaction toward the school building by providing an enjoyable area for school socialization and the psychological and physical health especially in the break time.

1.2.6 Objectives of the research

1. To assess the impact of the courtyard as a passive design solution for school buildings in hot areas and evaluate its environmental effects by reducing the energy consumption through all the academic year.
2. To identify the best orientation for the school courtyard in hot arid areas / the UAE
3. To identify the best ratio for courtyard area to built-up area (CA/BA) that can decrease energy consumption.
4. To identify the optimum ratios for the courtyard width to length (W/L) ratio for the best courtyard configuration for school buildings.
5. To identify the optimum height for the best courtyard configuration for school buildings..
6. To improve the thermal characteristics of the courtyard integrated into a school building by adding green areas.
7. To calculate the energy consumption according to the new microclimates, which was created according to the improvements on the design of the courtyard.
8. To Explore other secondary effects of the optimum school courtyard, such as the outdoor thermal comfort (PMV), which can improve student satisfaction in relation to school building by improving school socialization and providing enjoyable outside areas in addition to the psychological and physical health. Bearing in mind that the main concern of this research is the impact of the design of the courtyard on the indoor environment (indoor temperature and cooling load).

1.3 Methodology outline:

The research will follow a qualitative methodology, with different practical methods (figure 1.3) to establish more accurate comprehensive results with fewer uncertainties (Creswell 2003; Bell 2010; Robson 2011; Angell and Townsend 2011). The different methods will help to achieve the objectives and meet the expected outcomes. The research adopted case studies for investigations. The case studies are the public schools in the UAE. The reason behind choosing the public schools is that they have defined templates (mainly five), whereas the private ones have many design types. Moreover all of the public schools have courtyards but not all the private ones do. The courtyards in the public schools do not have clear standards that define the shape, the type, the proportions or the orientation of the courtyards in schools. Furthermore, the regulations only focus on the area of the play grounds in the schools. The data for the research was collected from annual statistics and journal articles and field measurements, in addition to information about the real case studies. The study will use a computer simulation: ENVI-met software to evaluate the outdoor and the indoor thermal performance of the school courtyard, and IESve software to calculate the energy consumption of the buildings with courtyards for the comparative analysis.

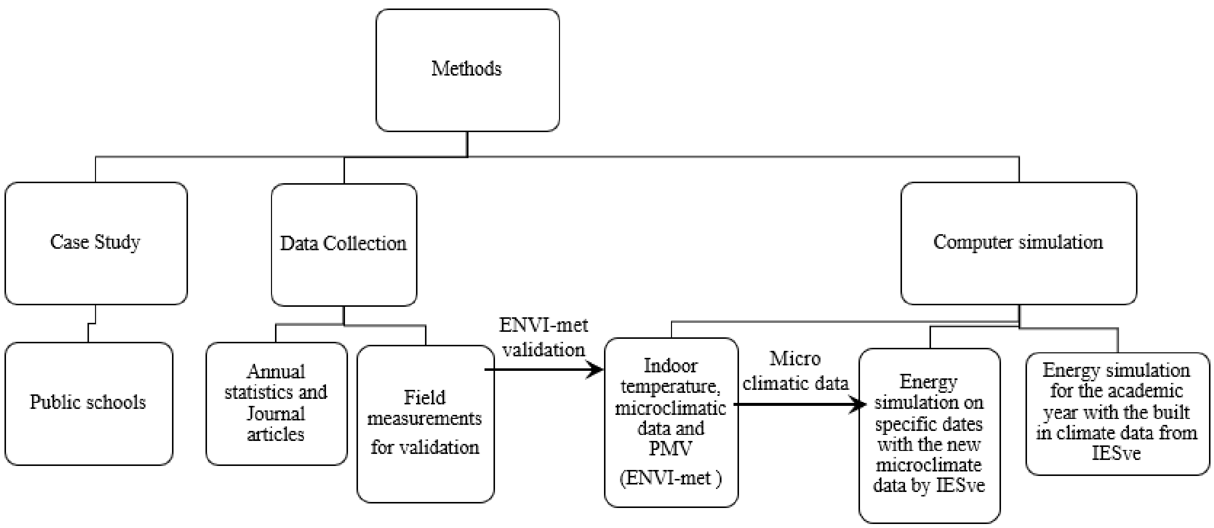


Figure 1. 3 : The recommended methods for the study.

1.4 The Research structure

UAE schools are assumed to form one of the highest sectors in the built environment that consumes a lot of energy for cooling and lighting, thus it is important to think about ways to reduce the energy consumption in these buildings. This research will investigate the role of the courtyard as a passive design solution for school buildings in the UAE, which can reduce the energy intake for cooling. The literature for this research, data collection, investigation and the results will be arranged in eight chapters as per the following:

1- Chapter one: Introduction

This chapter will include a general introduction about the research and the importance of the use of courtyards as passive design solutions in hot arid areas like the UAE. Moreover, it highlights the research problem and a brief about the methodology. In addition, this chapter will contain the aims, objectives, questions and the significance of the research.

2- Chapter two: Literature Review

This chapter will present a clear literature review related to the research questions and objectives. Starting with general ideas about passive design solutions in school buildings, then this chapter will include a wide overview of the courtyards design parameters, types, shapes and development of the courtyard in the past, present and expected future. This will be in addition to the thermal, lighting and social effect of the courtyards that make it a positive component in the school design. Moreover, this chapter will include a historical background about school building design in the UAE, and the present situation of the public schools that consume a lot of energy to maintain comfort for students. Then there will be a discussion of the sustainable necessities that should be available in the modern school design, such as courtyards as passive design solutions. The gathered data should include all the issues related to the research to create a solid base for the investigation and facilitate the process of answering the questions and achieving the objectives of the research.

3- Chapter three: Methodology

This chapter will discuss the methodology that will be used for this research and suits the aims, answers the questions and achieves the objectives with the proper justification for the approach. The research will follow the empirical aspect that depends on qualitative methods to find new applications of existing practice related to the role of the courtyard as a passive design solution for school buildings. This chapter will include the main methods of the research which are data collection, case studies and computer investigation (simulation and analysis). In this chapter, there will be a discussion for other issues like the research limitation.

4- Chapter four: Case studies and validation

This chapter will discuss in depth the current situations for the case studies which are the five main types of the public school buildings, including the climate, locations, sizes. Moreover, this chapter will investigate the present courtyards in the case studies of the public school buildings and their shapes, proportions, orientation and design, to highlight ways to improve their passive performance and efficiency. Furthermore, this chapter will focus on the data collection for the research analysis within different stages, such as interviews with staff members in the building sector from the Ministry of Education and Ministry of Public Works, as well as field notes about the school courtyard shape and characteristics. Moreover, in this chapter there will be a validation for the ENVI-met and IESve software. Finally, this chapter will include the simulation conditions, climate and dates, in addition to the simulation matrix and stages.

5- Chapter five: Courtyard Orientation.

In this chapter there will be modeling and investigation for the first parameter for the assessment of the school courtyard, which is orientation for all the cases in all directions in the current designs. The simulation and investigation will be conducted by ENVI-met software, then the results will be compared to choose the best model with the best orientation based on the indoor air temperature.

6- Chapter six: Courtyard Design and Energy Consumption

This chapter will include two stages: the first part of the first stage will include the data modeling and analysis for the best case from chapter five with the best orientation but with new parameters like the courtyard area, proportions, ratios, height and landscape. The computer simulation in this stage will be conducted using ENVI-met software. According to the results of the indoor air temperature from all cases, the optimum case for the courtyard in the school building will be defined. Then, the second of the first stage will include evaluation for the courtyard outdoor thermal comfort PMV, through the phases of the development of the optimum courtyard. This is done to highlight the ability of the courtyard to provide a comfortable pleasant and social outdoor space, which is expected to increase the satisfaction about the school buildings.

The second stage two will include calculations for the energy consumption savings according to the development of the optimum courtyard process. This part will adopt the IESve software for the energy consumption calculation and comparison. The gathered data results of the modeling will be analyzed in descriptive, interpretive and comparative manners to highlight the best characteristics and proportions for the courtyard which can produce a better environmental impact in the school buildings.

7- Chapter seven: Results, findings and conclusion.

This chapter will include two parts. The first part will summarize the objectives and findings. It will highlight the relationships between the research questions, aims and the final findings and conclusions of the study. This chapter will include clear results which will explain the significance of the courtyard proportions on the courtyard performance in improving the thermal performance of the school buildings in general, beside the important role of the landscaping on the efficiency of the courtyard to create sustainable schools in hot arid areas like the UAE. Finally, the results will highlight the comfort levels in the courtyard in the break time which is expected to improve the social life of the students. The results and the findings of this study will be important to improve healthy sustainable school buildings. The second part of this chapter will highlight two sections of recommendations: the first section will include design recommendations for school courtyards in hot areas based on the results of this research for architects, sustainable developers, educational developers, economic consultants as well as green building designers. The second section of recommendations will point to the related future studies about courtyards in the school buildings to be carried by others to complement and continue this research, which in return will cover the research limitations like galleries and shading devices in the courtyards, and that will expand the knowledge about the courtyards in school buildings as passive design solutions.

1.5 The research outline:

Table 1. 1: The research outline

Global concerns	Causative factors from the literature review	Research rationale and Motivations	Research Questions	Research Aims	Research objectives	Methods used for investigation
High level of CO2 Air pollution Climate change	High energy consumption by buildings in hot areas like UAE mainly for cooling	High energy consumption in the school buildings which led to more CO2 and more pollution Unlimited consumption of the electricity in the schools caused extra cost for fixing the damage of the CO2 emission	What role can the traditional courtyard concept play in the modern school buildings in order to minimize the energy consumption for cooling (environmental wise) thus reducing the electricity bill and the capital cost (economical wise) in hot arid areas?	Integrate a well-designed courtyard as successful passive design strategy in the school buildings-UAE to reduce the energy consumption (for cooling and lighting) and that will have positive environmental and economic effects, as courtyards showed by time its positive interaction with the hot climate.	To assess the impact of the courtyard as passive design solution for school buildings in hot areas and evaluate its environmental effects accordingly the economic effects by reducing the energy consumption.	Qualitative -Case study Field measurements Observation & Interviews Modelling using IES and ENVI-met Comparing the results
	Limited literature about the passive design solutions in schools in UAE	The need of green schools with passive design solutions like courtyards to save the energy	Can the suitable ratios and configurations of the school courtyard beside the green areas, increase its efficiency?	Define the characteristics of the optimum courtyard with relation to orientation, ratio to the built-up area, proportion, height and green area	To identify the best orientation for the school courtyard in hot arid areas /UAE	Modelling using ENVI-met with new parameters related to the orientation
					To identify the best ratio for courtyard area /built up area that can decrease the energy consumption.	Modelling using ENVI-met with new parameters related to courtyard area /built up area Comparing the results
					To identify the optimum ratios (width to length) for the best courtyard configuration for school buildings.	Modelling using ENVI-met with new parameters related to optimum ratios (width to length) Comparing the results
		The lack of the regulations related to the proper proportions for the present school courtyards			To identify the optimum height for the best courtyard configuration for school buildings.	Modelling using ENVI-met with new parameters related to height. Comparing the results
					To improve the thermal characteristic of the courtyard integrated in school building by adding green areas.	Modelling using ENVI-met with new parameters related to green areas Comparing the results
					To calculate the energy consumption according to the new microclimates which was created according to the improvements on the design of the courtyard.	Modelling using IES with new microclimates from ENVI-met Comparing the results
		The school courtyard is outdoor private isolated space, where students can spend their break time in it according to the level of the thermal comfort (PMV) and that will effect students satisfaction toward the school building in general.	Can the optimum courtyard have better outdoor thermal comfort (PMV) which can affect positively the students' satisfaction by improving the social interaction, pleasant outdoor space and the mental and physical wellbeing?	Highlight the thermal comfort improvement for the optimum school courtyard (PMV) which expected to affect positively the student satisfaction toward the student school building by providing enjoyable area for school socialization and the psychological and physical health.	To Explore other effects of the optimum school courtyard like the outdoor thermal comfort (PMV) which can improve the student satisfaction in relation to school building by improving the school socialization and providing enjoyable outside areas beside the psychological and physical health	Modelling using ENVI-met with new parameters related to PMV. Comparing the results

Chapter 2: Literature review

Harputlugil, Hensen and Celebi (2011) stated that schools are places that have significant importunate, where the forthcoming generations obtain their education, thus they should provide good thermal, acoustical and lighting conditions with less energy consumption. Cantón et al. (2014) stated that the courtyard can moderate the local weather circumstances for the school buildings, in addition to its social advantages.

2.1 Sustainable Architecture and Passive Design Concepts

Architecture is an important component to create a sustainable environment with less energy consumption (Mumovic & Santamouris 2009). Architects should manage to create sustainable architecture by considering the efficiency in the energy issues, water conservation, inexpensive maintenance, selection of the materials and waste management (figure 2.1, décor, 2015).

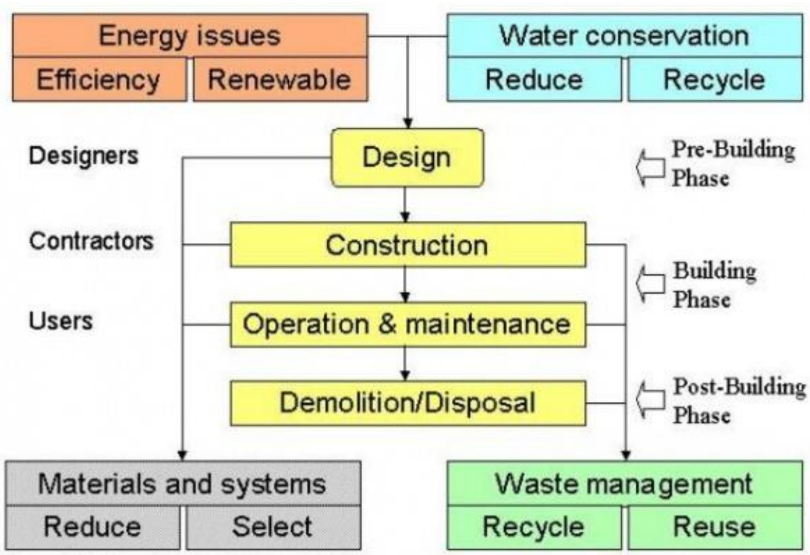
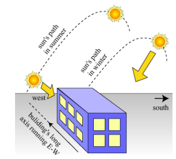
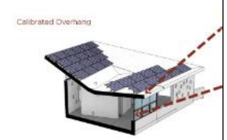
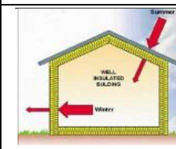
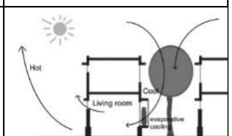


Figure 2. 1: Sustainable architecture (Decor 2015)

The role of the architect is important to avoid excess energy intake in buildings. Architects should take ideas from the traditional old architecture, because it was formed according to culture, climate and society to produce comfortable inner spaces with less energy consumption and less destruction to the natural wealth (Al Masri 2010). Gallo (1998) pointed to the architectural solutions as one of the basic divisions for a suitable microclimate. Katanbafnasab and Abu-Hijleh (2013) stated that the traditional solutions for design have become the core of the vernacular and sustainable architecture, most of these concepts are known as passive design strategies, and they are integrated in buildings design to improve the indoor thermal circumstances by consuming a minimum amount of energy (Anderson & Michal 1978; Clair 2009; Dili Naseer & Varghese 2010; Drach & Karam-Filho 2014).

Passive design strategies can reduce the energy required for cooling in hot areas (Markus 2016; Soflaei, Shokouhian and Mofidi Shemirani 2016). Passive design concepts do not depend on automatic or electrical provision, mainly they function as a response to the microclimate conditions (sun and wind), the building materials, the context of the location and so on. Rajapaksha, Nagai and Okumiya (2003) included the courtyard as an important component among the passive design solutions in the humid warm areas after investigating its potential using a CFD program. Kruzner et al. (2013) and Markus (2016) listed many passive design concepts, such as orientation, courtyards, shading devices and so on (Table 2.1). Tabesh & Sertyesilisik (2016) and Markus et al. (2017) stated that the courtyard is a good passive design solution that can be adopted for sustainable buildings all over the world. This research will adopt and investigate the courtyard as a successful passive design solution and integrate it in school buildings (with proper ratios) to improve the thermal performance of the building overall.

Table 2. 1: Examples for passive design strategies (passive design strategies 2016).

Passive design strategy	Image
Orientation: Locating the long side of the building to the east west direction to increase the solar light gain on the extended south side of the building.	
Shading devices above openings: Applying shading devices for the windows to decrease the midday sun axes in summer and allow it in winter.	
Insulation materials: Installing insulation materials to decrease heat gain or loss.	
Courtyard: Using the courtyard strategy in the building improves the natural ventilation, cooling and lighting with less energy intake.	

2.2 Courtyard

A courtyard is a surrounded area in a construction which is exposed to the sky regardless of the type of the surrounding areas (Hyde 2000; Almhafdy et al. 2013). Abass et al. (2016) and Forouzandeh (2018) defined the courtyard as a protected outside area which is opened from the top. Mishra and Ramgopal (2013) confirmed that the courtyard is an area opened to the skies and enclosed by rooms or buildings, which can be square or rectangular. Taleghani (2014) explained the difference between a patio, a courtyard and an atrium; wherein he defined the patio as a small kind of courtyard, and an example of the patio can be seen in Spanish-American households. He explained the atrium as a covered courtyard mostly with glass on top (figure 2.2). Antonio and Carvalho (2015) in their study claimed that, the importance of the courtyard is in its position in the center of the plot. They concluded that the courtyard elements, such as galleries, pavement, water and landscape, produce significant shade and light that affect positively our life and make the courtyard a natural curing space. In their analytical study about courtyard design Almhafdy et al.

(2013) insisted that the courtyard design should follow local, social, cultural and climatic factors, thus that the optimum courtyard design in some countries is not necessarily the best in others.

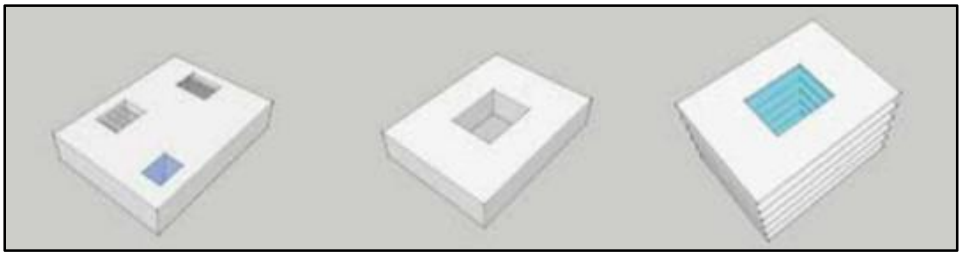


Figure 2. 2 : Left a patio, middle a courtyard and right an atrium (Taleghani 2014)

2.2.1 Courtyards timeline

A courtyard is a passive design strategy which was used in the past (Nasrollahi et al. 2017), and is still used in contemporary designs and is expected to be used in the modern and future designs for its ability in enhancing and moderating the inner spaces atmospheres, especially in the hot arid climates like the UAE.

2.2.1.1 Old courtyards: A courtyard is a pioneer passive concept that was formed thousands of years ago, since the Neolithic settlements (figure 2.3) as a response to social needs and climate conditions (Almhafdy et al. 2013). Sthapak and Bandyopadhyay (2014) mentioned that the residences of the four prehistoric urban nations of Egypt, China, Mesopotamia, and the Indus Valley as well as the residences of the Classical Roman and Greek eras, all indicate that the "courtyard form" is relatively timeless in the history of architecture. Taleghani (2014) mentioned that the courtyard's history shows that it spread in many places over the world (figure 2.4).

Figure 2. 3 : Old courtyard in the Neolithic settlements (Neolithic settlements 2016).

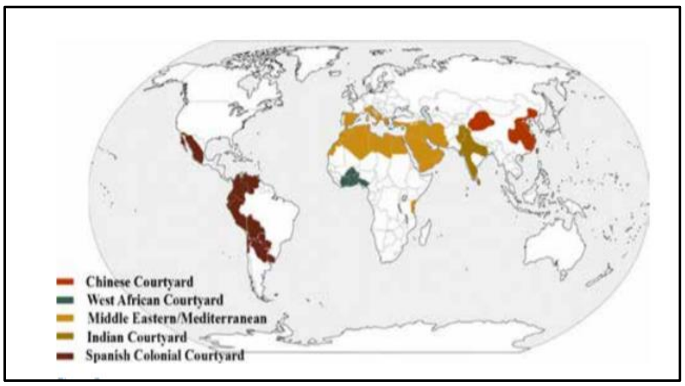


Figure 2. 4 : The distribution of courtyards around the world (Taleghani 2014).

Kolozali and Kolozali (2016) stated that courtyards managed to give a shield against the climatic forces with external threats such as hot dusty wind and capture the cool air in summer in traditional houses in Cyprus. El-Deeb, Sherif and El-Zafarany (2014) agreed that the courtyard is an effective passive solution for cooling the buildings in desert areas. Soflaei, Shokouhian and Mofidi (2016) concluded that the traditional courtyard history referred back to 3000 BC as it was used for different functions. Sthapak Bandyopadhyay (2014) listed some of the courtyard's historical purposes:1- psycho-social purpose as it gives a sense of enclosure and security. 2- cultural purpose as private space mainly for female residents. 3- economic purpose by reducing the building cost through constructing shared walls along with efficient land use. 4- climatic purpose as it was a climate modifier by cooling and shading the building.

Stage after stage, the courtyard was developed and used as a preferable design for houses in places with hot and dry microclimates (Edwards 2006). A researcher called Petruccioli made an assessment for three traditional houses with courtyards from Morocco, Spain and China, the assessment showed broad similarity in the courtyards, despite the variance in the context, sizes and surroundings (Edwards 2006). In the traditional Chinese houses the courtyard has several minor courtyards that provide a clear sense of privacy and harmony (Al Masri 2010). Maleki (2011) stated that the traditional courtyard in the Iranian desert architecture provided an effective space for social interaction beside modifying the thermal conditions of the building, especially if it contains landscape greenery.

The Islamic old courtyard became a common repeated element in the urban configuration. This courtyard was related to Islamic beliefs and other functional requirements, as it afforded thermal contentment in the internal spaces beside providing private isolated exterior space for the residents, especially females (Edwards 2006). Reynolds (2002) indicated that the courtyard was formed to be the women's private zone. Ratti, Raydan and Steemers (2003) mentioned that the courtyard was the result of the interaction between the climate and the building design in hot areas. They explained that the courtyard can improve the thermal comfort of the building. Moreover, courtyards reduce the direct solar influence on the building and provide barriers against the wind, dust and sand (Al Sammani 2014). A good example for the traditional courtyard in the UAE exists in Al Fahidi district, which has Islamic urban tissue (figure 2.5). The urban fabric of Al Fahidi district contains two types of courtyards: public and private ones. The public courtyards give a cool sense because of the air circulation that comes from the pathways into the courtyard (figure 2.6). These courtyards offer semi private and peaceful cooler public areas for the surrounding buildings (Shashua-Bar & Hoffman 2004). On the other hand, the private courtyards are located in the houses, as these courtyards provide a private area, adequate ventilation and thermal well-being. Most of the private courtyards have plants, fountains and internal staircases (figure 2.7) (Salameh 2015).

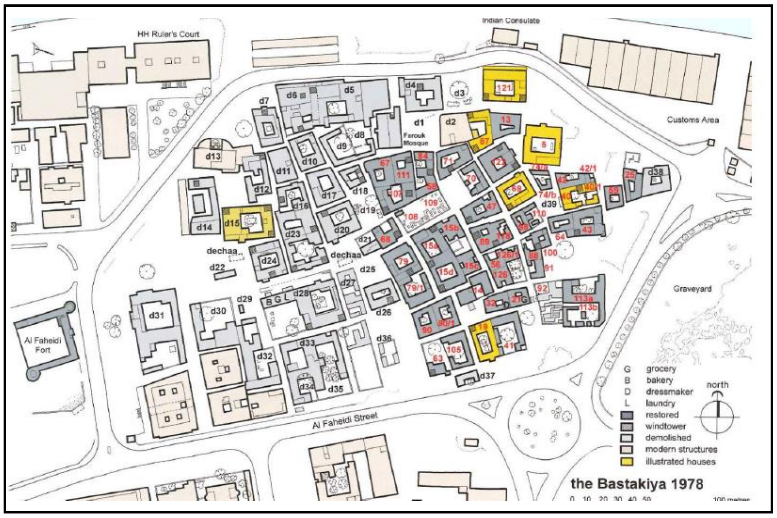


Figure 2. 5 : Al Fahidi urban layout shows integration of different types of courtyards on the urban level and in the houses. (Dubai Municipality 2015A)

Figure 2. 6 : Landscape in the Public courtyards in Al Fahidi district (Salameh 2015).

Figure 2. 7: The private courtyards have inner staircases that lead to the roofs (Salameh 2015).

2.2.1.2 Modern courtyard: The courtyard has been viewed as an old-style concept in contemporary architecture. The importance of the courtyard rose again after highlighting its efficiency in dealing with climate forces and improving the thermal settings in buildings, especially in hot environments. Edwards (2006) confirmed the importance of the traditional courtyard, he added that the traditional courtyard can be developed and implemented in the contemporary architecture in the UAE. He described the houses in the American University of Sharjah-UAE as an effective current model for the courtyard (figure 2.8). Edwards (2006) argued that the traditional courtyard is better than many modern architecture concepts, which are used in the UAE, as they do not encounter the climate and social requirements. Based on that the courtyard can be improved and integrated in the modern public and private buildings in the UAE.

Figure 2. 8: American University of Sharjah (AUS) (Lystseva 2016).

2.2.1.3 Future courtyard: The courtyard concept usage is still restricted despite its effectiveness in reacting with the hot climate. Markus et al. (2017) stated that the courtyard is a space with the potential to reduce the energy consumption in buildings. Many researchers have studied ways to implement the courtyard concept in future buildings by increasing its efficiency and capability to fit in the future construction, such as in high rise buildings. Al Masri (2010) made a study about integrating the courtyard in the midrise buildings up to 10 levels, which can provide homes for a large number of people. The study confirmed that the courtyard can be a practical element in high-rise buildings, but with some modifications related to the insulation, glassing and orientation.

A good example for a futuristic courtyard is in the Kingsdale Foundation School in London, which was created by the Architect Philip Marsh, who stated that the courtyard will provide the school with a distinctive atmosphere and natural lighting that will motivate the students to learn and to keep active (figure 2.9) (Kendall 2010). Another example for the future courtyard is found in the new concept of interrelated courtyards in Mount Litera School-India (figure 2.10), as these courtyards provide spaces for student activities in shaded and lit forms, constructed and unconstructed and in between spaces that offer "*a hierarchy of spaces for a hierarchy of activities through the day*" (Mount Litera School 2016; Behance.net 2016). Another good example for the future courtyard can be seen in Masdar City in Abu Dhabi in the UAE. Architect Norman Foster integrated a number of modern courtyards in the urban fabric of the city, these courtyards have new systems for the ventilation and shading to maximize the energy efficiency for the surrounding buildings (figure 2.11) (Masdar Development 2007).

Figure 2. 9: Futuristic courtyard at Kingsdale Foundation School (Kendall 2010).

Figure 2. 10: New concept of interrelated courtyards in Mount Litera School-India (Behance.net 2016), (Mount Litera School 2016).

Figure 2. 11: Future courtyards in Masdar city, which have special techniques for shading and ventilation to achieve maximum efficiency (Keoicsite.info 2016).

2.2.2 Courtyard and thermal comfort

A lot of research was conducted to assess and investigate the benefit of the courtyard's integration in contemporary architecture, mainly the thermal comfort that it provides in the building (figure 2.12). The thermal comfort is the state of awareness that reflects the satisfaction of the mind toward the thermal atmosphere, thus it is an individual experience that is guided by the interactive issues beside the biological and psychological factors (Nikolopoulou & Steemers, 2003; Khalfan & Sharples 2016). The thermal comfort can be defined as predicted mean vote (PMV), as it is related to a stable condition for heat balance for the human physique (Hussain & Oosthuizen 2012).

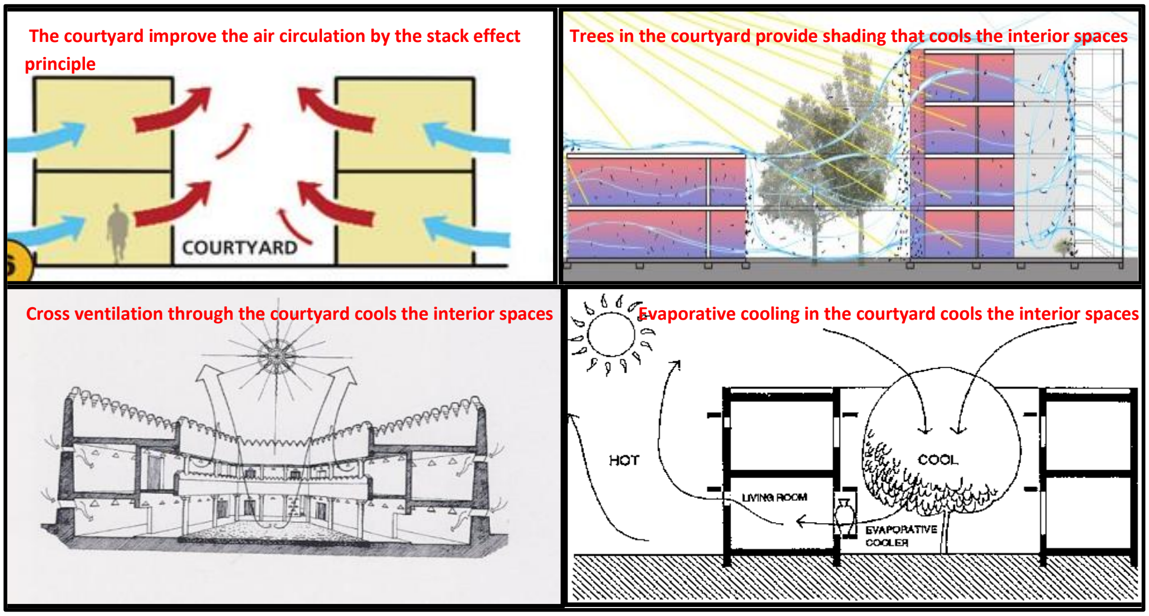


Figure 2. 12: Cooling strategies of the courtyard (courtyard cooling strategy, 2016).

Soltanzadeh (2011) stated that the courtyard was formed due to geographical and cultural reasons. Others like Sadafi et al. (2008), Taleghani, Tenpierik and van den Dobbelsteen (2014), Manioğlu and Oral (2015) and Abbaas, Munaaim (2017) and Baboli, Ibrahim, and Sharif (2015)pointed to the importance of the courtyard's role in improving the thermal conditions of buildings in hot areas. Hausladen, Liedl and Saldanha (2012) mentioned the courtyard as a solution for better thermal performance for the hot climate of Dubai. Tablada (2013) stated that the cool feeling of the air circulation in the courtyards in Havana is effective and clear, as in most cases the outdoor temperature is higher. Forouzandeh (2018) and Clair (2009) highlighted the role of the courtyard in minimizing the cooling energy required and supporting the ventilation of the building. Moreover, they pointed to the courtyards as voids that form barriers against dust and wind.

Reynolds (2002) listed three main factors that affect the thermal behavior of the courtyard which are: the ratios of the courtyard related to the building height, and the surrounding masses that affect heat loss and gain, and finally the inhabitants' actions and activities in the courtyard, like watering the plants or adding shading devices. Hyde (2000) stated that the orientation, wind direction and the economic constrains are the main three issues that should be considered when designing a courtyard. He explained the importance of the orientation of the courtyard as it defines the shaded ranges, airflow direction and thus the ventilation system. Sadafi et al. (2011) and Rodríguez Jara (2017) pointed to the courtyard as a successful passive design solution which can improve the thermal conditions of the adjacent spaces in hot areas.

Acosta, Navarro and Sendra (2014) insisted that the ventilation of the interior spaces of a house can be improved by its courtyard. Jamaludin et al. (2014) evaluated the courtyard's role in the ventilation for a midrise building, they explained that the speed and the type of the air circulation in a building within a courtyard depends on the time in the night or the day. They argued that the best ventilation can be achieved in the night time, and they also affirmed that the masses location and height around the courtyard significantly affect the ventilation system. Despite the fact that many researchers have studied the thermal behavior and ventilation of the courtyard, and they tried to improve it, most of their work was experimental.

Berkovic, Yezioro and Bitan (2012) carried out a quantitative study related to the thermal behavior in an entirely closed courtyard, and they examined the influence of the wind direction and shading elements on the courtyard. Their discussion was based on three factors which are horizontal shading components, trees and galleries. They decided that in areas with a hot arid climate the shading elements affect the thermal performance of the courtyard more than the wind direction. Moreover, they mentioned the importance of trees and galleries around the courtyard in reducing the temperature. Yaşa and Ok (2014) used a computer simulation (CFD fluent) to evaluate the solar heat gain of the closed courtyard with different proportions in different climatic areas in Turkey . They summarized that the influence of the courtyard is not the same in winter and summer despite its importance in the two cases. They concluded that the amount of heat gain for the building depends on the proportion of the courtyard, time of the year and the location of the building. Yaşa and Ok (2014) stated that converting the courtyard to be close to a square increases the shaded area inside it (figures 2.13 & 2.14), thus decreases the needed cooling energy on a hot day like 21st of July. On the other hand, this effect of the square shape has less negative consequences on a colder day like 21st January. Based on that, the yearly energy intake rises when the courtyard gets longer.

El-Deeb, Sherif and El-Zafarany (2014) used a computer simulation to evaluate courtyard performance in three different cities: Khargah, Alexandria and Cairo in Egypt, as hot arid areas, beside Berlin as an example of a temperate area (with a warm summer) for wider evaluation. The study found that the height and width/length proportions have different effects on the energy consumption of the building according to its climate. They insisted that the thicker masses of the buildings around the courtyard have better performance than the thinner ones. In another study Tsianaka (2006) studied the effect of the courtyard in the urban tissue in Athens; he stated that the difference in the temperature between the courtyard and the street can range between 1.5-3.5˚C according to the courtyard's form. Moreover, he added that the temperature in the courtyard is more stable and controlled than in the street, which usually fluctuated.

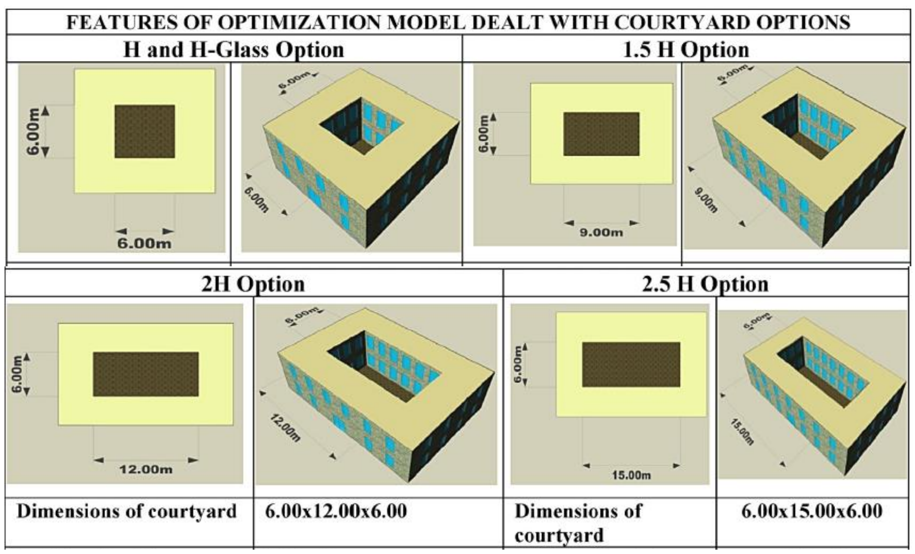


Figure 2. 13: Sample models which were adopted in the study of the courtyard optimization process (Yaşa & Ok 2014).

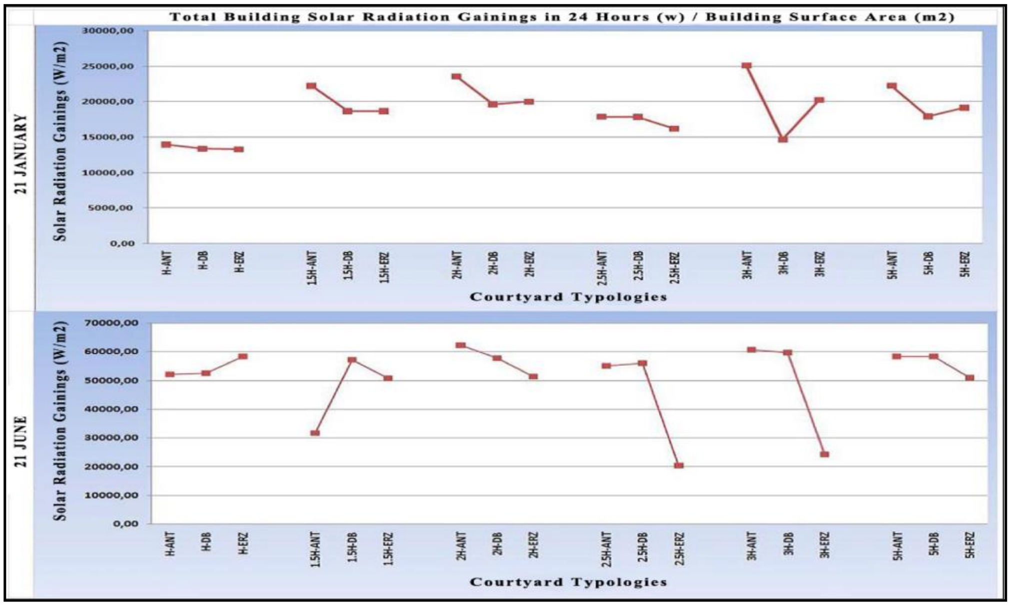


Figure 2. 14: Building solar radiation gaining's (Yaşa & Ok 2014).

Muhaisen and Gadi (2005) used a mathematical study for evaluating the performance of a circular courtyard; they determined the shaded spots and the sunlight projections in it, and finally they explored the influence of the circular outline of the courtyard on the thermal well-being. Muhaisen and Gadi (2006) conducted another study about the shade effect for a polygonal courtyard; they stated that the geometry and the ratios of the courtyard beside the sun location and the adjacent walls around the courtyard define the shaded area in it. Furthermore, they insisted that deep forms of the courtyards are more preferable in summer than winter to create stronger air circulation, and the shallow ones are better in winter to allow the entree of the sun inside the building. At the end, they proposed ratios for the courtyard as a practical solution concept for the building throughout the year. Ghaffarianhoseini, Berardi and Ghaffarianhoseini (2015) studied different configurations of courtyards in a hot, humid area in Kuala Lumpur. They insisted that the courtyard should have proper proportions and design to make the building energy efficient, as the heat gain and the shaded area depend on the design of the courtyard and its orientation (figure 2.15). Dili Naseer and Varghese (2010) conducted a survey among people in Kerala to evaluate their responses to the thermal comfort in traditional buildings with courtyards and modern ones without courtyards; it was clear in the study that the traditional buildings are more effective in providing thermal comfort than the modern ones (figure 2.16).

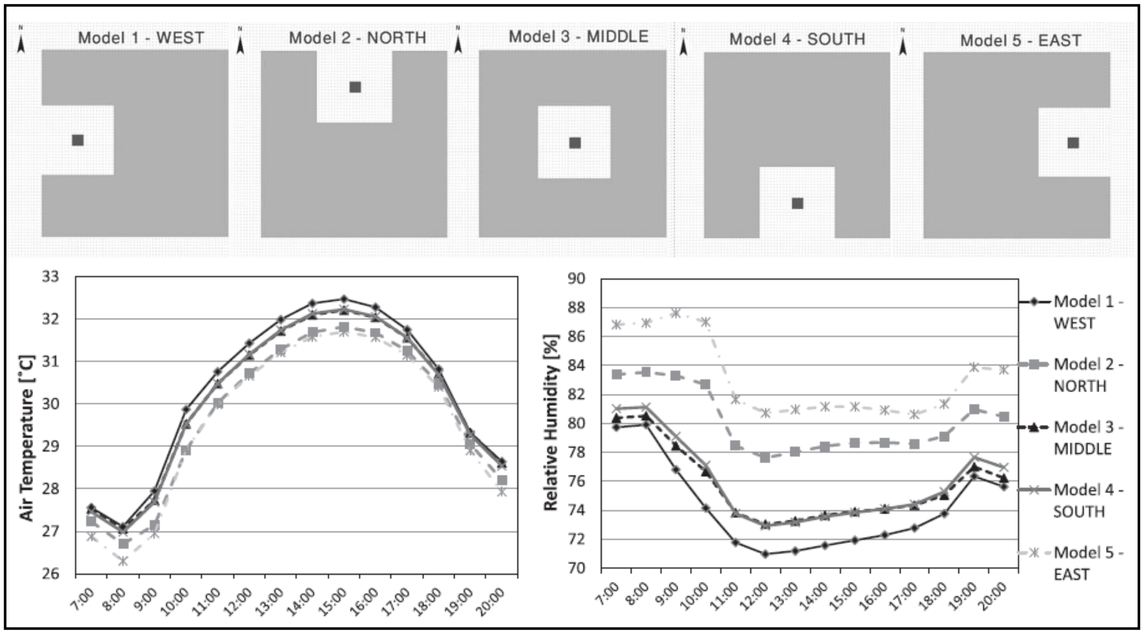


Figure 2. 15: Average air temperature (left) and humidity (right) in different configurations of courtyard (Ghaffarianhoseini, Berardi & Ghaffarianhoseini 2015)

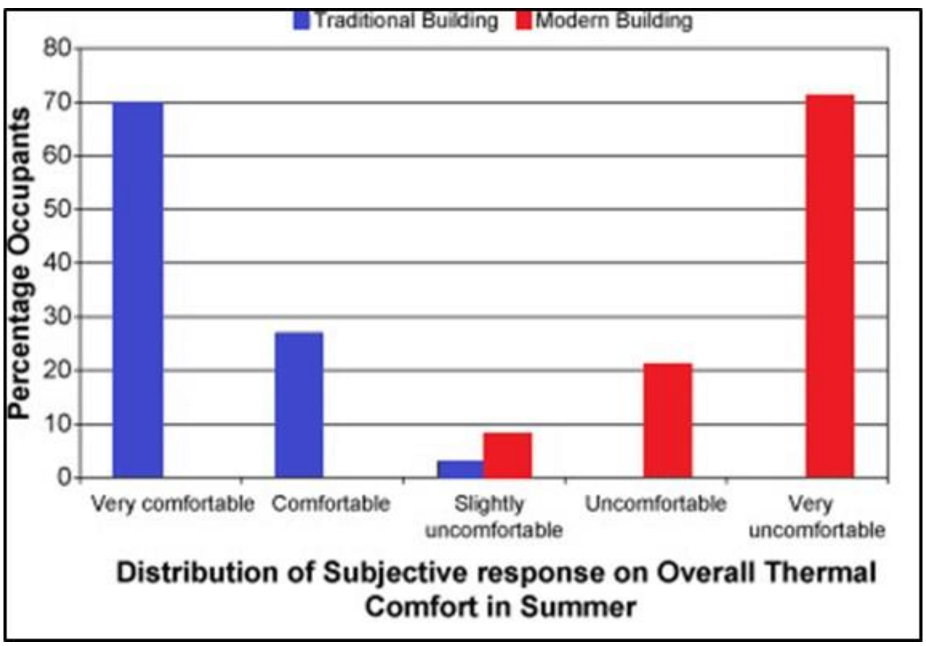


Figure 2. 16: People subjective responses on thermal comfort in summer(Dili Naseer & Varghese 2010).

Tablada et al. (2009) Stated that a lot of studies investigated the thermal comfort of people based on thermal feeling and impression in the tropical humid climates to suggest the suitable comfort levels. They mentioned many cases, among them: the first where the measured acceptable temperature with natural ventilation in classrooms was 27.1-29.3 ˚C in Singapore, while it was lower in the second case and about 26.8 ˚C in classrooms in Hawaii. They mentioned that the ASHRAE comfort standard rate for the temperature was 26.1˚C (Tablada, et al. 2009).

2.2.3 Courtyard and lighting

Suitable lighting is important for the interior spaces, as it provides a safe and comfortable optical atmosphere which enables the occupants to see and to understand the interior spaces. Moreover, proper lighting improves the performance of the visual chores. Electrical lighting is used when the natural lighting is inadequate. In study and work places lighting has three direct effects on the occupants, including the job visibility, the occupants' mood and finally the level of alertness. These three effects influence the productivity, efficiency and enthusiasm of the occupants (Fotios 2011).

In the case of schools, the lighting in the classrooms should be adequate to provide a suitable environment for learning, as most of the tasks in the classrooms depend mainly on the visual understanding. According to the earliest study conducted by consultants in the architectural engineering field and under the supervision of the Ministry of Public Works in the UAE to assess school performance, Al-Sallal (2010) insisted on the importance of the use of natural lighting in schools when it is possible, to decrease the use of artificial lighting and decrease the energy consumption. Accordingly, when the natural light accessed inside the inner spaces provides suitable visual comfort for the occupiers and decreases the energy use for electrical lighting (National Renewable Energy Laboratory with subcontractor Innovative Design 2015). In daytime, both the visual comfort and the energy use for lighting depend on the autonomy of the daylight.

The amount of the natural lighting does not only depend on the window sizes but it depends also on their location, shapes and the type of shading devices (Acosta, Campano and Molina 2016). Al-Sallal (2010) stated that the natural lighting in the classrooms is determined by the area and the orientation of the glazed openings, in relation to the depth of the classrooms (figure 2.17). He added that the limited exposure to day lighting causes problems in light diffusion, mostly in the cases of having deep classrooms with short outside walls; these cases when the design restricts the corridors sizes to decrease the expenses of the school building. Moreover Al-Sallal (2010) insisted that the problem of limited daylight can be solved by galleries, atria and mostly he recommended the establishment of courtyards in the schools. He added that courtyards can be efficiently used for lighting the surrounding classrooms. Grün and Urlaub (2015) highlighted the importance of natural lighting and natural features in schools, they proposed the courtyard as a solution for that (figure 2.18). Acosta, Navarro and Sendra (2014) stated that the courtyard is an important strategy for lighting, as well as for ventilation and cooling. Furthermore, they insisted that the height to width ratio in the courtyard affects the level of the daylight factor (figure 2.19). Muhaisen and Gadi (2005) mentioned the importance of courtyards in improving the natural lighting for the surrounding spaces. Al-Sallal and Abu-Obeid (2009) stated that in the schools the reduction of the penetrated natural lighting into the classrooms causes increases in the expected operative periods of artificial lighting. Maesano and Annesi-Maesano (2016) stated that better lighting conditions in the classrooms lead to better results for the students.

According to the previous research, the courtyard can improve the lighting in the school building , thus reduces the amount of the artificial lighting which usually consumes a lot of energy (direct electricity consumption), consequently reducing the amount of the artificial lighting will reduce the heat gain in the interior spaces and that will surely reduce the cooling load and the energy consumption in the building (indirect electricity consumption). Al-Sallal (2010) defined the best ratio for window/external walls of the classrooms as to be not less than 20% to provide suitable natural lighting for the classroom in the case that the classroom has a ratio height/depth around 1:2; this can be implemented for classrooms that have a depth around 9.1m.

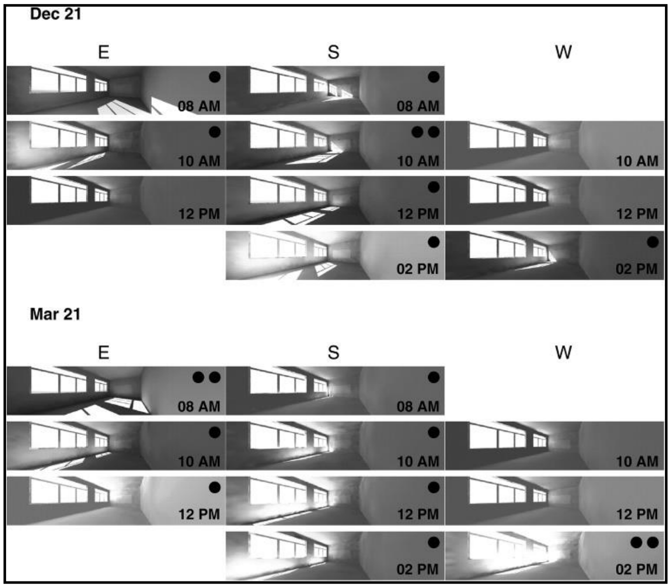


Figure 2. 17: Camera simulation for the natural light (a critical field of view) inside the classrooms for the East, South and West orientations (Al-Sallal 2010)

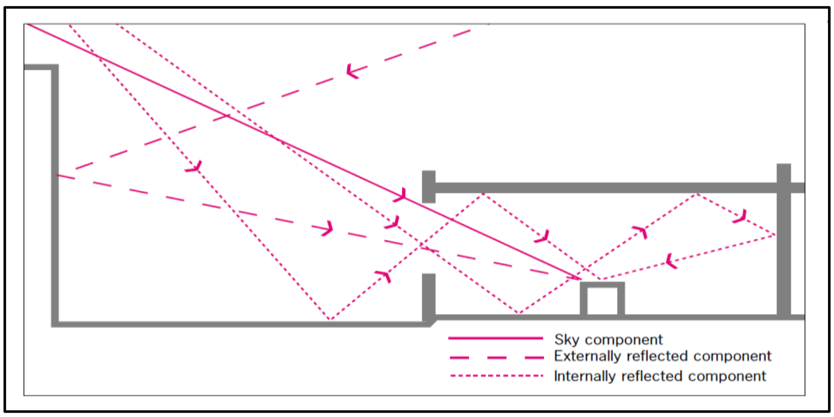


Figure 2. 18: The role of the courtyard in reflecting the natural light inside the classrooms(Gov.uk 1999).

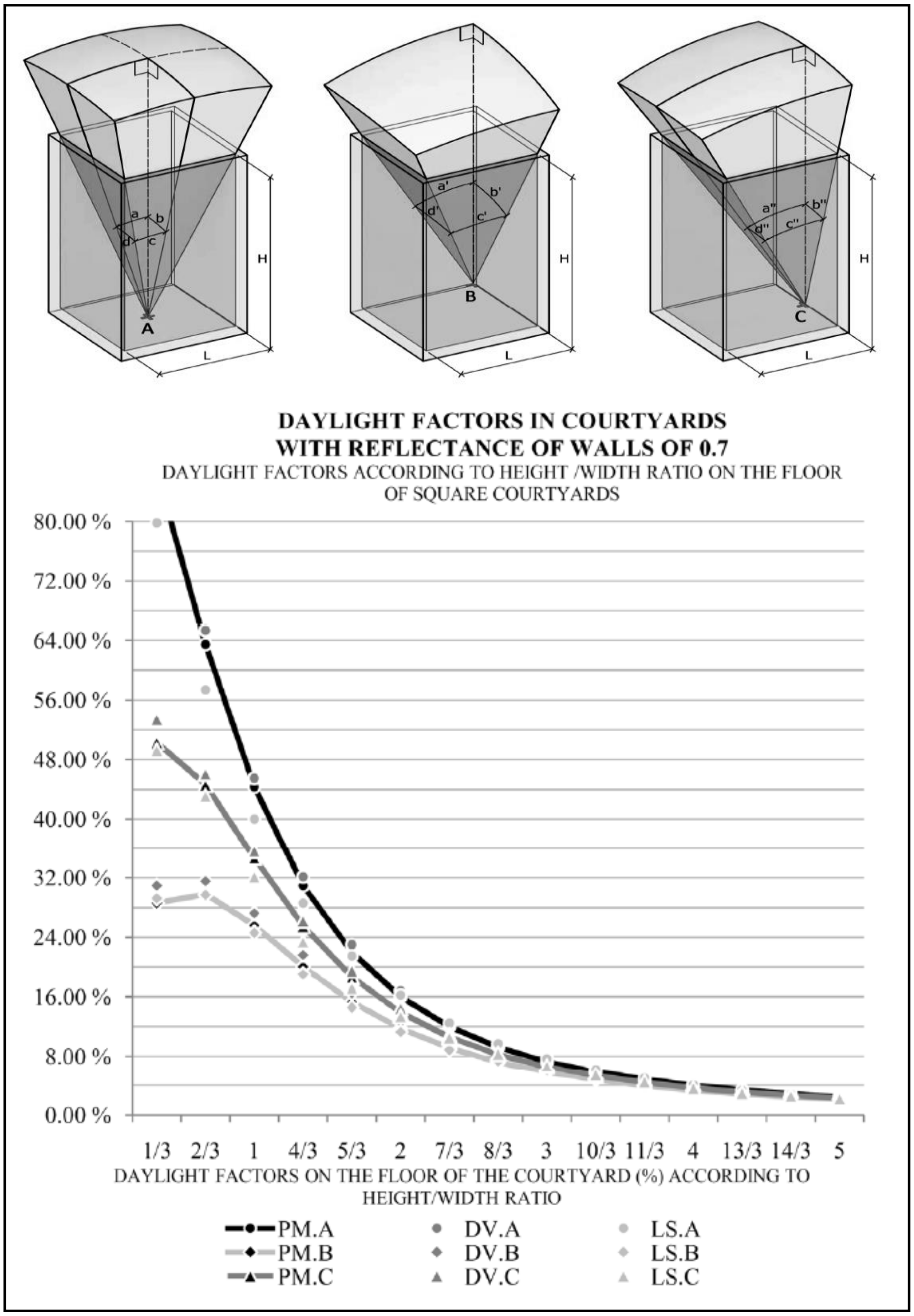


Figure 2. 19: Daylight factor on the floor of a closed courtyard according to height/width ratio (Acosta, Navarro & Sendra 2014).

2.2.4 Courtyard and student satisfaction

The satisfaction of the students is an important driver for better educational achievement. The student satisfaction can be achieved within the school building by better social interaction, enhanced learning motivations, mental and physical comfort and pleasant outdoor space. Martirosyan (2015) stated that the students' satisfaction is essential for better educational achievement. Courtyards can improve the students level of socialization, mental and physical well-being and happiness (Walden 2016). Kolozali and Kolozali (2016) Stated that the courtyard is essential in the passive and active social life for the students. Rigolon (2010) insisted on the importance of the presence of the courtyard space in a school building as an innovative reason for a better social and education atmosphere. Thus, courtyards can be an important cause to achieve student satisfaction. Moreover, Lau and Yang (2009) mentioned that natural features in the courtyard can improve the students' senses, meditation and mental well-being, and motivation. This agreed with Louv (2005) who stated in another study that "Natural settings are essential for healthy child development because they stimulate all the senses and integrate informal play with formal learning".

Ahmada and Yusofa (2010) insisted on the importance of the social interaction to overcome the hurdle between the students. Hawker (2012) pointed to the physical activities as drivers for not only physical fitness but also for mental health. The courtyards in the school provide outdoor private spaces for physical activities and emphasize on the external educational events (Rigolon 2010). Grün and Urlaub (2015) insisted that schools must provide natural lighting when it is feasible. They added that natural lighting enables the students to do their tasks comfortably and accurately and in addition it provides inspiring, interesting and pleasant environments, and that can be improved by courtyards. Buvik and Steiger (2012) and Heracleous and Michael (2017) pointed to the importance of designing energy efficient schools with suitable comfortable atmosphere for the students to increase their educational achievement and satisfaction. Matsuoka (2010) mentioned the direct effect of landscaping within the school building courtyard as a pleasing outdoor space that positively impacts on student satisfaction as it can reduce mental stress and tension. Gidlöf-Gunnarsson and Öhrström (2010) stated that the courtyard can improve the social interaction of the users and can give a sense of relaxation. Markus et al. (2017) pointed to the courtyard as a space for phycological health. Finally, the Maryland Department of Education

(2012) stated that if part of the activities of students are conducted in the courtyard that will improve the performance of the students, decrease discipline difficulties, encourage for education and support critical thinking amongst other positive effects.

Consequently, the school courtyard can have strong and positive social and psychological effects on the students, as courtyards can improve the social life and the satisfaction of the students in the school; accordingly that will improve their ability to study. Despite the limited time that students spend in the courtyard, this time is suitable for social interaction among them, especially if it is during the break, lunch or sport activities times and even in some science classes, if the courtyard contains plants and sand as well as other natural landscapes.

2.2.5 Courtyard microclimate behavior and design parameters

Soflaei Shokouhian and Mofidi Shemirani (2016) listed the main effects of the courtyard as a passive design solution 1-shade cast on the courtyard ground from the surrounding walls beside the shade on the southern wall of the courtyard; 2- shade cast from the trees in the courtyard; 3- the effect from the pool and the shrubs and flowers as they help in reducing the courtyard temperature; 4- the effect of the courtyard walls and trees in controlling the wind movement in the courtyard and the building. These effects control the thermal behavior of the courtyard, as any change in them will automatically change its microclimate. Koch-Nielsen (2002) stated that the courtyard should be designed in a way that decreases the thermal gain and encourages the breeze, while at the same time prevents the dusty hot wind. Al-Hafith et al. (2017) confirmed that the shade created by the surrounding walls on the courtyard affects its microclimate (figure 2.20), they added that this shade changes according to the orientation, the upper width and courtyard width and height.

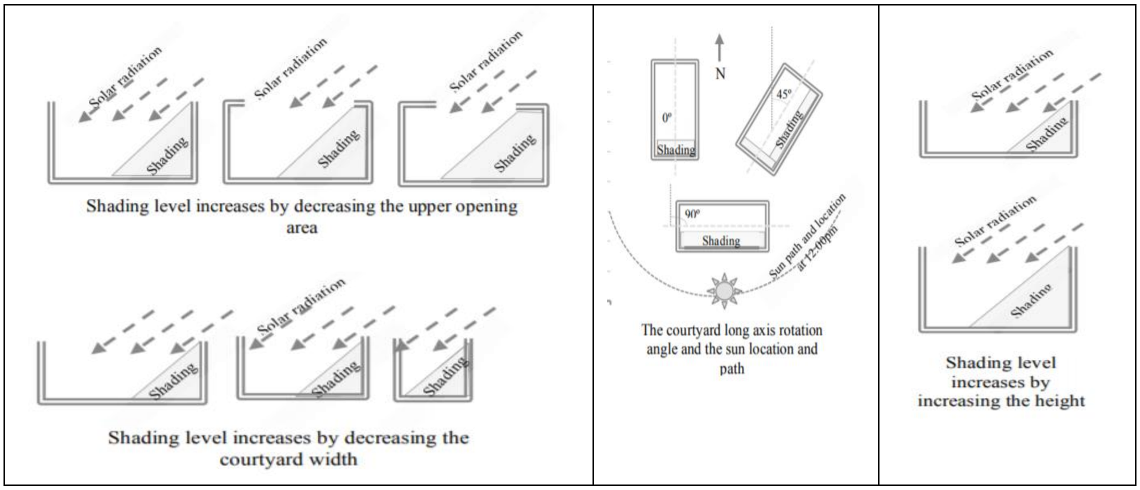


Figure 2. 20: Shade in the courtyard (Al-Hafith et al. 2017)

2.2.5.1 Courtyard microclimate behavior (stack effect)

Air circulation in the courtyard is usually created because of the stack effect (figure 2.21) **"***Stack ventilation uses temperature differences to move air. Hot air rises because it is lower pressure. For this reason, it is sometimes called buoyancy ventilation, the advantage of stack ventilation is that it does not need wind: it works just as well on still breezeless days, when it may be most needed*" (Sustainabilityworkshop.autodesk.com 2018). Rajapaksha, Nagai and Okumiya (2003) insisted that limited acquaintance to the sun for the courtyard improves its performance as a passive design solution according to the building form and that define the wind path and rate. They mentioned that the stack effect in the courtyard is affected mainly by the difference between the outdoor temperature and indoor temperature, accordingly that will define the airflow pattern and ventilation. They added that the higher air velocity with evaporative cooling will lead to higher humidity.

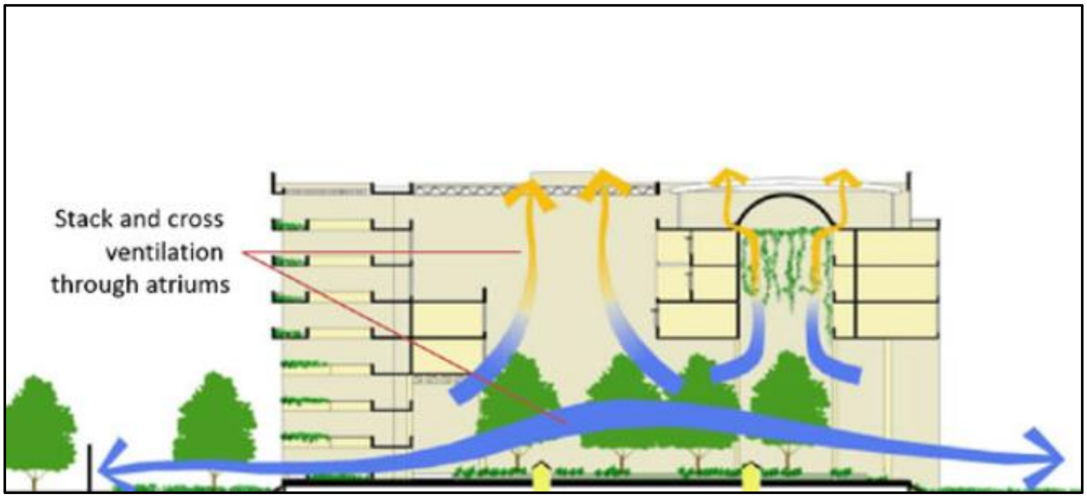


Figure 2. 21: Stack ventilation in a courtyard (NZEB 2018).

Tablada et al. (2005) connected the temperature spreading in the courtyard with the air circulation; they focused mainly on the air exchange in different sections of the courtyard from down to the top. They stated that the temperature expected to be more uniform in the courtyard space once the air vortex has its upper rate. Moreover, and according to the stack effect in the day time, the light warmed air escalates upwards to the outside of the courtyard and is replaced by the heavy cool outdoor air, mainly in the night time (Koch-Nielsen 2002). This process of exchanging the warm and the hot air can be explained due to the difference in the air pressure according to its temperature. As a result, the stack effect improves the ventilation, especially in hot arid areas, as it takes away the heat and moisture to accomplish thermal comfort (Koch-Nielsen 2002; Rajapaksha, Nagai & Okumiya 2003; Zakaria & Kubota 2014). Jamaludin et al. (2014) and Abdulkareem (2016) stated that in a courtyard building, the courtyard can improve the natural ventilation. In another study about stack effect and air circulation in the courtyard, Edwards (2006) stated that the courtyard in a building creates private solid and void spaces with different temperatures (thus, difference in air density) according to shade and exposition to sun, which creates two types of air circulation: 1- The first air circulation between the inner courtyard space and the exterior space both at day time and night time according to winter and summer conditions; 2- The second air circulation between the inner courtyard space and inner spaces of the building.

Thus, courtyard architecture directs the air circulation, decreases the surrounding surfaces temperatures and thus reduces the heat transfer by conduction to the inner spaces. Reynolds (2002) stated that the depth of the courtyard without openings can create a good air circulation because of the stack effect, however, Ok, Yasa and Özgunler (2008) argued that it is important to create openings in the vertical masses around the courtyard, particularly in the hot and humid areas where the cross ventilation through the building windows is not recommended because of the hot humid climate. They investigated the behavior of wind tunnels and circulation in a courtyard with opening the masses around the courtyard in different locations. They concluded that according to their case, the wind speed above the courtyard was 1.50-2.00 m/s, but in the lower area of the courtyard the wind speed was 3.50-4.00 m/s next to the masses openings (figure 2.22). Finally, Kolozali and Kolozali (2016) mentioned that courtyards managed to provide a shield against the climatic forces with external threats, such as hot dusty wind, and capture the cool air in summer in traditional houses in Cyprus and they suggested strategies for improvement in courtyard air circulation (stack effect, figure 2.23).

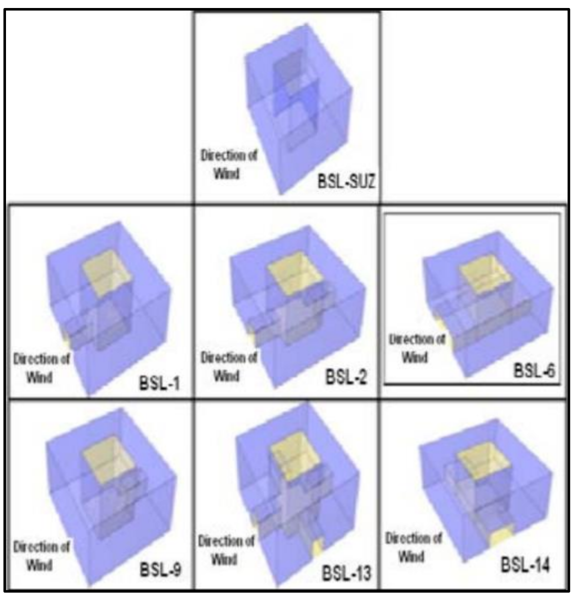


Figure 2. 22: The courtyard configurations with different openings in the masses around the courtyard (Ok, Yasa and Özgunler 2008).

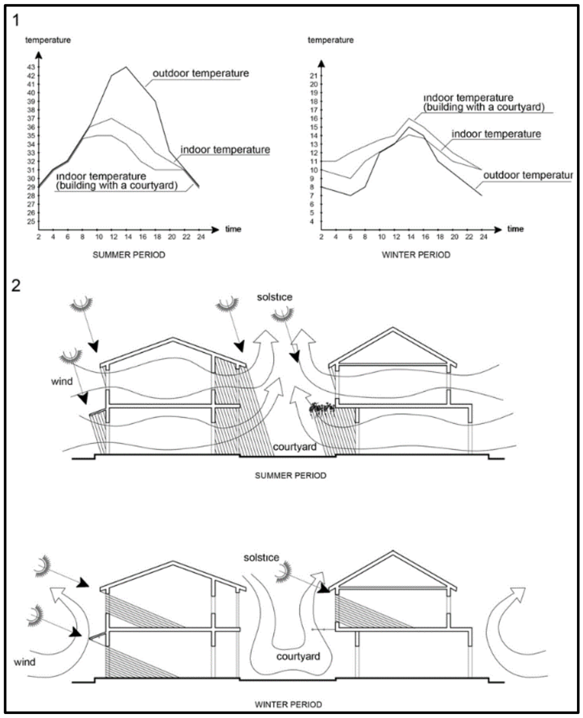


Figure 2. 23: Climatic study of courtyard building design. 1 - Temperature results, 2 - Strategy improvements (Kolozali & Kolozali 2016).

It is important to mention that the stack effect and air circulation affect the courtyard ventilation. Yousef, Lang and Auer (2017) used a computational fluid dynamics (CFD) simulation to evaluate the expected ventilation system in a courtyard building in a hot climate; they stated that the movement of air inside the courtyard has a steady state, as the courtyard shields the building from unwanted high wind speeds. In another study about the ventilation in the courtyard conducted by Tablada (2013), he stated that if the courtyard has even single side ventilation, it can provide cooler thermal conditions for the building, especially for the ground floor. He added that cross ventilation will increase the speed of the air in the courtyard and will produce better thermal conditions in the warm areas, despite the fact that the outdoor air temperature is very high (figure 2.24).

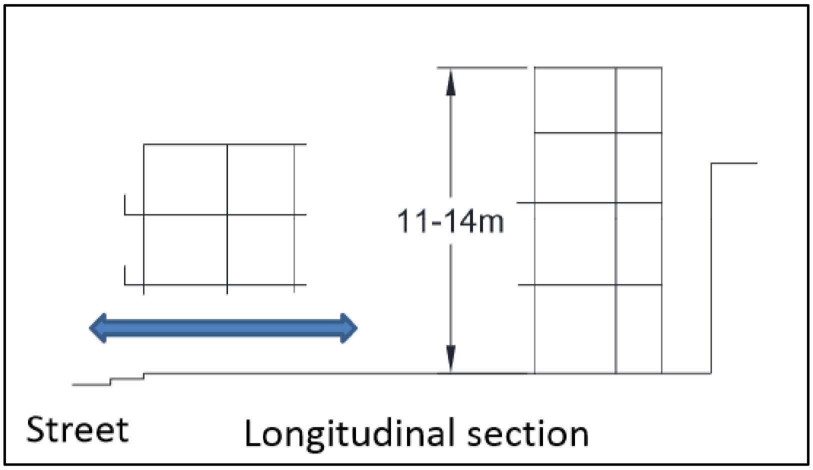


Figure 2. 24: One side ventilation for the courtyard can create good ventilation (Tablada 2013).

2.2.5.2 Courtyard and Design Parameters

The courtyard was designed to fulfill the different needs of the occupants, like the climatic, religious, social, economic, culture and architectural needs (Almhafdy et al. 2013; Mishra, & Ramgopal 2013). The design of the courtyard depends on different parameters that define its efficiency in improving the thermal performance for the whole building (Reynolds 2002; TERI 2004; BerKovic et al. 2012; Almhafdy et al. 2013; Tabesh & Sertyesilisik 2016; Markus et al. 2017). Among those parameters are the courtyard shape, orientation, proportion to the built-up area, courtyard height to width ratio and sky view factor, heights of the masses around the courtyard, and vegetation.

1- Courtyard shapes and types

A courtyard can be formed in a square, rectangular or circular outline (figure 2.25). Reynolds (2002) indicated that most of the courtyards in the past were designed as a square or rectangular shape. In the meantime, Edwards (2006) stated that circular courtyards can be seen in the vernacular architecture of the traditional samba village (figure 2.26). Recently, new forms for the courtyards appear, such as T and Y shapes, to fit with new design concepts and the contemporary needs (Saeed 2007). Sthapak and Bandyopadhyay (2014) agreed that the courtyard form changes according to site limitations, topography, and orientation amongst other factors. Muhaisen and Gadi (2005) studied the shade inside a polygon courtyard with different heights and ratios (figure 2.27).

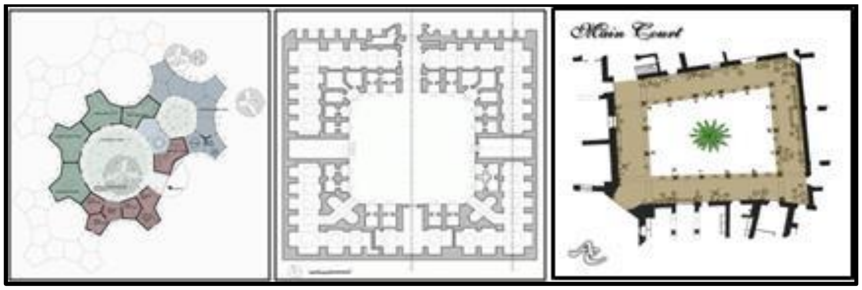


Figure 2. 25: Shapes of the courtyards (Shapes of the courtyards 2015).

Figure 2. 26: Circular courtyard in the vernacular architecture (Despacedesigns.com 2012).

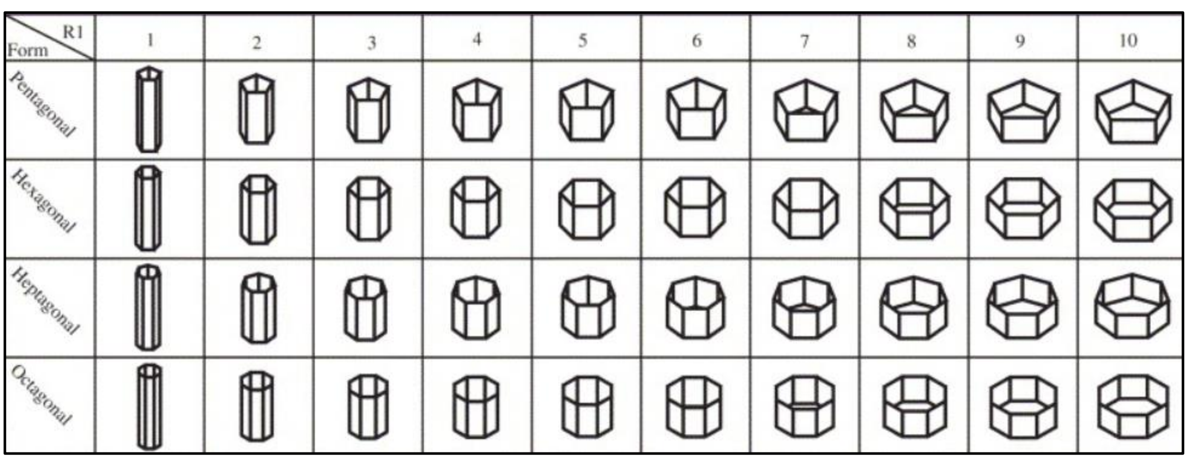


Figure 2. 27: Polygon investigated forms (Muhaisen & Gadi 2005).

Hyde (2000) listed the three most common design types of courtyards, which are partly opened, entirely enclosed and partly enclosed courtyards (figure 2.28). The entirely enclosed courtyard is more common in deep plans where it provides a high level of privacy, lighting and good ventilation. On the other hand, the partly closed courtyard is usually created between buildings and assumed to be a semi-private zone that has a shaded area. Finally, the partly opened courtyard provides the smallest amount of privacy but at the same time it provides direct access, ventilation and vision for the building (Hyde 2000). Reynolds (2002) declared that the courtyard can have a regular or irregular outline. In most cases it is placed in the core of the building, in other cases it can be separated from the surroundings by one or two walls.

Figure 2. 28: Courtyards types (Hyde 2000).

2- Courtyard orientation

Almhafdy et al. (2013) stated that the courtyard orientation has an effect on its thermal performance, as per their investigation, the air temperature in the courtyard is about 0.5 - 5 ˚C lower than the outdoor temperature according to its orientation. Forouzandeh (2018) agreed that the effect of the courtyard orientation on the thermal behavior of the building is clear. In another study Alzanfer (2014) stated that the orientation has an effect on the air temperature in the spaces between the buildings and the canyon with the same aspect ratio. Tablada et al. (2005) investigated the effect of the orientation of the courtyard on the ventilation of the adjacent rooms with different floors; they added that the location of the rooms around the courtyard affect their ventilation and their thermal comfort. More explanation for the effect of the courtyard orientation was clarified in Abdullah et al.'s (2013) study as they recommended that for the best thermal performance for a building, it is better to reduce the area of the walls facing west and east directions, as they are more exposed to high solar radiation. After analysis for the semi closed courtyard with different orientation Almhafdy et al. (2013) stated that the thermal performance of the semi closed courtyard will differ according to the orientation of its open side, which can reduce the temperature from 2-3˚C. They added that it is better to lower the courtyard openings for ventilation to obtain a better performance.

Other studies highlighted parameters that are related to courtyard orientation. Bagneid (2010) stated that shading cast according to sun location beside wind direction affect the thermal performance of the courtyard. Martinelli and Matzarakis (2017) investigated courtyard thermal performance, finding that the main impactor was the courtyard ratio based on the sun location and orientation. They stated that the shading factor (according to the solar access to the courtyard area) significantly affects the courtyard's performance and temperature, as the air inside the courtyard has limited mixing with the air around the building.

Ghaffarianhoseini, Berardi and Ghaffarianhoseini (2015) studied different configurations of the courtyards with different orientations in a hot humid area in Kuala Lumpur, they confirmed the effectiveness of the orientation of the courtyard on the thermal performance of the building. Martinelli and Matzarakis (2017) studied the proportions, orientation and the thermal comfort of the courtyard. They concluded that the orientation of the courtyard affects the sun cast and shading duration according to the sky view factor (SVF), which certainly affects the thermal comfort of the courtyard. Tablada (2013) recommended to have more effective courtyard performance by giving more attention to the orientation beside the factors of the climate, such as the wind direction and the sun path, more than the land plot shape. Al-Hafith et al. (2017), Edwards (2006) and Reynolds (2002) agreed that in the hot areas, it is better to have a rectangular courtyard design with its long axis laid in a west-east direction (figure 2.29, 2.30 & figure 2.31) to make the courtyard more efficient in reducing the building temperature by increasing the shaded area.

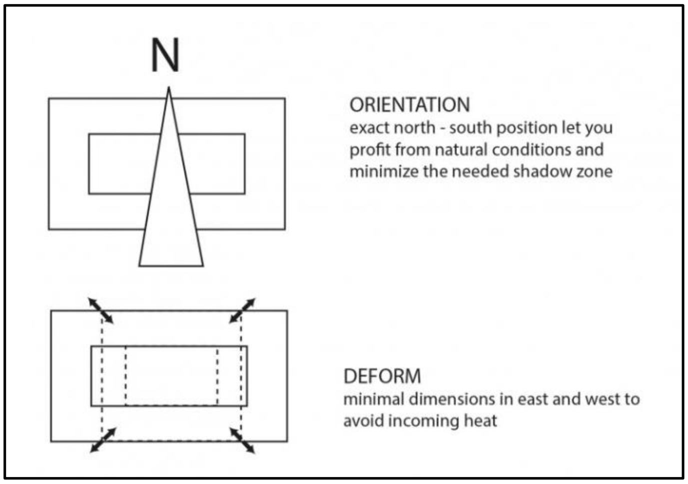


Figure 2. 29: Orientation for the courtyard (cityfoerster 2018).

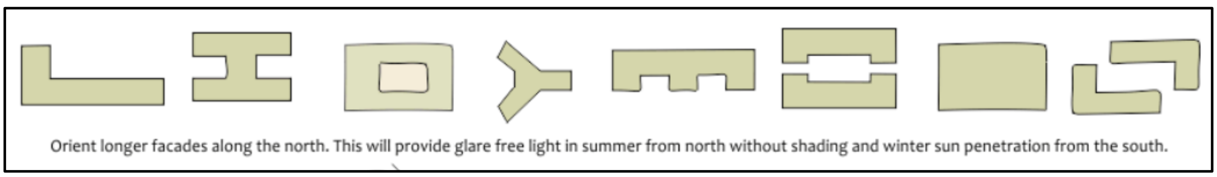


Figure 2. 30: Laying the long access of the courtyard east west direction

(Passive design 2018)

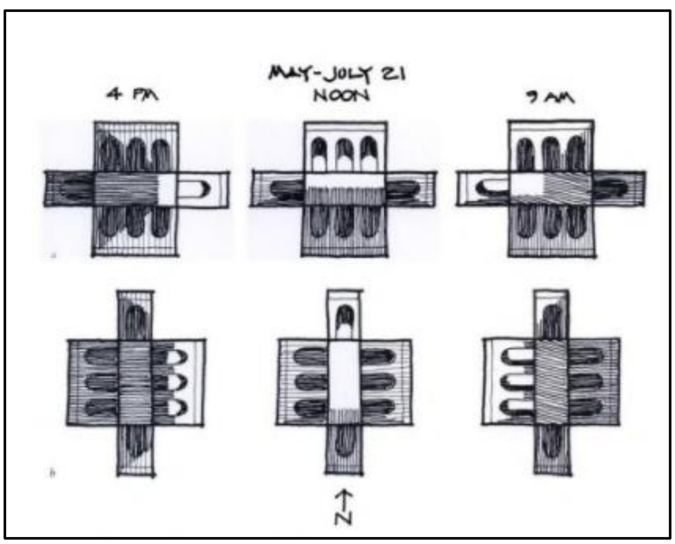


Figure 2. 31: Laying the long access of the courtyard east west better than north south to generate more shaded area inside the courtyard (Reynolds 2002).

The Maryland Department of Education (2012), Reynolds (2002) and Sthapak and Bandyopadhyay (2014) stated that the solar shadow index (SSI) can be calculated by dividing the south wall height by N-S floor width. Table (2.2) shows an example about the solar shadow index variation according to the orientation for the same courtyard with the same proportions (Appendix 2.1). Bradshaw (2010) stated that the solar radiation hits the building facades with different amounts according to their orientation and the sun’s latitude, as shown in table (2.3). He added that despite the fact that the cooling loads vary according to location, time of the day and function of the building, locating the shorter walls of the building to the east and west decreases the cooling load for the building in the summer.

Table 2. 2: Solar shadow index variation according to the courtyard orientation (Maryland Department of Education 2012)

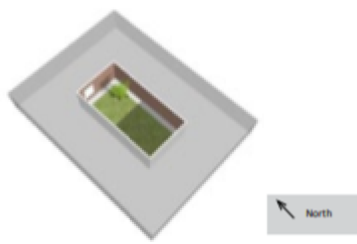
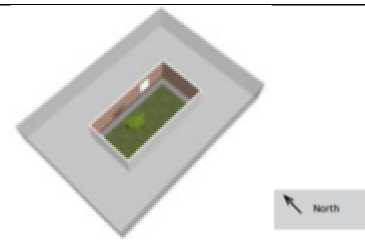
Courtyard details		
The courtyard size 25*50m The courtyard height is 15m Height of the south wall = W Width of the courtyard in the north south direction =X	Long walls directed N/S December 21 at noon SSI=W/X=15/50=0.3	Long walls directed E/W December 21 at noon SSI=W/X=15/25=0.6

Table 2. 3: The solar heat gain variation according to orientation (Bradshaw 2010).

Latitude	Season	Solar Heat Gain Relationships
Above 40°N	Winter	South more than 3 times the east and west
	Summer	East and west about 1.3 times the south
35°–40°N	Winter	South about 3 times the east and west
	Summer	East and west about 1.5 times the south
Below 35°N	Winter	South about 2 times the east and west
	Summer	East and west 2–3 times the north and south (at lower latitudes, north wall gains surpass south wall gains)

3- Courtyard ratio

The ratios of the courtyard control the thermal properties, lighting and ventilation. The courtyard ratio was calculated in different ways in relation to its height, width and length. In the following section, some studies that investigated the ratios of the courtyard with the expected effect on the thermal performance are noted. Chadalavada (2017) investigated the thermal performance of courtyards with different ratios in a Vernacular house in India, he stated that reducing the courtyard size, length and width as in figure (2.32) has a significant impact on the thermal performance of the building, as it reduces the inner temperature from7-9˚C, but unfortunately that produced a negative effect on the internal lighting. Rojas-Fernández et al. (2017) calculated the Aspect Ratio (AR = H/W) for different Mediterranean courtyards (figure 2.33). They stated that the efficient aspect ratio should differ according to the climate. The Maryland Department of Education (2012), Reynolds (2002) and Sthapak and Bandyopadhyay (2014) stated that the aspect ratio (AR) can be measured by dividing the courtyard floor area by the square of the average wall height around the courtyard. The AR is clarified as "the range of openness to sky". Thus, the higher the aspect ratio, the more visible the courtyard is to the sky (appendix 2.3).

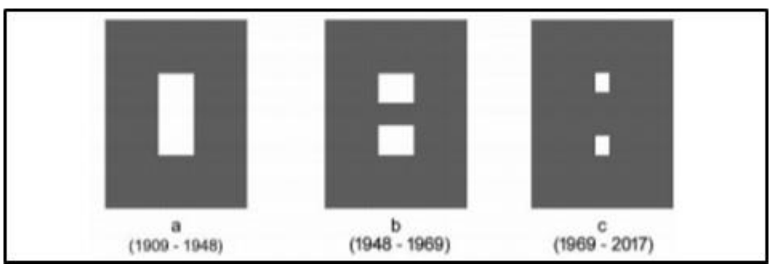


Figure 2. 32: Site plan for a building illustration shows the transformation of the courtyard size and type (Chadalavada 2017).

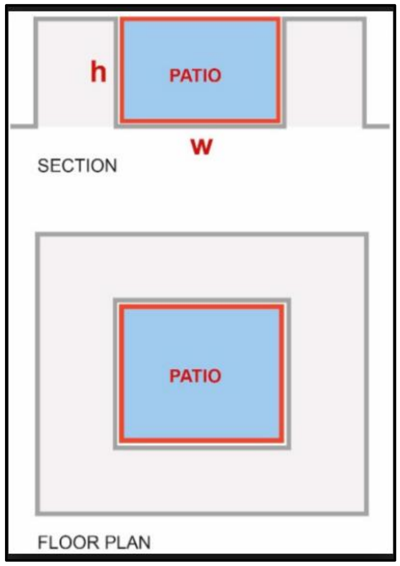


Figure 2. 33: Aspect Ratio (AR = h/W) for courtyard (Rojas-Fernández et al. 2017)

Koch-Nielsen (2002) confirmed that the thermal characteristics for the courtyard and for the surrounding spaces are mainly determined by the courtyard proportions. He added that the best recommended ratios are related to the height of the building, if the height of the courtyard is X it is better to have a width that ranges from X to 3X (figure 2.34). Hyde (2000) mentioned that a deep courtyard can expand the daytime interior shading time while a wide courtyard can improve the ventilation system.

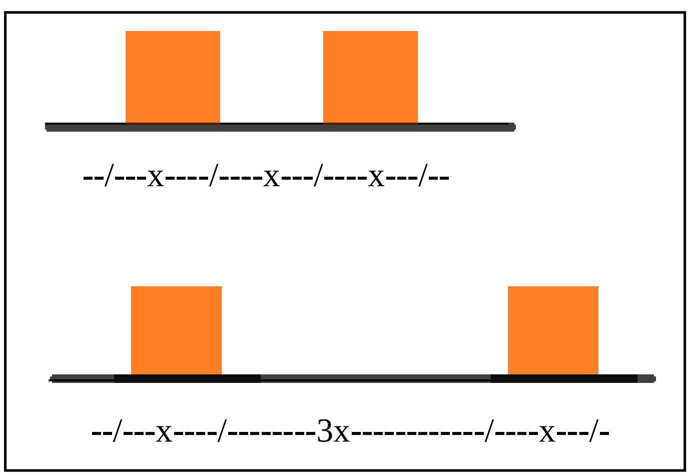


Figure 2. 34: The suggested proportions for the courtyard by Koch-Nielsen from X-3X where the height of the masses around the courtyard is X (Koch-Nielsen 2002).

Tablada et al. (2005) stated that the AR for the courtyard proportion width to height affects the movement of the air inside the courtyard, and thus, the ventilation and the thermal comfort especially in the upper floors. Alvarez et al. (1998) mentioned that the relationship between the air flow and the temperature inside the courtyard depends on the aspect ratio of the courtyard. They added that the low AR until 0.1 (shallow courtyards) has limited inverted air flow (little satisfaction) compared to the medium 0.3,0.5,1 where the velocity increases through the courtyard to the top (no satisfaction), on the other hand a deep courtyard with an AR beyond 1.5 has miner air velocity through the courtyard (high satisfaction).

Markus et al. (2017) and Aldawoud and Clark (2008) stated that the climate can be improved by the courtyard proportions. Moreover Taleghani, Tenpierik and van den Dobbelsteen (2014) added that the L/W ratio of the courtyard has a considerable effect on the energy consumption required to reach the thermal comfort in different areas. Almhafdy et al. (2013) stated that the thermal performance for a courtyard with surrounding height of six floors is better than one floor for the same design (length to width) and same type (semi opened). Tablada et al. (2005) and Markus et al. (2017) studied the aspect ratio effects on the movement of the air inside the courtyard, and thus the ventilation and the thermal comfort. They stated that recirculating air vortex defines the satisfaction in the courtyard according to its AR. After investigating the AR height to width for the courtyard, Martinelli and Matzarakis (2017) specified that the higher aspect ratio is more suitable in summer or in hot areas, as it shelters the courtyard from the sun but it may cause heat stress at night as it thwarts the long wave radiation collected by the mass of the building.

In another study about the proportions of the courtyards, it was clear that in a year-round study that a deep courtyard (higher H/W) is more preferable in hot areas than low ones, which are better in cold climates, because this improve the shading effect (Markus et al. 2017). This agreed with Martinelli & Matzarakis (2017), Muhaisen & Ghadi (2006) and Ghaffarianhoseini, Berardi and Ghaffarianhoseini (2015), as they argued that the thermal comfort increases with the courtyard height in warm areas, especially from 12pm till 3pm. Muhasian et al. (2006) stated that the proportional relationship between the courtyard parameter and the courtyard height is better to be 5m or above for better whole year performance. Fardeheb (2008) studied the AR (W/H) for courtyard designs, stating that lower AR leads to a cooler courtyard than the outdoor areas in the street.

Manioğlu and Oral (2015) insisted on the importance of the courtyard W/L ratio on its thermal performance, they defined it as shape factor for the courtyard. They stated that the least cooling loads for a building with a floor area 100m^2 was with courtyard ratio W/L = 0.2, while the least cooling loads for a building with a floor area 200m^2 was with courtyard ratio W/L = 1.2. This agreed with Merlier et al. (2018) as he clarified that the AR can be calculated as the proportions of the length to height (L/H) or else the proportions of length to width ratio (L/W), they added that there are ways that can describe the openness in the cities in the direction of the sun, such as the sky view factor (SVF) (figure 2.35). In another study by Martinelli and Matzarakis (2017) that investigated the SVF (sunshine duration) on courtyard performance, they stated that for a courtyard ratio H:W 5:5 the SVF is 0.1, while for a courtyard ratio H:W 2:5 the SVF is 0.7, thus the sunshine duration casted more on the shallower courtyards; this result might have a conflict effect between summer and winter. Other ratios related to courtyard were investigated in other studies like the courtyard to built-up ratio (CA/BA) like Tablada (2013) who stated that it is recommended that the courtyard area to the built-up area > 25% to have a better thermal performance for the building. Soflaei, Shokouhian and Mofidi Shemirani (2016) stated that in the traditional courtyards (good thermal performance) have courtyard area to the built up area that ranges between 18-44%.

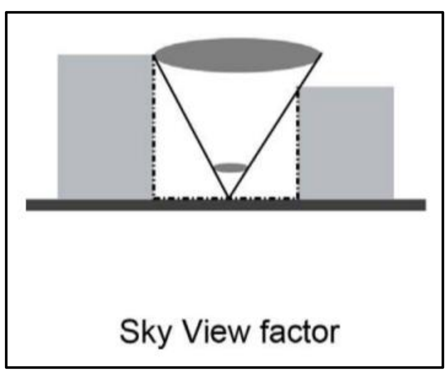


Figure 2. 35: The sky view factor (Merlier et al. 2018)

4. Courtyard surrounding walls heights

The height of the courtyard walls according to the surrounding masses define the shading inside it, which decreases the direct solar radiation and significantly affect the thermal performance of the courtyard and the building. Alzanfer (2014) stated that the deepest street canyons generate better and cooler conditions. Kolozali and Kolozali (2016) stated that the surrounding buildings should have a suitable height to shield against the hot wind. Jamaludin et al. (2014) evaluated the courtyard role in the ventilation for a midrise building, they explained that the speed and the type of the air circulation in a building within a courtyard depends on the time in the night or the day. They also affirmed that the masses location and height around the courtyard significantly affect the ventilation. Agreed with that Antonio and Carvalho (2015) as they stated that the higher the walls around the courtyard the cooler the temperature inside the courtyard, and thus the adjacent spaces. After investigating courtyard ratios in different climates Muhaisen (2006) stated that higher facades for the courtyards are more suitable in warm areas, while low facades are better in cold areas (figure 2.36). He recommended for better thermal performance of the courtyard should have the following: 1- Minimum 9m (3 floor) is a good height to produce proper shading in hot humid regions. 2- Minimum 6m (2 floor) in hot dry areas. 3- Minimum 3m (1 floor) in cold areas. This agreed with Markus et al. (2017) as he stated high enclosed masses are better for courtyard performance in hot areas and low ones for cold areas. Based on a study to examine the building heights around the courtyard, Tablada (2013) recommended that buildings with wide courtyards that have a width of more than 7m and have direct access to the street, to have a maximum height up to 14 m (3-4 floors) to achieve better thermal conditions in the courtyard and in the interior spaces.

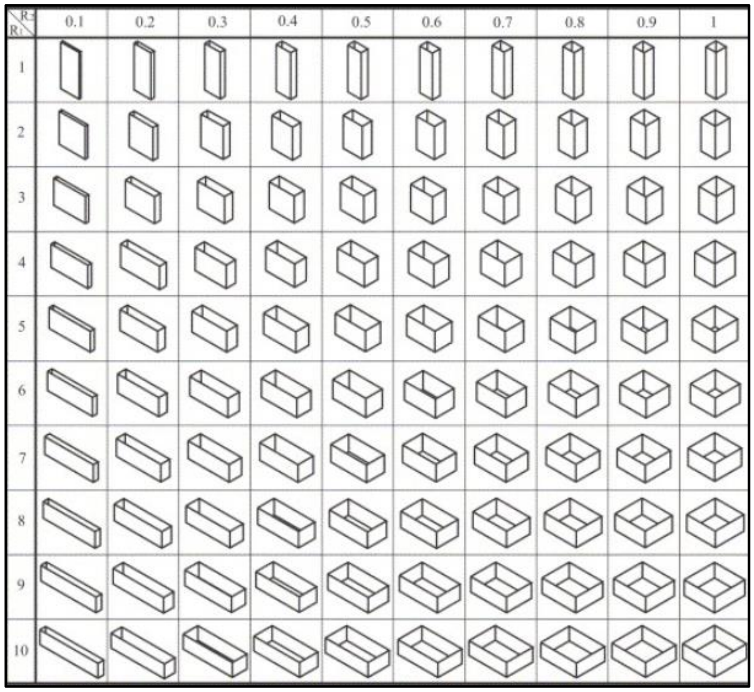


Figure 2. 36: Different rectangular forms for courtyards with different heights (Muhaisen 2006).

5. Courtyard and vegetation

Alvarez et al. (1998) stated that the courtyard, as a defined zone, has the potential to create a required microclimate by using water or greenery for cooling by evaporative cooling. Abanomi and Jones (2005) investigated the landscape effect on the thermal performance of a school building in Riyadh; they stated that landscape is an important element in schools in hot areas, as it helps in improving the microclimate of the building and helps in cooling the inner spaces by reducing the heat gain. They added that trees reduce the temperature by shading the ground beside evaporative cooling, and vegetation is more effective than wall screen shading elements. Furthermore, they clarified that having grass as a cover on the courtyard ground is better than a concrete pavement, as the grass reflects about 0.2% of the solar radiation, while the concrete reflects around 0.4%. They recommended to use deciduous trees in schools. Martinelli and Matzarakis (2017) stated that vegetation is one of many parameters that can improve the performance of the courtyard beside geometry, courtyard proportions and building materials.

After investigating the landscape in a university campus in Hong Kong. Lau and Yang (2009) stated that the greenery in the courtyard improves the social interaction, meditation, and thus the academic atmosphere. Safarzadeh and Bahadori (2005) mentioned that the presence of plants in the courtyard, such as trees and shrubs, can considerably improve the thermal performance of the courtyard, mainly because of the shade that they produce. Taleghani, Tenpierik and van den Dobbelsteen (2014) pointed to the importance of greenery in improving the courtyard's role and the thermal conditions of the building, wherein they stated that the grass mainly prevents the sun rays from reaching the courtyard's ground surface, thus the ground surface of the courtyard (soil or pavement) takes in less solar gain and reduces the temperature of the courtyard ground and the air coat over it through a process called evapotranspiration: "*the process by which water is transferred from the land to the atmosphere by evaporation from the soil and other surfaces and by transpiration from plants*" (Dictionary.ae. 2018) (Figure 2.37).

Kolozali and Kolozali (2016) stated that the greenery is important in the courtyards as it casts shadows for better thermal performance, defines the pathways, prevents the dusty air, protects the soil structure in addition to providing beauty for relaxation. They added that the greenery with water in the past was a special creator for morning coolness. Soflaei, Shokouhian and Mofidi Shemirani (2016) insisted on the importance of the vegetation in the courtyard for its positive effect on the building's microclimate beside its beautiful appearance and shade.

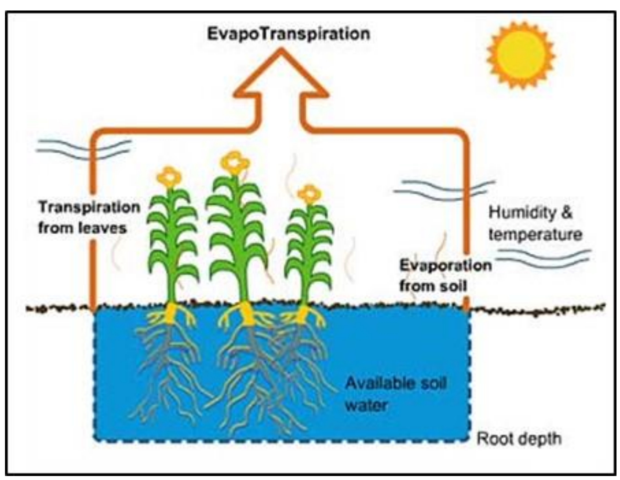


Figure 2. 37: The process of Evapotranspiration (Ecoursesonline.icar.gov.in 2018)

Cereghino et al. (2002) prepared a Renovation Proposal for the courtyard of Nathan Hale High school. Based on their proposal they advise that the plants in the courtyards should be native local plant species to help them to survive with less maintenance, especially in hot areas. They added that sensitive plants can be located in the shaded southern part of the courtyard, as shown in Figure (2.38).

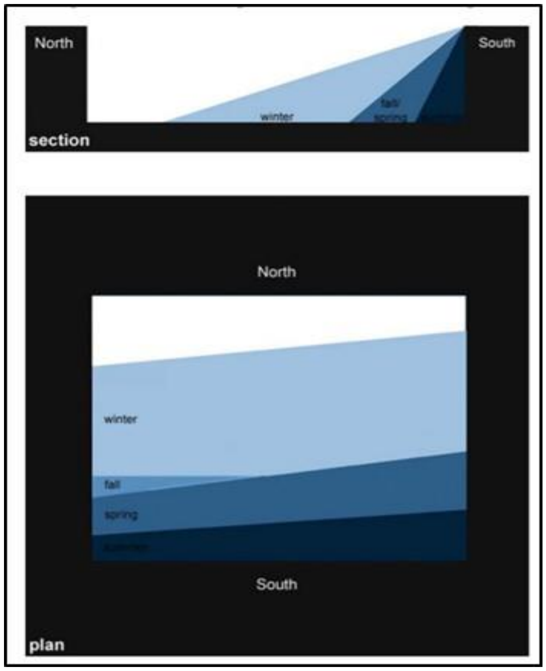


Figure 2. 38: Diagram for the sun shade inside a closed courtyard according to the seasons at noon at solstices at the southern part (Cereghino et al. 2002).

Martinelli and Matzarakis (2017) explained that albedo is a degree of the amount of light that hits a surface is reflected and not absorbed, thus more albedo for the surfaces in the courtyard increases the temperature in the courtyard as it increases the radiation reflected into the courtyard space; planting grass with less albedo compared to a concrete pavement will improve the thermal performance (figure 2.39). Kolozali and Kolozali (2016) suggested different types of greenery and plants in the courtyard, such as vines, flower beds, green wall screens and fruits such as citrus, that should be integrated in a proper way with other courtyard furniture and water elements (figure 2.40).

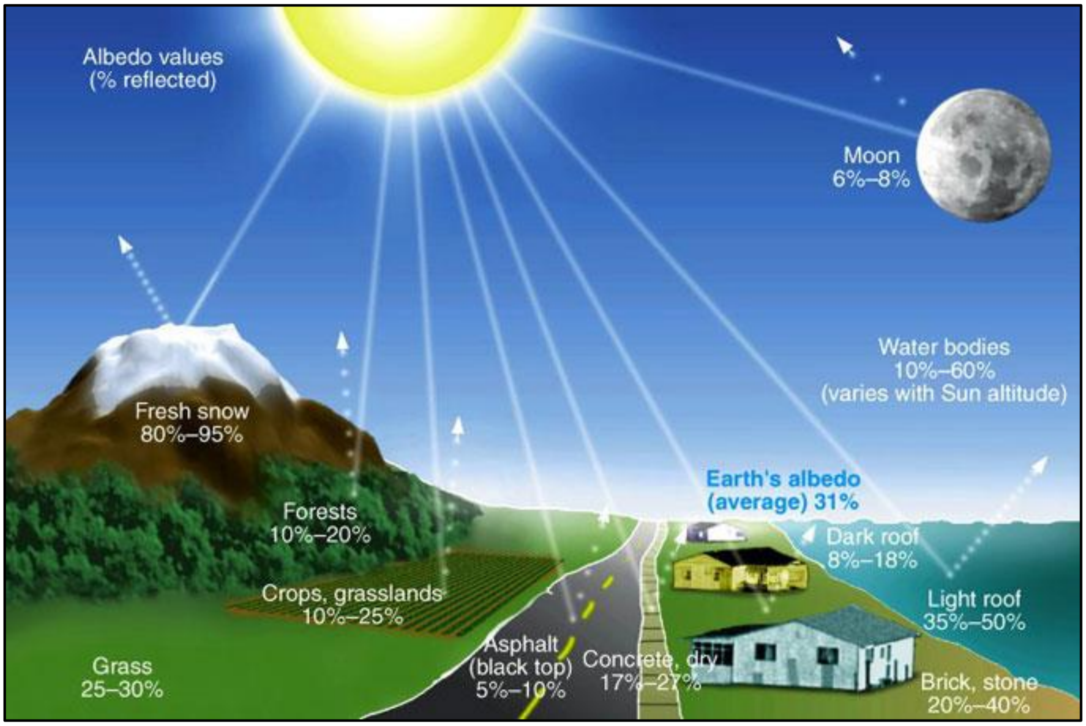


Figure 2. 39: The albedo for different materials including grass (Mar 2018).

Figure 2. 40: Landscape and courtyard furniture (Kolozali & Kolozali 2016)

2.3 Schools

Rigolon (2010) stated that the climatic concerns of the location are important factors that shape the school and define its type, in addition to the level of education and the number of students. He added that there is increasing demand for additional areas in schools to provide enough space for the modern style education and educational activities. Based on that, more energy will be required to provide a comfortable thermal education environment for the students beside running the added facilities.

2.3.1 The importance of sustainability in school buildings

Schools are educational buildings that should have suitable atmosphere for education, thus, they consume a lot of energy (Al-Khatatbeh & Ma'bdeh 2017; Zhang et al. 2017; Perez & Capeluto 2009). For example, Abanomi and Jones (2005) mentioned that the schools in the Kingdom of Saudi Arabia (KSA) depend mostly on electrical cooling systems, thus schools become leading electricity consumers in the daily peak period. Another example of the high energy consumption in schools was highlighted by Zomorodian and Nasrollahi (2013) as they stated the usual energy consumption in Iranian school buildings (which represent a large sector of public constructions), exceeds 160 kWh/m^2, and that represents about 2.5 times more than the energy consumption in modern schools in developed countries, which is about 65 kWh/m^2.

A global concern toward designing energy efficient schools is increasing (Elmasry & Haggag 2011). Many researchers and international programs like LEED (Leadership in energy and environmental design) and The Green School Building in USA and The Bright schools for the Future (BSF) in the UK, have tried to implement regulations to reduce the energy consumption in schools (Santamouris et al. 2007). The US Department of Energy in USA stated that schools can considerably decrease energy intake and expenses, where the savings can be transmitted for other improvements for the schools, such as new equipment, facilities and additional teachers, all that beside the environmental benefits (National Renewable Energy Laboratory with Subcontractor Innovative Design 2015).

Al-Khatatbeh & Ma'bdeh (2017) used passive design solutions (changing the building materials) for school buildings to improve the lighting and the thermal performance, thus reducing the energy consumption. Dimoudi and Kostarela (2009) and Abanomi and Jones (2005) stated that the energy effectiveness is essential in schools as it is related to the thermal well-being and the quality of the air in the internal spaces. Desideri and Proietti (2003), Hong, Koo and Jeong (2012) and Zhang et al. (2017) mentioned that the global interest in improving the energy efficiency in schools is increasing because schools represent a considerable sector of the built environment that consume a lot of energy to provide a standard level of comfort.

Dias Buvik and Steiger (2012) pointed to the importance of designing energy efficient schools which can provide environmental and economic benefits. Pereira et al. (2014) argued that the costs of energy consumed in the schools present the second most important payment after the teachers' wages. Uline and Tschannen-Moran (2008) studied school building specifications, services and design, and confirmed that the school building affects the social and educational practices for the students. Cradock et al. (2007) mentioned the relationship between the school size and the health of the students, as he insisted that the big area of the school provides more spaces for physical education beside having long walking distances for students which improves their health. However, the problem is that a big school consumes a lot of energy. Matsuoka and Kaplan (2008) pointed to the importance of the landscaping in the school yards as it provides nice and relaxing scenes; moreover, it can help in evaporative cooling for better thermal performance. The Department of US Energy stated that the smart techniques beside the school building design can reduce the energy intake to 75% of the original consumption, they highlighted basics that can involve reducing energy consumption, such as orientation and materials. Their outcomes can be considered as a design framework for sustainable school buildings in hot areas, which can help in reducing the energy consumption and deliver a comfortable atmosphere for education (National Renewable Energy Laboratory with subcontractor Innovative Design 2015).

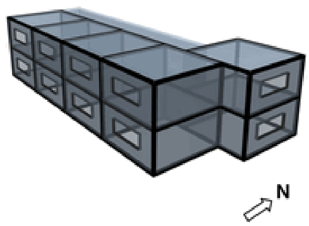
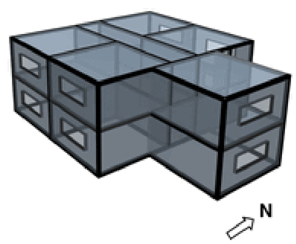
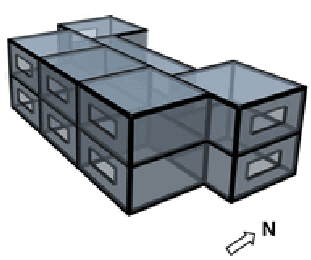
Abanomi and Jones (2005) sated that schools in KSA spend a huge amount of the Ministry of Education budget to accomplish qualitative and quantitative enhancements in the education plan and school buildings. Filippín (2005) made an evaluation for an architecture concept of a school building in Argentina to check its thermal performance. He claimed that school thermal performance was affected by both the occupants and the school design. Zomorodian and Nasrollahi (2013) proposed different architectural proposal concepts for sustainable school buildings in Iran, related to space arrangements, orientation, ideal window/wall proportion, shading and shape. The results disclosed that by adopting energy effective architectural concepts, the energy consumptions of the investigated case studies can be decreased by 31% in relation to the existing school buildings even with the same visual and thermal well-being. They recommended that to try their architectural strategies in other schools in hot areas.

Zhang et al. (2017) used Energy Plus software to investigate the effect of the geometry of school building on its thermal performance in the cold climate in China, according to: 1- Room depth; 2- Orientation: as they rotate the building according to the four main directions N,S,E,W to evaluate the effect of orientation on the buildings, they recommended that the part of west-directed spaces should be limited because of the probable summer heat risk. 3- Window to wall ratio: as they investigated ratios ranges from 10-90%. The study revealed that the schools with courtyards with a H shape were the best in the thermal performance and student preference. They insisted that the school geometry (e.g., shape, symmetry and golden section proportions) has a high effect on its thermal performance and psychological reactions beside the body efficiency of the users.

Abanomi and Jones (2005) investigated the prototype governmental school models in KSA, they used ECOTECT and HTB2 software to evaluate the actual thermal performance of the schools. They investigated different strategies, such as thermal insulation, shading devices, orientation, thermal mass, landscape and infiltration, to improve the indoor conditions of the school buildings with less energy consumption. Their study revealed many important results, among them the following: 1- Window shading and roof shading are important strategies in hot areas to reduce heat gain for the interior spaces; 2- Landscape is an important element in schools in hot areas, as it helps in improving the microclimate of the building and helps in cooling the inner spaces by reducing the heat gain. Trees reduce the temperature by shading the ground and by evaporative cooling; 3- Night ventilation as it helps in releasing the gained heat at daytime through the building masses at night if appropriate ventilation system is used from 00:00- 9:00 am; 4- Infiltration - which means unrestrained ways of ventilation- is a main factor that affects the indoor temperature in hot areas, thus it should be minimized to shield the indoor areas from the harsh hot outdoor climate. Schools need annual maintenance for the building envelope to reduce the infiltration, otherwise it will cause gaining a large amounts of heat inside the buildings; 5- Occupancy rate, as occupants have a clear effect on the inner air quality and direct source of heat gain in classrooms. They recommended that, it is better to reduce the occupants pattern in the classrooms, as the students are a source of heat gain. Each student produces, in a representative school, around 70-100 w/h according to his activity. Abanomi and Jones (2005) added that their strategies succeeded in decreasing the energy consumption, beside improving the indoor conditions. They suggested that their strategies can be applied for schools in cities with the same hot and dry climate of Riyadh.

Harputlugil, Hensen and Celebi (2011) investigated the thermal act of school buildings in Turkey. They tried to come up with strategies for school buildings that can cope with the different climates there. Their investigations were centered around three kinds of school buildings which are: hybrid, liner and finally cluster (table 2.4). The three kinds were formed according to base cell of the classroom with an area of 8m*8m. They nominated the cluster design as the best concept for school buildings in the climate of Turkey, for its high efficiency in dealing with heat gain and loss. Cantón et al. (2014) analyzed the thermal performance of a courtyard in a school building in Argentina by using field measurements. They mentioned that the courtyard positively affected the thermal performance of the school building. Zomorodian, and Nasrollahi (2013) categorized the previous studies about the reduction of the energy consumption in schools under three main collections: 1- Studies that adopt the optimization of mechanical and electrical operation of schools; 2- Studies that deal with the architectural concepts and constructional variables like thermal insulation and shadings; 3- Studies that adopt energy management aspects in school buildings. Based on that, it was clear that despite the positive thermal effect of the courtyard on the school buildings, however, only a limited number of earlier studies nominated it as a solution strategy for energy efficient schools.

Table 2. 4: Suggested design concepts for school buildings with the related data (Harputlugil, Hensen & Celebi.2011)

Schemes		Related information of each scheme
Linear scheme		Total area 802 m^2
		Floor area 401 m^2
		Vertical envelope total area 816 m^2
		Total envelope area 1618 m^2
Cluster scheme		Total area 736 m^2
		Floor area 368 m^2
		Vertical envelope total area 698 m^2
		Total envelope area 1434 m^2
Hybrid linear scheme		Total area 748 m^2
		Floor area 374 m^2
		Vertical envelope total area 880 m^2
		Total envelope area 1628 m^2

2.3.2 Schools in UAE –Historical Background

The education system in the UAE was informal at the beginning of the twentieth century, and it was restricted to the religious fields only, mainly Arabic and Quran lessons in the mosques or in private houses. The teachers were either mutawa or the mosque sheikh, usually the richest people in the neighborhood funded that traditional education method (Ministry of Education –UAE 2013) (Ghazal, 2014). After the 1930s the semi-formal schools started to appear supported by the pearl merchants (Ministry of Education –UAE 2013) Al Eslah School in Sharjah was constructed in the year 1935 and was the most famous semi-formal school at that time. Al Eslah School was opened for students from the gulf area (Sharjahmuseums.ae 2016). The school building materials were mud and coral stones. The school design followed the local and traditional strategy around a courtyard to provide natural cooling for the students in the day period, as at that time the air conditions were not used yet (figure 2.41).

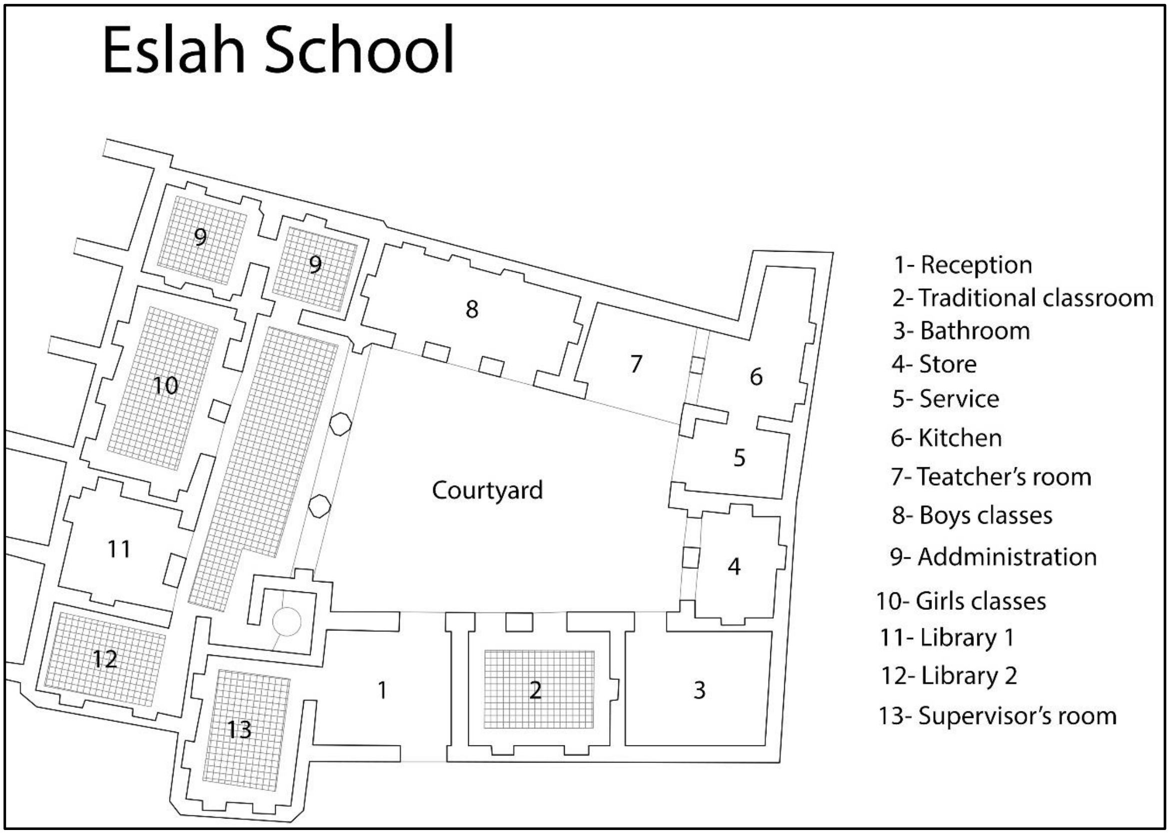


Figure 2. 41: Al Eslah school plan in Sharjah (the author after Al Buraimi group 2016)

The education was improved clearly between the years 1953-1971 by constructing formal schools. The first formal school was Al Qasimiah school in Sharjah, which was built in the year 1953 according to a traditional design around a courtyard (figure 2.42). In 1960, there were 20 schools for around 4000 students. After the discovery of oil and the establishment of the Federation in 1971, the UAE focused more and more on education development and school building designs, sizes and numbers (Moe.gov.ae 2016). Later on, the schools were categorized into four levels including: Kindergarten then Elementary before the Intermediate and finally the Secondary. At that time, all school buildings were built and supervised by the government until the private schools appeared as accompaniments to the governmental public schools (Moe.gov.ae 2016).

Figure 2. 42: Al Qasimiah school in Sharjah (Almajidcenter.org 2016).

In the present time, there are five types of educational school in UAE, including: Public formal schools, Private formal schools, Literacy schools, technical schools and finally religious schools. The main two types are the formal public and private schools. This research will focus and investigating the public school buildings designs to improve passive thermal characteristics. The number of public schools increased significantly in the last decades because of the increasing support from the UAE government to meet the need of the community. The number of schools was 132 in the year 1972 and it reached 718 schools by 2011, as the number of students grew from 40,115 students in 1972 to 264,459 students in 2011 (figure 2.43) (Ministry of Education –UAE 2013).

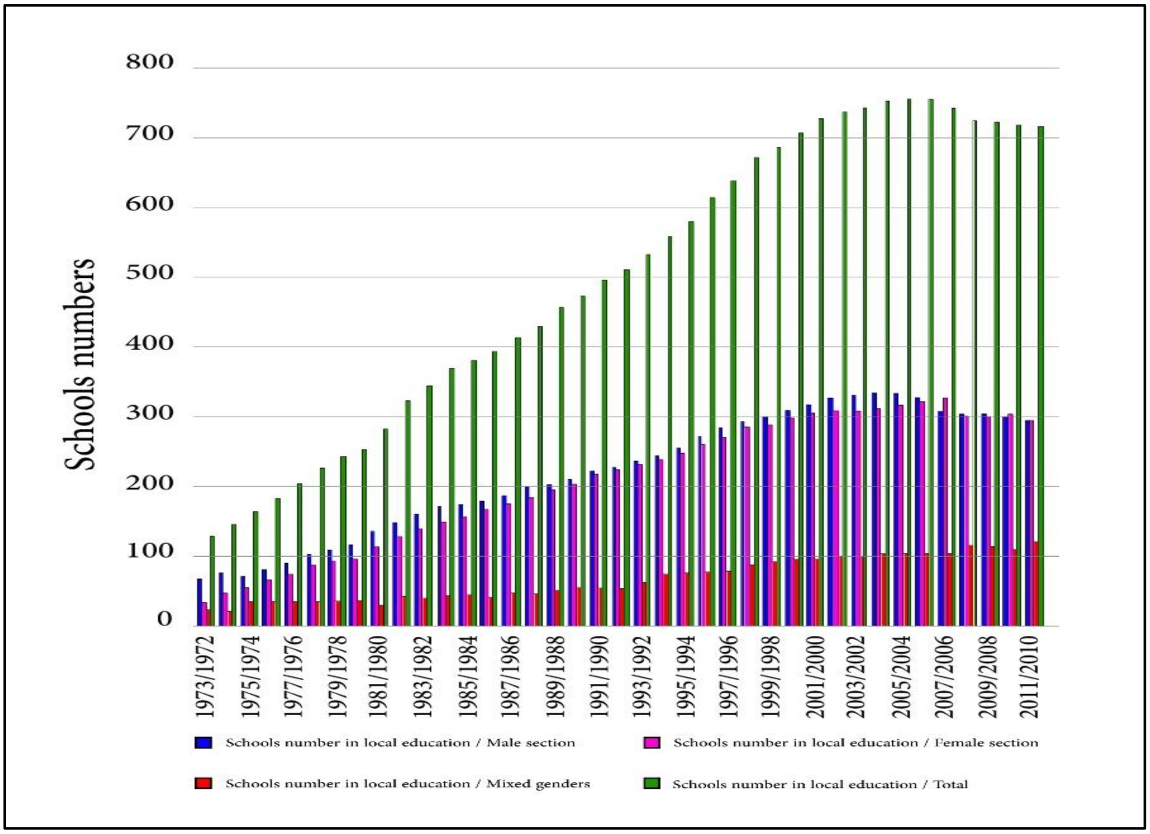


Figure 2. 43: The development in the school numbers between the years 1972-2011. (The author after the Ministry of Education –UAE 2013).

2.3.3 The Evolution in the design of the school buildings in the UAE

Both types of formal schools: private and public schools (under the supervision of the government) have regulations and guidelines enforced by the Ministry of Education for the design (Aboullail 2016), but these regulations do not include any standards that define the shape, the type or the proportions of the courtyards in the schools (appendix 2.2). These regulations only focus on the area of the play grounds in the schools, which are supposed to double the total areas of the classrooms (Ministry of Education 2015). The private schools do not have defined design templates for school buildings like public schools, thus the private schools have different shapes with or without courtyards (figure 2.44).

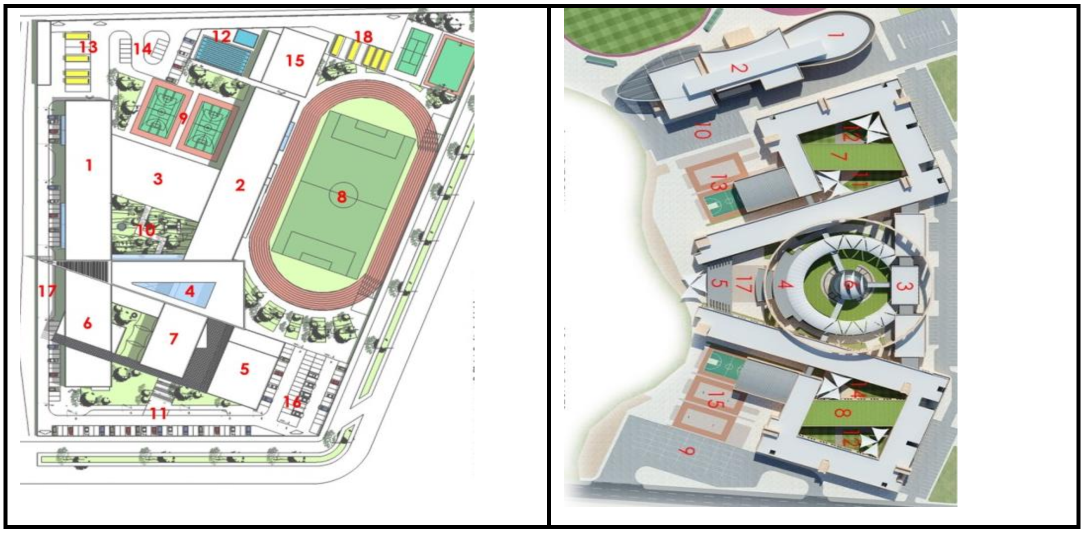


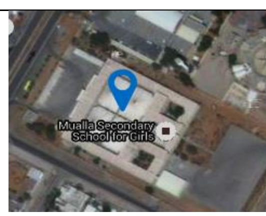
Figure 2. 44: Top views of two modern private schools in UAE-from left to right - Royal Indian School –Sharjah and SD and Al Barsha Campus plans- Dubai (Schools-UAE 2016)

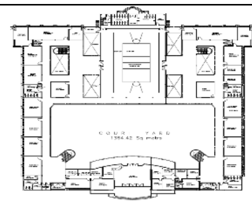
The Ministry of Education prepared several templates (prototypes) for the design of public schools, these templates went through a lot of changes and modifications since the year 1963. Table (2.5) points to the most important design stages for the public schools. The public school buildings in the UAE consumed around 18.5% from the education budget which was around 16.43% of the total budget of the country on the year 2010 (Ministry of Education -UAE, 2013).

Some design templates for the public school buildings were dominant among other types. All these templates have courtyards as a central area in their design but in different proportions and ratios. Some of these courtyards are either totally or partially covered. The research will focus on three types of public schools (which were designed before 2012) as case studies and they will be illustrated in the case study section in the methodology, beside two new templates (which were designed after 2012) to investigate the effect of the courtyard in enhancing the thermal conditions of the school building, and to alter their proportions to be more efficient in advanced design stages.

Usually prototypical school designs are used in all the country areas, irrespective to the difference in climatic characteristics between them, and they have a negative impact on their thermal performance, like the case in KSA (Abanomi & Jones 2005)

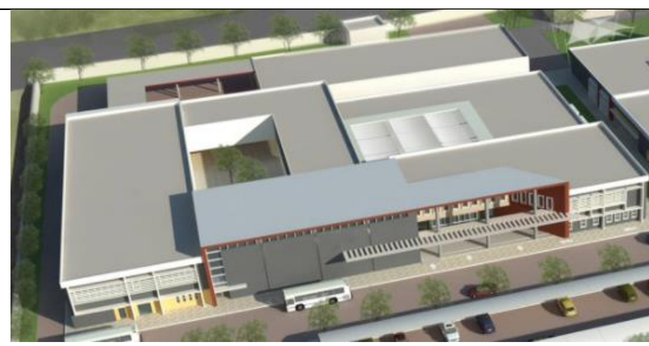
Table 2. 5: The evolution in the public school buildings design in the UAE (Ministry of Education -UAE 2013; Aboullail 2016).

Public school type and date of construction	School picture	General description
1.Kuwait design- 1963 Example: The Arabic Gulf secondary school –Sharjah		-Old model built by the government of Kuiate -Classes are arranged around unshaded courtyard -Lack of services and play grounds.
2.The village design (Al Qarawy)- 1978 Example: Tulaytelah school –Dubai		-The school is limited in the number of classes. -The school has U shape building with semi closed courtyard.
3-Khateb wa Alami Design -1975. Example: Qurtoba School-Dubai		-It is two floor building with 24 classrooms with services. -It has many courtyards, the large one is a closed courtyard. -Most of the playgrounds are not covered -The maintenance is expensive. -Difficult to control the students as it has many exits.
4- Ministry of Public work design –Old -1979 Example: Al Zahra secondary Female School –Sharjah		-This design was especially for secondary schools. -The school has U shape building with semi closed courtyard -It is two floor buildings with good services and equipment.
5-Ministry of Public work design 586. 1989 Example: Al Mualla Secondary Female School-Om Al Quwain		-It is two floor buildings with18 or 24 classes and with good services equipment and theater. -Added to the old design small library in the side of the courtyard. - It has closed courtyard most of it covered with canopy.
6- Ministry of Public work design 596- 1990 Example: Amenah Bint Wahab Secondary School-Dubai		-It is two floor buildings with 24 classes and with good services, equipment and theater. -It has closed courtyard most of it covered with canopy and it has covered playground.

7- Ministry of Public work design 740-2003		-It is two floor buildings with 24 classes and with high quality services, equipment and theater. -It has closed courtyard most of it covered with canopy and covered playground. -It has Air conditioned sport Hall.

The ministry of education started working on advanced design templates for school buildings in 2010. These templates include designs for primary and secondary schools (table 2.6) and will be used as case studies for this research, in addition to the three old design templates. These schools have high capital cost because of the large spaces and modern equipment, moreover they need a lot of energy to create comfortable indoor atmosphere.

Table 2. 6: Modern public school buildings.

Modern school design type	Perspective for the school building
1-Primary school -UPA1 The school has 25 classrooms, multipurpose room, 3 labs, 2 activity rooms, indoor and outdoor playing areas, administration section …etc. Example: Al Noof Primary School & Kindergarten – Sharjah	
2-Secondry school – UPA-fin The school has 38 classrooms, multipurpose rooms, 6 labs, activity rooms, indoor and outdoor playing areas, administration section …etc. Example: Al Gharayen 2 Elementary schools – Sharjah	

2.3.4 Schools and sustainability in UAE

Zomorodian and Nasrollahi (2013) stated that the school building orientation affects the energy consumption for cooling and lighting. Al-Khatatbeh and Ma'bdeh (2017) mentioned that the high occupancy of the classrooms in the school building is a direct reason for the high energy consumption to provide suitable indoor thermal and lighting conditions. This is in alignment with Elmasry and Haggag (2011) who stated that schools are considered as high energy consumption buildings due to the distinctive occupancy patterns. Schools in the UAE consume around 100 kWh/m2/year (Swiss International Scientific School Dubai 2015) and this is a great amount of energy compared to schools in Greece for instance, which consume about 57 kWh /m2/year because of the Mediterranean climate (Hernandez, Burke and Lewis 2008; Dias Pereira et al. 2014). In the UAE, most of this energy is consumed for cooling, despite the fact that schools are occupied for limited number of hours (average eight hours). Al-Sallal (2010) stated that schools in the UAE are designed in a way that increases the solar gain for the internal spaces and that require a lot of energy for cooling. Energy expenses in schools represent a high value among the total expenses spent by schools. For instance, according to the US Department of Energy, schools can save up to 25% of the total expenses on energy by using efficient techniques (Zhang et al. 2017).

The number of schools in the UAE is increasing in high rate, as the international schools become 511 schools in the year 2015 compared with 439 schools in 2014, which is an indicator for the fast growth in the education sector (Gulfnews 2015). The classrooms in schools indeed represent the most congested and functional spaces that emit huge amounts of heat, the estimated heat source of a classroom represents approximately 5 kW (Brebbia & Beriatos 2011; Elmasry & Haggag 2011). Demanuele, Tweddell and Davies (2010) highlighted the importance of defining the amount of energy consumption in schools in the design stage, they added that the students' behavior in the school is a major factor for increasing the heat gain, and consequently the energy consumption.

The UAE has worked lately on different agendas for renewable energy production and energy efficiency in buildings to reduce the energy consumption from fossil fuels. The Amra Bint Abdulrahman Secondary public school in Abu Dhabi was the first public school in the UAE to join the Green Schools Alliances, as this association tries to find clever solutions for schools to be sustainable, reduces the impact of the climate and links the students to the nature. Green Schools

Alliances affect 3.6 million students all over the world in around 5,726 schools, which represent more than 550 million ft^2 of built environment (Greenschoolsalliance.org 2016). In the case of Dubai many schools have started to consider energy efficiency as an important issue in schools. The Swiss International Scientific School in Dubai is considered the first school in the Middle East with low energy consumption as it achieved the first Swiss MINERGIE green label. The founder of this school, Mr. Omar Danial, stated that this school adopted a thermal barrier for the school which includes new techniques for insulation and new materials for air tightness to reduce the energy consumed for cooling in the hot climate of Dubai, as these techniques minimize the heat transfer. He added that the school succeeded to reduce energy consumption from around 100 KwH/m2/year to 34.9 KwH/m2/year and that showed a high responsibility of protecting the natural resources (Swiss International Scientific School Dubai 2015). In 2015 eleven schools were rewarded in the UAE for their efforts in reducing their energy consumption by 17%, as they participated in the World Eco–School Program (Gulfnews 2016).

All the previous achievements in energy efficiency for school buildings were based on individual efforts from the schools' founders or administrations, and they were not controlled by a direct mandatory governmental regulation for sustainable schools. Thus, there should be criteria for the green school building design, such as adopting passive design strategies (for instance, courtyards) to reduce energy consumption, beside following specific technologies for improving energy efficiency and finally by adopting improved operation and maintenance systems.

2.4 Schools and courtyards

Eddy (2018) insisted that the courtyards are essential outdoor spaces in schools, as they provide the students with pleasant outdoor spaces for playing, socializing and relaxation. Furthermore, they engage students into a real scientific outdoor lab about plants and climates (figure 2.45). Moreover, he added that a courtyard with a suitable design could inspire the students and improve their educational achievements. In 2012 there was a proposal by the landscape architect Broadway Malyan for an Eco courtyard in a green school in Abu Dhabi to improve the natural lighting and the thermal performance of the school. The eco-friendly courtyard included types of vertical gardens (tree shape), one composed of natural plants with an irrigation system, and the other with PVC panels to provide clean energy along with more shade (figure 2.46) toward improving the thermal performance and reducing the energy consumption of the school. Other benefits of this e-courtyard included a suitable atmosphere for science lessons related to plants growth and life cycles, as well as the PVC as a renewable energy source (World Landscape Architecture 2018). It is clear that in eco-friendly courtyards the architect focused more on the content of the courtyard than the courtyard proportions and ratios to improve the thermal performance of the school.

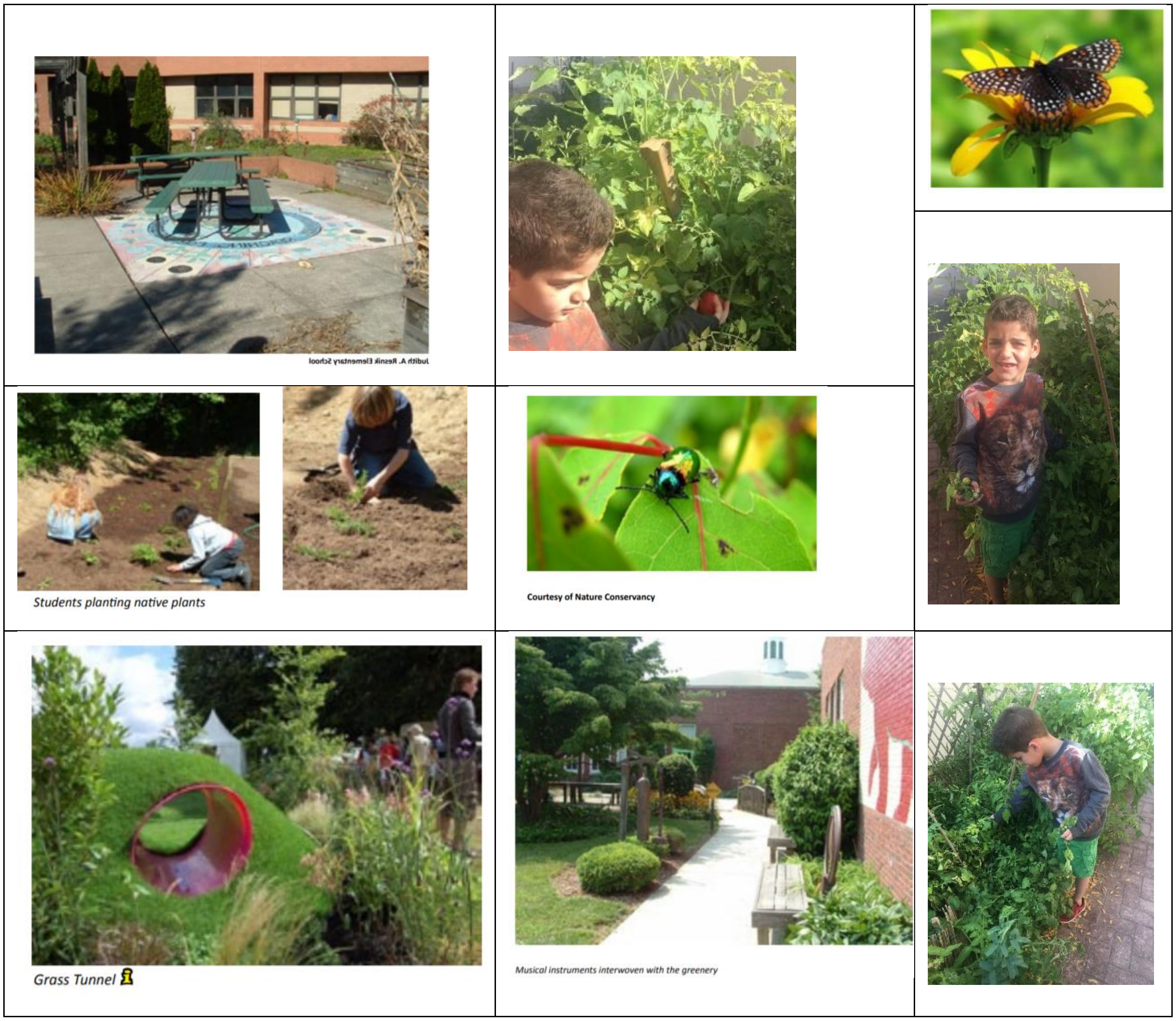


Figure 2. 45: Activities and design for school courtyard (author; Maryland Dep. of Education 2012)

Figure 2. 46: Eco tree in the Eco courtyard in the green school in Abu Dhabi (World Landscape Architecture 2018)

There were some other studies that investigated the courtyard in educational buildings. Rigolon (2010) categorized the school buildings in Europe into four main types based on their plans and according to selected case studies. The four types of the plans are: courtyard plan, block plan, cluster plan and town-like plan (figure 2.47). He added that the courtyard plan is the common traditional type in schools. This type was common in the past and is still used in the present for schools that focus on outdoor activities. This type provides private outside space for the school where students spend time in a psychologically comfortable environment. Rigolon (2010) specified two main properties for this type: first, it supports considerably the formation of the sense of proprietorship in the community of the school; second, it delivers a visual emphasis on the central spaces as it provides a comfortable sense for the students for being in an enclosed outdoor space surrounded by different types of openings.

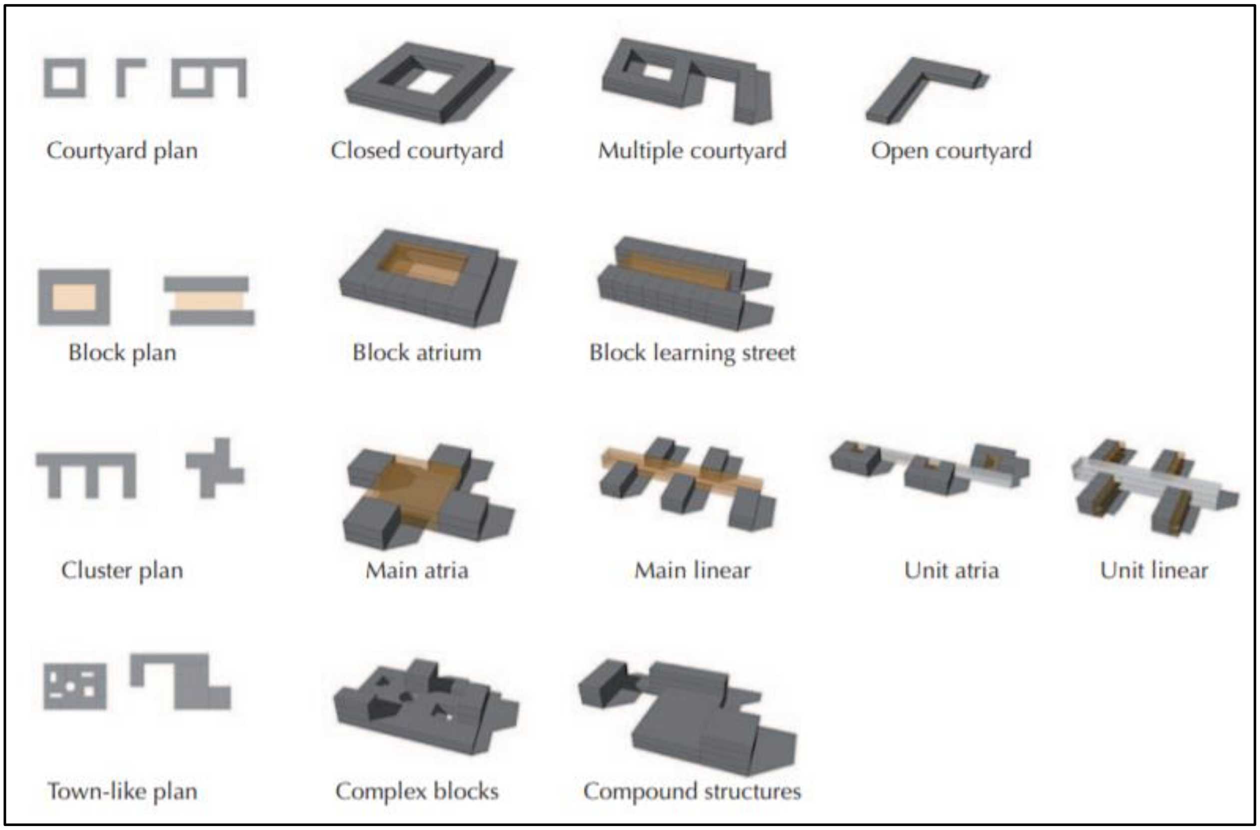


Figure 2. 47: The different types of school buildings (Rigolon 2010).

Rigolon (2010) itemized three main types of schools with courtyards: solo courtyard, double open and closed courtyards and finally schools with several courtyards. He added that the location of the courtyard defines the school plan layout and the formation of the outdoor spaces. The outdoor spaces can be closed or left open according to the location, climate and style of the school building. For instance, in France the preschool in Chaource is designed around an open courtyard as the landscape was a significant element. In the school with the courtyard it is considered as the core space for socialization, thus the internal spaces in the building are mainly for circulation and to access the classrooms. Finally, Rigolon (2010) stated that the traditional concept of courtyard is considered as an old fashioned design and needs improvements to be more effective. Kolozali and Kolozali (2016) sated that the courtyard in schools is important to create a suitable and comfortable atmosphere. They added that the greenery is important in the courtyards as it casts a shadow for better thermal performance, defines the pathways, prevents the dusty air and also provides its beauty for relaxation. They classified the most popular courtyards in the educational buildings (figure 2.48). They concluded that the closed shape and U shape are the two common shapes. They stated that the height of the surrounding walls of the courtyards are not defined, as they are built according to the designed area. Finally, they mentioned an additional advantage for the courtyards in the school, in that it has the ability to split the building masses from each other according to the function.

Figure 2. 48: Examples for the courtyard in educational institutions (Kolozali & Kolozali 2016).

Zhang et al. (2017) investigated the effect of the geometry of different types of school buildings on their thermal performance (figure 2.49) according to 1- Orientation: rotating the building according to the four main directions N, S, E, W to evaluate the effect of orientation; 2- Window to wall ratio: which ranged from 10-90%; and 3- Room depth. The study was in the cold climate in China. The results of the study revealed that the schools with courtyards in a H shape were the best in the thermal performance and students preference.

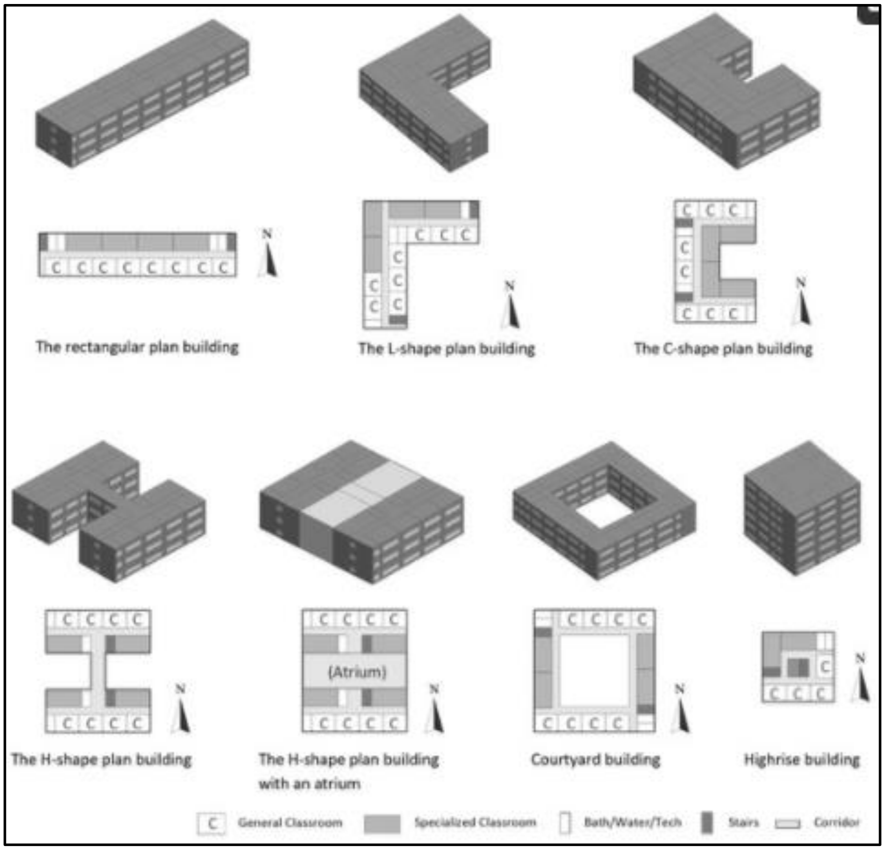


Figure 2. 49: The school types and shapes that was investigated in the study (Zhang et al. 2017).

The Maryland Department of Education (2012) prepared a guide booklet for planning, building and using the courtyard in the school. They stated that the courtyard in a school has many advantages related to having a nature playground, fun activities, better indoor lighting beside creating a more sustainable school. They insisted to address the courtyard as an important component of the school building structure, as they noted that the courtyard was mostly related to residential and commercial buildings. They recalled that at the beginning of the last century most schools were planned as courtyard buildings to provide suitable lighting and private natural space. Then in the years 1940 and 1950 the courtyard was ignored after depending on artificial lighting, ventilation and cooling systems. Recently the idea of the courtyard came back as a good sustainable concept in schools, mainly for lighting and leisure.

Furthermore, the Maryland Department of Education (2012) added that courtyard integration in the building design increases the points for LEED certification by adding points for better lighting, conserving habitat and reducing the heat gain by shading from the courtyard walls. The Maryland Department of Education (2012) listed many regulations to design a successful school courtyard, among them: studying the sunbath and shade cast to orient the building in the right direction, defining the direction of the wind to shield from it, as well as many other detailed rules (appendix 2.4), but they unfortunately did not define exact ratios for the courtyard.

The Maryland Department of Education (2012) and Tai et al. (2006) suggested that the courtyard gardens are better to be designed according to a theme related to literature. They suggested that after fulfilling the standards related to the environment, the function and the safety building codes, the courtyard design should have a theme after famous novels, for example, by connecting the concept of the courtyard design with the landscape theme of a famous book like Alice in Wonder Land (figure 4.50). They added that this will add another advantage for the school courtyard to enrich the imagination and inspiration of the students and give them more leisure besides encouraging them to read.

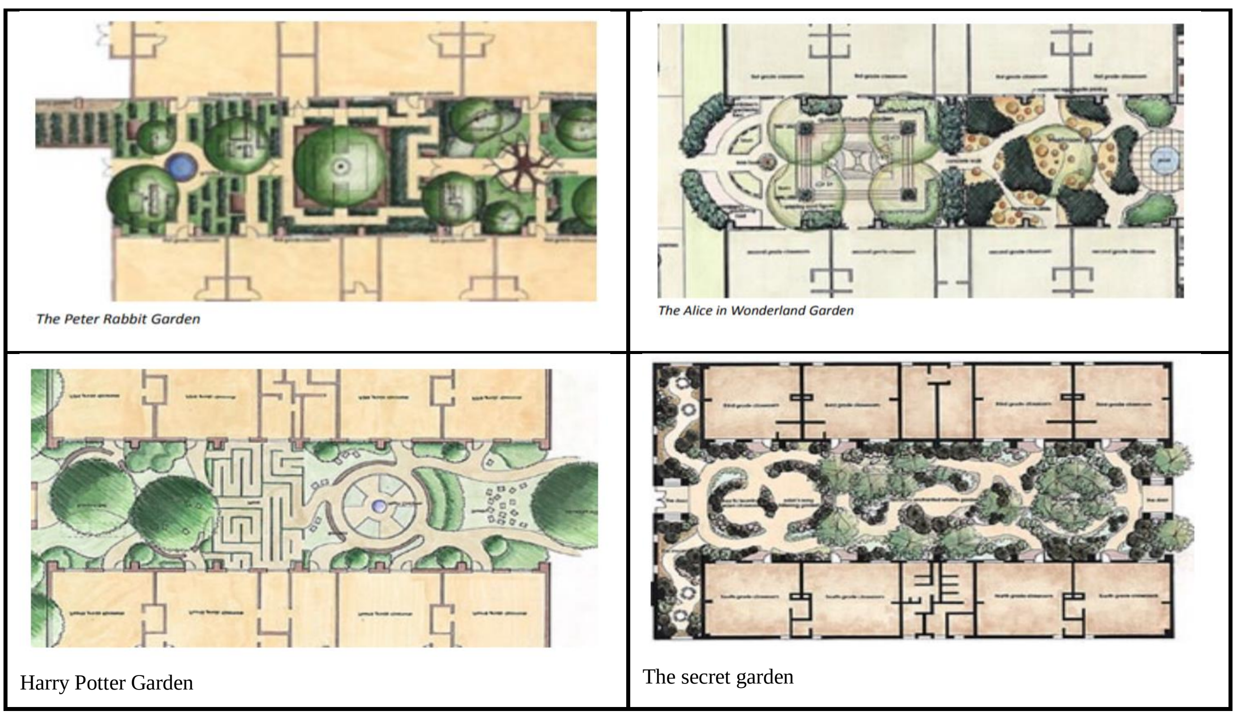


Figure 2. 50: Sample themes for a school courtyard garden (The Maryland Department of Education 2012)

2.5 Schools and the academic calendar with the daily activities:

The academic calendar differs from country to country according to the traditions, climate and other related issues. In UAE the main vacation is on Summer mostly (June, July and August) beside another two short vacations on Winter around one month, and on Spring around two weeks. The students spend around seven to eight hours in the school every day including one or two breaks around half an hour each, depending on the grade or class number. Most of the learning classes are taken in the classrooms, while students can spend the time of the break time and sport classes in the courtyards if the climate is comfortable according to the time of the year. Fadeyi et al. (2014) stated that each student spends around 1300 hours per year in his classroom, thus the school environment should be healthy and comfortable. Santamouris et al. (2007) mentioned that the school interior environment is affected mainly by the energy consumption, thermal comfort and finally the quality of the air in the building.

Al-Khatatbeh and Ma'bdeh (2017) mentioned that the high occupancy of the classrooms in the school building is a direct reason for the high energy consumption to provide suitable indoor thermal and lighting conditions. This is in alignment with Elmasry and Haggag (2011) who stated that schools are considered as high energy consumption buildings due to the distinctive occupancy patterns. Schools in the UAE consume around 100 kWh/m2/year (Swiss International Scientific School Dubai 2015) and this is a great amount of energy compared to schools in Greece for instance, which consume about 57 kWh /m2/year because of the Mediterranean climate (Hernandez, Burke and Lewis 2008; Dias Pereira et al. 2014). In the UAE, most of this energy in schools is consumed for cooling, despite the fact that schools are occupied for limited number of hours (average eight hours), as the schools are designed in a way that increases the solar gain for the internal spaces and that require a lot of energy for cooling. Energy expenses in schools represent a high value among the total expenses spent by schools. For instance, according to the US Department of Energy, schools can save up to 25% of the total expenses on energy by using efficient techniques (Zhang et al. 2017).

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Courtyards are vital open-air spaces in schools, as they offer a pleasant outdoor area for the students for playing, socializing and relaxation. Additionally, they engage students into a real scientific outdoor lab.

2.6 Summary and conclusion

Based on the literature a courtyard has many environmental, social and economic benefits which can be summarized as:

- Courtyard was designed to fulfill the different needs of the occupants like the climatic, religious, social, economic, culture and architectural needs (Almhafdy et al. 2013; Mishra, & Ramgopal 2013).
- Many studies recommended that, the courtyard is an effective passive design solution for buildings in hot areas. As the courtyard acts like a channel for the warm air to be cleared and substituted by cooler air. This mechanism decreases the entire building temperature throughout the night time till it reaches its least rate at sunrise (Al-Hafith et al. 2017).
- Moreover, it was clear according to the literature that the courtyard's effects on the building vary according to many parameters that define its efficiency in improving the thermal performance for the whole building (Reynolds 2002; TERI 2004; BerKovic et al. 2012; Almhafdy et al. 2013; Tabesh & Sertyesilisik 2016; Markus et al. 2017). Among those parameters are the courtyard shape, orientation, proportion to the built-up area, courtyard ratio height to width and SVF, heights of the masses around the courtyard, and vegetation. For example, the according to the orientation and the surrounded walls of the courtyard, shading created inside the courtyard, which reduces the heat gain from solar radiation and subsequently decreases the temperature.

Unfortunately, few studied the courtyard as a solution for school buildings, further more they didn't define the suitable ratios and orientation for it in school buildings on hot areas. The research aims to integrate a well-designed courtyard as a successful passive design strategy in the school buildings-UAE to reduce the energy consumption for cooling and that will have positive environmental and economic effects , as courtyards proved by time its positive interaction with the hot climate. On the other hand the study aims to highlight the thermal comfort improvement for the optimum school courtyard (PMV) , which expected to affect positively the student satisfaction toward the school building by providing enjoyable area for school socialization and the psychological and physical health especially in the break time .

Based on the literature a list of parameters will be formed to evaluate and improve the courtyard thermal performance in the school building within three stages:

Stage one: Courtyard investigation according to the orientation : (Zhang et al., 2017) used investigated the effect of the geometry of school building on its thermal performance , according to 1- orientation rotate the building according to the four main directions N,S,E,W to evaluate the effect of orientation.

Stage two : Courtyard design . This stage will include parameters to evaluate the courtyard design: 1- Courtyard ratios width/Length. Manioğlu and Oral (2015) insisted on the importance of the courtyard W/L ratio on its thermal performance, they defined it as shape factor for the courtyard. 2- Courtyard area to built up area ratio CA/BA. Soflaei, Shokouhian and Mofidi Shemirani, (2016) stated that in the traditional courtyards (good thermal performance) have CA/BA ranges between 18% -44% . 3- Courtyard outline shape square and rectangular . (Tabesh & Sertyesilisik (2016) stated that the geometry of the courtyard is critical issue as the courtyard performance mainly depend on the amount of solar radiation access to it . They argued that because of the sun location and radiation a square courtyard is ideal in relations of energy savings . 4- Courtyard walls height Antonio and Carvalho (2015) stated that the higher the walls around the courtyard the cooler the temperature inside the courtyard thus the adjacent spaces. 5- Courtyard greenery and landscape . Safarzadeh and Bahadori (2005) mentioned that the presence of plants in the courtyard such as trees and shrubs can considerably improve the thermal performance of the courtyard, mainly because of the shade that they produce . Taleghani, Tenpierik and van den Dobbelsteen (2014) pointed to the importance of greenery in improving the of courtyard role in improving the thermal .

Despite the fact that the main concern of this research is decreasing the cooling energy, but there will be evaluation for the Courtyard Thermal comfort at the end of stage two to highlighted additional advantage for the courtyards. The stack effect in the courtyards improves their ventilation and the air circulation especially in the hot arid areas, as it take away the heat and moisture to accomplish the thermal comfort (Koch-Nielsen 2002; Rajapaksha, Nagai & Okumiya 2003; Zakaria & Kubota 2014). The reference for defining the thermal comfort is ASHRAE, which was used widely to find the PMV in many researches like Salata (2016) . Thermal comfort inside the courtyards will be investigated at the break time 10:00 am to show the level of improvement in the outdoor thermal comfort the optimum courtyard can provide for the students in the break time parallel to the courtyard's ability in reducing the indoor temperature.

Stage three: Energy consumption . Investigation for the energy saving according to the optimum configurations implemented in the previous stages by using IESve software. Safarzadeh and Bahadori (2005) mentioned that the courtyard can be of elements that can decrease the energy consumption of the building beside the trees , water pools,…etc. Ghaffarianhoseini, Berardi and Ghaffarianhoseini (2015) pointed to the capability of the courtyard in reducing the cooling load.

Chapter 3: Methodology

3.1 Introduction

Buildings have a considerable effect on the environment because of the high energy consumption ratios and usage (Heeren et al. 2015). Buildings in the UAE consume a lot of energy. Afshari, Nikolopoulou and Martin (2014) stated that 87% of the electricity consumed by the residential, governmental and commercial divisions is consumed by the air conditioning. These results were based on statistics by the Municipality of Abu Dhabi City. The courtyard was introduced in many studies as a passive design solution for buildings in general to improve the thermal conditions and reduce energy consumption. Almhafdy et al. (2013) investigated the role of the courtyard by investigating the literature review with observation for courtyards in Malaysian Hospitals. In the same manner, Zakaria and Kubota (2014) used a literature review to evaluate the performance of the courtyard in residential hot arid areas like Malaysia. They focused mostly on ventilation beside the shading effect.

Yaşa and Ok (2014) used a computer simulation using the CFD program to evaluate the solar heat gain of the closed courtyard with different proportions in different countries. Despite the fact that there are a lot of studies about courtyards in buildings in general few are related to school courtyards (Al-Sallal 2010; Cantan et al. 2014; Acosta, Campano & Molina 2016; Jamaludin et al. 2014; Shashua-Bar & Hoffman 2004), therefore, there is still a lack of comprehensive view for such a strategy, especially in school buildings. Based on that, this research's main goal is to fill part of this gap about the best courtyard configuration in school buildings in hot arid areas like the UAE. The research will follow a qualitative mixed method to achieve more accurate comprehensive results with less uncertainties (Creswell 2003; Bell 2010; Robson 2011; Angell and Townsend 2011). The main methods will include Case Study (public schools), Data Collection (annual statistics and journal articles), field measurements, interviews and observation computer investigation for indoor temperature and energy simulation. The different methods will help to achieve the objectives toward the expected outcomes.

3.2 Courtyard thermal performance with different investigation methods

The courtyard is a traditional passive design solution that has attracted designers in contemporary architecture as a sustainable strategy in the buildings especially in hot areas. The literature indicates that the researchers have adopted different methods to highlight the role of the courtyard as a climate modifier. Some of them have used the literature from previous studies, while others have used field measurements or software to investigate the effects of the courtyard as a passive design solution. Each of the researchers have focused on one or more of the courtyard properties like shading or ventilation due to the courtyard ratio, height, galleries and orientation.

The literature listed three main methods among the others, which were more common in the courtyard investigation either on real or virtual case studies:

- Literature review: Almhafdy et al. (2013) and Zakaria and Kubota (2014) used literature review to evaluate the performance of the courtyard in buildings. A similar approach was adopted by Kolozali and Kolozali (2016) who highlighted the role of courtyard in architecture design according to its climatic effect. Markus (2016) and Tabesh and Sertyesilisik (2016) stated that the geometry of the courtyard is a critical issue for the courtyard's performance after investigating the literature related to courtyards.
- Experimental field measurements: Soflaei, Shokouhian and Mofidi Shemirani (2016) used empirical field study to investigate the thermal performance in traditional courtyards. Canton et al. (2014) conducted a research by using field measurements in a refurbished school building (one floor level) as a case study to assess the thermal impact of the courtyard.
- Computer modelling: Yaşa and Ok (2014) used a computer simulation by CFD program to evaluate the solar heat gain of the closed courtyard with different proportions in different countries. Abanomi and Jones (2005) investigated the prototype governmental school models in KSA, they used ECOTECT and HTB2 software to evaluate the actual thermal performance of the schools. They investigated different strategies, such as thermal insulation. Aldawoud and Clark (2008) used DOE2.IE software to investigate the thermal impact of the courtyards on the buildings in various climate areas in the USA.. Manioğlu and Oral (2015) used Energy Plus and Design builder software to investigate the courtyard proportion's effects on the cooling and heating energy of the building. Al-Masri and Abu-Hijleh (2012) used the IESve software to investigate the effects of courtyards on the thermal performance of midrise buildings. Ghaffarianhoseini, Berardi and Ghaffarianhoseini (2015) used ENVI-met to investigate the courtyard thermal effect.

Furthermore, some researchers adopted more than one method to investigate the courtyard's role, such as Tsianaka (2006) who studied the effect of the courtyard on the urban tissue, he used field measurements and Cluster Thermal Time Constant prediction model (CTTC). Others adopted more than software in their research, as Sharmin and Steemers (2015) who used ENVI-met software to predict the outdoor microclimate temperature for buildings with courtyards, and they used IESve for energy calculations.

According to the literature of the methodology related to courtyard thermal performance, it was clear that the literature-based investigation is a useful approach that helps in highlighting the potential parameters of the courtyard design, but it was not enough to improve the thermal performance of the courtyard. Moreover, the experimental and field-based studies are expensive as it is difficult to conduct a real experiment on a real school building according to the required proportions of the courtyard and difficult access to school buildings. Additionally, the difficulties in investigating new scenarios for the courtyards in schools were covered. Furthermore it was found that the computer simulation was a suitable tool for investigating the courtyard's performance for the existing and proposed scenarios.

As a result, this research will use the literature from the previous studies related to courtyards to define the potential points for improvement for school courtyards, and the computer simulation to investigate new scenarios to improve the thermal performance of the school courtyard until reaching the optimal courtyard in hot areas. Furthermore, the field measurements will be used only to validate the computer software.

3.3 Research Methodology

The methodology which will be adopted in this research aims to answer the questions and achieve the objectives (table 3.1). As Ismail (2005) stated that the methodology should deal with the variables of the study and deliver the right approach to meet the questions and solve the research problem. The goals of this research are to identify standards and strategies for the design of courtyards in school buildings to reduce the energy consumption and decrease the negative impact of such buildings on the environment, as mentioned before. Accordingly, that will fill the gap of the missing literature about the courtyards in the schools in hot arid areas like the UAE.

Table 3. 1: The methodology map of the research.

Global concerns	Causative factors from the literature review	Research rationale and Motivations	Research Questions	Research Aims	Research objectives	Methods used for investigation
High level of CO2 Air pollution Climate change	High energy consumption by buildings in hot areas like UAE mainly for cooling	High energy consumption in the school buildings which led to more CO2 and more pollution	What role can the traditional courtyard concept play in the modern school buildings in order to minimize the energy consumption for cooling (environmental wise) thus reducing the electricity bill and the capital cost (economical wise) in hot arid areas?	Integrate a well-designed courtyard as successful passive design strategy in the school buildings-UAE to reduce the energy consumption (for cooling and lighting) and that will have positive environmental and economic effects, as courtyards showed by time its positive interaction with the hot climate.	To assess the impact of the courtyard as passive design solution for school buildings in hot areas and evaluate its environmental effects accordingly the economic effects by reducing the energy consumption.	Qualitative -Case study Field measurements Observation & Interviews Modelling using IES and ENVI-met Comparing the results
		Unlimited consumption of the electricity in the schools caused extra cost for fixing the damage of the CO2 emission				
	Limited literature about the passive design solutions in schools in UAE	The need of green schools with passive design solutions like courtyards to save the energy	Can the suitable ratios and configurations of the school courtyard beside the green areas, increase its efficiency?	Define the characteristics of the optimum courtyard with relation to orientation, ratio to the built-up area, proportion, height and green area	To identify the best orientation for the school courtyard in hot arid areas /UAE	Modelling using ENVI-met with new parameters related to the orientation
					To identify the best ratio for courtyard area /built up area that can decrease the energy consumption.	Modelling using ENVI-met with new parameters related to courtyard area /built up area Comparing the results
		The lack of the regulations related to the proper proportions for the present school courtyards			To identify the optimum ratios (width to length) for the best courtyard configuration for school buildings.	Modelling using ENVI-met with new parameters related to optimum ratios (width to length) Comparing the results
					To identify the optimum height for the best courtyard configuration for school buildings.	Modelling using ENVI-met with new parameters related to height. Comparing the results
					To improve the thermal characteristic of the courtyard integrated in school building by adding green areas.	Modelling using ENVI-met with new parameters related to green areas Comparing the results
					To calculate the energy consumption according to the new microclimates which was created according to the improvements on the design of the courtyard.	Modelling using IES with new microclimates from ENVI-met Comparing the results
		The school courtyard is outdoor private isolated space, where students can spend their break time in it according to the level of the thermal comfort (PMV) and that will effect students satisfaction toward the school building in general .	Can the optimum courtyard have better outdoor thermal comfort (PMV) which can affect positively the students' satisfaction by improving the social interaction, pleasant outdoor space and the mental and physical wellbeing?	Highlight the thermal comfort improvement for the optimum school courtyard (PMV) which expected to affect positively the student satisfaction toward the school building by providing enjoyable area for school socialization and the psychological and physical health.	To Explore other effects of the optimum school courtyard like the outdoor thermal comfort (PMV) which can improve the student satisfaction in relation to school building by improving the school socialization and providing enjoyable outside areas beside the psychological and physical health	Modelling using ENVI-met with new parameters related to PMV. Comparing the results

The research will follow an empirical aspect that depends on qualitative mixed methods to achieve more accurate comprehensive results with less uncertainties. The investigations in this research are to find new applications of existing practice related to the role of the courtyard as a passive design solution for school buildings. Robson (2011) emphasized on the distinction of adopting multiple methods in the research to increase the accuracy and to reduce the unsuitable certainty of the results. Many studies in the architectural environmental field adopted different methods to investigate different parameters related to courtyards, such as shading means, for instance, Alfarra (2014), Alzanfer (2014) and Race (2013) and others like those shown in table (3.2) and table (3.3) to evaluate courtyard performance. Accordingly, the qualitative mixed method based on case studies seemed to be the most appropriate approach for this research to tackle its problem and to highlight the environmental impact of the courtyard in schools.

Table 3. 2: Shading methods in the courtyard and its related effects on the thermal conditions as reported in the previous studies (Zakaria and Kubota, 2014).

Climate	Shading means	Effects	Methods	Ref.
Hot-dry	Courtyard orientation	• Courtyard facing south provides more shading percentage (30-70%) during summer. • North and south orientation provide the highest amount of shade. • Hot-dry: Optimum shading when courtyard in northeast -southwest or north-south direction (approximate of 60% shade area)	• Semi-open courtyard facing south direction • Courtyard axially elongated to north-south direction • Courtyard axially elongated to north-south or northeast-southwest direction.	Meir et al., 1995. Berkovic et al., 2012. Muhaisen, 2006.
	Courtyard roof	• Significantly lower courtyard temperature (3°C below maximum outdoor temperature) • Reduce 18-21% of indoor energy consumption based on the respective case models.	• Adjustable courtyard roof • Fabric canopy roof	Al-Hemiddi et al., 2001. Canton et al., 2014
	Courtyard galleries	• Application of the galleries provides the best thermal comfort during peak hour (PMV: 0.5-1.0)	• Application of galleries along the court-yard perimeter	Berkovic et al., 2012.
Hot-humid	Courtyard Orientation	• Hot-humid: Optimum shading when courtyard in north-east-southwest direction (approximate of 65% shaded area) • Lower air temperature than outdoor in north and south direction (2% lower)	• Courtyard axially elongated to northeast -southwest direction • Semi-open courtyard facing north or south.	Muhaisen, 2006. Almhafdy et al., 2013.
	Courtyard roof	• Reduce courtyard heat gain during peak hour (13:00) approximately 85%. • Improve thermal condition in the adjacent of courtyard zone.	• Raised courtyard roof with 500 mm height	Sadafi et al., 2011.
	Courtyard verandah	• Lower air temperature by 1.5 °C compared with maximum outdoor (Synchronizing with upper courtyard temperature).	• Shade the areas that adjacent to indoor opening.	Dili et al., 2010.
	Canopy of trees	• Lower indoor mean temperature of the adjacent room with higher relative humidity.	• Canopy of trees adjacent to the window.	Jamaludin et al., 2014.

Table 3. 3: Examples for different methods that can be used to obtain the objectives of this research.

Methods	**Investigation field**	**Reference**
Qualitative • Case studies • Field visits and survey • Computer simulation	• Daylight in classrooms in UAE • Thermal effect of the courtyards • Analysis of energy savings for lighting	• *(Al-Sallal 2010)* • *(Cantan et al. 2014)* • *(Acosta, Campano & Molina 2016)*
• Case studies • Field measurements	• Ventilation and temperature in the interior spaces around courtyard • The thermal behavior in an entirely closed courtyard • Evaluation of passive cooling of urban streets and courtyards with trees.	• *(Jamaludin et al.2014)* • *(Berkovic, Yezioro & Bitan 2012)* • *(Shashua-Bar & Hoffman 2004)*

The qualitative research will investigate the role of the courtyard in the school buildings and evaluate its environmental impact, thus economic effects, by reducing the energy consumption for cooling. The investigation will depend on existing courtyards in school buildings as case studies as a base followed by different steps including data collection, field measurements (for the temperatures) and finally computer simulation. These steps are to find the optimum proportions for the courtyards with the best efficiency for reducing energy consumption. Shah and Corley (2006) pointed to the power of the qualitative method in improving existing practices. Groat and Wang (2013) stressed that the qualitative approach in architectural studies should comprise different methods, including interpretive literature background, followed by suitable case studies, then computer simulation and finally rational analysis to solve the research problem.

Moreover, this research will have a comprehensive descriptive analysis based on the collected data to create a broad understanding of the current condition of the study. The descriptive analysis will highlight innovative implications and ideas in the existing knowledge and make it clear to others (Stake 1995). Several researchers started their investigations into the thermal performance of the courtyard by descriptive analysis. Jamaludin et al. (2014) evaluated the ventilation process for a building (university college) with a courtyard. The researcher started their investigation with a descriptive method to understand the existing situation of the case study which led to the research points of interest. The descriptive analysis in this research will focus on the courtyards in the current schools, and it should be followed by interpretive statements, to create critical connected reasoning for the new parameters for the courtyard proportions towards more efficient ones. Glense (2010) stated that in the interpretive analysis the researcher assumed it to be an instrument for the investigation in the research. The researcher in this case interacts in a certain environment and after that he concludes his observations, interpretations and declarations as assumptions. Emerson, Fretz and Shaw (2011) stated that the ethnographic practice is required for the interaction in the certain environment as it assists in identifying the behavior of the individuals in the area of the research. In this research it is important to visit the field of the investigation, mainly the case studies of the school buildings, especially in the time when the temperatures are measured in the courtyard. The field notes in this case will describe the students' behavior in the courtyard to observe the places where the students prefer to gather in the courtyard area in relation to their satisfaction with the temperature. The field notes and measurements will help to understand the effect of the temperature in the courtyard on the students' behavior. Moreover, the field measurement will provide accurate data about the temperature in the existing school courtyards to understand the relationship between the temperature and the existing proportions of the courtyard (height to length).

3.4 Research approach and justification

Most of the researchers and studies in the construction field are based on problem solving (Farrell 2011). This research will focus on solving a problem which was created by the shortage in the available studies about the environmental and economic roles and effects of courtyards in the school buildings as passive design solution in hot areas like the UAE. As mentioned before a majority of the studies focused on the courtyard's thermal effects on houses. Consequently, there were insufficient theories and regulations about the optimum proportions (height to length) beside the thermal comfort of the courtyards in schools. Thus, the limited information about this issue led to a direct need to investigate the environmental, thermal comfort impacts of the courtyards in schools. In this research there will be a sequential process of simulation for models related to courtyards in school buildings depending on different parameters to highlight the best configurations and proportions. Another strategy that has a positive impact on the courtyard thermal performance will be investigated, which is soft scape (plants).

The previous studies related to courtyards used different methods and approaches based on literature, experimental and field studies beside computer simulations. The literature-based investigation is an appropriate approach that helps in in the guidance to the potential parameters of the courtyard design, but this approach alone was not convenient to improve the thermal performance of the courtyard. Moreover, the experimental and field-based studies are expensive and difficult to conduct. Actually, it is not easy to conduct a real experiment on a real school building according to the required proportions of the courtyard and it is difficult to access the school building for field measurements. Furthermore, it was found that the computer simulation was suitable tool for investigating the courtyard's performance for the existing and proposed scenarios.

Thus, this research will adopt a qualitative methodology based on mixed methods that accommodate the different investigations related to the courtyards. The investigations include more than one method because they have different questions, and each question requires a suitable method to answer it and to achieve the related objective (table 3.4). Consequently, more than one tool will be used for the investigation in this research, including case studies, field measurements, field notes, computer simulation and analysis. Furthermore, Bell (2010) who proposed many methods for the research work including surveys, ethnography, case studies and experiments.

As a consequence, this research will use the literature from the previous studies related to courtyards to state the potential paths for development for school courtyards, and the computer simulation to examine new setups to expand the thermal performance of the school courtyard until reaching the optimal courtyard in hot areas. Groat and Wang (2013) stated that computers are the best tools for research simulation to create a virtual world that reflects the real one. Furthermore, the field measurements will be used once to validate the computer software only.

The research will start with gathering existing data from the available sources and studie about courtyards to revise, modify its proportions, expand the knowledge in this field and finally define a set of recommendations about the best integrations of the courtyards in school buildings. These recommendations will improve the thermal and the economic performance of the school and reduce the negative impacts of the school buildings on the environment and mitigate the climate change.

Table 3. 4: The relationship between objectives and the methods used in this research.

Research objectives	Methods used for investigation
1-To assess the impact of the courtyard as passive design solution for school buildings in hot areas and evaluate its environmental effects accordingly the economic effects by reducing the energy consumption.	*Case study (Qualitative) *Field measurements *Observation & Interviews *Modelling using IES and ENVI-met *Comparing the results
2-To identify the best orientation for the school courtyard in hot arid areas /UAE	*Modelling using ENVI-met with new parameters related to the orientation *Comparing the results
3-To identify the best ratio for courtyard area /built up area that can decrease the energy consumption.	*Modelling using ENVI-met with new parameters related to courtyard area /built up area *Comparing the results
4-To identify the optimum ratios (width to length) for the best courtyard configuration for school buildings.	*Modelling using ENVI-met with new parameters related to optimum ratios (width to length) *Comparing the results
5- To identify the optimum height for the best courtyard configuration for school buildings.	*Modelling using ENVI-met with new parameters related to optimum height. *Comparing the results
6-To improve the thermal characteristic of the courtyard integrated in school building by adding green areas.	*Modelling using ENVI-met with new parameters related to green areas *Comparing the results
7- To calculate the energy consumption according to the new microclimates which was created according to the improvements on the design of the courtyard.	*Modelling using IES with new microclimates from ENVI-met *Comparing the results
8- To Explore other effects of the optimum school courtyard like the outdoor thermal comfort (PMV) which can improve the student satisfaction in relation to school building by improving the school socialization and providing enjoyable outside areas beside the psychological and physical health	*Modelling using ENVI-met with new parameters related to PMV. *Comparing the results

3.5 Methods used in the Research

The main methods that are used in this research include case studies, data collection and computer simulation (figure 3.1), to investigate the current thermal situation for the courtyards and define the best configuration for courtyards in the school buildings with the best thermal performance.

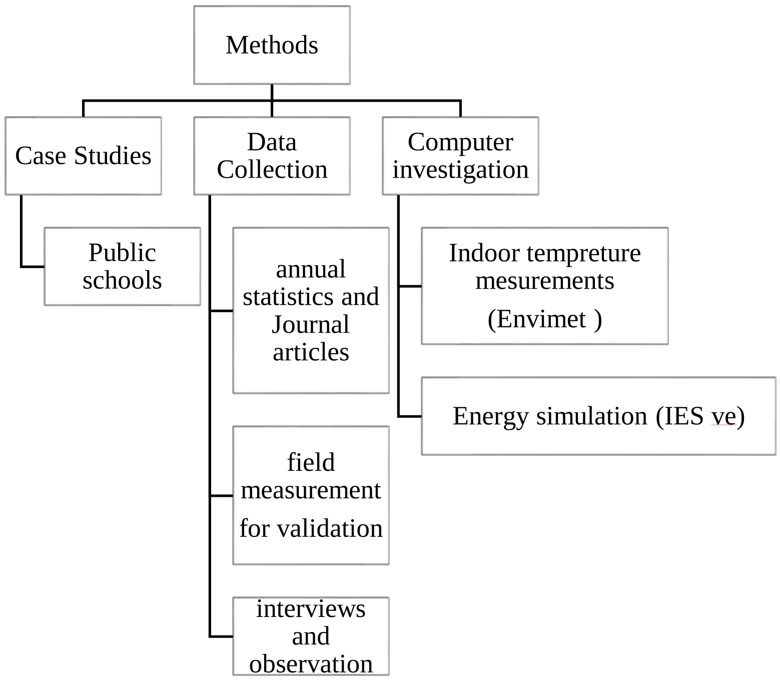


Figure 3. 1: The main methods used in the research.

3.5.1 Data collection

Groat and Wang (2013) pointed to data collection as a starting point for the architectural research in both qualitative and quantitate methods. In this research the data collection for the research qualitative methodology will give comprehensive understanding about the courtyards performance in current school buildings in the UAE. The data will be gathered from different resources, such as annual statistics of the schools from the Ministry of Education, reports of the Ministry of Education, journal articles about the schools and the courtyards' environmental impacts, interviews with staff members in the building sector from the Ministry of Education, field notes about the school courtyard shape and characteristics (like shading devices and galleries if they exist), field notes related to the students behavior in the courtyards, field measurements for the temperature in the courtyard and so on. The gathered information will be analyzed in descriptive, interpretive and comparative manners to highlight the parameters for the final stage of the research which should conclude the best characteristics and proportions for the courtyard to have a better environmental and thermal impact.

The gathered data should include all the issues related to the research to create a solid base for the literature review and then the investigation. Furthermore, it will facilitate the process of answering the questions and achieving the objectives of the research.

3. 5.2 Case studies

The case study is a main component of this research, as it provides realistic understanding about the existing conditions of the study. Yin (2003) pointed to the case study as "*an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when boundaries between phenomenon and context are not clearly evident*". Many researchers adopted a case study (studies) in their investigation about the courtyard's thermal impact on the building despite the fact that most of these were houses. The case studies will explain the mechanisms of the courtyards that reduce the energy consumption for cooling in the building as a passive design concept. Canton et al. (2014) conducted a research by using field measurements in a refurbished school building (one floor level) as a case study to assess the thermal impact of the courtyard on the interior spaces of the building in Argentina. Filippín (2005), Banerjee and Annesi-Maesano (2012) and Jamaludin et al. (2014) used buildings with courtyards as case studies to investigate the environmental impact of the courtyards.

According to the previous explanation in the literature, there are two types of schools in the UAE: public schools (under the supervision of the government) and private schools. Both types have regulations and guidelines enforced by the Ministry of Education (Aboullail 2016), (Ministry of Education 2015), but these regulations do not include any standards that define the shape, the type or the proportions of the courtyards in schools. These regulations only focused on the area of the play grounds in the schools. The Ministry of Education built the public schools according to several templates. All these templates have courtyards but in different proportions. This research will adopt five public existing schools according to the five design templates as case studies. Three templates will be drawn upon from the old ones till 2012 (explained in the literature) (figure 3.2), in addition the newest two templates after 2012 (figure 3.3).

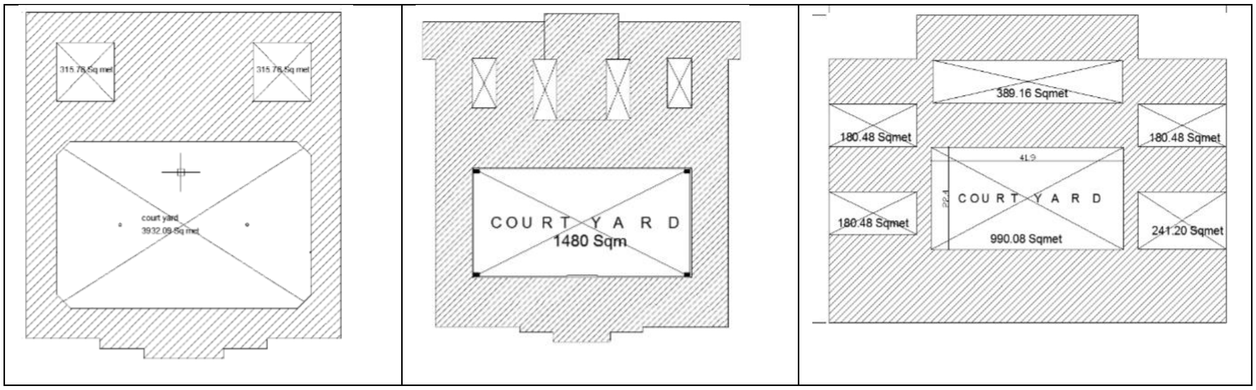


Figure 3. 2: Site plan for the three templates of the public schools before 2012 (Ministry of Education - UAE 2013)

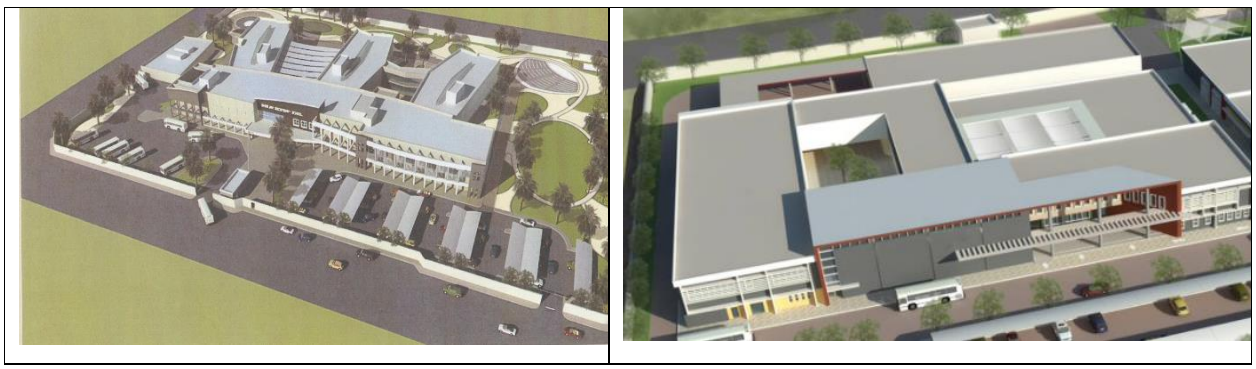


Figure 3. 3: for the two templates of the public schools after 2012 (Ministry of Education - UAE 2013)

The reason behind choosing the public schools as case studies is that they have limited design templates (governmental), have courtyards and are easier to be studied and investigated than the private schools, which have hundreds of design plans, beside that many private schools do not have courtyards. Furthermore, the courtyards in the public schools do not have clear standards that define the shape, the type, the proportions or the orientation of the courtyards in schools. The regulations only focused on the area of the play grounds in the schools. The context of the case studies will be the UAE as a sample of a hot arid climate. All the case studies will be investigated to highlight the impact of the courtyards on the thermal behavior of the schools, as each one has different proportions, areas and sizes for the courtyards. The investigation of the case studies will include interviews with members from the Department of Public Works, field measurements for the temperatures, field notes (observations) and computer simulation. The investigation for the case studies will give clear understanding for the current role and impact of the courtyard on the thermal performance and energy consumption in the public schools in the UAE. A comparative analysis based the case studies will be conducted to define the optimum required proportions for better future performance. The results of the investigations on the case studies can be used for both future sustainable green private and public schools.

3.5.3 Computer investigation

The computer simulation is an important tool in the architectural research (Groat and Wang 2013). Shen, Chow and Darkwa (2013) used ECOTEC software for modelling buildings to define the cooling demand in relation to the outdoor temperature. Zomorodian and Nasrollahi (2013) used Design Builder to investigate the architectural design configuration for school buildings to decrease the energy consumption in hot and dry areas of Iran. Cantón et al. (2014) used field measurements and Energy Plus software to evaluate the energy performance of courtyards in schools in Argentina. Yousef Mousa, Lang and Auer (2017) used computational fluid dynamics (CFD) simulation to evaluate the expected ventilation system in a courtyard building in a hot climate. Aldawoud and Clark (2008) used DOE2.IE software to investigate the thermal impact of the courtyards on the buildings in various climate areas in the USA. Ghaffarianhoseini, Berardi and Ghaffarianhoseini (2015) used ENVI-met to investigate the courtyard’s thermal effect on the buildings in Kuala Lumpur, Malaysia.

In spite of the availability of many computer software programs that can be used to simulate the environmental impact of the buildings, this research will consider two software programs: ENVI-met software and IESve software for building simulation. The reason for using two software programs was that the study will search for the best courtyard among the school case studies and then improve the thermal performance for this courtyard by improving its design. The improvements of the courtyard design create different microclimates according to the adopted scenarios, thus there was a need to use ENVI-met software as it is superior in calculating the microclimates for the buildings according to their configurations, but unfortunately ENVI-met software cannot calculate the energy consumption neither can it assess the reduction in the cooling load for the developed scenarios. Thus, it was necessary to use IESve software, which is capable of calculating the cooling loads for the school building according to its courtyard configuration. In the following section, a more detailed explanation of the two adopted software programs is given.

ENVI-met software: It is a three-dimensional micro meteorological model (Huttner 2012). It is capable of simulating the real microclimate models (Huttner, Bruse and Dostal 2008; Lee, Mayer and Chen 2016; Salata et al. 2016). This software includes 3D high resolution modeling for the microclimate for the buildings, based on physical, atmospheric and fluid standards (Pass and Schneider, 2016) (figure 3.4). It is capable of calculating the exterior humidity, air temperature, soul temperature and radiative flux. Furthermore, it is capable of calculating the surface temperature of the building according to energy balance of heat exchange between the building surfaces and the outdoor temperature, which can lead to the indoor temperature of the building. The ENVI-met can evaluate the effect of vegetation and water features on the microclimates for the buildings (Simon 2016). Huttner (2012) stated that ENVI-met enables forcing the real climate boundary condition (air temperature and humidity) for the model to create real microclimate bases on real inputs to produce more accurate results. Jin et al. (2017) used ENVI-met software to evaluate the effects of buildings geometry and wind movement upon pedestrian areas in cold climates of China, as they stated it is a widely used and effective accurate software. Despite the fact it has some limitations like the ability to change the wind speed and direction according to real hourly input data (Salata et al. 2017).

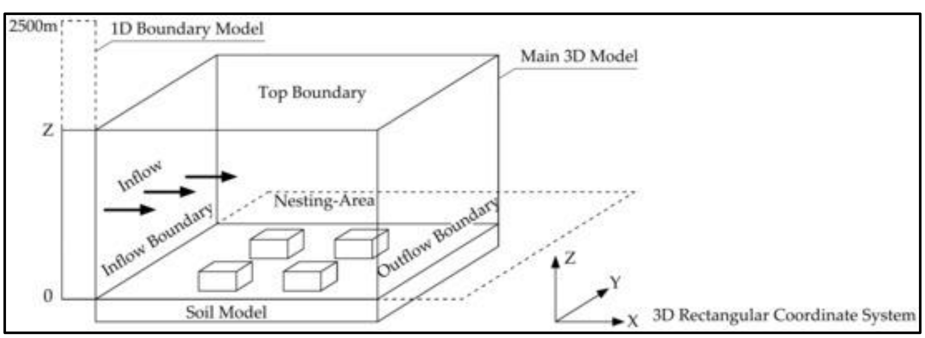


Figure 3. 4: ENVI-met 3D model (Jin et al. 2017)

The three main variables that will be calculated according to the ENVI-met:

1- Outdoor air temperature for the new microclimates that will be created according to the configurations and the orientation of the courtyards. Huttner (2012) stated that the air temperature in ENVI-met is calculated according to equations related to heat radiation and exchange, humidity and vegetation, among others.

2- Indoor air temperature of the building; as ENVI-met can calculate this indoor temperature according to heat exchange between the outdoor atmosphere and the exterior walls of the building, and between exterior walls of the building and the air inside it (Huttner 2012) (figure 3.5). This is important to define the energy consumption for the building heating and cooling requirements, thus it is an indicator for the best configuration in each stage, as it defines how much the indoor temperature decreases while trying to reach the optimum configuration for the courtyard.

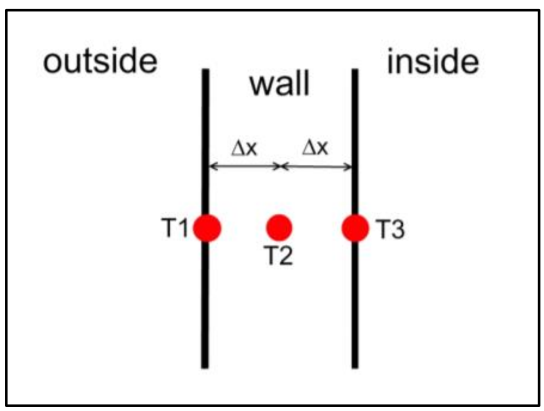


Figure 3. 5: ENVI-met 3 node wall model (Huttner 2012).

3- Thermal comfort, the effect of the outdoor microclimate on human comfort and perception. This is mostly related to air temperature, wind speed, humidity and radiant temperature as external effects, in addition to other effects related to the human body, such as gender, age clothing and metabolism. Based on that ENVI-met can calculate the PMV predicted mean vote, which has been used for indoor and outdoor thermal assessment. It is mainly related to the energy balance of the human body. ENVI-met calculates this according to the ASHRAI scale where +3 is hot and -3 is very cold (Huttner 2012).

IES ve software: Integral Environmental Solution - Virtual Environment is designed in a way that encounters the requirements of architects to create sustainable architecture with less energy consumption, and thus less harm for the environment (figure 3.6) (Iesve.com 2018). Crawley et al. (2008) mentioned that IESve software is a pioneer in the modelling of the environmental performance of buildings. This software is widely used because of the good accuracy and ease of use (Hammad and Abu-Hijleh 2010). Moreover, this software gives a variety of analysis about the building, such as indoor air temperature, energy consumption, carbon emissions and so on. (Iesve.com 2018). Michael who has 10 years involvement and experience in simulating numerous global projects for sustainable evaluation and rating, used IESve. He stated that because of the expectations of the climate change and the rising outdoor air temperature; buildings are expected to consume more energy for cooling, which will increase the CO_2 emissions. Thus, it is better to optimize the building design in a way that reduce the energy consumption for cooling. IESve can be a direct key to defining the expected cooling loads (Bollock, 2018).

Almhafdy et al. (2015) used the CFD in IESve software to evaluate the performance of the courtyard configuration in a building by changing the aspect ratio and the shading devices in a hot humid climate. They stated that the aspect ratio width to length plays a significant role in the courtyard performance as it directly affects the shading area inside the courtyard. They added that the U-shape type, which has aspect ratio width to length 1:2 (rectangular), acts better than U-type that has AR 1:1 (square). Touqan, Taleb and Salameh (2017) used IES software to investigate the best strategies to reduce the energy consumption in a villa in Dubai. The three strategies included improved thermal insulation for the walls, a green roof and finally using PVC panels to produce clean energy. Al-Masri & Abu-Hijleh (2012) used the IESve software to investigate the effect of courtyards on the thermal performance of midrise buildings. Kim, Augenbroe and Suh (2013) used the IESve for proportional research to compare the standards of rating for LEED and ISO-CEN building energy consumption. Some of the buildings which were tested for the study included courtyards.

Almhafdy et al. (2013) used the IESve software to evaluate the effect of courtyard policy on a hospital building in Malaysia. Their study was used to show the thermal effect of the courtyard as a passive design solution. They validated the software with field measurements. They stated that the comparison of air temperature between the field measurements and the simulation results by IESve gave acceptable results. That confirmed that IESve is a suitable instrument for simulation. Chadalavada (2017) used IESve software to investigate the thermal performance of courtyards with different proportions in a vernacular house in India. Salameh and Taleb (2017) used IESve software evaluate the thermal performance of courtyards and their effect on school buildings in hot areas in the UAE.

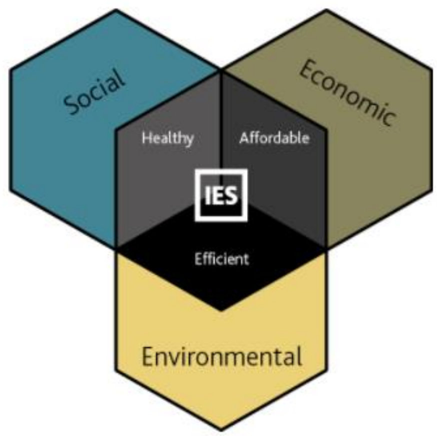


Figure 3. 6: IESve software main fields (Iesve.com 2018).

The computer simulation in this research will be used for the case studies on more than one stage from the beginning till the end:

1- The first stage will include modelling for the case studies with the original courtyards in the current conditions in different orientations to choose the best model with the lowest indoor temperature for the school building by ENVI-met.

2- The second stage will include simulation to choose the best courtyard according to different design parameters.

3- The third stage will include computer simulation for the best configuration by IESve to calculate the energy savings.

Both software has been validated in chapter 4.

3.6 Pilot studies

The pilot studies are an important step before proceeding with the research as Van Teijlingen and Hundley (2002) stated that "*Pilot studies are a crucial element of a good study design*", they added that despite the fact that implementing a pilot study does not provide assurance of success for the main research, but it does increase the probability of success. Pilot studies include a variety of significant roles and can deliver important understandings for the research. Furthermore, they explore the suitability of the tools and software used in the research and provide the researcher with training in his investigation field, beside many other advantages.

Three pilot studies were conducted in preparation for this research. Some are related to the software to be used and the others are related to the courtyard's impact (as a passive design solution) on building performance and on the students. Two of the pilot studies were published and the third one is in the process of being published (table 3.5).

Table 3. 5: List of pilot studies

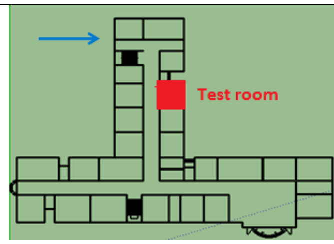
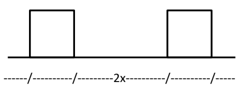
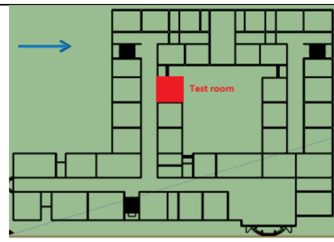
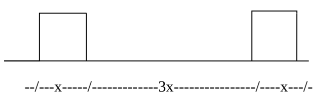
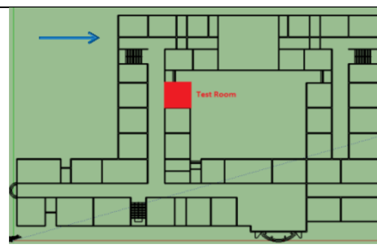
	The study	Purpose	Status
1-	Courtyard as Passive Design Solution for School Buildings in Hot Area	Investigate the school courtyard ratios and its effect on the thermal performance of the school building.	Published in Proceedings of the 2nd World Congress on Civil, Structural, and Environmental Engineering (CSEE'17) Barcelona, Spain – April 2 – 4, 2017 Paper No. AWSPT 141 ISSN: 2371-5294 DOI: 10.11159/awspt17.141
2-	Low carbon cooling approach for residences in the UAE. A case study in Dubai	Validate the IES software	Published in Proceedings of the 2nd World Congress on Civil, Structural, and Environmental Engineering (CSEE'17), Barcelona, Spain – April 2 – 4, 2017, Paper No. AWSPT 127, ISSN: 2371-5294, DOI: 10.11159/awspt17.127.
3-	Courtyard design in schools and its influence on Students' Satisfaction	To investigate student acceptance for courtyard, as extra encouragement for using this effective passive design solution	Under process to be published

The following contains summaries for the three pilot studies which were conducted prior to the research to give insight about the research topic and investigate the suitability of the tools that are planned to be used.

3.6.1 Courtyard as a Passive Design Solution for School Buildings in Hot Areas

In the study there was an investigation about the thermal behavior and ventilation for an existing school building in Sharjah (Al Murooj English school) compared with two other proposed cases for the school future expansion that have two different proportions for closed courtyards. The proposed cases are based on Koch-Nielsen's (2002) suggestions as he stated that the size and the height of the courtyard strongly affect the thermal properties of the courtyard and the adjacent spaces. Koch declared that if the height of the courtyard walls is X then the best width for the courtyard ranges from X to 3X. The investigation was conducted using IESve software for simulation of the cases 2X and 3X, and the proportion of 1X was overlooked as it was small for a school building (table 3.6). The study proved that the school building with 2X courtyard was better in terms of thermal performance. The school with a 2X courtyard had less solar gain (figure 3.7), sun exposure (table 3.7) and air temperature (table 3.8) (figure 3.8). Based on that, the case of 2X had the lowest cooling sensible plant (figure 3.9). It was obvious that the proportions of the courtyard affect the thermal behavior of the inner school spaces.

Table 3. 6: The three simulation cases of the study (Salameh & Taleb 2017).

Cases of the analyses	Top view of the simulation cases	Perspective for the simulation cases
The first stage : The original school without the closed courtyard. It has semi opened courtyard.		
The second stage: The school with closed courtyard that has width 2X, where X is the courtyard height. 		
The third stage: The school with closed courtyard that has width 3X, where X is the courtyard height. 		

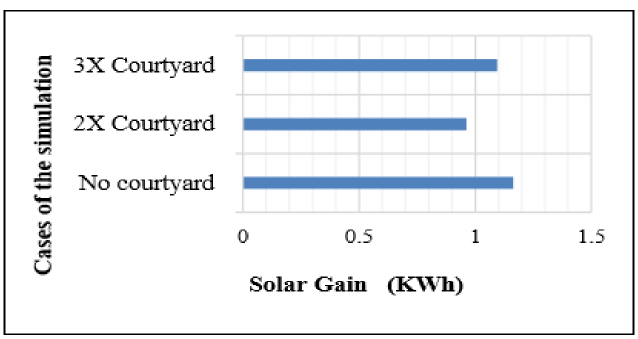


Figure 3. 7: Solar gain for the test room in the three cases of the school building (Salameh & Taleb 2017).

Table 3. 7: Sun exposures on the north wall of the test room (Salameh & Taleb 2017).

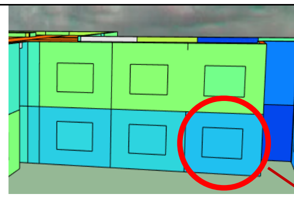
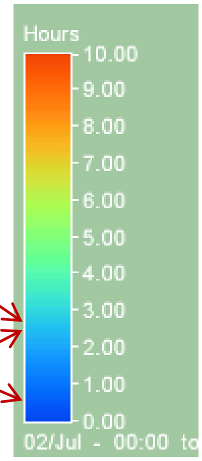
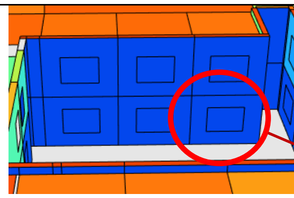
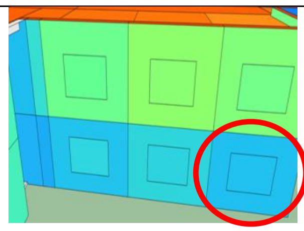
Cases	Sun exposures	Sun exposure by hours
Case 1: No courtyard		
Case 2: **2X courtyard**		
Case 3: **3X courtyard**		

Table 3. 8: air temperature in the trest room (Salameh & Taleb 2017).

Simulation cases of the school	Minimum temperature/ test room		Maximum temperature /test room		
	The value °C	The date	The value °C	The time	Mean
3X Courtyard	17.44	27/Jan	41.56	06/Aug	30.03
2X Courtyard	17.43	29/Jan	36.10	06/Aug	24.21
No Courtyard	18.34	27/Jan	43.73	06/Aug	31.67

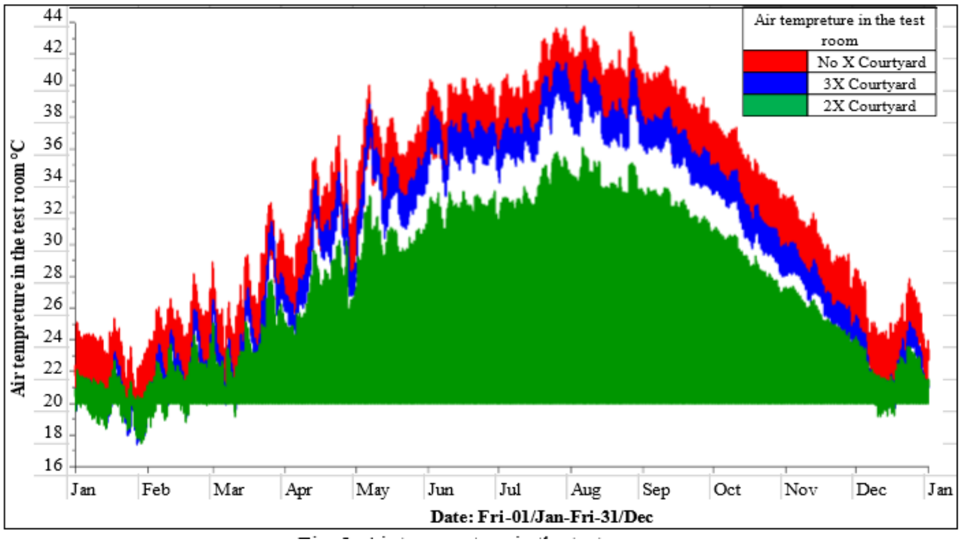


Figure 3. 8: Air temperature in the test room (Salameh & Taleb 2017).

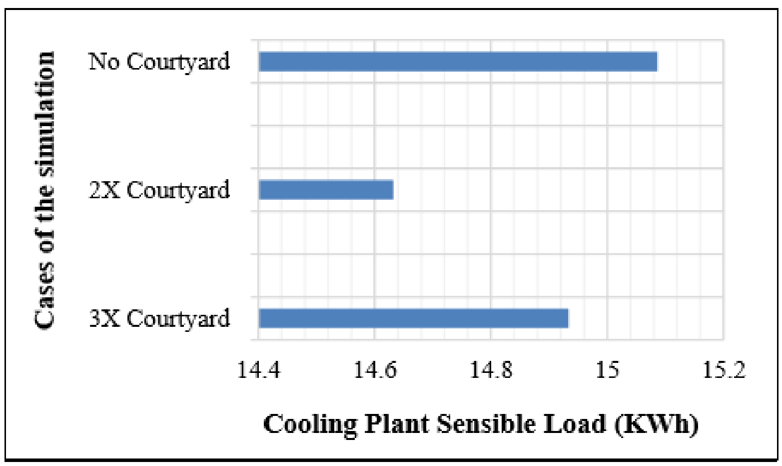
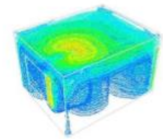
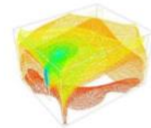
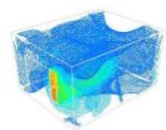
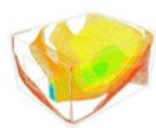
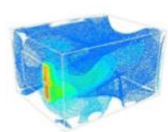
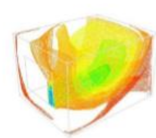


Figure 3. 9: Cooling plant sensible load in the test room (Salameh & Taleb 2017).

Additionally, the investigation proved that in the case of natural ventilation,, the air in the case 2X courtyard has the highest velocity, and thus the lowest local mean age (table 3.9). Based on that, the 2X courtyard had a better ventilation system than the other two cases, that caused the CO_2 concentration (ppm) in the test room in the case of the 2X courtyard to decrease to 448 ppm (figure 3.10), which is in the proper range or less. Gov.uk (2016) stated that the average CO_2 concentration should not be more than 1,500 ppm in educational buildings.

According to the study of Al Murooj English school, the building should have a courtyard with a length equivalent to twice its height in order to have a better inner environment. Moreover, this study proved the capability of the courtyard to improve the thermal performance of the indoor spaces of the school building and proved the suitability of the IESve software to show that.

Table 3. 9: Air velocity and local mean age inside the test room (Salameh & Taleb 2017).

Cases of the simulation	Velocity of the air in the test room m/s		Local mean age of the air surface	
Case 1: No closed courtyard school No X	m/s 0.55 0.49 0.44 0.38 0.33 0.27 0.22 0.17 0.11 0.06 0.00 Velocity		Min 12.115 11.01 9.912 8.811 7.709 6.608 4.405 3.304 2.202 1.101 0.000 LMA	
Case 2: 2X courtyard school	m/s 0.94 0.88 0.78 0.66 0.57 0.45 0.38 0.29 0.19 0.09 0.00 Velocity		min 7.498 6.749 5.999 5.249 4.499 3.749 2.999 2.249 1.499 0.749 0.000 LMA	
Case 3: 3X courtyard school	m/s 0.89 0.80 0.71 0.62 0.53 0.44 0.36 0.27 0.18 0.09 0.00 Velocity		min 7.682 6.914 6.145 5.377 4.609 3.841 3.072 2.304 1.536 0.768 0.000 LMA	

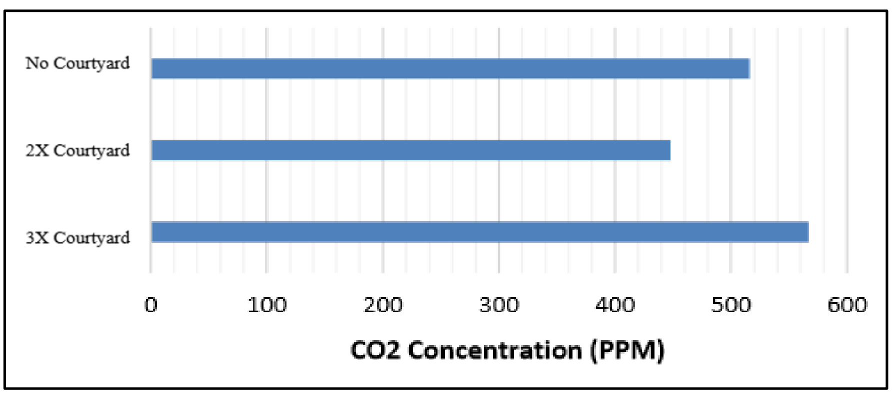


Figure 3. 10: Comparison of the CO_2 concentration (ppm) in the test room in the three school building cases (Salameh & Taleb 2017).

3.6.2 Low carbon cooling approach for residences in the UAE. A case study in Dubai

This research delivered a low carbon application for a villa in Dubai to reduce the energy consumption, mainly for cooling. The research used three policies that can be implemented as a design for a sustainable villa. IESve and RETScreen software were adopted to investigate the suggested polices. The three polices included: first, a suitable wall structure and materials with better thermal insulation. Second, a green roof instalment to reduce the passage of heat through the roof. Third, installation of PVC photovoltaic panels to generate clean energy and decrease dependence on generated fossil fuel-electricity. After implementing the three polices, the results proved their efficiency in reducing the energy consumption for the villa. The overall energy reduction was about 15.45 MWh, and that represented around 19.6% of the whole base case cooling intake (table 3.10) (table 3.11) (Touqan, Taleb & Salameh 2017).

Table 3. 10: Evaluation for the base and competent exterior insulation case (Touqan, Taleb & Salameh 2017).

	Base case	Efficient case
Wall configuration	– Perlite Plaster (2 cm) – Concrete block (20 cm) – Perlite Plaster (1.5 cm)	– Perlite Plaster (2 cm) – Polyurethane Board (6.3cm) – Concrete block (20 cm) – Perlite Plaster (1.5 cm)
U-value	1.65 W/m².K	0.32 W/m².K
Total chiller energy consumption	78.56 (MWh)	71.58 (MWh)
Cooling load during hottest month of August	In the range of 61 kW to 82 kW	In the range of 53 kW to 75 kW

Table 3. 11: Assessment for the plane roof and green roof (Touqan, Taleb & Salameh 2017).

	Plane Roof	Green Roof
Roof Configuration	– Gravel (5 cm) – Polystyrene (5 cm) – Membrane (0.4 cm) – Reinforced Concrete (25 cm) – Plaster (Dense) (1 cm)	– Cultivated Peat Soil 133%D.W. Moisture (8 cm) – Gravel-Based Soil (5.5 cm) – Insulation (3 cm) – Fibreboard (0.3 cm) – Roofing Felt (0.18 cm) – LW Concrete 40 LBS - HF-C14 (7.5 cm) – Polystyrene (5 cm) – Membrane (0.4 cm) – Reinforced Concrete (25 cm) – Plaster (Dense) (1 cm)
U -value	0.4812 W/m².K	0.1982 W/m².K
Cooling plant sensible load during hottest month of August for master bedroom	From 6.5 kW to 8.7 kW	From 5.5 kW to 7.9 kW
Total annual power consumption for master bedroom	22.14 (MWh)	19.2 (MWh)
CFD: Temperature in master bedroom, 15th August 12:00 PM	26 C°	24C°

3.6.3 Courtyard design in schools and its influence on Students' Satisfaction

This study explored other influences for the courtyard on the users' satisfaction. The study focused on the well-being and psychological issues. The study aimed to highlight the relationship between the satisfaction of the students and the courtyard design of the school. In order to collect the required data a questionnaire was circulated in two schools among secondary students in Sharjah-UAE. According to the data, six hypotheses were created to examine and certify the relationship, and finally the Statistical Package for Science Software (SPSS) program was used to apply several tests, such as regression analysis and correlation coefficient to investigate the created hypotheses. The results proved the presence of a significant relationship between the School Courtyard (design, area, thermal comfort and landscaping) and level of Student Satisfaction by statistical evidence (table 3.12). The investigation has opened the door for a clear understanding about the reasons behind the students' satisfaction in relation to school courtyard design. Accordingly, the courtyard of a school is considered as an important element in shaping the students’ satisfaction, which will surely affect their educational achievement. Thus, courtyard design should be taken in consideration as a vital physical component when designing a school in addition to any other important components, such as the level of staff experience and the school curriculum.

Table 3. 12: Pearson Correlation coefficient test results

		Physical and Mental Well-being	**Pleasant Outdoor Space**	**Learning Motivation**	**Suitable place for social interaction and break meal**
Courtyard Area and Services	Pearson Correlation	.436**	.503**	.256**	.309**
	Sig. (2-tailed)	.000	.000	.000	.000
	N	291	291	291	291
Courtyard Decoration and Environmental Comfort	Pearson Correlation	.443**	.514**	.333**	.306**
	Sig. (2-tailed)	.000	.000	.000	.000
	N	291	291	291	291

**** “The **Pearson** product-moment **correlation coefficient** is a measure of the strength of the linear relationship between two variables. It is referred to as **Pearson's correlation** or simply as the **correlation coefficient**. ... A perfect positive linear relationship, r = 1”. (Pearson Correlation, 2018)*

The pilot studies where important to confirm the importance of the topic of the research as a passive design solution in school buildings in hot arid areas, which is considered as a pleasant architectural element for the students. Furthermore, they proved the that the IESve software used in research field is effective.

3.7 Limitations of the research

This research will focus on the courtyards in the public schools only, as all these schools have courtyards. The modified courtyards can recommend a model followed by both public and private schools. The research investigation field will focus on the cooling sensible load in the public schools and the environmental effects of the courtyard. Other topics will be excluded from the scope of the research, such as the social aspects of a courtyard and potential improvements in educational achivement, safety in the courtyards related to the heights, lighting in the interior spaces and galleries, as well as the effects of sound and noise inside the courtyard. Finally, there were some limitations related to the software used in the research, for example IESve software limitation in predicting the effect of vegetation in the courtyard on the cooling sensible load for the school buildings especially when calculating the cooling load for the whole academic year.

3.8 The methodology map

Figure (3.11) shows the main three stages of the research, including stage one which was concerned about the school courtyard orientation, stage two which investigated the design of the school courtyard until reaching the optimum courtyard design, and finally stage three which was concerned about the cooling load of the schools with courtyard on specific dates and on the whole academic year.

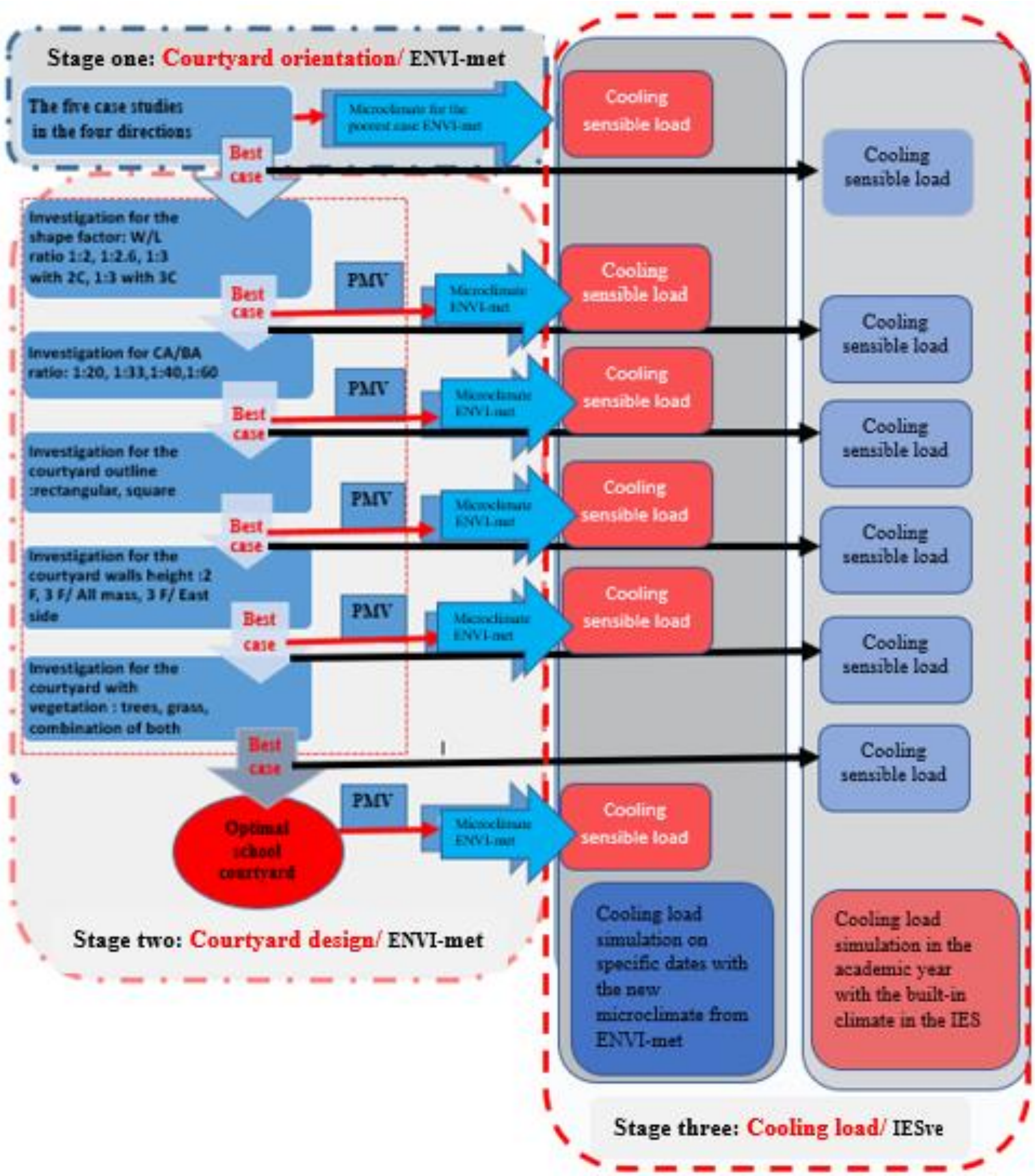


Figure 3. 11: The methodology map including the main three stages of the research.

Chapter 4: Case studies and Software validation

The case study is a focal element of this research, as it offers representative considerations about the existing conditions of the study as Yin (2003) stated. A lot of researchers adopted a case study (studies) in their research about the courtyard's thermal effect, mainly on houses or buildings in general. The case studies will explain the mechanisms of the courtyards that reduce the energy consumption for cooling in the building as a passive design concept. Canton et al. (2014), Filippín (2005), Banerjee and Annesi-Maesano (2012) and Jamaludin et al. (2014) used buildings with courtyards as case studies to investigate the environmental impact of the courtyards.

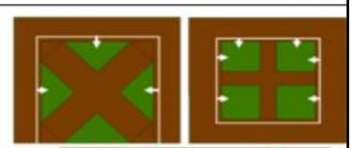
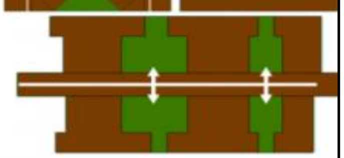
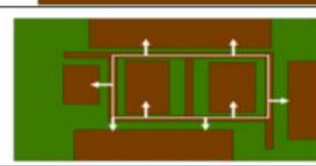
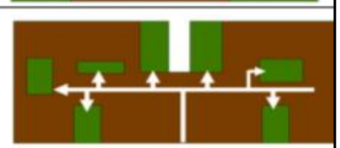
4.1 Case studies

4.1.1 Case study selection

According to the previous explanation in the literature. The public and private schools in the UAE have regulations and guidelines enforced by the Ministry of Education (Aboullail 2016; Ministry of Education 2015). The school buildings regulations do not have any standards that define the school courtyard characteristics or orientation (figure 4.1). The regulations focused only on the area of the playgrounds in the schools to be double the area of the classrooms. The Ministry of Education built the public schools according to several templates. All these templates have courtyards but in different proportions. Almhafdy et al. (2013) investigated the courtyard's performance in Malaysian hospitals. He studied nine hospitals and classified them under five categories (as shown in table 4.1) according to different courtyard configurations. Zhang et al. (2017) investigated the geometry constraints for school buildings in cold areas in China. Their investigation included data on 207 buildings, which were categorized into seven groups according to their plans (figure 4.2). This research will investigate the public school buildings in the UAE by adopting five configurations of courtyards in five templates for existing public schools (old and new) as case studies. The first three cases (as shown in table 4.2) are from the old ones developed before 2012, and the last two cases are new templates developed after 2012.

Figure 4. 1: One type of the public school building with different orientations in Ajman-UAE (google map 2018).

Table 4. 1: The main templates with the common configuration for the Malaysian hospitals adopted by Almhafdy et al. (2013)

Courtyard configuration		Description	Example	Graphical illustration
Cluster Courtyard	Multiple	The design of the hospital creates 4 fully enclosed courtyards	Sungai Buloh Hospital	
	Spinal	More than one courtyard attached to the hospital central circulation route.	Sultanah Nora Ismail Hospital	
Closed courtyard		The courtyard is fully enclosed (4 sides)	Tengku Ampuan Rahimah Hospital	
Open courtyard		Group of building blocks frame open spaces into courtyards	Banting Hospital	
Interlinked		Courtyards located different floor and for different purposes	Serdang Hospital	

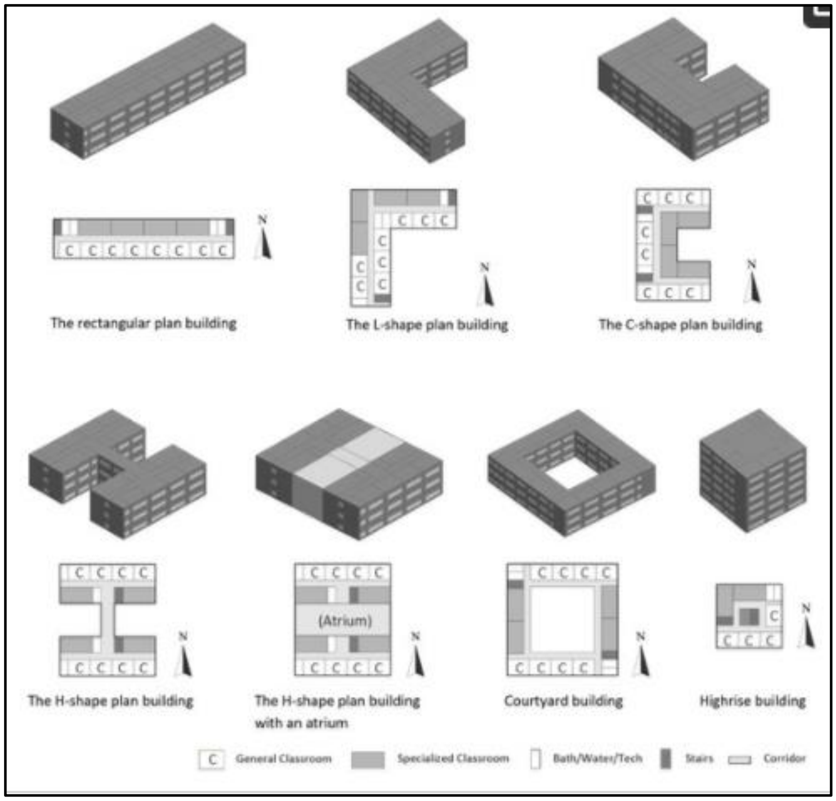
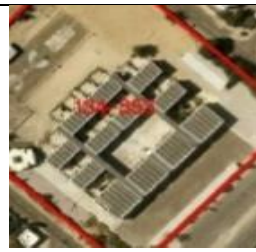
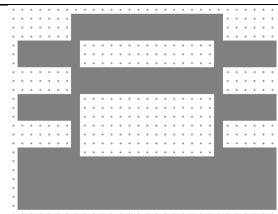
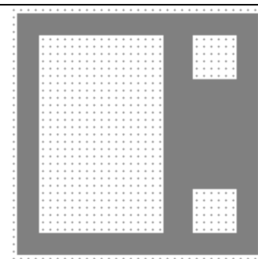
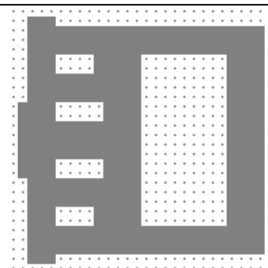
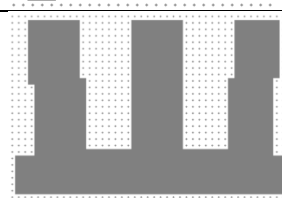
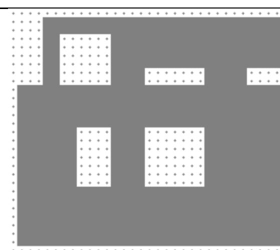


Figure 4. 2: The case studies for schools in Zhang et al. (2017) research.

Table 4. 2: The case studies for the research

Public school type and date of construction	School picture	School site plan	General description for the spaces functions
1-Khateb wa Alami Design -1975. **KAT** Example: Qurtoba School- Dubai			-It is two floor building with 24 classrooms with services. -It has many courtyards, the large one is a closed courtyard. -Most of the playgrounds are not covered
2-Ministry of Public work design 1989 **586** Example: Al Mualla Secondary Female School-Om Al Quwain			-It is two floor buildings with18 or 24 classes and with good services equipment and theater. -It has closed courtyard most of it covered with canopy.
3- Ministry of Public work design 1990 **596** Example: Amenah Bint Wahab Secondary School-Dubai			-It is two floor buildings with 24 classes and with good services, equipment and theater. -It has closed courtyards
4- UPA- fin - Design 2012 **UPA- fin** Example: Al Gharayen 2 Elementry schools – Sharjah			-The school has 38 classrooms, multipurpose rooms, 6 labs, activity rooms, indoor and outdoor playing areas, administration section …etc.
5- UPA1- Design 2012 **UPA1** Example: Al Noof Primary School & Kindergarten – Sharjah			- The school has 25 classrooms, multipurpose room, 3 labs, 2 activity rooms, indoor and outdoor playing areas, administration section …etc.

The reasons behind choosing the public schools as case studies are:

I. Public schools have limited design templates (governmental), unlike private ones, which have tens of design plans.

II. All of the public schools have courtyards but not all the private ones.

III. The courtyards in the public schools do not have clear standards that define the shape, type, proportions or orientation for the courtyards in schools.

The regulations only focused on the open areas of the playgrounds in the schools only. The context of the case studies will be the UAE as a sample of a hot arid climate. All the case studies will be investigated to highlight the impact of the courtyards on the thermal behaviour of the schools, as each one has different proportions, areas and sizes for the courtyards. The investigation of the case studies will include interviews with members from the Department of Public Works, field measurements for the temperatures, field notes (observations) and computer simulation. The investigation for the case studies will give clear understanding for the current role and impact of the courtyard on the thermal performance and energy consumption in the public schools in the UAE. A comparative analysis based on the case studies will be conducted to define the optimum required proportions for better future performance. The results of the investigations on the case studies can be used for both future sustainable green private and public schools.

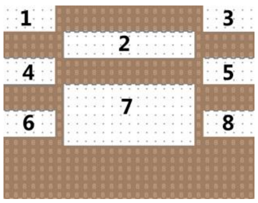
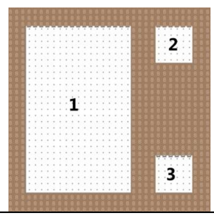
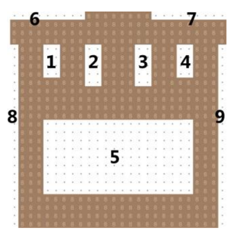
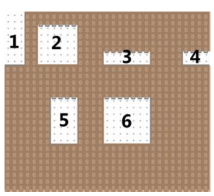
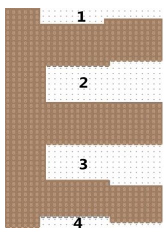
4.1.2 Case studies description

It is clear in table (4.3) that the school designs have different types of courtyards including closed, semi-closed and semi-opened courtyards. The dominate type included closed courtyards in different sizes (big and small). The old three types KAT, 586 and 596 mostly have central big rectangular courtyards, used for different types for activities including social gathering and sport.

- School KAT has a central closed rectangular courtyard surrounded by closed and semi-opened small courtyards, reflective symmetry arrangement of courtyards all with a total area around 2,331m^2.
- Looking at school 586 has the main spaces distributed around a central big rectangular closed courtyard, beside two square, small courtyards used mainly for lighting. Moreover, there was a reflective symmetry arrangement of courtyards in the design. The total area for the courtyards was around 4,779 m^2.

- In the case of 596 school, it was clear that the school was of a similar design as 586 but with a smaller size and minor changes, as it has big central closed rectangular courtyard, beside three small, rectangular courtyards for lighting. The courts area in 596 is around 2,340m^2.
- The interlinked group of courtyards with different sizes found in school UPA1 as the building has six closed courtyards of a medium to small size with an area around 1,431m^2, thus it has the smallest area for the courtyards compared to the other schools.
- Finally, School UPA-fin has two big semi-opened courtyards with the same size and with an area around 2,682m^2. The two courtyards have the same ratios and are designed next to each other. The courtyards were used for different functions including lighting, ventilation and playground for activities.

Table 4. 3: Design Description for the case studies investigated in the research.

School name	Plot Area (m2)	No. of outdoor space	Type of outdoor space	Design description
KAT 	5742 m^2	Court 1	Semi-opened court	The design of the school have central closed rectangular courtyard surrounded by closed and semi closed small courtyards Reflective symmetry arrangement of courtyards in the design
		Court 2	Closed court	
		Court 3	Semi-opened court	
		Court 4	Semi-closed court	
		Court 5	Semi-closed court	
		Court 6	Semi-closed court	
		Court 7	Closed court	
		Court 8	Semi-closed court	
586 	9801 m^2	Court 1	Closed court	The design of the school is around a central big closed courtyard, beside three small courtyards for lighting Reflective symmetry arrangement of courtyards in the design
		Court 2	Closed court	
		Court 3	Closed court	
596 	6085 m^2	Space 1	Closed court	The design of the school is around a central big closed courtyard, beside three small courtyards for lighting Reflective symmetry arrangement of courtyards in the design
		space 2	Closed court	
		space 3	Closed court	
		space 4	Closed court	
		space 5	Closed court	
		space 6	Recessed space	
		space 7	Recessed space	
		space 8	Recessed space	
		space 9	Recessed space	
UPA1 	7533 m^2	Court 1	Semi-opened court	Th3e design of the school building created six closed courtyards that medium to small in size Interlinked arrangement for the courtyards in the design
		Court 2	Closed court	
		Court 3	Closed court	
		Court 4	Semi-closed court	
		Court 5	Closed court	
		Court 6	Closed court	
UPA-fin 	10206 m^2	Court 1	recessed space	The design of the school consists of two equal semi closed courtyards Reflective symmetry arrangement of courtyards in the design
		Court 2	Semi-closed court	
		Court 3	Semi-closed court	
		Court 4	recessed space	

4.1.3 Interviews

The researcher conducted interviews with different people who had direct or indirect relations to the design and development of school buildings. The interviews were conducted to better understand the school buildings' characteristics. Some interviews were conducted with architects from the Public Work Ministry, and others with teachers, and architects from the Dubai Municipality.

One of the interviews was conducted with architect Alaa Aboullail who has worked for 20 years in the architecture department which is responsible for the school buildings development. He explained briefly the development of schools. Furthermore, he gave an explanation about a good example for the existing public school building designs, highlighting the Khateb wa Alami (KAT) Design, which is one of the most popular designs that was adopted by the Ministry of Education for the public schools for many years. There are around 82 schools that are built according to this design at the present time (Aboullail 2016).

This design created two floor buildings with 24 classrooms and other spaces for the services and equipment around a central cell, which is the main closed courtyard (Ministry of Education –UAE 2013) (figure 4.3). Most of the playgrounds in the school are not covered. The design of the interior spaces in the school was based on a 3.2m module, which was repeated three times in the classrooms, and more than three times in the other facilitates, such as the art room (figure 4.4). There are some problems in this design, such as controlling and monitoring the students when they are out of the classrooms as the school has many exits and blind areas. There is another problem related to the expensive maintenance.

Figure 4. 3: Khateb wa Alami school Design (KAT) (Aboullail 2016).

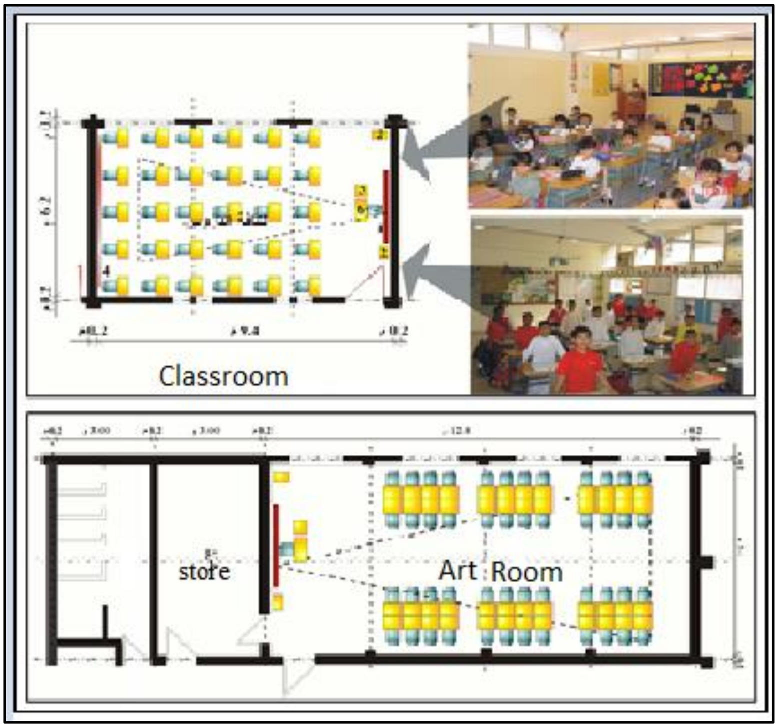


Figure 4. 4: The classroom design (up), the art room design (down) in Khateb wa Alami school (Aboullail 2016).

The design of the school used the corridors around the courtyard as a source for ventilation and lighting (fig 4.5). In limited places, cavity walls were used especially at the end of the extended corridors to reduce the heat gain, as the cavity wall is superior in thermal performance. The constructors did not pay that much attention to the orientation of the school building on the ground and the wind direction, thus the amount of the lighting for the classrooms differed according to the shape of the plot and how the developers placed the design on it regardless of the direction. Consequently, that created improper lighting and sometimes glare in the classrooms, which forced the school administration to use curtains or shutters to reduce the glare.

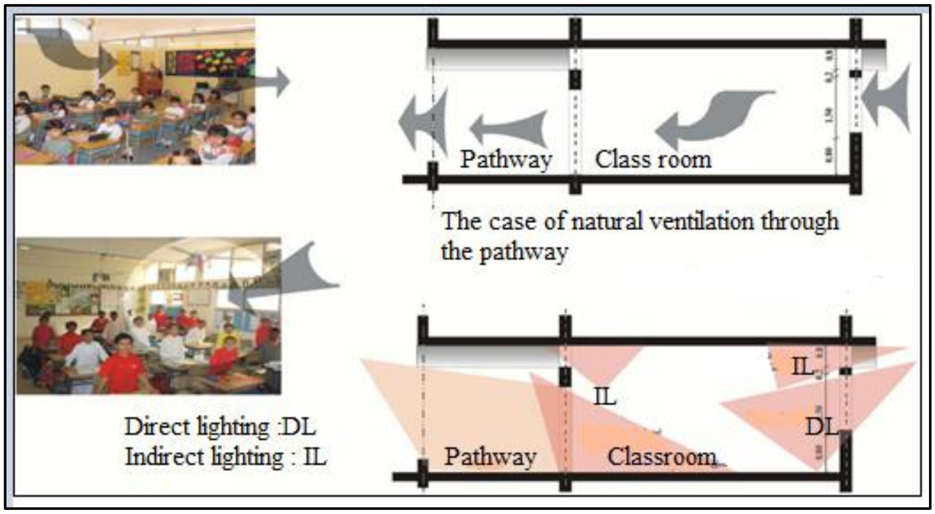


Figure 4. 5: Ventilation (UP) and lighting (down) in Khateb wa Alami school (KAT) (Aboullail 2016).

4.1.4 Field visits and observation

The researcher conducted some site visits to courtyards in old buildings as well as new buildings to feel and observe the effect of the thermal performance of the courtyards on reality:

1- The researcher visited the traditional courtyards in UAE that exists in Al Fahidi district, which have traditional urban fabric. The urban fabric of Al Fahidi district includes two types of courtyards: public and private ones. The public courtyards give a clear cool sense because of the air movement that comes from the pathways into the courtyard. It was felt that those courtyards create semi-private and peaceable cooler public spaces for the neighboring buildings, which is in agreement with what Shashua-Bar and Hoffman (2004) stated. Furthermore, the private courtyards are positioned in the center of the houses, as the function of these courtyards is to provide an isolated private area, which gives suitable ventilation system beside the interesting clear cool breeze which provides thermal wellbeing in hot areas. The researcher noticed that most of the private courtyards have vegetation elements, fountains, staircases and galleries around them, as a transmission space between the courtyard and the inner rooms (Salameh 2015).

2- The researcher visited some public schools, including an existing school in Ajman called That Al Netaqeen School. The school was a 586 type design. The visit was conducted on the 2nd of May 2017, the weather was nearly hot. It was clear that parts of the courtyard were shaded in the morning, which gave the students comfortable conditions for activities like sport classes. During the break time, nearly at 10:00 AM, part of the courtyard was shaded, but still the thermal conditions in it were better than outside in the street. It was noticed that the students preferred to play in the shaded area. The atmosphere inside the courtyard gave a high sense of privacy, isolation and relaxation feeling, despite it being an outdoor space. At noon, the temperature was lower than the outside temperature in the street. Moreover, the courtyard was nearly all paved with concrete pavement tiles, with limited plantation. There were no water features inside it. It is important to mention that on that day, the researcher took field measurements for the air temperature to validate ENVI-met software. It was noticed that some courtyards have shading devices and some not. According to the site visits the courtyards were used for lighting, ventilation and activities. The closed courtyards found in the older schools.

4.2 Software Validation

The validity and the reliability are important to the research quality and related directly to a list of standards including: direct goals, right arrangements, suitable methods, clear defined results, impressive presentation, and finally philosophical critique (Groat & Wang 2013). In this research there will be more than one source for collecting the data to avoid any bias and to be more realistic (Jack & Raturi 2006) and to be more accurate (Robson 2011). Moreover, the data will be analyzed with more than one tool and method to cover all the sides of the problem. The software used, which included ENVI-met and IESve, will be validated in the first stages of the research either by the field measurements of the temperature or by support from the literature. The validity of the computer simulation is used to make the results of the computer simulation in the later stages more reliable. Almhafdy et al., (2013) mentioned in their study that calibration of the simulation data with the field measurement is needed to validate the results.

4.2.1 ENVI-met software Validation

Literature validation: Pass and Schneider (2016) compared the performance of ENVI-met with Austal2000 software. They stated that the software is acceptable for simulation in the microclimate. Ghaffarianhoseini, Berardi and Ghaffarianhoseini (2015) included in their research a comparison between field measurements of air temperature and predicted ones by ENVI-met software to check the reliability of the simulated data. They found obvious levels of correlation between the simulated data and the measured ones (figure 4.6). The results of the comparison validated the computer simulation for later stages. Battista et al. (2016) compared the field measurements from a site in Rome with values from a simulation of air temperature from ENVI-met for the same site for validation. They concluded that the ENVI-met software is capable of simulating the real microclimate models. Moreover Lee, Mayer and Chen (2016) stated that the ENVI-met delivers a high accuracy in modeling the microclimates of urban fabric. They used it to investigate the effect of grass and trees on thermal comfort and heat stress. Taleghani, Tenpierik and van den Dobbelsteen (2014) conduct a study about the importance of the courtyard's role in improving the thermal conditions of the buildings in the Netherlands. They made a validation for ENVI-met software between the field measurements and the simulation results. The validation results confirmed the accuracy of the ENVI-met software. Forouzandeh (2018) made a research by using ENVI-met software to validate the microclimate's thermal condition in a semi-closed courtyard area. He found that the outcomes for air temperature and relative humidity displays a good relationship between virtual and measured values. They added that this is proof of the capability of ENVI-met for predicting the thermal performance of the semi-closed courtyard. Salata et al. (2017) stated that many studies used the coefficient of determination R square to validate the ENVI-met the validation is reliable, if R square →1. Moreover, Huttner (2012) validated ENVI-met software by comparing measured and simulated data for different surfaces. The results revealed high correlation between the two types of data according to R square as in figure (4.7).

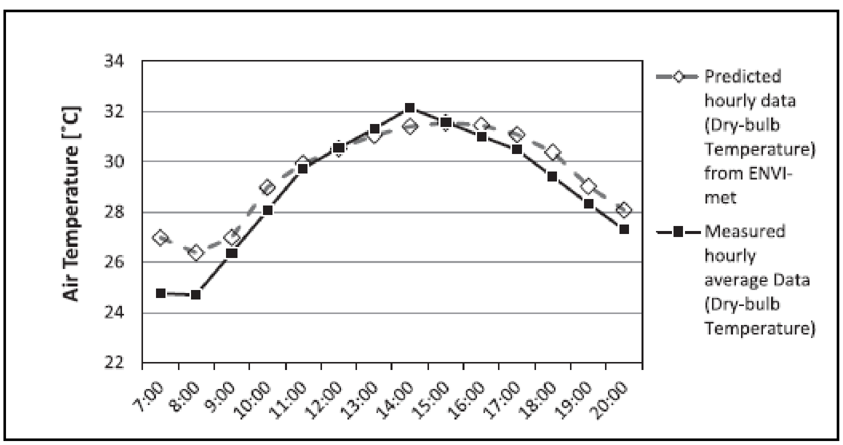
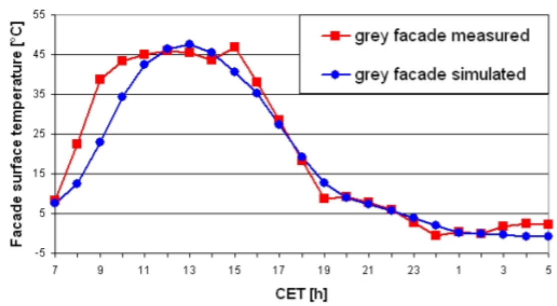
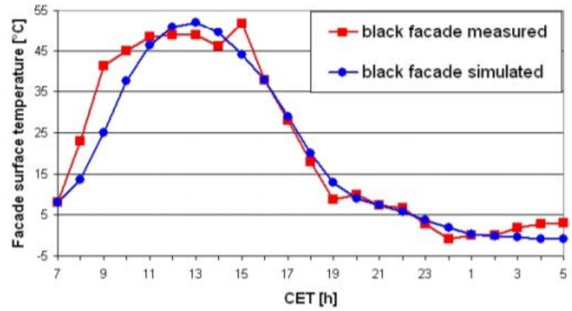


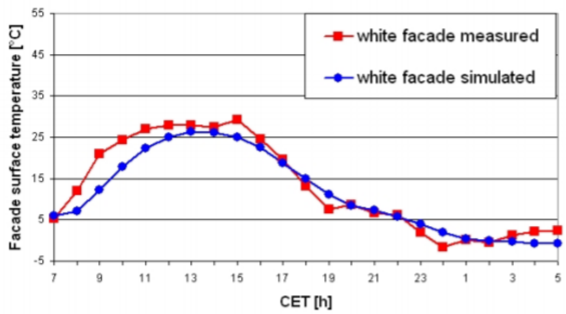
Figure 4. 6: Comparison between measurements and simulated data for validation (Ghaffarianhoseini, Berardi & Ghaffarianhoseini 2015).



Measured and simulated surface temperature of grey roof element



Measured and simulated surface temperature of black roof element



Measured and simulated surface temperature of white roof element

	root mean square error [K]	R^2
black roof element	5.0	0.93
grey roof element	4.8	0.91
white roof element	3.1	0.87

Figure 4. 7: Comparison between measured and simulated data for different surfaces (Huttner 2012).

<u>Validation using field measurements of the case study schools</u>

For validation, field measurements for air temperature were taken from the site and compared with the simulation values from ENVI-met software. The field measurements for air temperature were taken on the 2nd of May from an existing school in Ajman called That Al Netaqeen (figure 4.8), which is based on the 586 design template. The air temperature was measured by an Extech 45170 (Hygro-Thermo-Anemometer-Light Meter Pocket Size 4-in-1) meter. This meter is an ergonomic pocket of a small size, it has a large size LCD for displaying the measurements of humidity, air temperature and air velocity (Extech.com 2018) (figure 4.9). The Extech 45170 meter has a range between 32 to 122°F (-0 to 50 ˚C) for measuring temperature. Moreover, this kind of meter has a resolution around 0.1oF/˚C and accuracy around ± 2.5oF (± 1.2o˚C) (appendix 4.1).

Figure 4. 8: Field measurements in That Al Netaqeen school.

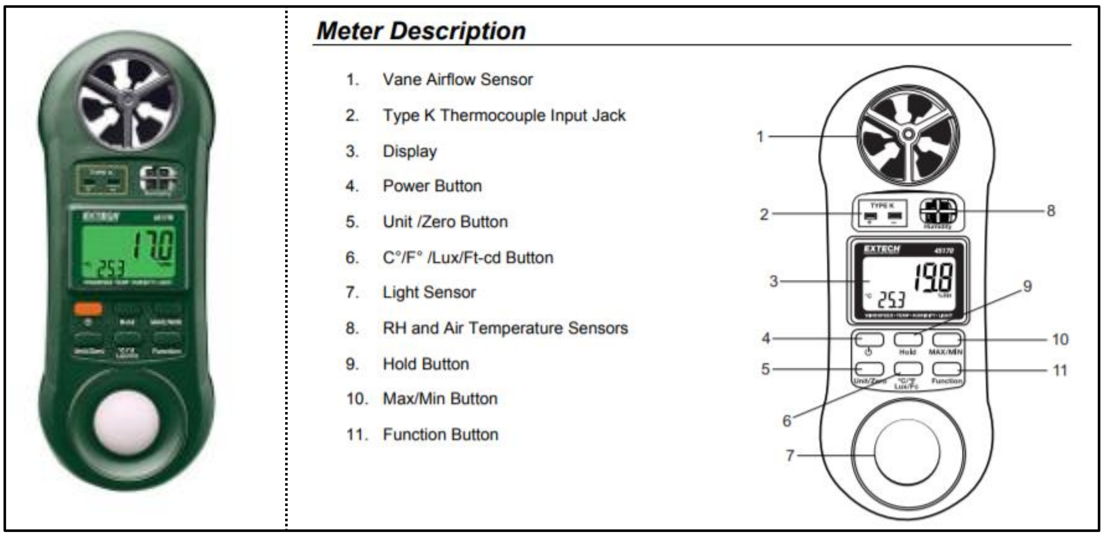


Figure 4. 9: Extech 45170 meter details (Extech.com 2018).

The existing school with a 586 template was modeled with the same characteristics of the measured school on the 2nd of May 2015. The measurements were taken from 14 points (figure 4.10). There were three timings used for measurements, which were 10:30am, 12:30pm and 2:30pm. The simulation was done by ENVI-met software with the extracted hourly temperature and humidity from IESve software. The simulation conditions were as shown in figure (4.11).

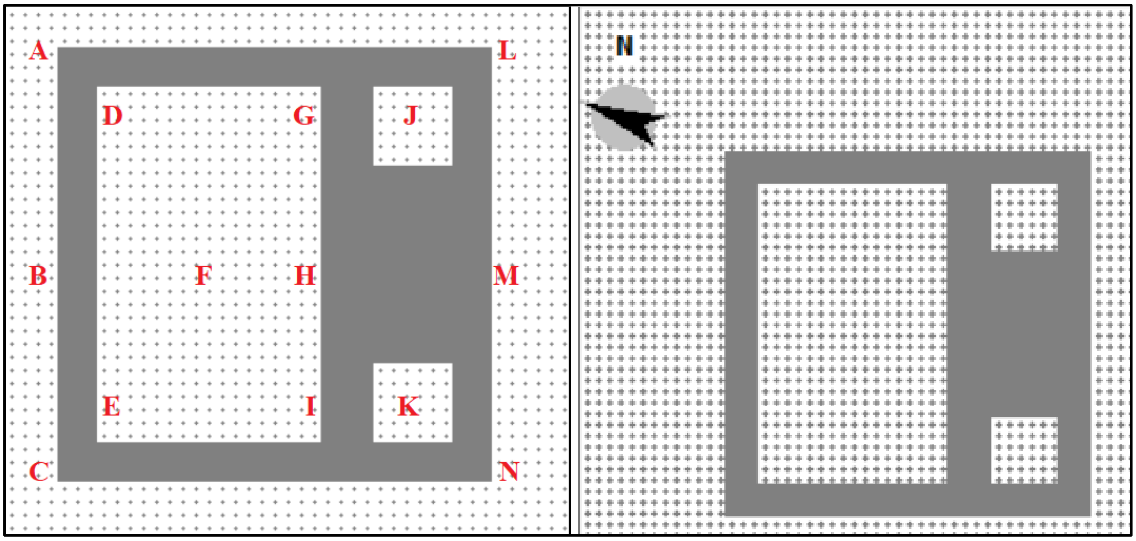
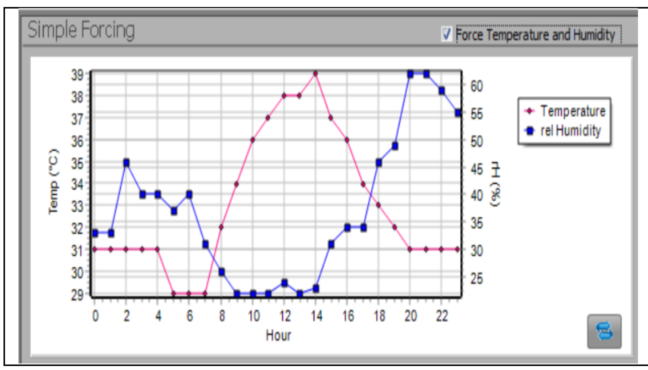


Figure 4. 10: The 14 points in the school which were used for temperature measurements for validation.



Output Directory: =
Start Simulation at Day (DD.MM.YYYY): =02.05.2017
Start Simulation at Time (HH:MM:SS): =00:00:00
Total Simulation Time in Hours: =24
Wind Speed in 10 m ab. Ground [m/s] =4
Wind Direction (0:N..90:E..180:S..270:W..) =315
Roughness Length z0 at Reference Point [m] =0.01
Initial Temperature Atmosphere [K] =306.150
Specific Humidity in 2500 m [g Water/kg air] =7.0
Relative Humidity in 2m [%] =50

Figure 4. 11: The input data conditions for the validation simulation in ENVI-met

After the field measurements and the computer simulation, a comparison between the output data of air temperature from the simulation and their relative data from the field measurements was undertaken (table 4.4). There was a difference between both data sets, which can be explained according to Taleghani (2015) that the ENVI-met does not consider the sky conditions, such as clouds in its input data beside that the ENVI-met undervalue the night temperature due to the mislaid of heat storage in the surfaces of the buildings. Elnabawi, Hamza and Dudek (2016) argued that the reason behind having higher measured air temperature compared to the simulation that surfaces and structural elements in the real location adjust and change the solar radiation and accordingly release a huge amount of long wave radiation. Moreover, the measurements were taken after each other in sequence with minor differences in timing, while the ENVI-met gives the average temperature for each point within one hour.

Table 4. 4: Values for the air temperature measured and predicted by ENVI-met for 14 points in the school building.

	10:30am		12:30 AM		2:30 PM	
Location point	ENVI-met data	Measured data	ENVI-met data	Measured data	ENVI-met data	Measured data
A	36.4	41.0	39.0	46.8	38.9	45.4
B	36.4	42.3	39.1	45.9	38.9	45.6
C	36.4	42.0	38.9	45.2	38.5	44.5
D	35.6	40.0	38.0	44.1	38.4	44.3
E	35.5	39.5	37.8	44.5	37.6	43.2
F	35.3	40.6	37.6	44.1	37.7	43.0
G	35.3	39.3	37.7	43.6	38.4	45.0
H	35.2	40.0	37.5	43.8	37.8	42.2
I	35.3	39.5	37.5	44.0	37.5	42.5
J	35.1	40.0	37.5	44.1	37.9	44.7
K	35.2	40.9	37.5	42.9	37.8	43.2
L	35.5	40.0	37.8	43.2	37.9	43.9
M	35.1	40.0	37.3	45.0	37.6	44.5
N	36.2	42.0	39.1	46.6	39.1	46.0

Figure (4.12) shows the scatterplot for the simulated and measured temperature data. It was clear that the research showed a good correlation between simulated and measured data, with R square 0.895. The R square value was good in relation to other measurements as shown in table 4.5, which is also supported by the findings of other experimental studies that were included in Salata's (2016) study.

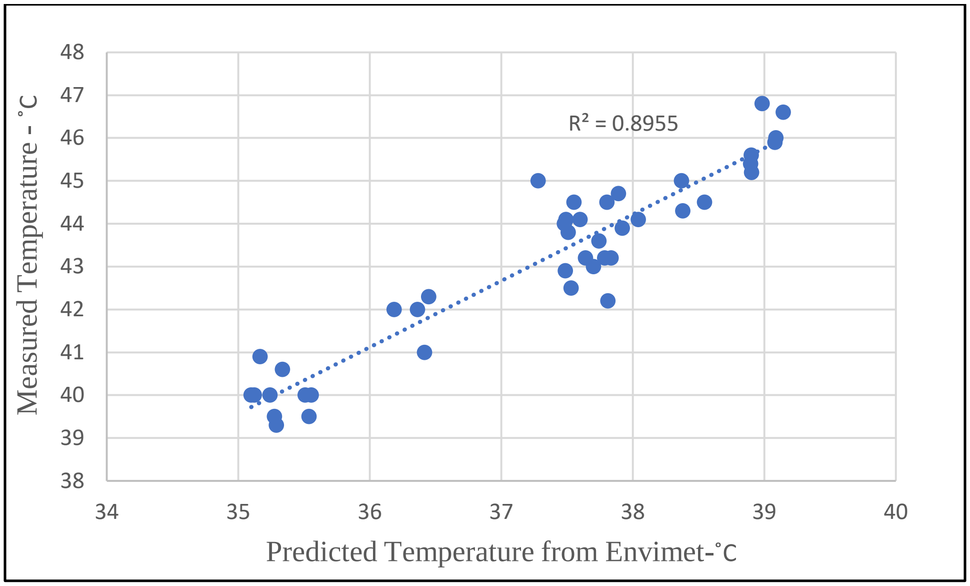


Figure 4. 12: Scatterplot for the simulated and measured temperature data.

Table 4. 5: Validation results between simulated and measured data from other studies (Salata et al. 2016)

Study	City	Variable	R^2 [−]
• Lee etal. (2016)	Freiburg, Germany	T_A	0.85
		T_{MR}	0.86
• Wang et al. (2016)	Toronto, Canada	T_A	0.69[a]
• Duarte et al. (2015))	Sao Paulo, Brazil	T_A	–
• Acero and Herranz-Pascual (2015)	Bilbao, Spain	T_A	0.96[a]
		T_{MR}	0.71[a]
• Ghaffarianhoseini et al. (2015)	Kuala Lumpur, Malaysia	T_A	0.96
• Taleghaniet al. (2015)	Netherlands	T_A	–
• Song and Park (2015)	Changwon City,S. Korea	T_A	0.52[a]
• Jänicke etal. (2015)	Berlin, Germany	T_A	0.87
		T_{MR}	0.95
• Conry et al. (2015)	Chicago, USA	T_A[c]	–
		T_A[d]	–
• Wang and Zacharias (2015)	Beijing, China	T_A	0.81
• Qaid and Ossen(2015)	Putrajaya, Malaysia	T_A	0.69
• Middelet al. (2014)	Phoenix, USA	T_A	–
• Hedquist and Brazel (2014)	Phoenix, USA	T_A	0.89
• Müller et al. (2014)	Oberhausen, Germany	T_A	0.97
• Chenet al. (2014)	Freiburg, Germany	T_{MR}	0.25

[a] Mean value.
[b] 1.5 above theground.
[c] Initialization from WRF(Weather Research and ForecastingModel) output.
[d] Initialization from observations.

4.2.2 IESve software Validation

Literature validation:

The Integrated Environmental Solutions Virtual Environment (IESve) software is widely used because of its good accuracy and ease of use (Hammad & Abu-Hijleh 2010). Moreover, this software provides a variety of analysis tools that are related to buildings, such as indoor air temperature and energy consumption, as well as carbon emissions. (Iesve.com 2018). Chadalavada (2017) used IESve software to investigate the thermal performance of the courtyard with different proportions in vernacular houses in India. Al-Masri and Abu-Hijleh (2012) used the IESve software to investigate the effect of courtyard on the thermal performance of midrise buildings. Kim, Augenbroe and Suh (2013) used the IESve for comparative research related to the standards of rating for LEED and ISO-CEN building energy consumption. Some of the buildings which were tested for the study had courtyards. Almhafdy et al. (2013) used the IESve software to evaluate the courtyard strategy alternatives and microclimate effects on a hospital building in Malaysia. His study showed the thermal performance for the courtyard as a passive design solution. The adjustment of air temperature between the field quantities for the measurements and the simulation results by IESve gave acceptable values that were in a satisfactory boundary. That confirms that IESve is a suitable instrument for evaluating courtyard performance.

Moreover, IESve software was used to evaluate the thermal performance in school buildings. Abdaljawad (2016) used this software to evaluate the effect of walls and windows in Ministry Schools in the UAE, based on the energy consumption and lighting impacts. He added that it slandered software in the UK. It is worth mentioning that those schools are part of the case studies in this research. Heracleous and Michael (2017) used IESve software to evaluate the thermal comfort based on the internal temperature for school buildings with courtyards in Cyprus. Moreover, Salameh and Taleb (2017) used IESve software to evaluate the effect of courtyards as a passive design concept for school buildings in hot areas, by investigating the school courtyard ratios and the effect on thermal performance and energy consumption of school buildings in the UAE. Based on that, IESve is perceived as an acceptable tool for investigating school buildings' performance.

Validation using actual energy consumption data

It was not possible to access the school buildings and install tools for field measurements for software validation for two main reasons: first, the school management did not allow for field measurements under any conditions and it was not possible to obtain the actual electricity bills from the schools, thus it was difficult to conduct the validation. Second, if the field measurements were accessible, this was only during the schooling time, where the air conditioning was on; thus, field measurements in this case will give the same air temperature which is the set point at most times. Based on that, it was impossible to measure the temperature inside the classrooms without the air-conditioning in a schooling day or any other day, thus the research relies on the literature for validation of the IESve software.

4.3 Simulation conditions

The simulation conditions will include an overview of the simulation climate, dates, stages and finally investigation matrix.

4.3.1 Simulation climate

The research will be conducted in a hot and humid climate in the UAE, which is located in in Middle East/southwest of Asia. The UAE lies between 22°50′ and 26° north latitude and between 51° and 56°25′ east longitude (En.wikipedia.org, 2018).

Figure 4. 13: UAE location (utlr.me 2018)

The related climate and weather data for the UAE is hot and humid. Liedl, Hausladen and Saldanha (2012) stated that the UAE has subtropical drylands. Mostly, it has clear skies and a high level of solar radiation and evaporation according to the sun path (figure 4.14) and solar latitude (figure 4.15). Ahmed and Shaikh (2013) stated that the UAE, according to its location, receives a huge amount of solar radiation as it is located in the solar belt of the earth between latitudes of 40° N and 40° S. Most of the solar radiation is reflected back to heat up the surrounding spaces.

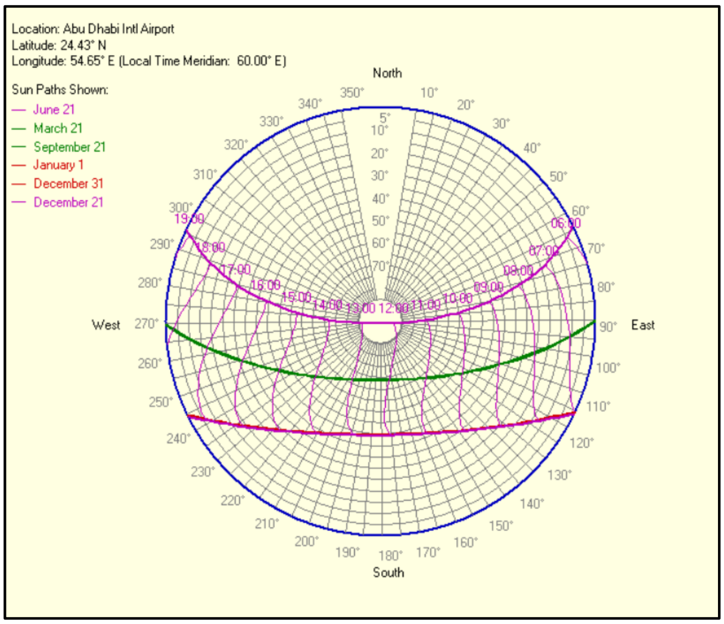


Figure 4. 14: Sun path (IESve).

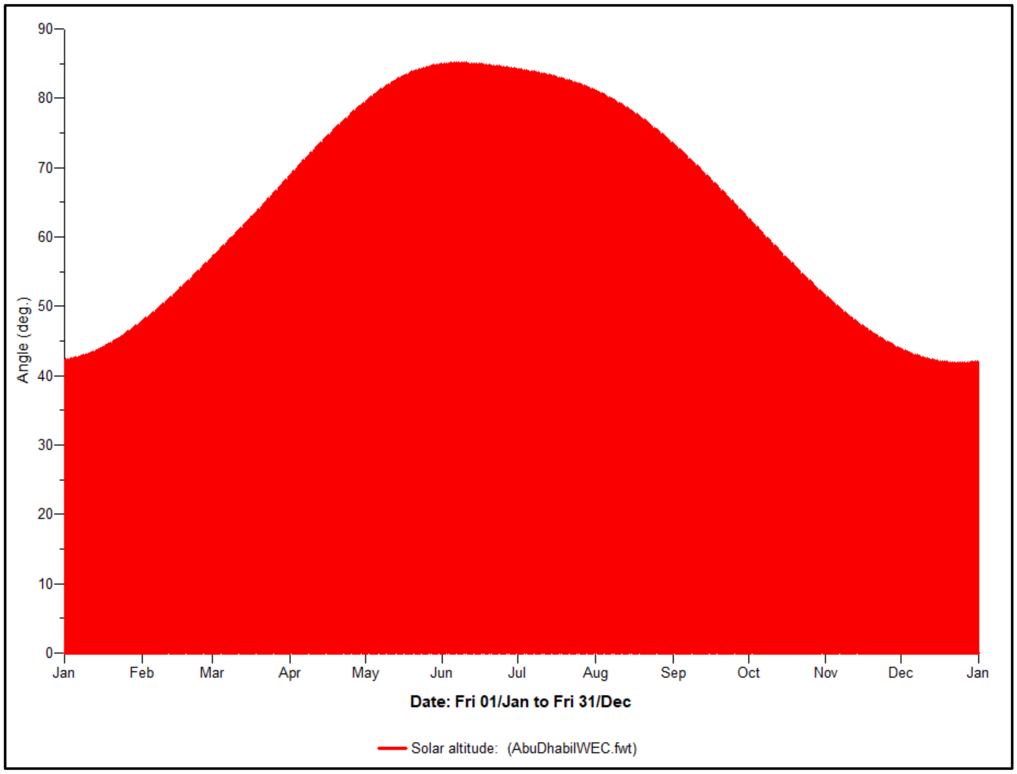


Figure 4. 15: Solar altitude (IESve).

Hausladen, Liedl and Saldanha (2012) stated that the level of solar radiation in the UAE is very high in the summer. They added that the horizontal surfaces receive the highest level of solar radiation. They mentioned that the on 21st June, the highest level of radiation of the year is observed. They added that in the summer, the east and west facades receive the highest levels of radiation compared to the south façade, which receives less radiation, and the north facade receives the least amount.

Hejase and Assi (2013) stated that the amount of solar radiation is high in the UAE, due to the high number of sunshine-hours. They added that the annual average amount of solar radiation is around 9.22 kWh/m2 on horizontal surfaces due to annual average 12 hours of sun shine per day (table 4.6). They added that the UAE has clear sky weather conditions for a minimum 60% of the whole year.

Table 4. 6: Solar radiation kWh/m2 (G_0) and sunshine-hours (S_0) in UAE (Hejase and Assi, 2013)

Month	G_0	S_0
JAN	6.68	10.71
FEB	7.84	11.21
MAR	9.25	11.86
APR	10.49	12.56
MAY	11.26	13.15
JUN	11.56	13.46
JUL	11.43	13.31
AUG	10.84	12.79
SEP	9.73	12.12
OCT	8.30	11.42
NOV	6.98	10.83
DEC	6.33	10.54
Annual	***9.22***	***12.00***

Moreover, and based on the characteristics of the UAE climate, it typically experiences very high temperatures most of the year, with the maximum reading for the dry pulp (figure 4.16) being about 47˚C and the wet bulb (figure 4.17) about 31˚C. Most of the urban cities lay on the coastal area, and thus they are more humid than the inner desert areas. Hausladen, Liedl and Saldanha (2012) stated that in Dubai the difference in temperature between night and day is greater in the summer than in winter. They added that the night temperature can be high in summer, thus it is not suitable for natural cooling. The weather between December and March is warm and is assumed as the best time in the climate of the UAE. The precipitation and rainfall are very limited in the UAE, and most of it falls between December to March time. Regarding the humidity is high and cause problems for cooling systems. The average relative humidity is about 30-50%, and it might increase in the coastal regions to reach 60% from May to September (Feroz 2015).

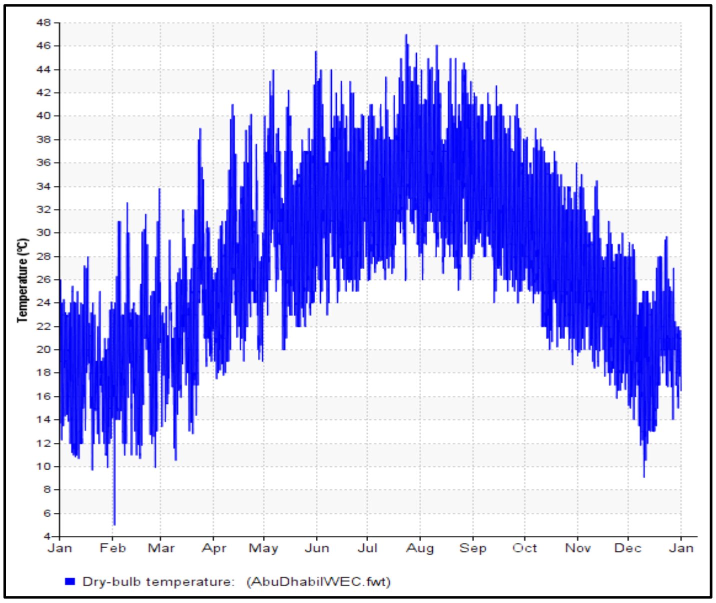


Figure 4. 16: Dry bulb temperature (IESve).

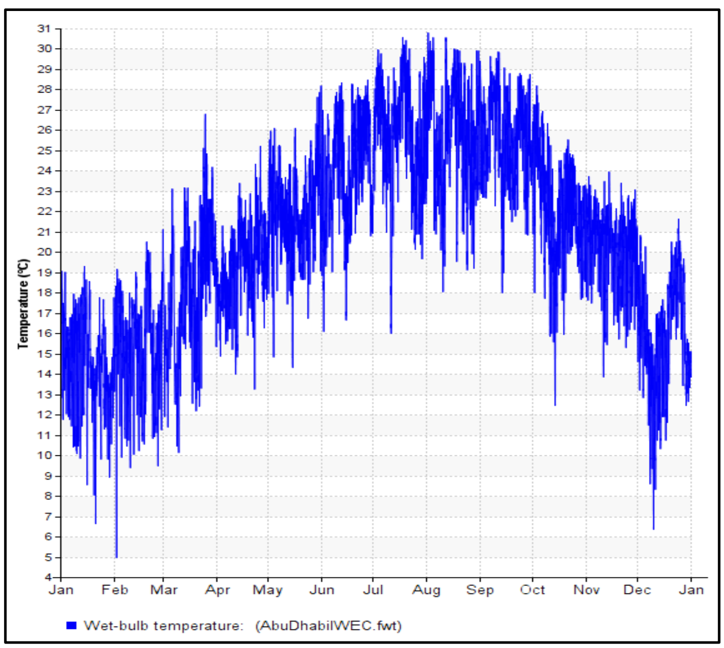


Figure 4. 17: Wet pulp temperature (IESve).

The dominant blowing wind in the UAE is from the North West direction (figure 4.18), and it is named Al Shamal wind, recording average amount from 2.7 to 5.5 m/s (figure 4.19). Small rates of winds from different directions through the whole year.

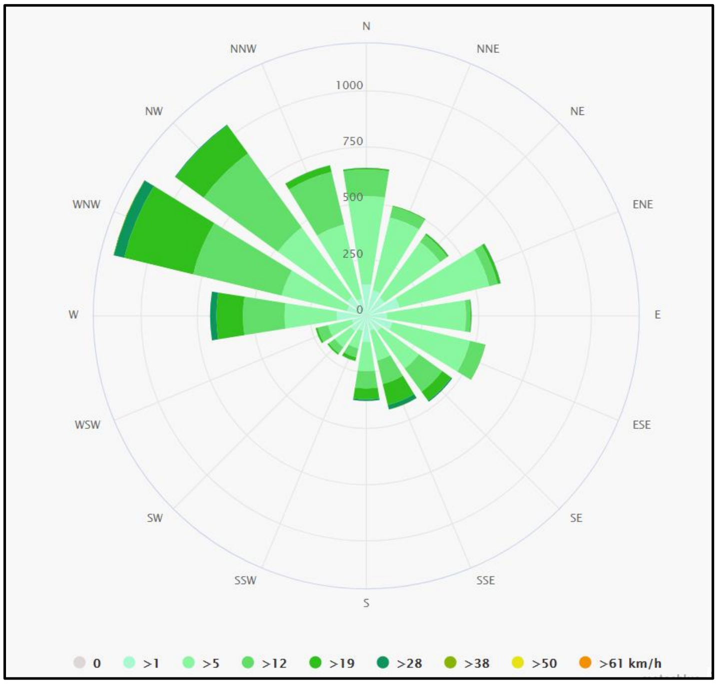


Figure 4. 18: Wind rose (IESve).

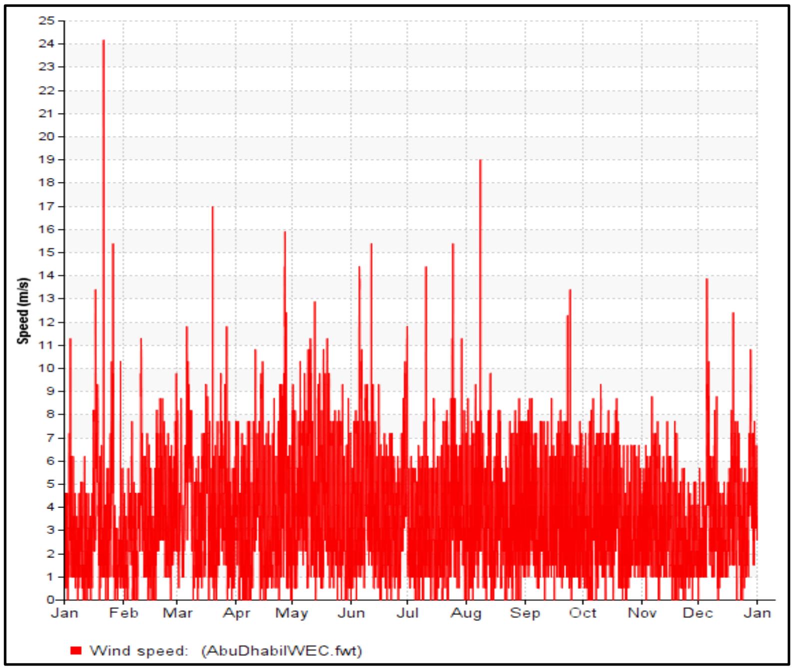


Figure 4. 19: Wind speed (IESve).

4.3.2 Simulation dates

The simulation will be conducted on two parts : Th first part will be on the solstice and equinox dates that lays on schooling days, where the temperature is above the comfort zone 27˚C in schools (Mass.gov 2018). Khalfan and Sharples (2016) defined the comfort zone range between 20-27˚C according to Schnieders' thermal comfort chart (figure 4.20). The courtyards are considered semi closed areas that should provide comfortable spaces for many activities for students. According to figure 4.21, the selected two dates are 21st of September (maximum temperature) and 21st of March (minimum temperature) within the schooling days. Based on that the courtyards in the case studies will be evaluated on two days that have the maximum and the minimum temperature in the schooling days, which are above the comfort level, as the main challenge in the hot arid areas, such as Dubai, is to reduce the energy consumption for cooling (Feroz 2015). Based on that, the days with a temperature less than comfort level were excluded. The simulations hourly temperature for evaluating the parameters of the courtyard will be taken from IESve software as a reference for 21st of March and 21st of September, and then forced in ENVI-met software.

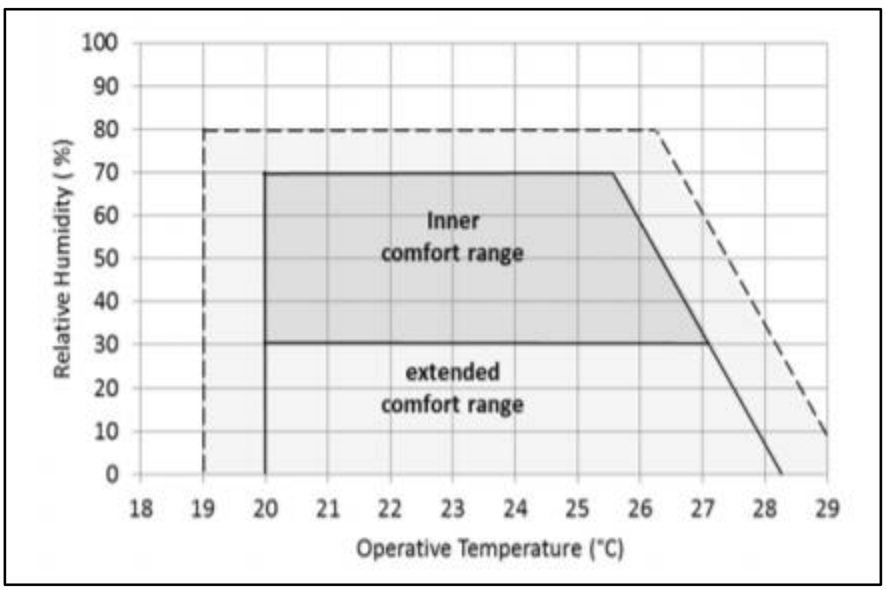


Figure 4. 20: Schnieders' thermal comfort chart (Khalfan & and Sharples 2016).

The second part of simulation will be conducted through all the academic year with the original built in climate of UAE in the IESve software without modifications.

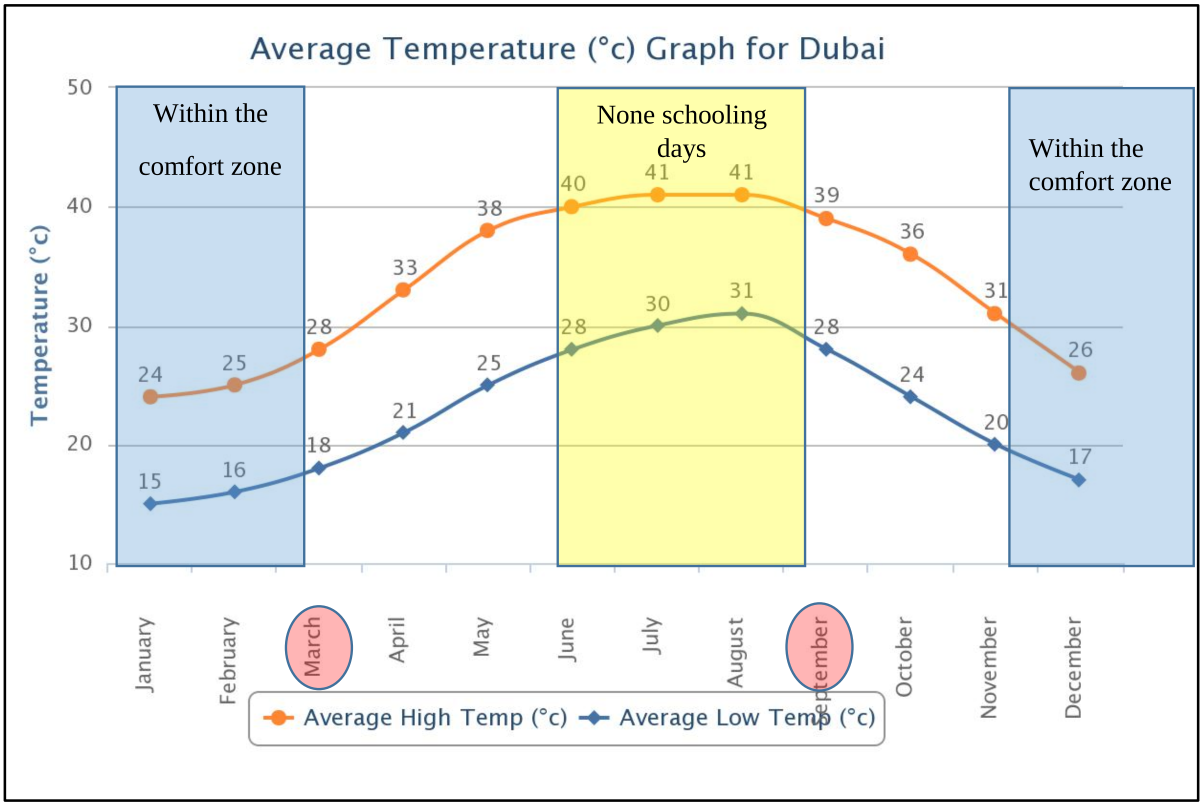


Figure 4. 21: Selected dates for simulation

4.3.3 Simulation stages

The literature review indicated that the research related to the courtyards in school buildings in hot arid areas is partial. This research will try to complete part of this gap by highlighting the courtyard as a passive design solution for school buildings toward sustainable schools. The investigation in this research will consider different configurations and characteristics for the courtyard through different simulations to examine only the courtyard effects, while many other parameters are constant, such as building location, materials, height, glassing ratio in the walls, size of the main model and size of the cell. The scope of the research is designed according to five case studies for present school buildings with courtyards. Moreover, the scope of the research is arranged through three stages to achieve the aim and meet the objectives of this research related to the effects of the courtyards on the energy consumption of the school buildings. The stages have different phases, as each phase will inspect one variable, for instance, courtyard orientation, ratio and height. The preferable configuration will be taken to the next stage for further improvements and the others will be eliminated. The stages will be arranged as the following:

Stage one: Courtyard investigation according to the orientation: Zhang et al. (2017) investigated the effect of the geometry of school buildings on its thermal performance, according to: 1- Orientation: rotate the building according to the four main directions N, S, E and W to evaluate the effect of orientation, as same with Almhafdy et al. (2013) as he investigated the courtyard in the four main directions N, S, E and W (figure 4.22). Based on the previous studies there will be a simulation for the original school buildings (five case studies) in the four directions (changing each one to the N, S, E and W) to check the effect of orientation on the courtyard air temperature and school building indoor temperature to define the best model design with best orientation.

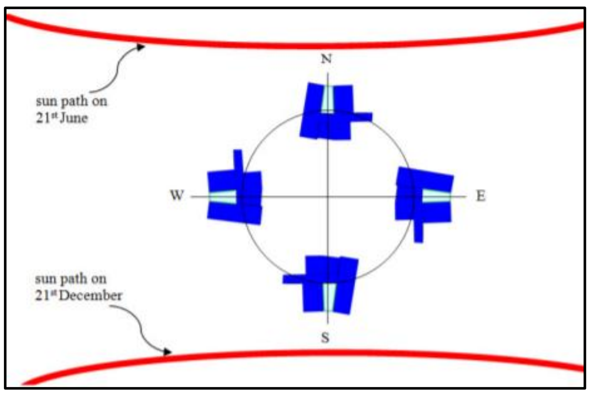


Figure 4. 22: courtyard orientation investigation in the four main directions N,S, E and W (Almhafdy et al., 2013).

Stage two: Courtyard design and thermal comfort

After choosing the best model and orientation with the lowest indoor temperature for the school building, there will be further investigation for the courtyard configuration into two sections. The first section will include evaluating for different variables to improve the thermal performance of the courtyard design on different phases according to the literature review. The second section will evaluate for the thermal comfort for the results from section one; the process in this stage is detailed below.

Section one: Courtyard design

1- Phase one: Courtyard ratios width/length. Manioğlu and Oral (2015) insisted on the importance of the courtyard W/L ratio on its thermal performance, they defined it as shape factor for the courtyard. They stated that the least cooling loads for a building with a floor area of $100m^2$ was with courtyard ratio W/L = 0.2, on the other hand the least cooling loads for a building with a floor area of $200m^2$ was with a courtyard ratio W/L = 1.2. Based on that the effective shape factor W/L for the courtyard differs according to the built-up area and climate. In this research the best case for a school building from Stage one will be examined according to the shape factor W/L with different ratios while keeping the CA/BA fixed (constant) and equal to 40% to define the best shape factor for the school building with its original area. The suggested shape factors W/L for investigation are: 1:2, 1:2.6, 1:3 with two courtyards and 1:3 with three courtyards.

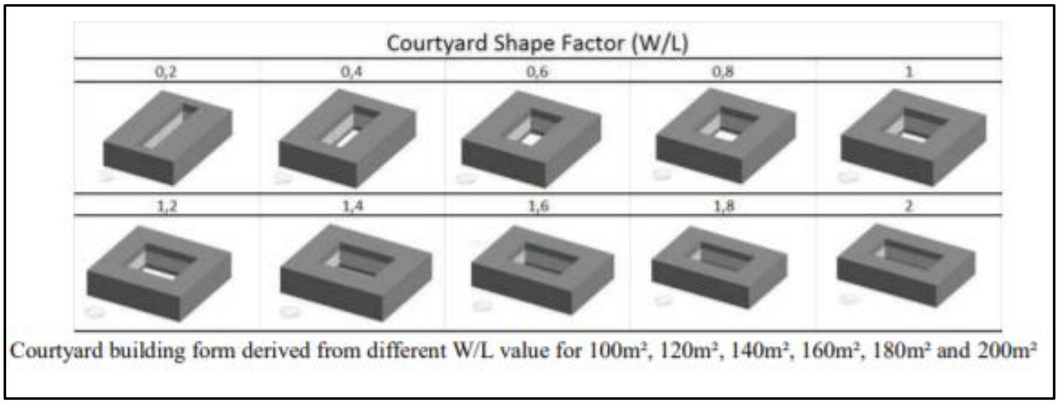


Figure 4. 23: Shape factor for different courtyards (Manioğlu and Oral 2015).

2- Phase two: Courtyard area to built-up area ratio CA/BA. Tablada (2013) stated that it is recommended that the courtyard ratio to the built-up ratio should be > 25% to have better thermal performance for the building, taking into consideration that he concluded that for houses. Manioğlu and Oral (2015) investigated the courtyard proportion with different CA/BA; they stated that the effective courtyard proportions vary according to the built-up area of the building. Moreover, Soflaei, Shokouhian and Mofidi Shemirani (2016) stated that in the traditional courtyards (good thermal performance) have CA/BA ranges between 18-44%. Based on that, the suggested CA/BA ratios for investigation are: 1:20, 1:33, 1:40 and 1:60.

3- Phase three: Courtyard shape outline. Tabesh and Sertyesilisik (2016) stated that the geometry of the courtyard is a critical issue as the courtyard's performance mainly depends on the amount of solar radiation access to it. They argued that because of the sun's location and radiation a square courtyard is ideal in relation to the energy request. That agreed with Yaşa and Ok

(2014), who stated that converting the courtyard to be close to square increases the shaded area inside it, and thus decreases the needed cooling energy on a hot day, like 21st of July. On the other hand, this effect of the square shape has less effect on a colder day like 21st of January. Based on that, the yearly energy intake rises when the courtyard gets longer. The evaluation for this phase will be on two shapes for the courtyard, square and rectangular, from the previous level.

4- Phase four: Courtyard walls height. Antonio and Carvalho (2015) stated that the higher the walls around the courtyard the cooler the temperature inside the courtyard, and thus the adjacent spaces. After investigating courtyard ratios in different climates Muhaisen (2006) stated that higher facades for the courtyards are more suitable in warm areas, while low facades are better in cold areas. He recommended for better thermal performance of the courtyard a minimum 9m (3 floor) as a good height to produce proper shading in hot humid regions. Koch-Nielsen (2002) confirmed that the thermal characteristics for the courtyard and for the surrounding spaces are mainly determined by the courtyard proportions. He added that the best recommended ratios are related to the height of the building, if the height of the courtyard is X it is better to have width that ranges from X to 3X. Hyde (2000) mentioned that the deep courtyard can expand the daytime interior shading time while the wide courtyard can improve the ventilation system. Based on that, the buildings around the courtyard in the school building will be investigated by adding one floor (on parts or on all) the top of the original two floors in the modified model from the previous phase.

5- Phase five: Courtyard greenery and landscape. Safarzadeh and Bahadori (2005) mentioned that the presence of plants in the courtyard, such as trees and shrubs, can considerably improve the thermal performance of the courtyard, mainly because of the shade that they produce. Taleghani, Tenpierik and van den Dobbelsteen (2014) pointed to the importance of greenery in improving the courtyards role in relation to the thermal conditions of the buildings. Ghaffarianhoseini, Berardi and Ghaffarianhoseini (2015) investigated the effect of the vegetation in the courtyard on the thermal comfort of the courtyard. They investigated the original courtyard without greenery with courtyards with 100% grass, 25% trees, 50% trees, and finally 100% trees. They found that the trees are capable of modifying the thermal comfort inside the courtyard. In this phase of the research there the greenery in the best courtyard from phase four will be investigated. The greenery will be investigated according to three selections, trees only, grass only and finally trees and grass.

Section two: Courtyard Thermal comfort:

The stack effect improves the ventilation and air circulation in the courtyards, especially in hot arid areas, as it takes away the heat and moisture to accomplish the thermal comfort (Koch-Nielsen 2002; Rajapaksha, Nagai & Okumiya 2003; Zakaria & Kubota 2014). Taleghani et al. (2014) investigated the thermal comfort of courtyard models (figure 4.24) with different proportions. They found that the courtyard design with the least discomfort time is 50% achieved with the 10*50 EW courtyard because of the least solar radiation. The thermal comfort of the courtyard will be investigated in this section for the best five models of the phases of section one from stage two. The reference for defining the thermal comfort is ASHRAE standard (table 4.7) which was used widely to find the PMV in many studies, including Khalfan and Sharples (2016) and Salata (2016), who mentioned it as a suitable reference to define the PMV thermal comfort inside the courtyards. In this section, an investigation for the thermal comfort inside the courtyards at the break time for the students at 10:00 AM will be conducted. This will also evaluate the level of improvement in the outdoor thermal comfort through the process of choosing the optimum courtyard.

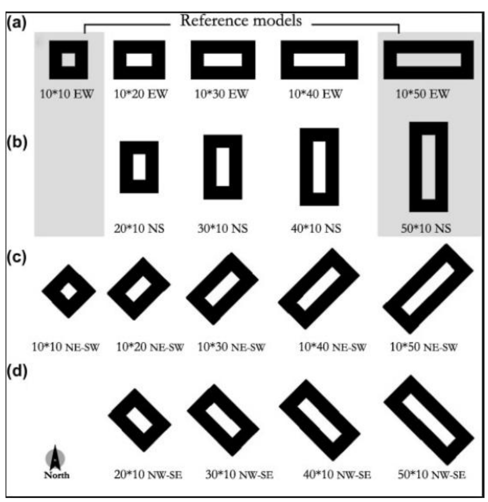


Figure 4. 24: Investigated models for the thermal performance and thermal comfort(Taleghani et al. 2014).

+3.0	Hot
+2.0	Warm
+1.0	Slightly Warm
0.0	Neutral
-1.0	Slightly Cool
-2.0	Cool
-3.0	Cold

Table 4. 7: ASHRAE thermal sensation scale (Khalfan & Sharples 2016).

<u>Stage three: Energy consumption</u>

In this stage there will be an investigation of the energy saving according to the optimum configurations implemented in the previous stages by using IESve software. Safarzadeh and Bahadori (2005) mentioned that the courtyard can be one of the elements that can decrease the energy consumption of the building, in addition to the trees, water pools and other green landscaping. Ghaffarianhoseini, Berardi and Ghaffarianhoseini (2015) pointed to the capability of the courtyard in reducing the cooling load.

4.3.4 The research matrix

Table 4. 8: The research matrix.

<table>
<tr><th>The Research stages.</th><th>Investigation field</th><th>Software</th><th>Investigated model</th><th>Fixed parameters</th><th>Investigated parameter</th><th>Investigating details</th></tr>
<tr><td rowspan="4">Stage one</td><td rowspan="4">Courtyard orientation</td><td rowspan="4">ENVI-met</td><td rowspan="4">All the selected models of schools (case studies)</td><td rowspan="4">• Buildings characteristics
• Building height
• Input software data</td><td rowspan="4">Orientation</td><td>North</td></tr>
<tr><td>East</td></tr>
<tr><td>West</td></tr>
<tr><td>South</td></tr>
<tr><td rowspan="6">Stage two</td><td rowspan="6">Courtyard design modification</td><td rowspan="4">ENVI-met</td><td rowspan="4">The best model from the previous phase</td><td rowspan="4">• Buildings characteristics
• Building height
• Orientation</td><td rowspan="4">Courtyard ratio width/Length.
W/L</td><td>1:2</td></tr>
<tr><td>1:2.6</td></tr>
<tr><td>1:3 2 courtyards</td></tr>
<tr><td>1:3 3courryards</td></tr>
<tr><td rowspan="2">ENVI-met</td><td rowspan="2">The best model from the previous phase</td><td rowspan="2">• Buildings characteristics</td><td rowspan="2">Courtyard area to built up area ratio CA/BA</td><td>1:20</td></tr>
<tr><td>1:33</td></tr>
</table>

				• Building height • Orientation • W/L ratio		1:40
						1:60
		ENVI-met	The best model from the previous phase	• Buildings characteristics • Building height • Orientation • W/L ratio	Courtyard Aspect ratio and shadow index	1:1
						1:3
		ENVI-met	The best model from the previous phase	• Buildings characteristics • Building height • Orientation • Courtyard ratio	Courtyard walls height	2 F
						3 F/ All mass
						3 F/ East Side
		ENVI-met	The best model from the previous phase	• Buildings characteristics • Building height • Orientation • Courtyard ratio • Courtyard walls height	Courtyard with vegetation	With trees only
						With grass only
						With grass and trees
	Courtyard and thermal comfort	ENVI-met	The best models from the previous five phases	• Buildings characteristics • Building height • Orientation • Courtyard ratio • Courtyard walls height • Courtyard vegetation	Courtyard thermal comfort PMV	Evaluation of PMV at 10 am (break time for students)
Stage three	Courtyard and building energy consumption	IESve	The best models from the previous five phases in stage two	• Buildings characteristics • Building height • Orientation • Courtyard ratio • Courtyard walls height • Courtyard vegetation	Energy consumption for the school buildings based on new microclimates from ENVI-met	Energy consumption on the simulation dates in September and March
					Energy consumption for the school buildings based on the built-in climate data in IESve	Energy consumption for the whole academic year

Chapter 5 : Courtyard orientation

Simulation and discussion

The literature investigation indicated that the research related to the courtyards in school buildings in hot arid areas like the UAE is limited. This research will try to fill part of this gap by highlighting the courtyard as a passive design solution for school buildings toward sustainable schools. Courtyards in school buildings will be investigated in this research in three stages in chapter 5 and chapter 6. This chapter will include the simulation and discussion for courtyard orientation for all the case studies in order to choose the best school template with the best orientation.

5.1 Simulation scale

School buildings in the UAE consume a lot of energy. Afshari, Nikolopoulou and Martin (2014) stated that 87% of the electricity consumed by the residential, governmental and commercial divisions in Abu Dhabi UAE is used for cooling. Moreover, in these divisions 70% of the energy load is consumed by the air conditioning. Figure 5.1 shows the percentage of air conditioning load -determined by humidity, temperature and solar gains- in relation to the electricity intake outline for the year 2010 (1st January to 31st December). It was clear that the indoor air temperature has the leading effect on the energy consumption required for cooling. Based on that the direct scale for choosing the best cases in the research will be the indoor air temperature (T_{in}) in the school buildings, taking into consideration that the T_{in} will be calculated through the simulation of the school buildings by ENVI-met software buildings dynamics section. The indoor air temperature will be used as an indicator for the energy consumption rate linked to thermal variations and improvements of the courtyard investigations associated with the shapes and orientations. This was based on Al-Khatatbeh and Ma'bdeh (2017) who insisted that the solar gain (direct and indirect) on the building mostly affects the air temperature component more than the other components of the thermal comfort.

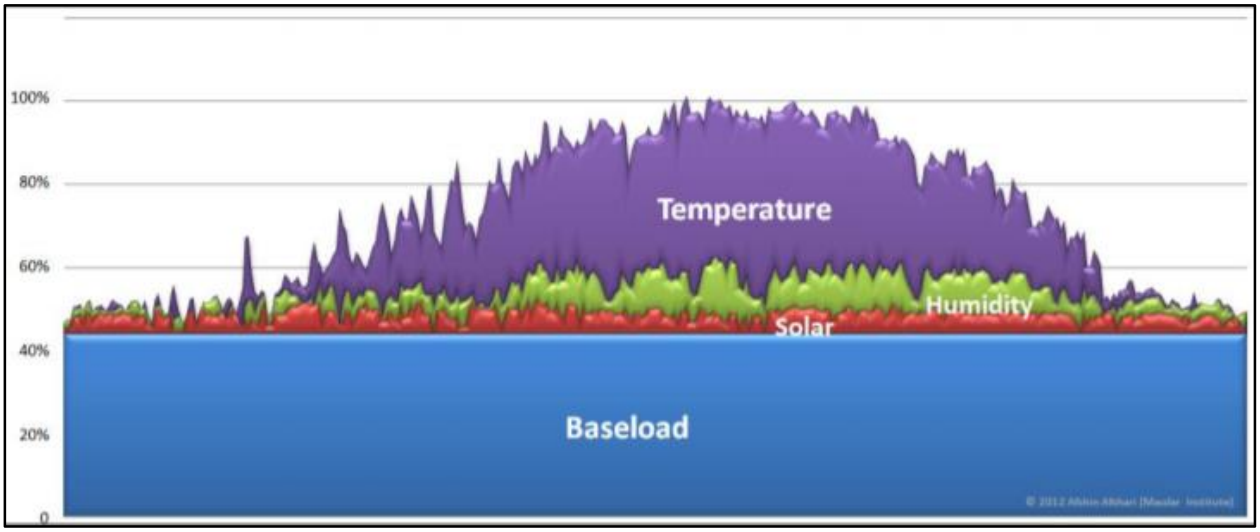


Figure 5. 1: The percentage of air-conditioning load—determined by humidity, temperature and solar gains— in relation to the electricity intake outline for the year 2010 (1st January to 31st December), taking in regard that base-load part is similarly consumed by air-conditioning as annual running for the equipment (Afshari, Nikolopoulou & Martin 2014).

5.2 Simulation Conditions

In the ENVI-met software, the 3D models for the school buildings were generated into the ENVi-met boundary. The wind power outline was derived directly to the side of the inflow boundary of the basic 3D model. The input data which includes initial temperature, wind direction and speed, roughness type of the site, humidity and temperature was forced in the software (Jin et al. 2017). The hourly temperature and humidity data was forced in the software too. Huttner (2012) stated that ENVI-met enables enforcing the real climate boundary condition (air temperature and humidity) for the model to create real microclimate based on real inputs to produce more accurate results. Some parameters were fixed in all the simulation cases in relation to building location, materials, glassing ratio in the walls, size of the main model and size of the cell to produce results that define the effects of the courtyard configurations in relation to the investigation matrix.

Files were created in the “Manage workspaces” app for each model of the school buildings (five case studies) in the four directions (N, E, S and W) individually. Then models were built in the “Spaces” app in the ENVI-met software with the following conditions (figure 5.2) :

1- The location Dubai – UAE.

2- The school building assumed to be 2 floors high, where each floor equals 4 m.

3- The building materials were fixed as concrete slab hollow block and concrete walls hollow block, as default for all the models in all simulation scenarios.

4- The openings set as 20% of the exterior walls as fixed parameters based on Al-Sallal (2010) who defined the best ratio for window/external walls of the classrooms as to be not less than 20%.

5- The area for each school changed according to its design template.

6- Main model area: x-Grids= 60, y-Grids=60, z-Grids=20.

7- The cell size: dx=3m,dy=3m, dz=2m, this size was chosen after several attempts for best performance.

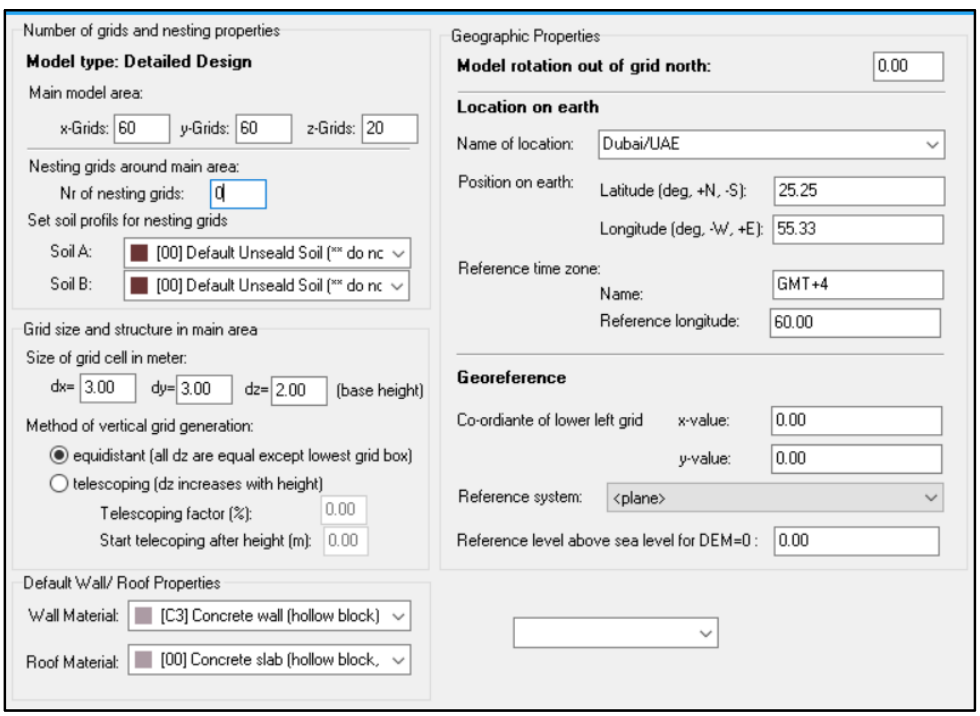


Figure 5. 2: Basic settings for the simulated models.

Before the simulation the main conditions were set in "ConfgWizard" according to the following: Total Simulation Time in Hours is 24 hrs. Wind Speed in 10 m ab. Ground is 4 m/s.

Wind Direction (0:N..90:E..180:S..270:W..) is 315. Roughness Length z0 at Reference Point [m] is 0.01. Specific Humidity in 2500 m is 7.0 g Water/kg air. Relative Humidity and Initial Temperature Atmosphere differs according to the forced data weather for the simulation dates. Output interval main files is 60 min. Output interval text output files is 30 min. After the simulation was implemented, the final results were displayed by the "Leonardo 2014" app.

5.3 Simulation dates profiles:

The simulation was conducted on two dates, 21^{st} of September and 21^{st} of March, according to what was explained in Chapter 4.

5.3.1 Weather details for 21^{st} September

The weather data (air temperature and relative humidity) for the date 21^{st} September was taken from IES software weather data and forced hourly in the Configuration Wizard in the ENVI-met software (Appendix 5.1). This was done in order to produce more accurate real microclimate for the results as Huttner (2012) stated. The maximum air temperature was 39˚C at 2pm, and the lowest air temperature was 25˚C at 6am. On the other hand, the maximum relative humidity was 88% at 4am, and the lowest relative humidity was 26% at 2pm.

5.3.2 Weather details for 21^{st} March

The weather data for the date 21^{st} March was taken from IESve software weather data and forced in the Configuration Wizard in the ENVI-met software (appendix 5.2) to produce more accurate real microclimate for the results. The maximum air temperature was 32˚C at 2pm, and the lowest air temperature was 17˚C at 2am. On the other hand, the maximum relative humidity was 88% at 12am, and the lowest relative humidity was 21% at 11am.

5.4 Stage one: courtyard orientation Simulation

This section will include the simulations for the first stage of the research, which is a simulation for the five schools-based models (case studies) in the four directions (changing each one to the N, S, E, W) as in table 5.1 and table 5.2. This stage aims to evaluate the effect of the orientation on the temperature of the courtyard, thus T_{in} for the school building which represents the average indoor temperature for the school building and it will be calculated through the ENVI-met simulation. Therefore, this section will include five parts related to the five case studies. Each part will include results of the simulation on two dates which are 21st March and 21st September. Accordingly, the selected two dates are 21st of September (maximum temperature) and 21st of March (minimum temperature) within the schooling days. Despite the fact that the simulation will run for 24 hours, only the results of the schooling time for 8 hours (from 7am to 2pm) will be illustrated. Moreover, the analysis will show the distribution of air temperature in the schools' courtyards at 10am, which is the break time for the students in the school.

Table 5. 1: The basic school models in the four basic orientations.

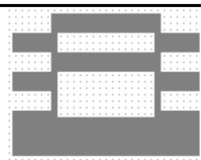
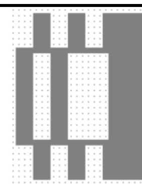
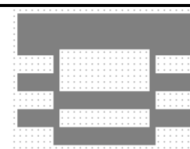
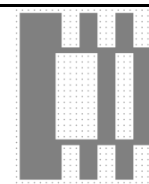
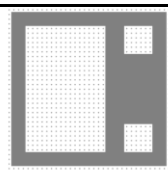
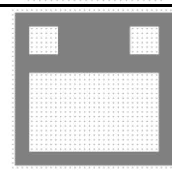
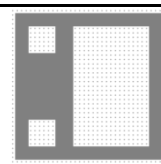
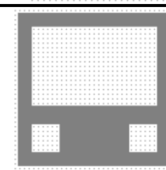
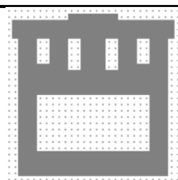
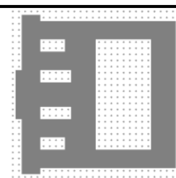
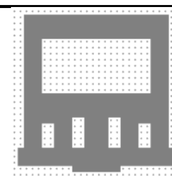
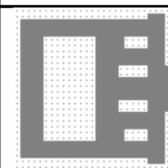
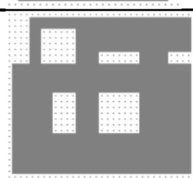
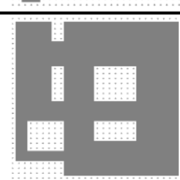
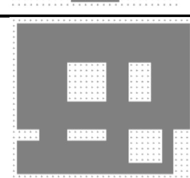
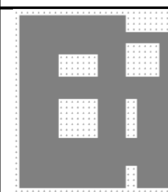
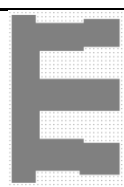
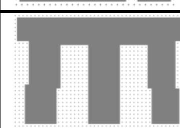
School model	North direction	East direction	South direction	West direction
KAT				
586				
596				
UPA1				
UPA-fin				

Table 5. 2: Stage one from the research matrix and stages.

The Research stages.	Investigation field	Software	Investigated model	Fixed parameters	Investigated parameter	Investigating details
Stage one	Courtyard orientation	ENVI-met	All the selected models of schools (case studies)	• Buildings characteristics • Building height • Input software data	Orientation	North
						East
						West
						South

5.4.1 School KAT:

The school KAT (table 5.3) was simulated in the four directions with the same original courtyard ratios and configuration of the basic model. The effect of school building orientation appears on T_{in} within the schooling time. Table 5.4 shows the 3D base case school KAT building with the four different orientations. It was clear in figure 5.3 that the different orientations for the school have illustrated slight difference in the T_{in} on the 21^{st} of September. The simulation on the 21^{st} of March shows slight difference as well, as shown in figure 5.4.

Table 5. 3: The characteristics for school KAT (sKAT).

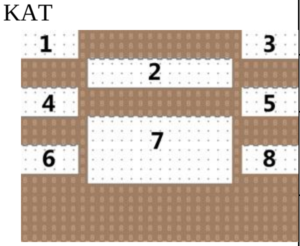
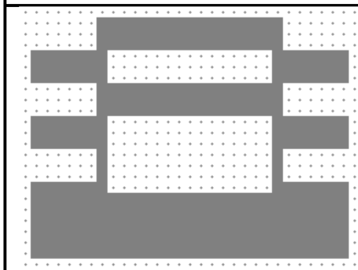
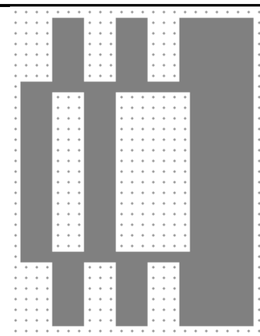
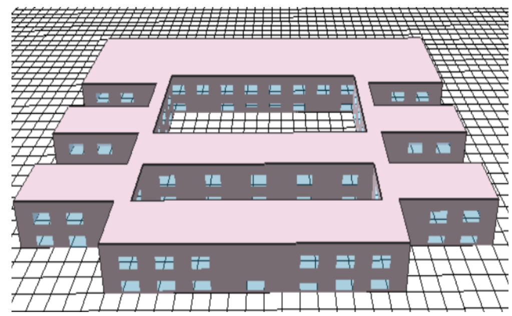
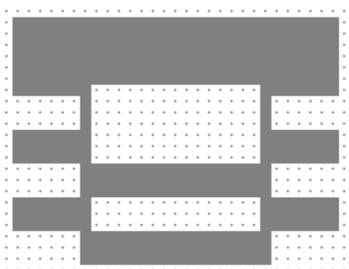
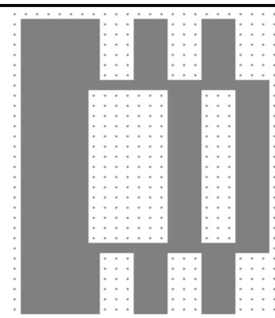
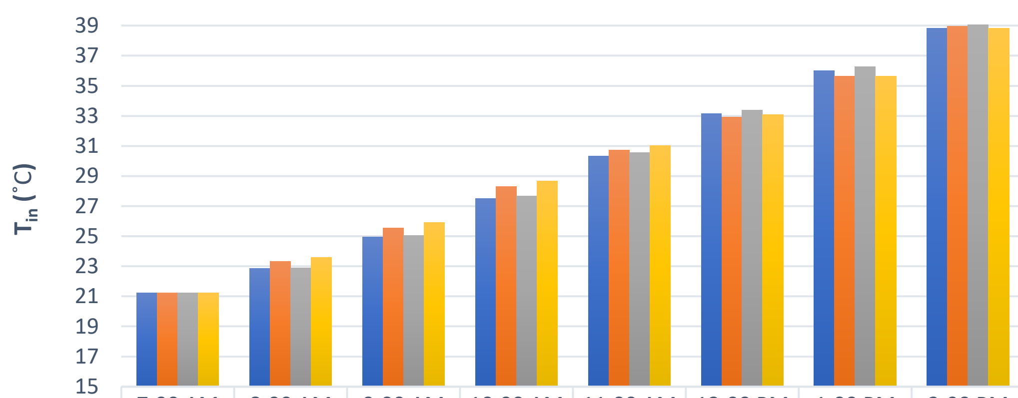
School name	No. of outdoor space	Type of outdoor space	Area of outdoor space	Courtyards area	Built Up	Courtyards /plot area ratio	Courtyards/ built up area ratio
KAT  Plot Area (m2) (29*3)* (22*3)= 5742 m2	Court 1	Semi-opened court	(6*3)*(3*3)= 162 m^2	Courts = 2331	(5742) - (162+ 405 + 162 + 162 + 162 + 162 + 954 + 162) = 3411 m^2	2331/5742= 41%	2331/3411= 0.68%
	Court 2	Closed court	(15*3)*(3*3)= 405 m^2				
	Court 3	Semi-opened court	(6*3)*(3*3)= 162 m^2				
	Court 4	Semi-closed court	(6*3)*(3*3)= 162 m^2				
	Court 5	Semi-closed court	(6*3)*(3*3)= 162 m^2				
	Court 6	Semi-closed court	(6*3)*(3*3)= 162 m^2				
	Court 7	Closed court	(15*3)*(3*3)= 954 m^2				
	Court 8	Semi-closed court	(6*3)*(3*3)=162 162 m^2				

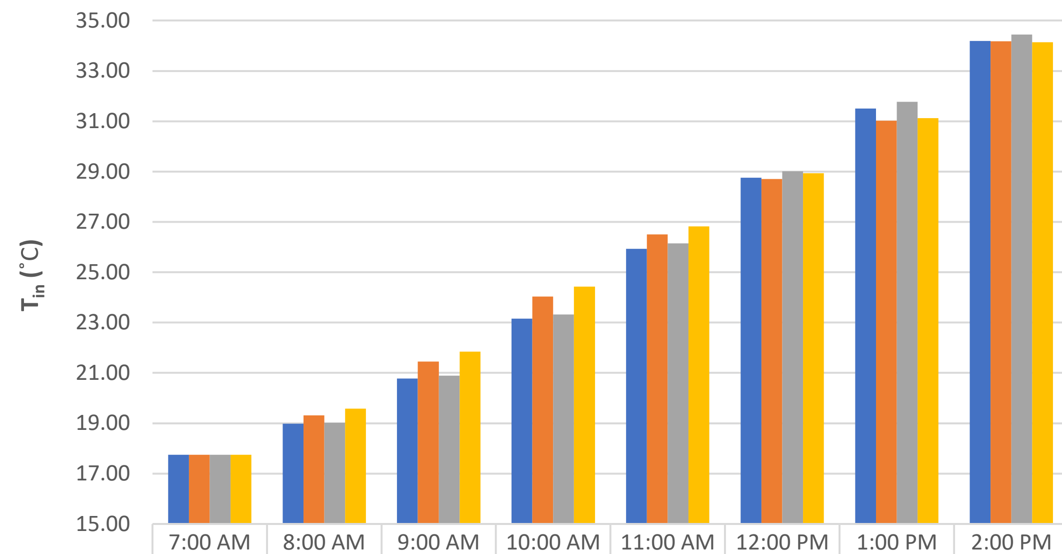
Table 5. 4: The base case for school KAT with the four different orientations.

Different orientations for base case of sKAT		3D for the base case of sKAT
 sKAT21sepN	 sKAT21sepE	
 sKAT21sepS	 sKAT21sepW	



	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM
KAT21sepN	21.22	22.86	24.96	27.5	30.32	33.14	36.02	38.83
KAT21sepE	21.23	23.32	25.55	28.29	30.73	32.91	35.63	38.96
KAT21sepS	21.21	22.90	25.07	27.67	30.54	33.38	36.27	39.06
KAT21sepW	21.24	23.59	25.93	28.65	31.01	33.07	35.66	38.84

Figure 5. 3: Hourly T_{in} for school KAT 21st September within schooling time in the four orientations.



	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM
KAT21marN	17.75	18.98	20.78	23.16	25.93	28.76	31.51	34.20
KAT21marE	17.75	19.31	21.46	24.03	26.50	28.71	31.03	34.19
KAT21marS	17.75	19.02	20.89	23.33	26.15	29.01	31.77	34.44
KAT21marW	17.75	19.58	21.85	24.42	26.83	28.93	31.12	34.15

Figure 5. 4: Hourly T_{in} for School KAT 21st March within schooling time in the four orientations.

Figure (5.5) illustrates the average hourly T_{in} for School KAT 21st September within the schooling time in the four orientations. The averages confirm that school KAT to the north direction has the least average T_{in} with an amount around 29.36˚C, and that is 0.39˚C less than the poorest case to the west direction. That can be explained due to the change in the amount of received solar radiation on the exterior walls, beside the effect of wind direction on the school building according to the orientation. On the 21st of March, as shown in figure 5.6, school school KAT north had the least average T_{in} too with an amount around 25.13˚C, and that was 0.45˚C less than the worst case to the west direction. Thus, school KAT north direction had the best performance and the lowest T_{in} on the two simulation dates, and the school KAT west had the poorest performance on both simulation dates, because the main courtyards school KAT to north are oriented E→W so a lower amount of solar radiation hits the ground of the courtyard. This is in agreement with the results reported by Yaşa and Ok (2014) as they stated the east-west direction for the courtyard is as good start point for designing a courtyard. Almhafdy et al. (2013) added that the courtyard oriented on an east-west direction is suitable to decrease the solar radiation.

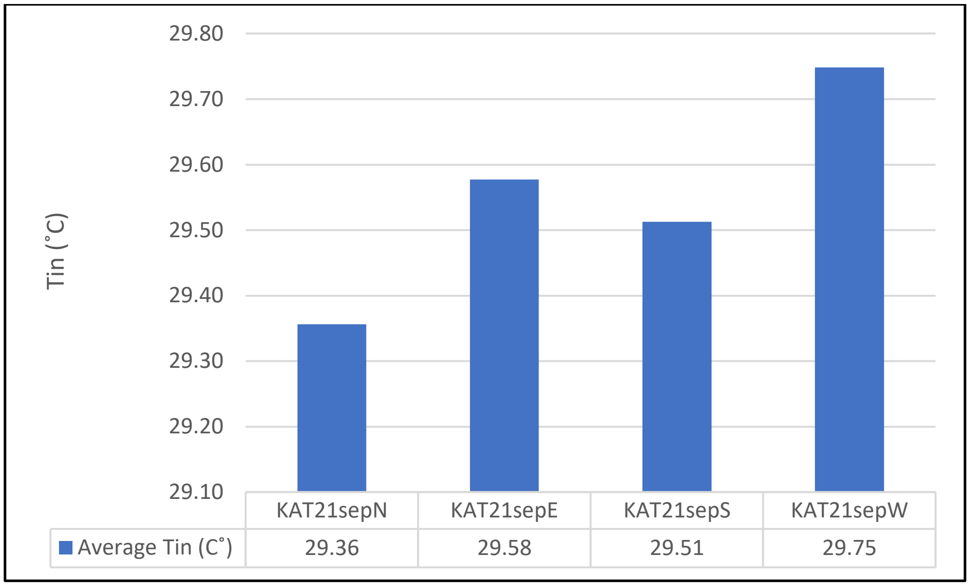


Figure 5. 5: Average hourly T_{in} for School KAT within schooling time in the four orientations.

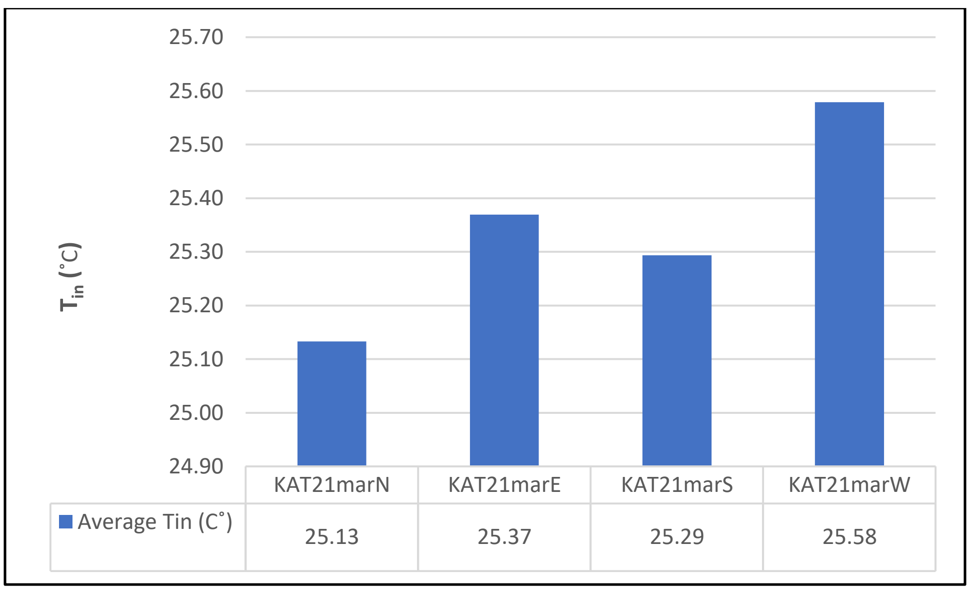


Figure 5. 6: Average hourly T_{in} for School KAT 21st March within the schooling time in the four orientations.

Tables (5.5) and (5.6) show the air temperature distribution at position view plane K=3 which equals 1.4m height at 10am on both dates of the simulation (appendix 5.3). The height was chosen at 1.4m because it represents the closest height to the average height of the students. This time was chosen because it represents the break time for the students in the school. It was clear according to the table 5.5 and table 5.6 that the air temperature around the school building and in the main closed courtyard differs in the four cases on both dates of the simulation for the school KAT according to the four orientations. Despite the fact that the difference was slight, it was clear that the main closed courtyard for the best case to the north had acceptable air distribution with relation to the other cases. Note that this courtyard area is about 954m^2 and that represents half of the total courts area for this school. Moreover, it reached a lower range temperature of 31.60˚C at its low right corner (blue color), thus it will be better for students playing in it. Moreover, the air temperature with a lower boundary will produce less average air temperature, and thus less heat transmission (conduction) through the walls, which will help to slow the heat gain inside the building and reduce the T_{in}. On 21st of March the school KAT had similar readings to each other with slight differences in the main courtyard of the school KAT north that had more areas with the lowest temperature boundary 26.4˚C. Moreover the main courtyard in the four orientations had a temperature that lays within the comfort zone and under 27˚C, which was positive for the students to spend comfortable time for playing and socializing in.

Bearing in mind that the simulated outdoor temperature is 32.91˚C while the microclimate courtyard inner temperature (best case to the north) ranges between 31.6-32.2˚C at 10am on the 21st of September. Furthermore, the simulated outdoor temperature is 28.3˚C while the microclimate courtyard inner temperature (best case to the north) ranges between 26.4-27.0˚C at 10am on the 21st of March. Comparing the outdoor simulated temperature to the courtyard inner temperature, the results revealed that the temperature inside the courtyard was less by 0.71-1.31˚C on 21st of September and less by 1.3-1.9˚C on 21st of March than the simulated outdoor temperature. This agrees with Feroz (2015) who found different amounts of variations in temperature according to orientation, these amounts vary from 0.1-0.5˚C between different configurations for courtyard buildings with different orientations. On the other hand, Almhafdy et al. (2013) stated that, the courtyard orientation has an effect on its thermal performance, as per their investigation, the air temperature in the courtyard is about 0.5-5˚C lower than the outdoor temperature according to its orientation.

Table 5. 5: Outdoor air temperature distribution around the school KAT on 21st September.

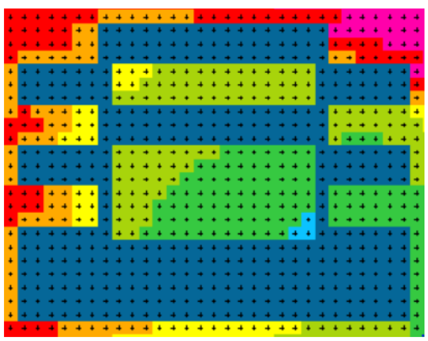
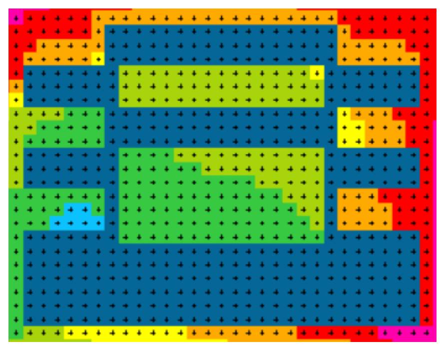
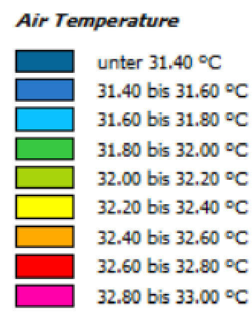
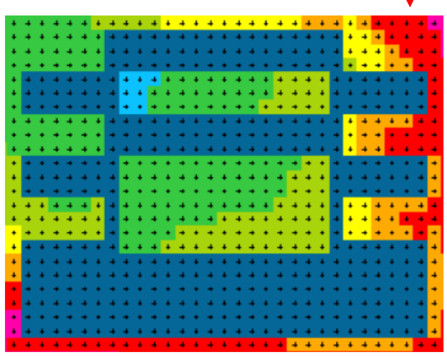
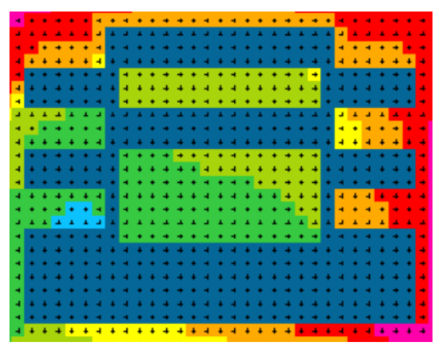
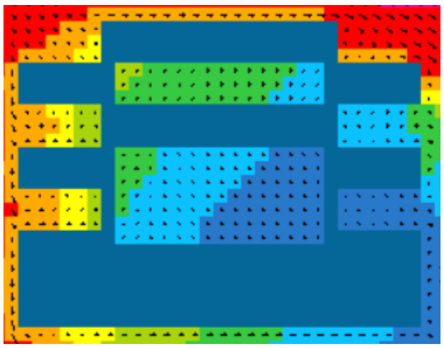
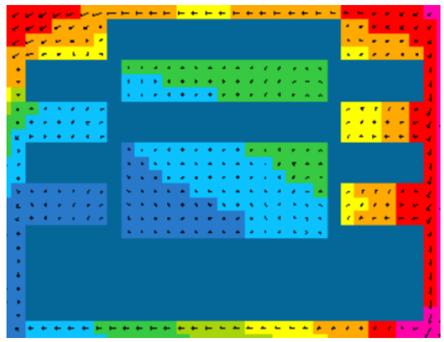
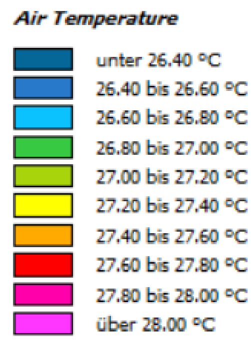
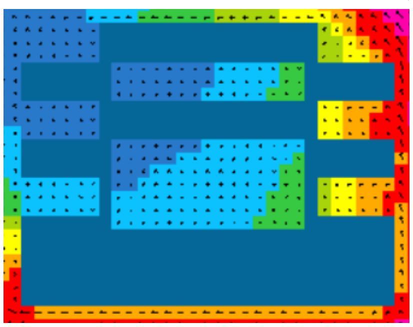
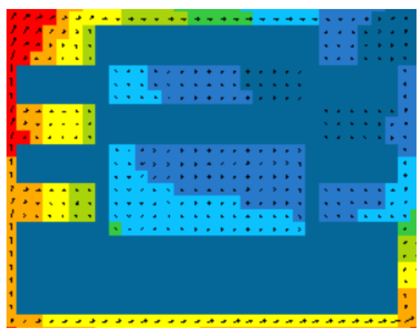
<table>
<tr><td colspan="2">Outdoor air temperature distribution around the school KAT and in the two main courtyards.</td><td>The key</td></tr>
<tr><td>sKAT21sepN
</td><td>sKAT21sepE
</td><td rowspan="2">
</td></tr>
<tr><td>sKAT21sepS
</td><td>sKAT21sepW
</td></tr>
</table>

Table 5. 6: Outdoor air temperature distribution around the school KAT on 21st March.

Outdoor air temperature distribution around the school KAT and in the two main courtyards.		The key
sKAT21marN 	sKAT21marE 	
sKAT21marS 	sKAT21marW 	

5.4.2 School 586:

The school 586 (table 5.7) was simulated in the four directions with the same original courtyard ratios and configuration of the basic model. The effect of the school building orientation appears on the T_{in} within the schooling time. Table 5.8 shows the 3D base case school 586 building with the four different orientations. It was clear in figure 5.7 that the different orientations for the school have illustrated different T_{in} on the 21st of September. The simulation on the 21st of March shows a difference as well, as detailed in figure 5.8.

Table 5. 7: The characteristics for school 586 (s586).

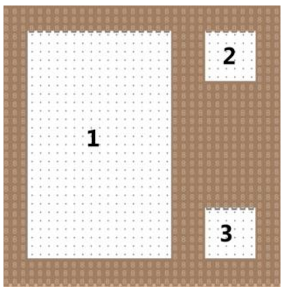
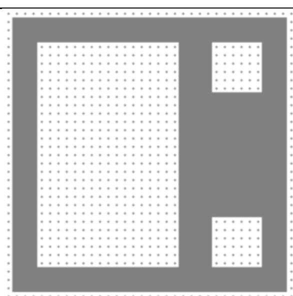
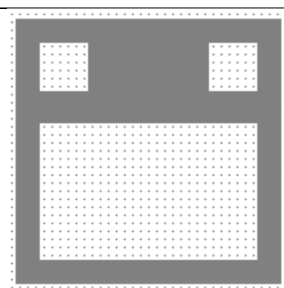
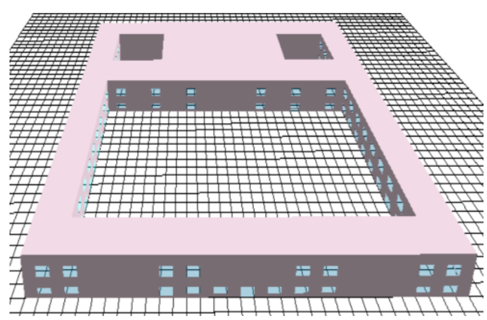
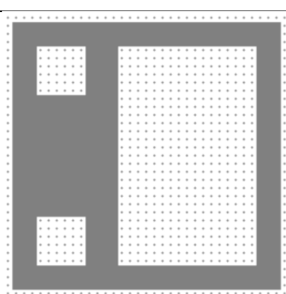
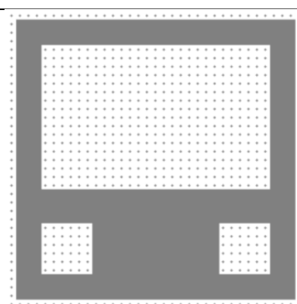
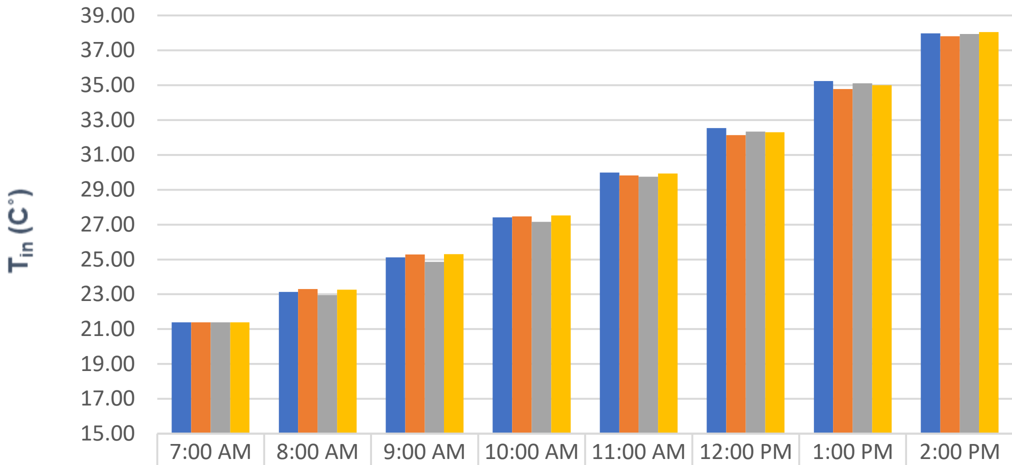
School name	No. of outdoor space	Type of outdoor space	Area of outdoor space	Courtyards area	Built Up	Courtyards /plot area	Courtyards/ built up area
586  Plot Area (m2) (33*3)* (33*3)= 9801 m^2	Court 1	Closed court	(17*3)*(27*3)= 4131 m^2	Courts = 4779 m^2	(9801) - (4131 + 324 + 324) = 5022 m^2	4779/9801= 0.49%	4779/5022= 95%
	Court 2	Closed court	(6*3)*(6*3)= 324 m^2				
	Court 3	Closed court	(6*3)*(6*3)= 324 m^2				

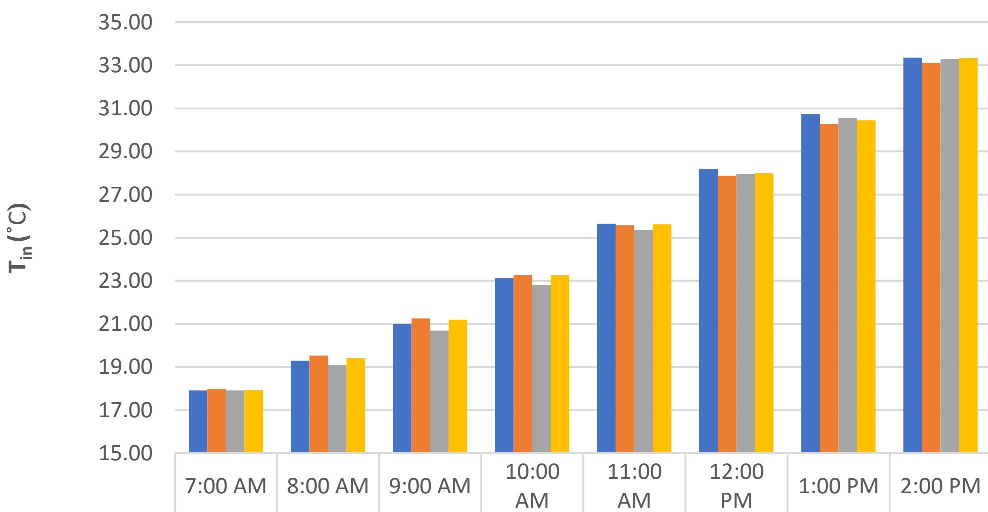
Table 5. 8: The base case school 586 with the four different orientations.

Different orientations for base case of s586.		
 s586.21sepN	 s586.21sepE	
 s586.21sepS	 s586.21sepW	



	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM
586-21sepN	21.39	23.13	25.11	27.42	29.99	32.53	35.24	37.97
586-21sepE	21.40	23.31	25.29	27.47	29.83	32.14	34.79	37.81
586-21sepS	21.39	22.96	24.86	27.16	29.75	32.34	35.12	37.95
586-21sepW	21.38	23.26	25.30	27.52	29.93	32.30	35.00	38.05

Figure 5. 7: Hourly T_{in} for School 586 21st September within schooling time in the four orientations.



	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM
586-21marN	17.92	19.30	20.99	23.12	25.64	28.19	30.73	33.36
586-21marE	17.98	19.53	21.25	23.26	25.57	27.87	30.27	33.12
586-21marS	17.92	19.10	20.70	22.82	25.36	27.96	30.57	33.29
586-21marW	17.92	19.41	21.19	23.25	25.62	27.99	30.45	33.35

Figure 5. 8: Hourly T_{in} for School 586 21st March within schooling time in the four orientations.

Figure (5.9) illustrates average hourly T_{in} for School 586 21st September within schooling time in the four orientations. The previous averages confirm that school 586 has slight differences in the average T_{in} according to its orientations. This difference is about 0.16˚C between the best case to the south with a temperature of 28.94˚C, and the upper case to the north with a temperature of 29.10˚C. That slight difference can be explained due to the symmetrical form of the school with a huge dominant closed courtyard in the middle with an area 4,131m^2 and that represents around 0.85% of the total area of the courts. Changing the huge rectangular closed courtyard orientation will produce slight differences in the air temperature on the surfaces that are exposed to the sun radiation, which will affect T_{in} in the same. On the date 21st of March according to table figure 5.10, school 586 south had the least average T_{in} too with amount around 24.71˚C, with about 0.2˚C less than the worst case to the north direction. Thus, school 586 to the north direction had the best performance and the lowest T_{in} on the two simulation dates, and school 586 had the poorest performance on both simulation dates. This can be explained due to the large area of the courtyard in school 586, which was around 4,131m^2 (the largest among all case studies) compared to the height of the surrounding masses which was 8m, thus changing the orientation will not produce a big difference for T_{in}, as Ghaffarianhoseini, Berardi and Ghaffarianhoseini (2015) stated after investigating the effect of the courtyard orientation on the air temperature that courtyards enclosed by short walls are not suitable for hot humid areas, because of the week cooling and stack effect. The difference in air temperature will be slight between different orientations as solar radiation will not be avoided based on orientation. Moreover, the main courtyard for this school has a high SVF and Edwards (2006) stated that a high SVF decreases the efficiency of the courtyard's performance.

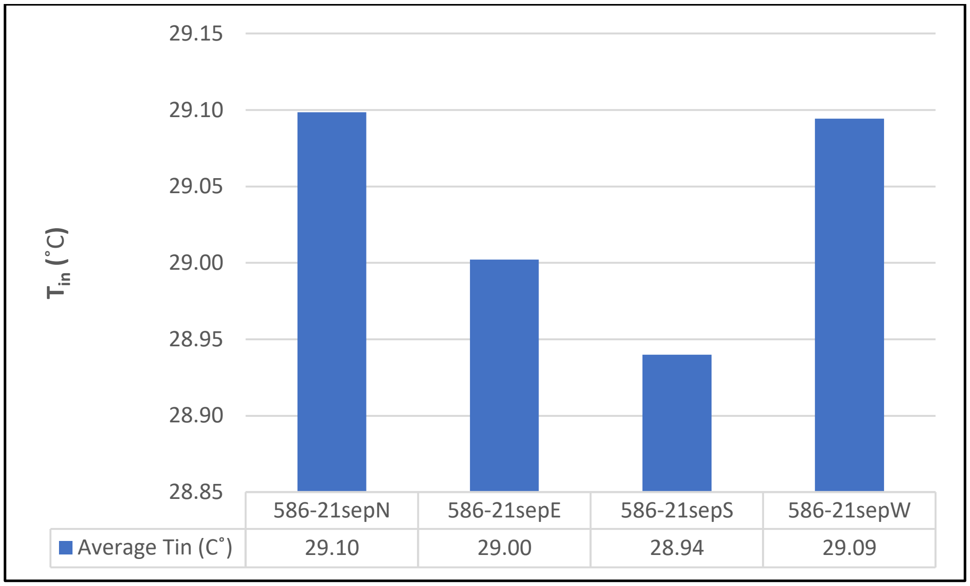


Figure 5. 9: Average hourly T_{in} for School 586 21st September within schooling time in the four orientations.

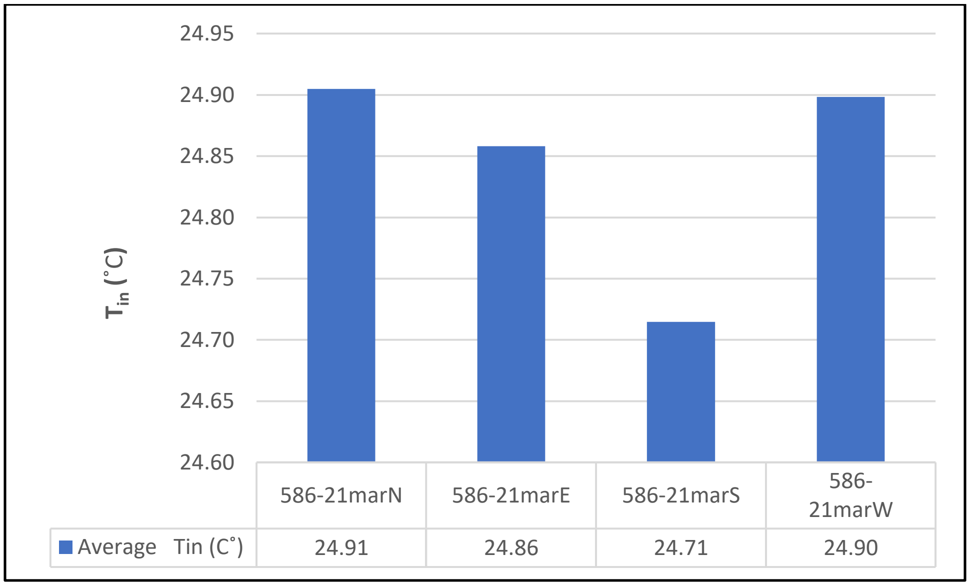


Figure 5. 10: Average hourly T_{in} for School 586 21st March within schooling time in the four orientations.

Tables (5.9) and (5.10) show the air temperature distribution at position view plane K=3 which equals 1.4m in height at 10am on both dates of the simulation. This time was selected since it represents the break time for the students in the school. It was clear according to the tables that the air temperature around the school building and in the main closed courtyard differ in the four cases on both dates of the simulation for the school 586 according to the four orientations. Despite the fact that the difference was slight, but it was clear that the main closed courtyard for the best case to the north had acceptable air distribution with relation to the other cases on 21st of September 5. Note that this courtyard area is about 4,131m^2, which represents 85% of the total courtyard area for this school. Moreover, the main courtyard in 586 to the south has a more homogeneous air temperature ranging between 31.8-32.0 ˚C. On the other hand, the school 586 to the north and west had places with air temperature of 32.8 ˚C and 32.6 ˚C, respectively. Thus, school 586 to the south is better for students playing and gathering. Moreover, the air temperature with a lower boundary will produce a lower average air temperature, and thus less heat transmission (conduction) through the walls, which will help to slow the heat gain inside the building and reduce the $T_{in.}$ On the 21st of March the school 586 to the south had better distribution with the lower air temperature range 26.4-26.6˚C inside the main courtyard than the other three cases. Moreover, the main courtyard in the four orientations have places that lays above the comfort zone 27˚C on 21st of March, unlike the school KAT, the main courtyard of which was smaller compared to school 586. This can be explained due to the large area of the courtyard in relation to its surrounding heights, which effect the shadow index and the thermal performance.

In view of that the simulated outdoor temperature is 32.93˚C, while the microclimate courtyard's inner temperature (best case to the south) ranges between 31.8-32.4˚C at 10am on the 21st of September. The simulated outdoor temperature is 28.3˚C while the microclimate courtyard's inner temperature (best case to the south) ranges between 26.4-27.2˚C at 10am on the 21st of March. Comparing the simulated outdoor temperature to the courtyard's inner temperature, the results revealed that the temperature inside the courtyard is less by 0.53-1.13˚C on 21st of September and less by 1.1-1.9˚C on 21st of March than the simulated outdoor temperature.

Ghaffarianhoseini, Berardi and Ghaffarianhoseini (2015) stated that courtyards with a large area and enclosed by short walls are not suitable for hot humid climates, as they added that those courtyards with short walls can have worse thermal conditions than the outdoor areas around the building, because of the ineffective air circulation. Moreover, this school has thin masses with thickness of 9m enclosing the main huge courtyard with area around 4,131m^2 from three sides, which caused uncomfortable temperatures inside. El-Deeb, Sherif and El-Zafarany (2014) insisted that the thicker masses of the buildings around a courtyard have better performance than the thinner ones.

Table 5. 9: Outdoor air temperature distribution around the school 586 21st of September and in the courtyards with different orientations.

<table>
<tr><td colspan="2">Outdoor air temperature distribution around the school 586 and in the courtyards with different orientations.</td><td>The key</td></tr>
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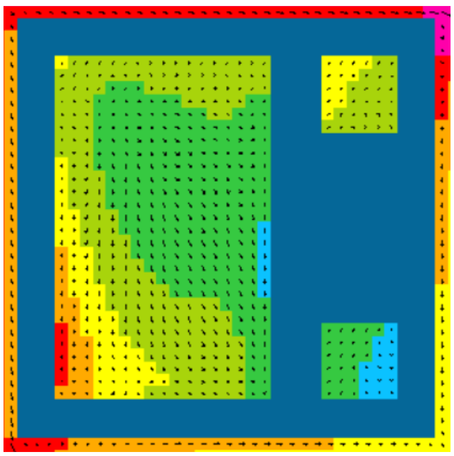
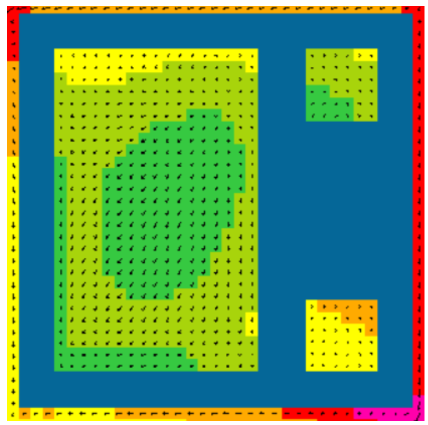
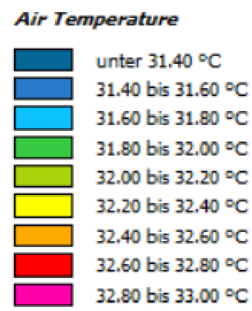
</td><td>s586-21sepE
</td><td rowspan="2">
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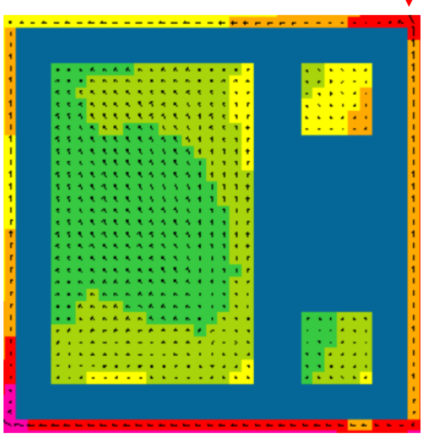
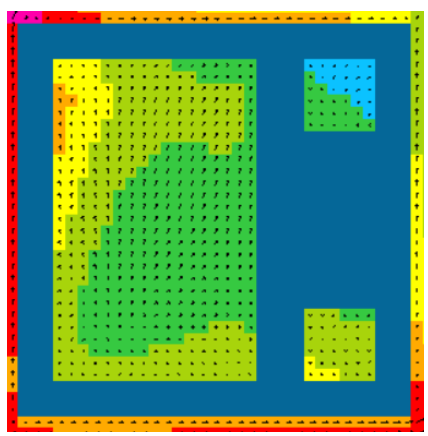
</td><td>s586-21sepW
</td></tr>
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Table 5. 10: Outdoor air temperature distribution around the school 586 on 21st March and in the courtyards with different orientations.

<table>
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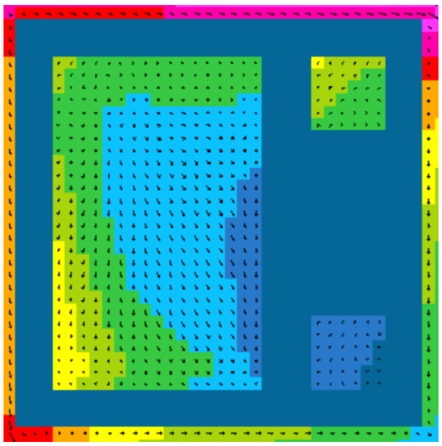
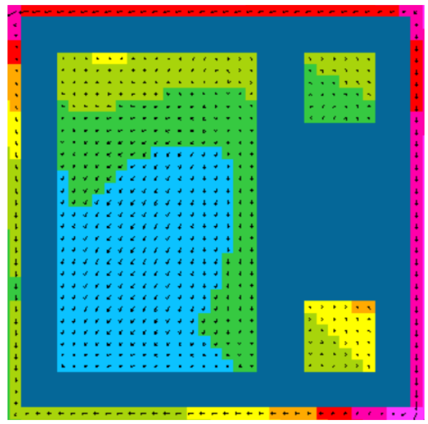
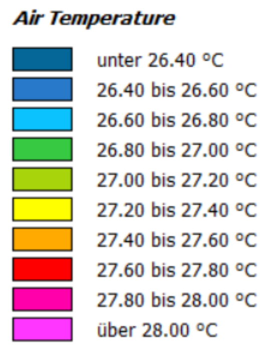
</td><td>s586-21marE
</td><td rowspan="2"></td></tr>
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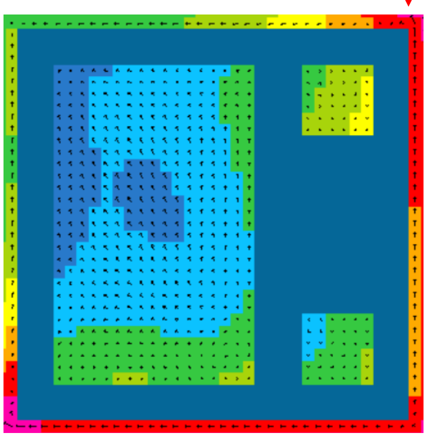
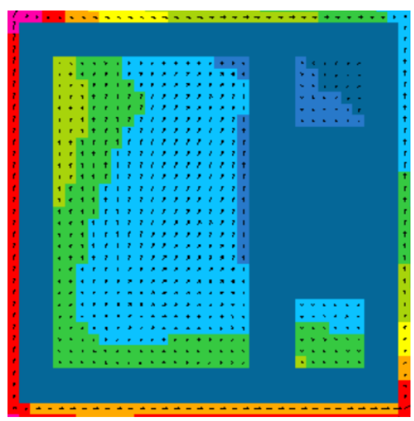
</td><td>s586-21mar W
</td></tr>
</table>

5.4.3 School 596:

The school 596 (table 5.11) was simulated in the four directions with the same original courtyard ratios and configuration of the basic model. The effect of school building orientation appears on the T_{in} within the schooling time. Table 5.12 shows the 3D base case school 596 building with the four different orientations. It was clear in figure 5.11 that the different orientations for the school illustrated different T_{in} on the 21st of September. The simulation on the 21st of March shows a difference as well, as shown in figure 5.12.

Table 5. 11: The characteristics for school 596 .

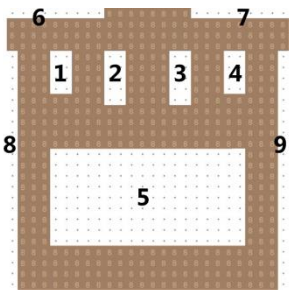
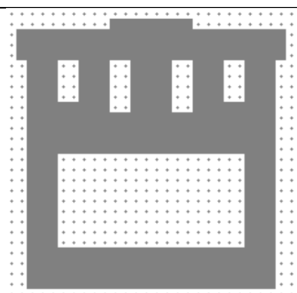
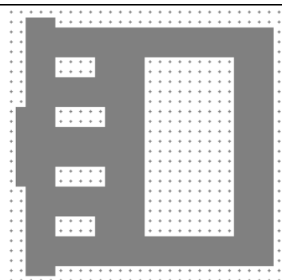
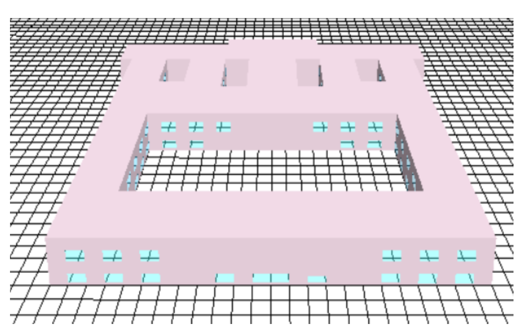
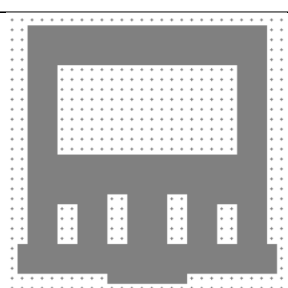
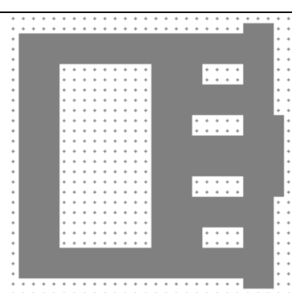
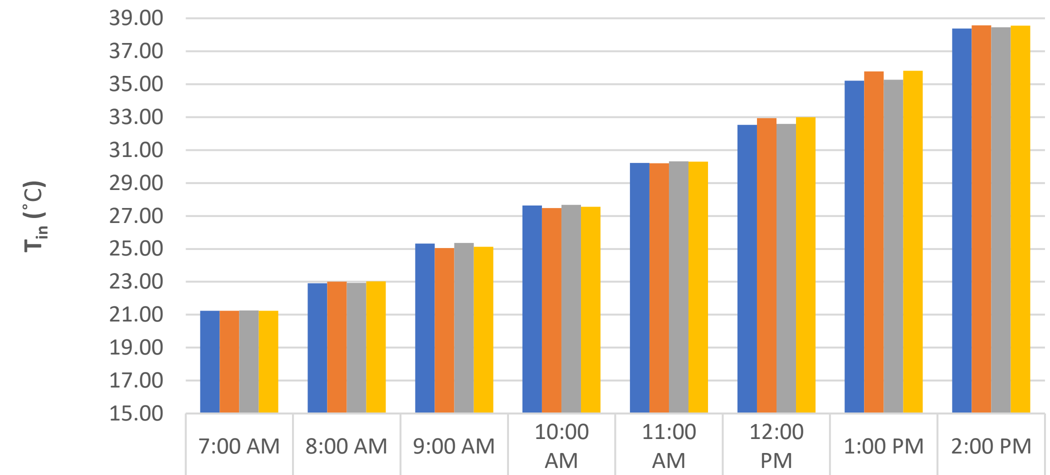
School name	No. of outdoor space	Type of outdoor space	Area of outdoor space	Courtyards area	Built Up	Courtyards /plot area ratio	Courtyards/ built up area ratio
596  Plot Area (m2) (26*3) * (26*3)= 6085 m^2	Space 1	Closed court	(2*3)*(4*3)= 72 m^2	Courts=1782 Reassessed spaces=558 Total=2340	(6085)-(72 + 90 + 90 + 72 + 1458 + 81 + 81 + 198 + 198)= 3745 m^2	1782/6085 = 29 %	1782/3745 = 48 %
	space 2	Closed court	(2*3)*(5*3)= 90 m^2				
	space 3	Closed court	(2*3)*(5*3)= 90 m^2				
	space 4	Closed court	(2*3)*(4*3)= 72 m^2				
	space 5	Closed court	(18*3)*(9*3)= 1458 m^2				
	space 6	recessed space	(1*3)*(9*3)= 81 m^2				
	space 7	recessed space	(1*3)*(9*3)= 81 m^2				
	space 8	recessed space	(1*3)*(22*3)= 198 m^2				
	space 9	recessed space	(1*3)*(22*3)= 198 m^2				

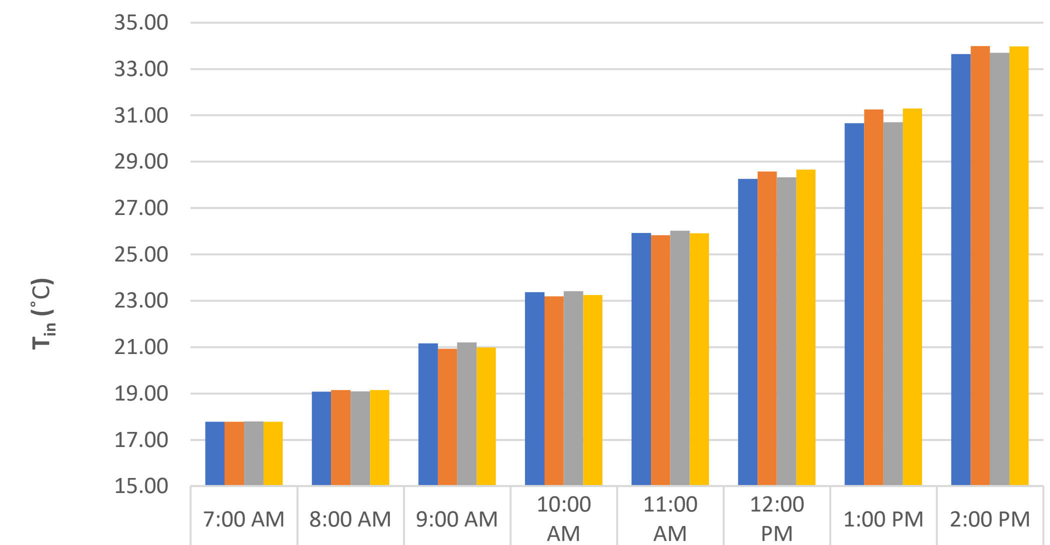
Table 5. 12: The base case school 596 with the four different orientations.

Different orientations for base case of s586.		
 s596.21sepN	 s596.21sepE	
 s596.21sepS	 s596.21sepW	



	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM
596-21sepN	21.24	22.91	25.32	27.63	30.22	32.53	35.22	38.37
596-21sepE	21.24	23.00	25.05	27.49	30.20	32.94	35.77	38.58
596-21sepS	21.26	22.93	25.37	27.68	30.31	32.59	35.27	38.45
596-21sepW	21.25	23.03	25.12	27.55	30.30	33.00	35.81	38.56

Figure 5. 11: Hourly T_{in} for School 596 21st September within schooling time in the four orientations.



	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM
596-21marN	17.79	19.08	21.16	23.37	25.93	28.27	30.66	33.64
596-21marE	17.78	19.15	20.92	23.19	25.84	28.58	31.25	33.98
596-21marS	17.80	19.10	21.20	23.42	26.02	28.33	30.71	33.69
596-21marW	17.79	19.15	20.98	23.25	25.92	28.66	31.30	33.98

Figure 5. 12: Hourly T_{in} for School 596 21st March within schooling time in the four orientations.

Figure 5.13 illustrates the average hourly T_{in} for School 596 21st September within schooling time in the four orientations. The previous averages confirm that school 596 has slight differences in the average Tin according to its orientations. This difference is about 0.15˚C between the best case to the north with a temperature of 29.18˚C, and the upper case to the west with a temperature of 29.33˚C. That slight difference can be explained due to the symmetrical form of the school with a huge dominant closed courtyard in the middle with area 1,458m^2 and that represents around 62% of the total area of the courts. Changing the huge rectangular closed courtyard orientation will produce a slight difference in the air temperature on the surfaces that are exposed to the sun radiation, and that for sure will affect the T_{in} in the same. On the date 21st of March according to figure (5.14), school 596 south had the least average T_{in} too with amount around 24.99˚C, with about 0.14˚C less than the worst case to the west direction. Thus, school 596 to the north direction had the best performance and the lowest T_{in} on the two simulation dates, and the school 596 to the west had the poorest performance on both simulation dates.

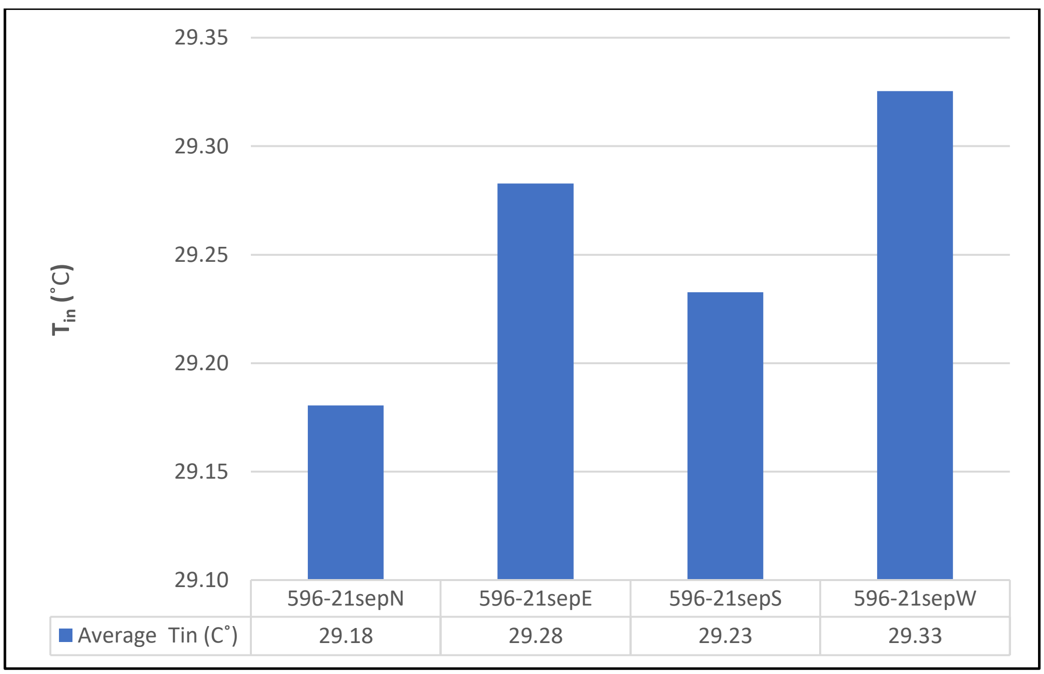


Figure 5. 13: Average hourly T_{in} for School 596 21st September within schooling time in the four orientations.

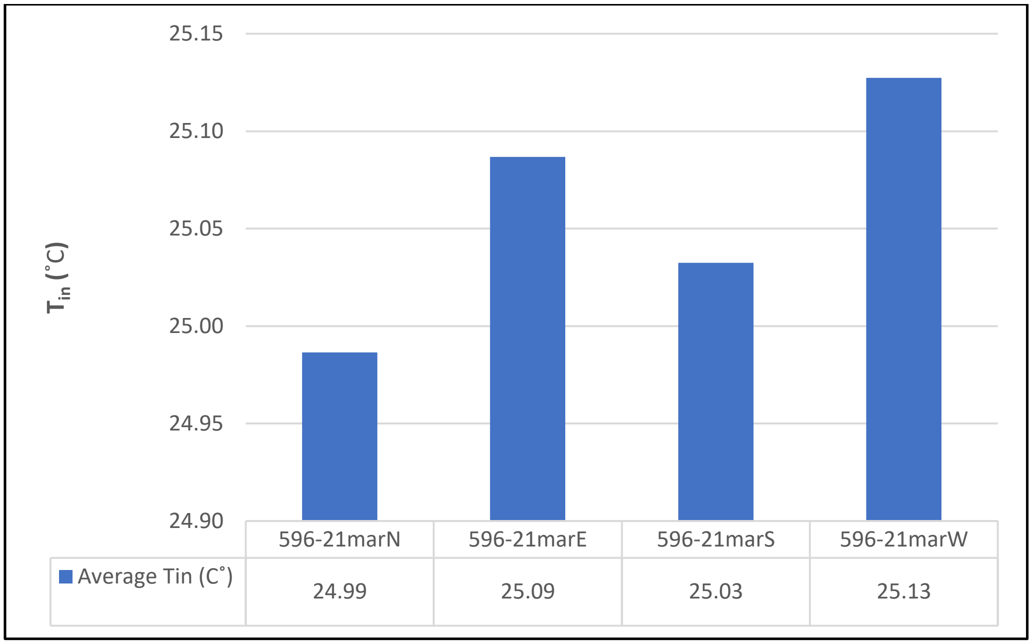


Figure 5. 14: Average hourly T_{in} for School 596 21st March within schooling time in the four orientations.

Tables 5.13 and 5.14 show the air temperature distribution at position view plane K=3 which equals 1.4m height at 10am on both dates of simulation. This time was selected since it represents the break time for the students in the school. It was clear according to the tables that the air temperature around the school building and in the main closed courtyard differ in the four cases on both dates of the simulation for the school 586 according to the four orientations. Despite the fact that the difference was slight, it was clear that the main closed courtyard for the best case to the north had acceptable air distribution with relation to the other cases on 21st of September. Note that this courtyard area is about 1,458m^2, which represents 62% of the total courts area for this school. Moreover, the main courtyard in 596 to the north have more homogeneous air temperature most of it ranges between 31.6-32.2˚C. On the 21st of March the school 596 to the north had air temperature measurement and distribution with ranges 26.4-27.0˚C inside the main courtyard. The distribution in the other cases was acceptable also. Accordingly, in school 596 the air temperature measurement and distribution lay within the comfort zone and under 27.0˚C inside the main courtyard. In contrast, the four courtyards, including school KAT, and unlike school 586, which have places that were above the comfort zone 27˚C on 21st of March, because the main courtyard in school 586 is about 2.8 times the main courtyard size in school 596. Thus, the large area of the courtyard in relation to its surrounding heights, affects the shadow index and the thermal performance.

Moreover, the simulated outdoor temperature is 32.91˚C while the microclimate courtyard inner temperature (best case to the north) ranges between 31.6-32.4˚C at 10am on the 21st of September. The simulated outdoor temperature is 28.3˚C while the microclimate courtyard inner temperature (best case to the north) ranged between 26.4-27.0˚C at 10am on the 21st of March. Comparing the simulated temperature to the courtyard inner temperature, the results revealed that the temperature inside the courtyard is less by 0.51-1.31˚C on 21st of September and less by 1.3-1.9˚C on 21st of March than the synoptic outdoor temperature. This agreed with Almhafdy et al. (2013) who stated that, the courtyard orientation has an effect on its thermal performance, as per their investigation the air temperature in the courtyard is about 0.5-5˚C lower than the outdoor temperature according to its orientation.

Table 5. 13: Outdoor air temperature distribution around the school 596 and in the courtyards with different orientations

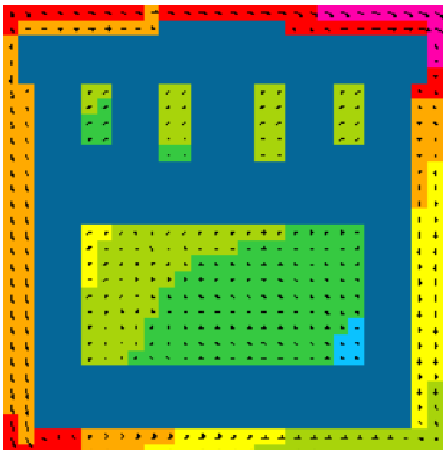
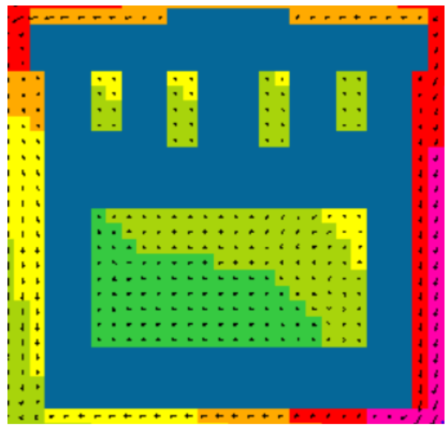
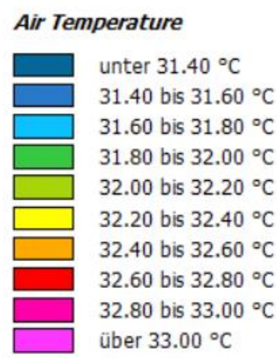
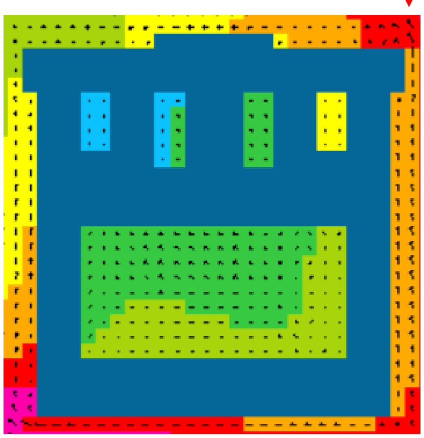
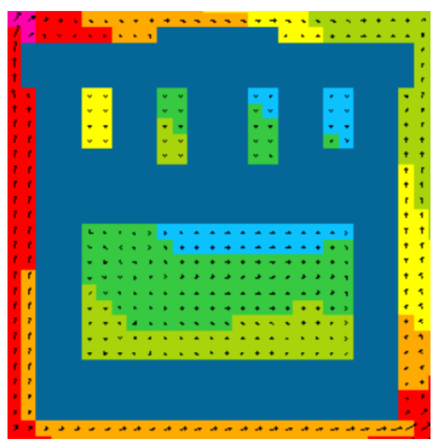
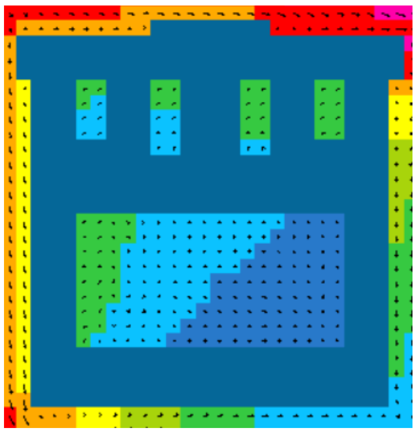
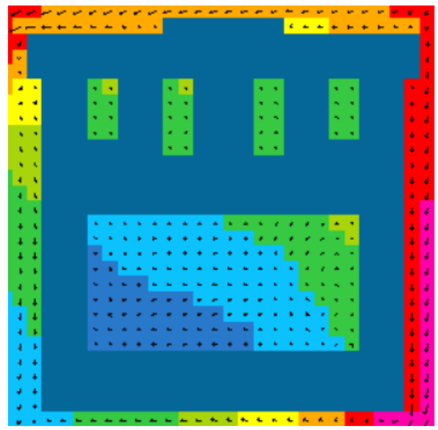
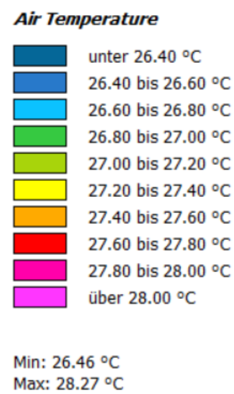
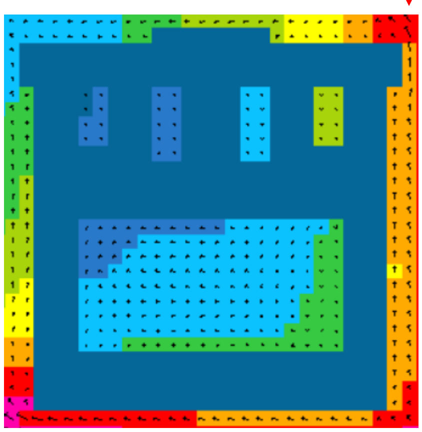
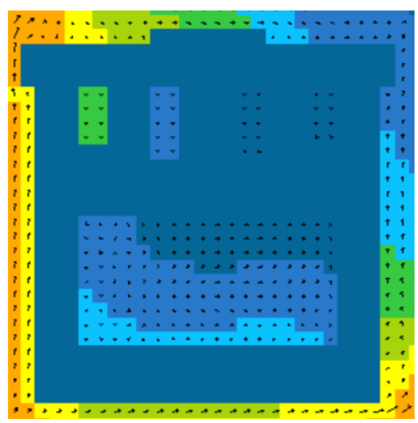
<table>
<tr><td colspan="2">Outdoor air temperature distribution around the school 596 and in the courtyards with different orientations.</td><td>The key</td></tr>
<tr><td>s596.21sepN
</td><td>s596.21sepE
</td><td rowspan="2">
</td></tr>
<tr><td>s596.21sepS
</td><td>S596.21sepW
</td></tr>
</table>

Table 5. 14: Outdoor air temperature distribution around the school 596 and in the courtyards with different orientations

Outdoor air temperature distribution around the school 596 and in the courtyards with different orientations.		The key
s596 21marN 	s596 21marE 	
sKAT21mar S 	sKAT21mar W 	

5.4.4 School UPA1:

The school UPA1 (table 5.15) was simulated in the four directions with the same original courtyard ratios and configuration of the basic model. The effect of school building orientation appears on the indoor air temperature within the schooling time. Table 5.16 shows the 3D base case school UPA1 building with the four different orientations. It was clear in figure 5.15 that the different orientations for the school illustrated different T_{in} on the 21st of September. The simulation on the 21st of March shows difference as well as in figure 5.16.

Table 5. 15: The characteristics for school UPA1 (sUPA1)

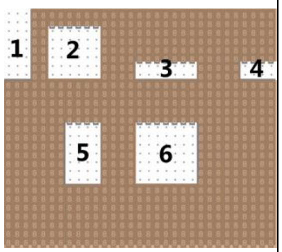
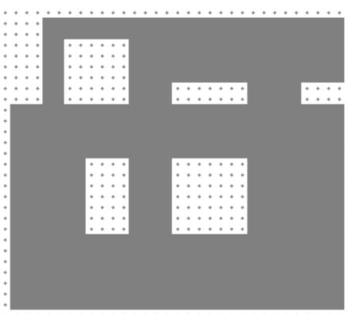
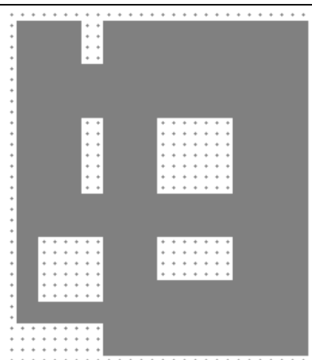
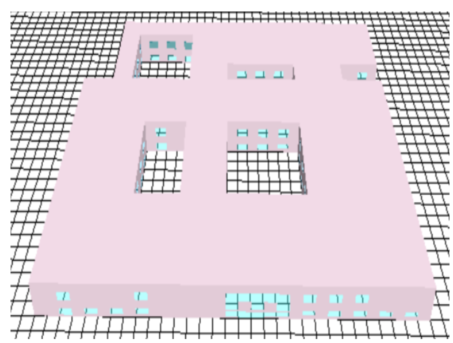
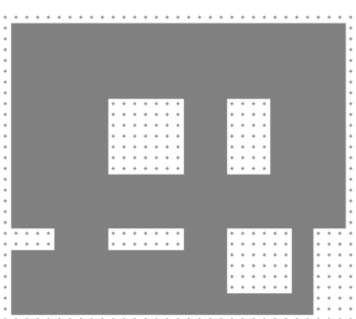
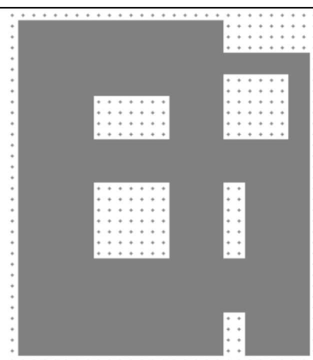
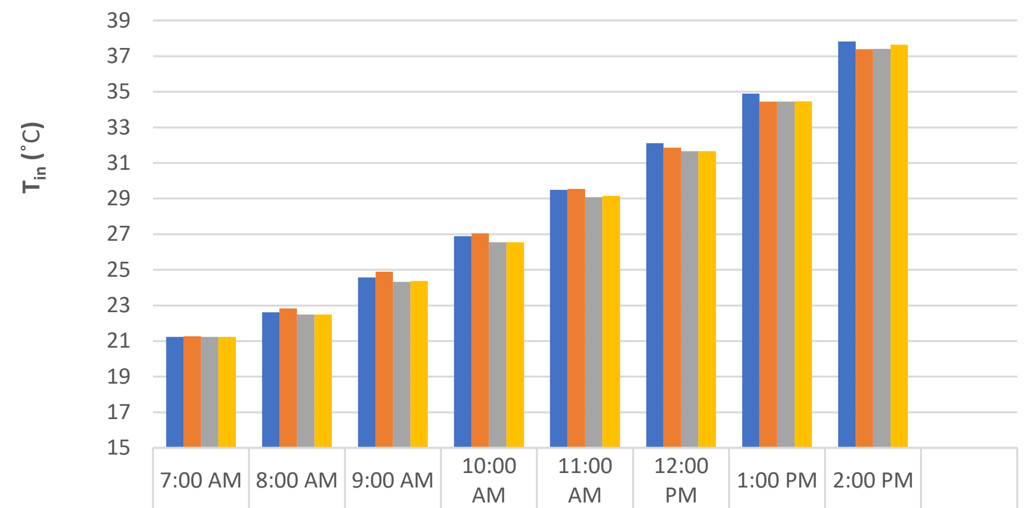
School name	Plot Area (m2)	No. of outdoor space	Type of outdoor space	Area of outdoor space	Courtyards area	Built Up	Courtyards /plot area	Courtyards/ built up area
UPA 	(31*3)*(27*3)= 7533 m^2	Court 1	Semi-opened court	(3*3)*(8*3)= 216 m^2	Courts=1431	(7533) - (216 + 324 +126 + 72 + 252 + 441) = 6102 m^2	1431/7533= 19%	1431/6102= 23%
		Court 2	Closed court	(6*3)*(6*3)= 324 m^2				
		Court 3	Closed court	(7*3)*(2*3)= 126 m^2				
		Court 4	Semi-closed court	(4*3)*(2*3)= 72 m^2				
		Court 5	Closed court	(4*3)*(7*3)= 252 m^2				
		Court 6	Closed court	(7*3)*(7*3)= 441 m^2				

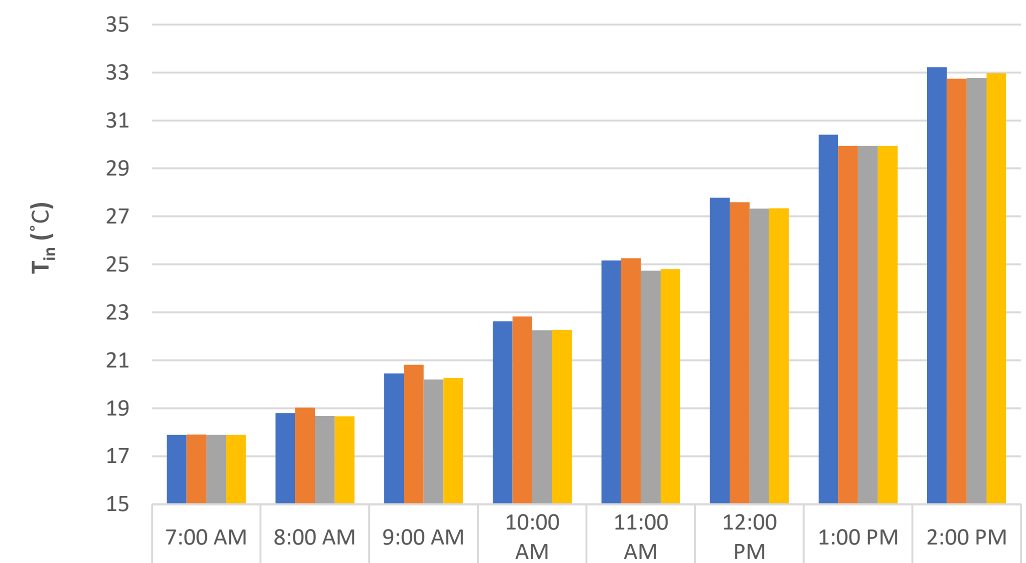
Table 5. 16: The 3D base case school UPA1 with the four different orientations.

Different orientations for base case of sUPA-1.		
 sUPA21sepN	 sUPA21sepE	
 sUPA21sepS	 sUPA21sepW	



	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM
UPA21sepN	21.24	22.62	24.57	26.89	29.49	32.11	34.89	37.82
UPA21sepE	21.27	22.83	24.89	27.05	29.55	31.86	34.44	37.4
UPA21sepS	21.24	22.49	24.32	26.54	29.08	31.67	34.44	37.41
UPA21sepW	21.24	22.49	24.37	26.55	29.15	31.66	34.46	37.64

Figure 5. 15: Hourly T_{in} for School UPA 21st September within schooling time in the four orientations



	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM
UPA21marN	17.893	18.804	20.454	22.623	25.159	27.78	30.412	33.217
UPA21marE	17.902	19.029	20.817	22.831	25.258	27.59	29.947	32.745
UPA21marS	17.888	18.679	20.199	22.261	24.732	27.319	29.942	32.775
UPA21marW	17.89	18.67	20.271	22.275	24.806	27.338	29.935	32.972

Figure 5. 16: Hourly T_{in} for School UPA1 21st March within schooling time in the four orientations.

Figure 5.17 average hourly T_{in} for school UPA1 on 21st September within schooling time in the four orientations. The previous averages confirm that school UPA1 exhibits slight differences in the average T_{in} according to its orientations. This difference is about 0.31˚C between the best case to the south with a temperature of 28.40˚C, and the upper case to the north with a temperature of 28.71˚C. Despite the fact the difference was slight but it is more than the school 586 and school 596, which have closed courtyards like UPA1. This can be explained due to the small size of the courtyards in school UPA1, as it has four small courtyards, where the biggest one has an area of about $441m^2$ and it is considered small in relation to the other types that have a dominant closed courtyard like schools 596 and 586, which have a closed courtyard with areas $1,458m^2$ and $4,131m^2$, respectively. On the 21st of March, according to figure 5.18, school UPA1 to the south had the least average T_{in} also with an amount around 24.22˚C, with about 0.32˚C less than the worst case to the north direction. Thus, school UPA1 to the south direction had the best performance and the lowest T_{in} on the two simulation dates, and the school UPA1 to the north had the poorest performance on both simulation dates.

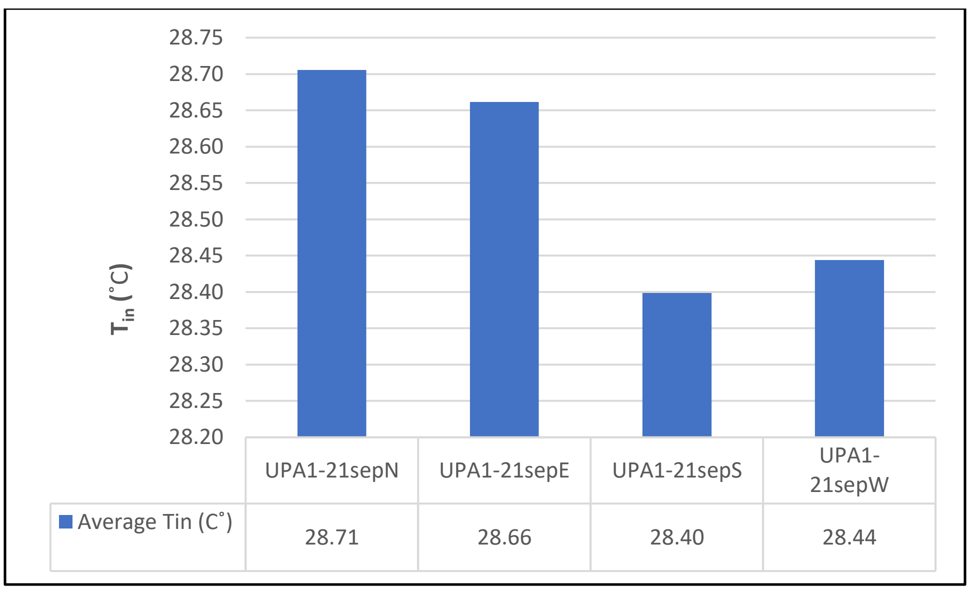


Figure 5. 17: Average hourly T_{in} for School UPA1 21st September within schooling time in the four orientations.

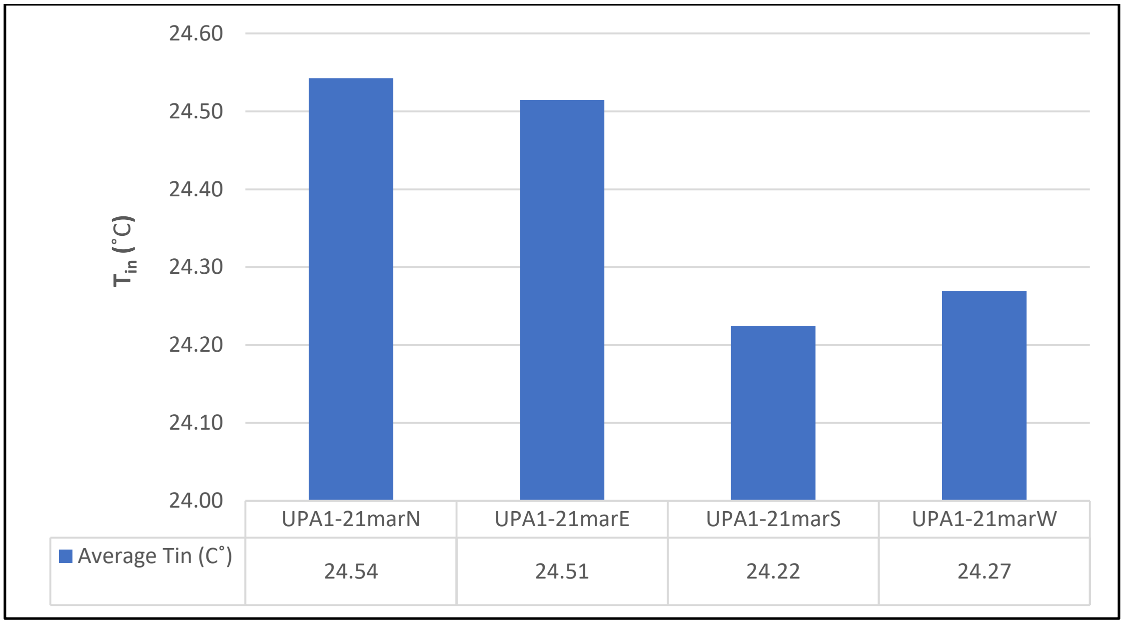


Figure 5. 18: Average hourly T_{in} for School UPA1 21st March within schooling time in the four orientations.

Tables 5.17 and 5.18 show the air temperature distribution at position view plane K=3, which equals 1.4m in height at 10am on both dates of the simulation. This time was selected as it represents the break time for the students in the school. It was clear according to the tables that the air temperature around the school building and in the main closed courtyard differ in the four cases on both dates of the simulation for the school UPA1 according to the four orientations. Despite the fact that the difference was slight, it was clear that the small internal closed courtyards for the best case to the south had acceptable air distribution with relation to the other cases on 21st of September that reached 31.6˚C in some areas. On the date 21st of March the school UPA1 to the south had air temperature measurement and distribution with ranges 26.4-27.0˚C inside the four main closed internal courtyards. The same distribution was in the case of west and north directions. Accordingly, in school UPA1 to the south, west and north the air temperature measurement and distribution with ranges under the comfort zone 27.0˚C inside the closed courtyards, unlike school UPA1 to the east where the air temperature inside the courtyards reached 27.2˚C.

Furthermore, the simulated outdoor temperature is 32.92˚C while the microclimate courtyard inner temperature (best case to the south) ranged between 31.6-32.2˚C at 10am on the 21st of September. The simulated outdoor temperature is 28.3˚C while the microclimate courtyard inner temperature (best case to the south) ranges between 26.4-27.0˚C at 10am on the 21st of March. Comparing the synoptic temperature to courtyard inner temperature, the results revealed that the temperature inside the courtyard is less by 0.72-1.32˚C on 21st of September and less by 1.3-1.7˚C on 21st of March than the simulated outdoor temperature. Almhafdy et al. (2013) mentioned that, the courtyard orientation can reduce the air temperature in the courtyard within a range 0.5-5˚C according to other parameters.

Table 5. 17: Outdoor air temperature distribution around the school UPA1 and in the courtyards with different orientations.

<table>
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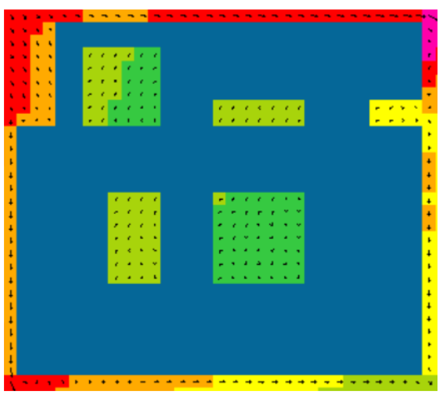
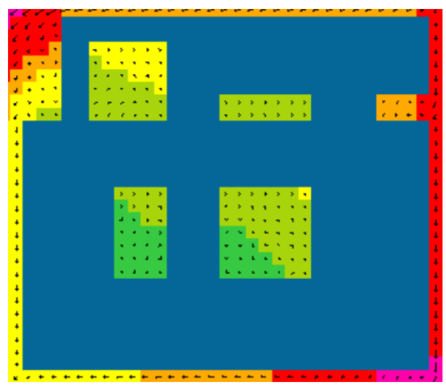
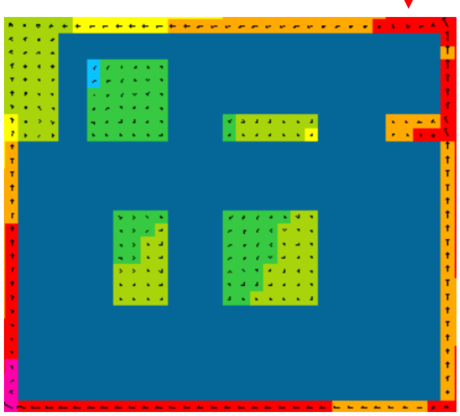
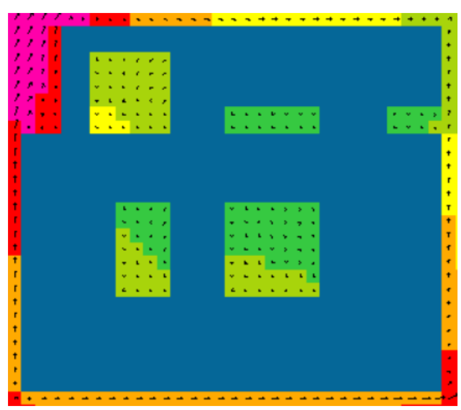
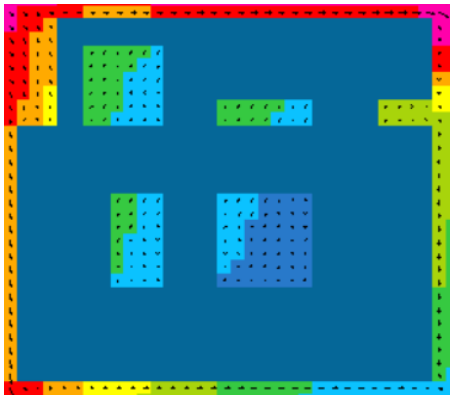
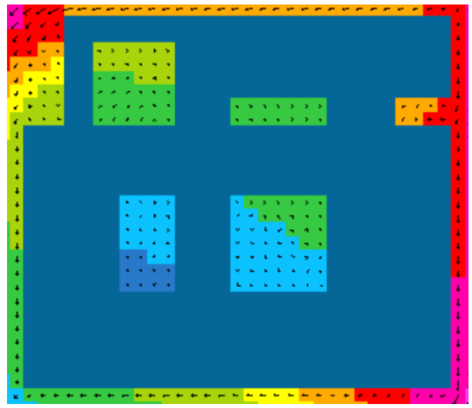
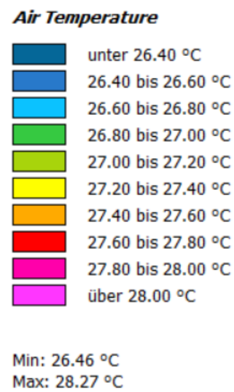
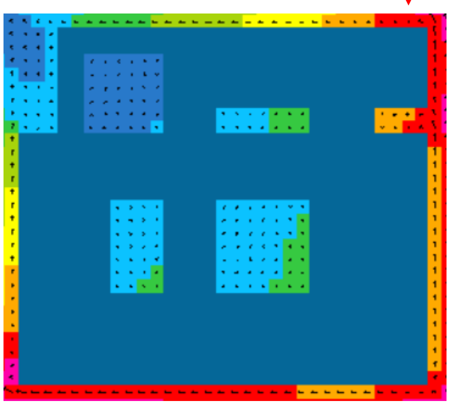
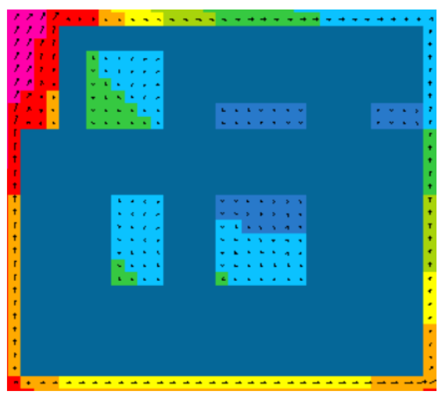
</td><td>sUPA1-21sepE
</td><td rowspan="2">
</td></tr>
<tr><td>sUPA1-21sepS
</td><td>sUPA1-21sepW
</td></tr>
</table>

Table 5. 18: Outdoor air temperature distribution around the school UPA1 and in the courtyards with different orientations.

Outdoor air temperature distribution around the school UPA1 and in the courtyards with different orientations.		The key
sUPA1-21marN 	sUPA1-21marE 	
sUPA1-21marS 	sUPA1-21marW 	

5.4.5 School UPA-fin:

The school UPA-fin (table 5.19) was simulated in the four directions with the same original courtyard ratios and configuration of the basic model. The effect of school building orientation appears on the indoor air temperature within the schooling time. Table 5.20 shows the 3D base case school 586 building with the four different orientations. It was clear in figure 5.19 that the different orientations for the school have illustrate different T_{in} on the 21st of September. The simulation on the 21st of March shows difference as well, as shown in figure 5.20.

Table 5. 19: The characteristics for sUPA-fin.

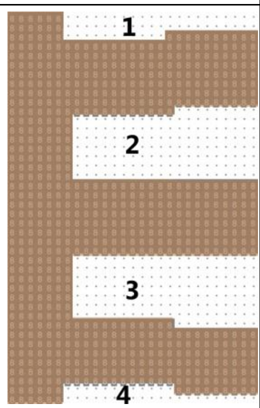
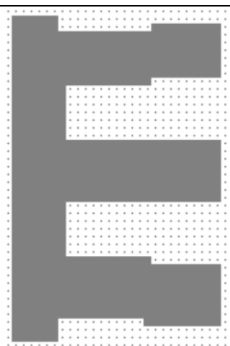
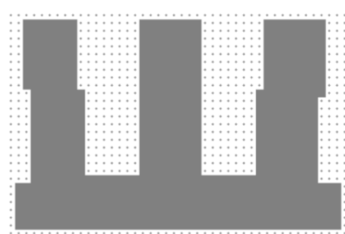
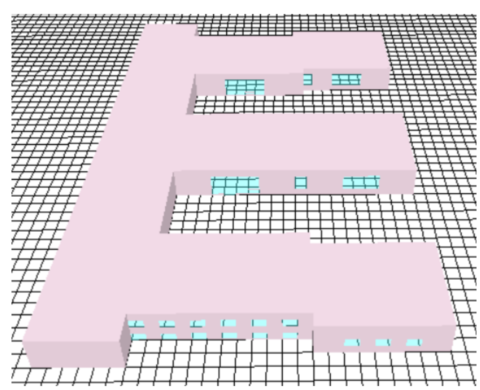
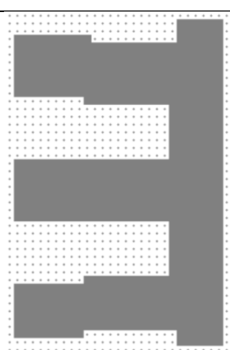
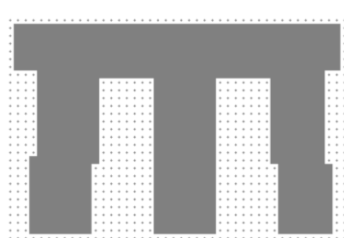
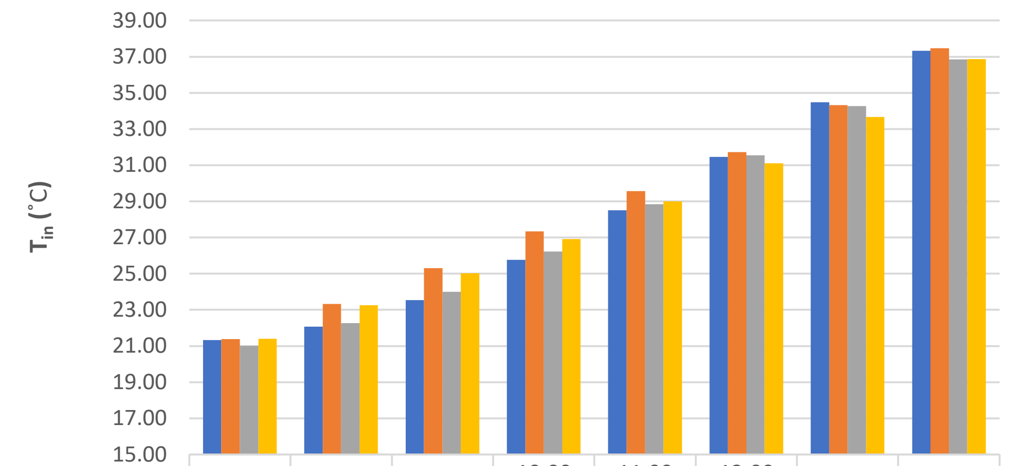
School name	No. of outdoor space	Type of outdoor space	Area of outdoor space	Courtyards area	Built Up	Courtyards /plot area Ratio	Courtyards/ built up area ratio
 Plot Area (m2) (27*3) * (42*3)= 10206 m2	Court 1	recessed space	((21*3)*(3*3))-((10*3)*(1*3))= 477 m^2q	Courts = 2682 m^2 recessed space= 774	(10206) - (477 + 1341 + 1341 + 297) = 6750 m^2	2682/10206= 26%	2682/6750= 40%
	Court 2	Semi-closed court	((20*3)*(8*3))-((11*3)*(1*3))= 1341 m^2				
	Court 3	Semi-closed court	((20*3)*(8*3))-((11*3)*(1*3))= 1341 m^2				
	Court 4	recessed space	((21*3)*(2*3))-((9*3)*(1*3))= 297 m^2				

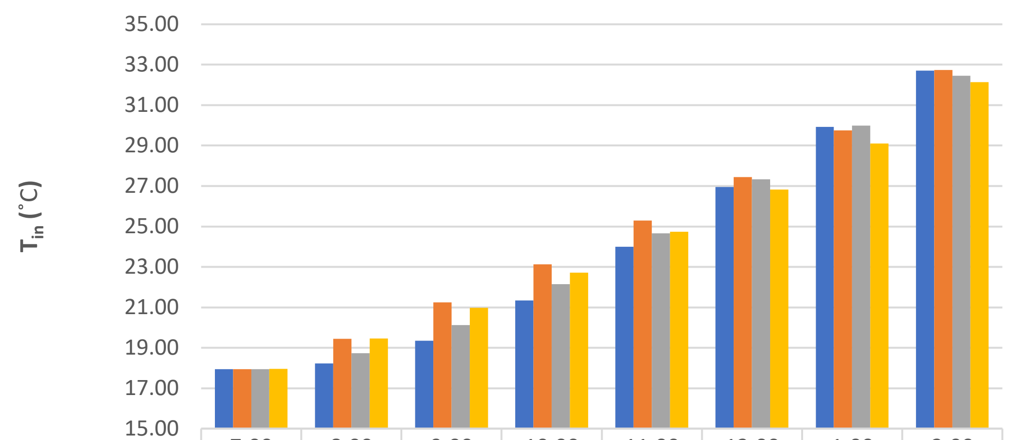
Table 5. 20: The 3D base case sUPA-fin with the four different orientations.

Different orientations for base case of sUPA-fin.		
 sUPA-fin21sepN	 sUPA-fin21sepE	
 sUPA-fin21sepS	 sUPA-fin21sepW	



	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM
UPA-fin-21sepN	21.33	22.07	23.54	25.76	28.50	31.46	34.48	37.33
UPA-fin-21sepE	21.37	23.33	25.31	27.35	29.56	31.73	34.32	37.47
UPA-fin-21sepS	21.01	22.26	24.00	26.23	28.84	31.55	34.27	36.85
UPA-fin-21sepW	21.40	23.25	25.02	26.92	29.01	31.10	33.67	36.87

Figure 5. 19: Hourly T_{in} for School UPA-fin 21st September within schooling time in the four orientations



	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM
UPA-fin-21marN	17.95	18.23	19.35	21.34	24.00	26.95	29.92	32.70
UPA-fin-21marE	17.94	19.44	21.25	23.13	25.29	27.45	29.76	32.73
UPA-fin-21marS	17.95	18.74	20.14	22.15	24.66	27.34	29.98	32.45
UPA-fin-21marW	17.97	19.46	20.98	22.71	24.74	26.82	29.11	32.13

Figure 5. 20: Hourly T_{in} for School UPA-fin 21st September within schooling time in the four orientations.

Figure 5.21 average hourly T_{in} for UPA-fin on 21st September within schooling time in the four orientations. The previous averages confirm that sUPA-fin has higher difference in the average T_{in} according to its orientations than the other schools. This difference is about 0.75˚C between the best case to the north with temperature 28.06˚C, and the higher case to the east with temperature 28.81˚C. Despite the fact the difference was still small, it is more than in the previous cases. This can be explained due to the asymmetrical form of the school when located to the north beside the location of the opened areas of the two main courtyards, which are open to the west in this case. The school has two similar courtyards each one has an area 1,341m^2. Changing the rectangular semi-closed courtyard orientation will produce a greater difference in the air temperature on the surfaces that are exposed to the sun radiation as in this case, which will affect the T_{in} in the same. On the 21st of March according to figure 5.22, school UPA-fin to the north had the least average T_{in} also, with an amount around 23.80˚C, which is 0.82˚C less than the worst-case direction to the east. Thus, school UPA-fin to the north direction had the best performance and the lowest T_{in} on the two simulation dates among all the schools, and the school UPA-fin to the east had the poorest performance on both simulation dates.

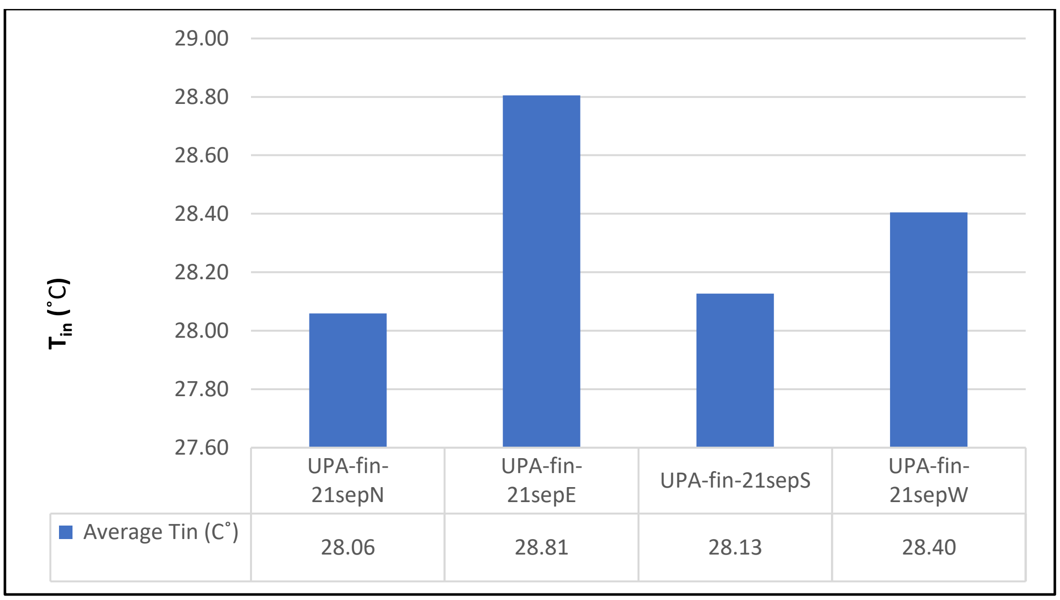


Figure 5. 21: Average hourly T_{in} for School UPA-fin 21st September within schooling time in the four orientations.

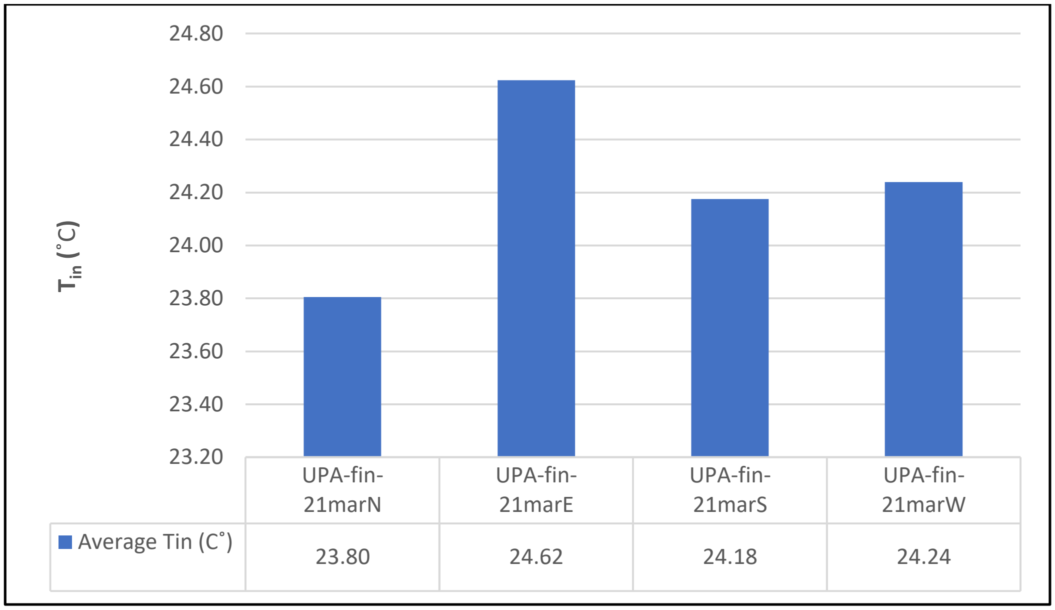


Figure 5. 22: Average hourly T_{in} for School UPA-fin 21 September within schooling time in the four orientations.

Tables 5.21 and 5.22 show the air temperature distribution at position view plane K=3, which equals 1.4m in height at 10am on both dates of simulation. This time was selected since it represents the break time for the students in the school. It was clear according to the tables that the air temperature around the school building and in the main two semi-closed courtyards differ in the four cases on both dates of the simulation for the sUPA-fin according to the four orientations. Despite the fact that the difference was slight, it was clear that the main two semi-closed courtyards for the best case to the north had acceptable air distribution with relation to the other cases on 21st of September. Note that each courtyard area is about 1,314m^2, and their air temperatures ranged between 31.8-32.4˚C. On the 21st of March the school UPA-fin to the north had air temperature measurements and distributions with ranges from 26.4-27.0˚C inside the main two semi-closed courtyards. The same distribution was observed in the case of the west direction. Accordingly, in sUPA-fin to the north and west have air temperature measurements and distributions with ranges under the comfort zone of 27.0˚C inside the main two semi-closed courtyards, unlike sUPA-fin to the south and east, where the air temperature inside the courtyards reached 27.8˚C. This can be explained due the opening direction of the courtyard, which affects the hot air penetration, and thus the thermal performance.

Bearing in mind that the simulated outdoor temperature is 32.92˚C while the microclimate courtyard inner temperature (best case to the north) ranges between 31.8-32.4˚C at 10am on the 21st of September. The simulated outdoor temperature is 28.22˚C while the microclimate courtyard inner temperature (best case to the north) ranges mostly between 26.4-27.0˚C at 10am on the 21st of March. Comparing the synoptic temperature to the courtyard inner temperature, the results revealed that the temperature inside the courtyard is less by 0.52-1.12˚C on 21st of September and less by 1.22-1.82˚C on 21st of March than the synoptic outdoor temperature. Almhafdy et al. (2013) stated that the thermal performance of the semi-opened courtyard will differ according to the orientation of its open side

Table 5. 21: Outdoor air temperature distribution around the school UPA-fin and in the courtyards with different orientations.

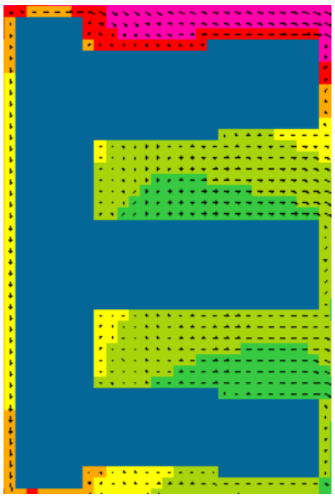
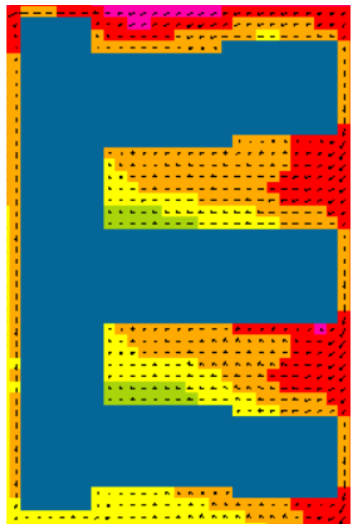
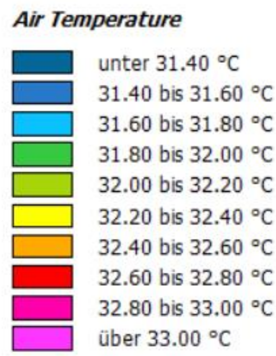
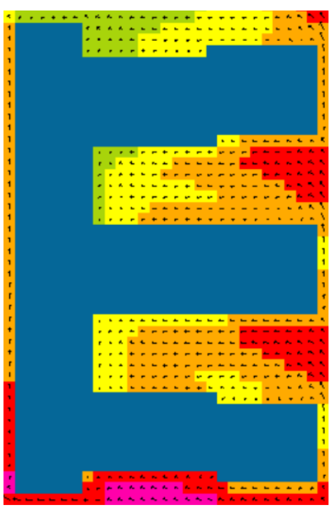
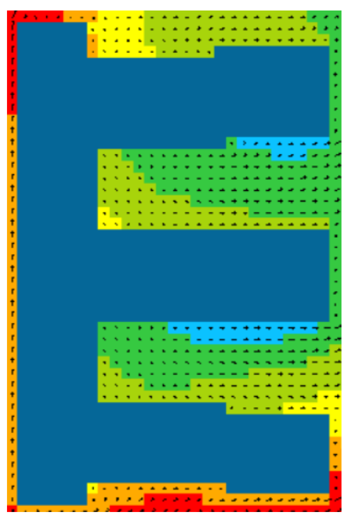
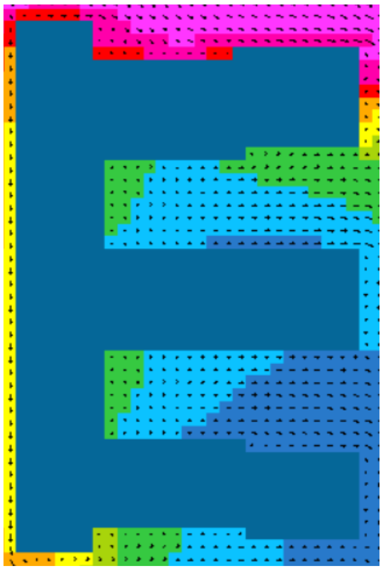
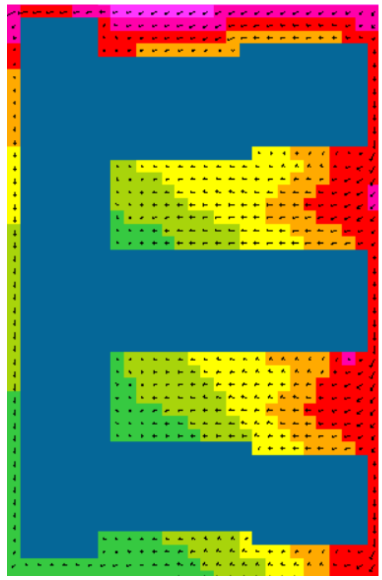
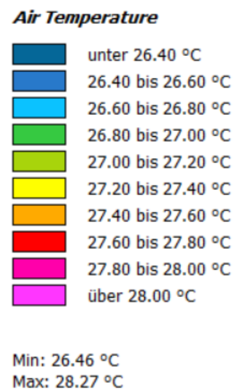
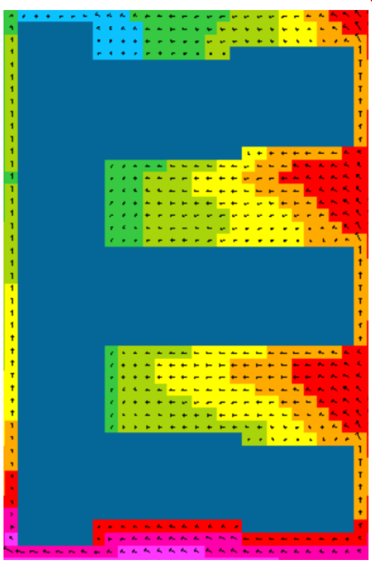
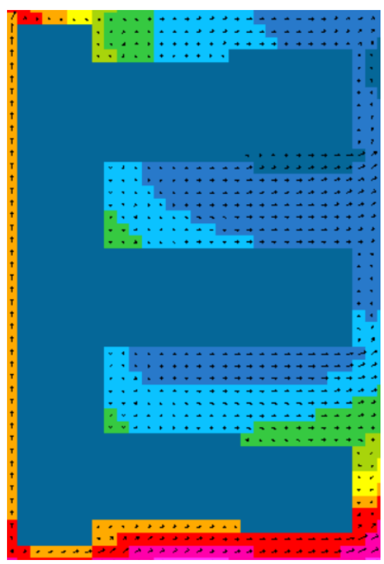
<table>
<tr><td colspan="2">Outdoor air temperature distribution around the school UPA-fin and in the courtyards with different orientations.</td><td>The key</td></tr>
<tr><td>sUPA-fin21sepN
</td><td>sUPA-fin21sepE
</td><td rowspan="2">
</td></tr>
<tr><td>sUPA-fin21sepS
</td><td>sUPA-fin21sepW
</td></tr>
</table>

Table 5. 22: Outdoor air temperature distribution around the school UPA-fin and in the courtyards with different orientations.

<table>
<tr><th colspan="2">Outdoor air temperature distribution around the school UPA-fin and in the courtyards with different orientations.</th><th>The key</th></tr>
<tr><td>sUPA-fin21sepN
</td><td>sUPA-fin21sepE
</td><td rowspan="2">
</td></tr>
<tr><td>sUPA-fin21marS
</td><td>sUPA-fin21marW
</td></tr>
</table>

5.5 Discussion for stage one:

Orientation is to locate the building relative to climate differences according to the sun's path and wind dominate direction. Good orientation improves the energy effectiveness of the building, moreover it makes it more livable with less expenses to run. Orientation is assumed to be one of the passive design strategies for cooling, as it reduces the undesirable sun and blocks the hot winds despite the fact it allows access for cooling breezes (Yourhome.gov.au 2017). Thus, orientation is important as a passive cooling tactic for all the buildings in the hot humid UAE. Orientation for buildings in the UAE should reduce the direct sunlight and the hot wind, meanwhile it improves access for the breeze.

A simulation for the five types of school buildings using ENVI-met software on the 21st of September and 21st of March was conducted to evaluate the present proportions and types of the schools' courtyards in different orientations, as shown in table 5.23 and figure 5.23 for 21st of September and table 5.24 and figure 5.24 for 21st of March. The variation in T_{in} in the first hours of schooling time 7-9am was minor compared to the variation from 9am-2pm.

Moreover, the findings show that there were different effects of the courtyards orientation according to their types, proportions and ratios on the T_{in} of the school building. The variation in T_{in} according to the orientation agreed with Cantón et al. 2014; Alzanfer 2014 and Tablada et al. 2005 as they pointed to the effect of the courtyard orientation on its thermal behavior. Tablada (2013) stated -according to his study- that the improved thermal conditions by orientation of the courtyard can reduce the air temperature in the courtyard by a minimum 1.4˚C despite the fact that the outdoor temperature was high like the case in Havana.

The school UPA-fin presented the lowest T_{in} among the other types of schools with average T_{in} ranges from 28.81-28.06˚C according to orientation. Moreover, the school UPA-fin school oriented to the north recorded the best orientation for the courtyard with average T_{in} around 28.06˚C during the schooling time from 7am till 2pm on the 21st of September (highlighted with white text in table 5.23). School KAT recorded the highest averages for the T_{in} among the other cases with a range of 29.36-29.75˚C on the same date in September (highlighted with red text in table 5.23). On 21st of March, again school UPA-fin school oriented to the north recorded the best orientation for the courtyard with average T_{in} around 23.80-24.62˚C (highlighted with white text in table 5.24), and again school KAT recorded the highest averages for the T_{in} among the other cases with a range of 25.58-25.13˚C on the same date (highlighted with white text in table 5.24). Based on that sUPA-fin to the north direction recorded -1.7˚C compared to school KAT to the west direction on the 21st of September and recorded -1.75˚C on the 21st of March. This can be explained as the courtyard in school UPA-fin to the north is closed from the north and west in a way that blocked the north west warm air from entering it, which agreed with Tablada et al. (2005) who stated that the courtyard can protect from dusty unwanted air, which plays a considerable role in the thermal behavior of the building. As a result, sUPA-fin to the north direction was highlighted as the best scenario among the other cases of schools (figure 5.25) and recommended for further improvement in stage two.

Table 5. 23: The T_{in} for all the schools in the four main orientations on 21st of September.

N	Time	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	Average
1	KAT21sepN	21.23	22.86	24.96	27.50	30.32	33.14	36.02	38.83	29.36
2	KAT21sepE	21.23	23.32	25.55	28.29	30.73	32.91	35.63	38.96	29.58
3	KAT21sepS	21.21	22.90	25.07	27.67	30.54	33.38	36.27	39.06	29.51
4	KAT21sepW	21.24	23.59	25.93	28.65	31.01	33.07	35.66	38.84	29.75
5	586-21sepN	21.39	23.13	25.11	27.42	29.99	32.53	35.24	37.97	29.10
6	586-21sepE	21.40	23.31	25.29	27.47	29.83	32.14	34.79	37.81	29.00
7	586-21sepS	21.39	22.96	24.86	27.16	29.75	32.34	35.12	37.95	28.94
8	586-21sepW	21.38	23.26	25.30	27.52	29.93	32.30	35.00	38.05	29.09
9	596-21sepN	21.24	22.91	25.32	27.63	30.22	32.53	35.22	38.37	29.18
10	596-21sepE	21.24	23.00	25.05	27.49	30.20	32.94	35.77	38.58	29.28
11	596-21sepS	21.26	22.93	25.37	27.68	30.31	32.59	35.27	38.45	29.23
12	596-21sepW	21.25	23.03	25.12	27.55	30.30	33.00	35.81	38.56	29.33
13	UPA1-21sepN	21.24	22.62	24.57	26.89	29.49	32.11	34.89	37.82	28.71
14	UPA1-21sepE	21.27	22.83	24.89	27.05	29.55	31.86	34.44	37.40	28.66
15	UPA1-21sepS	21.24	22.49	24.32	26.54	29.08	31.67	34.44	37.41	28.40
16	UPA1-21sepW	21.24	22.49	24.37	26.55	29.15	31.66	34.46	37.64	28.44
17	UPA-fin-21sepN	21.33	22.07	23.54	25.76	28.50	31.46	34.48	37.33	28.06
18	UPA-fin-21sepE	21.37	23.33	25.31	27.35	29.56	31.73	34.32	37.47	28.81
19	UPA-fin-21sepS	21.01	22.26	24.00	26.23	28.84	31.55	34.27	36.85	28.13
20	UPA-fin-21sepW	21.40	23.25	25.02	26.92	29.01	31.10	33.67	36.87	28.40

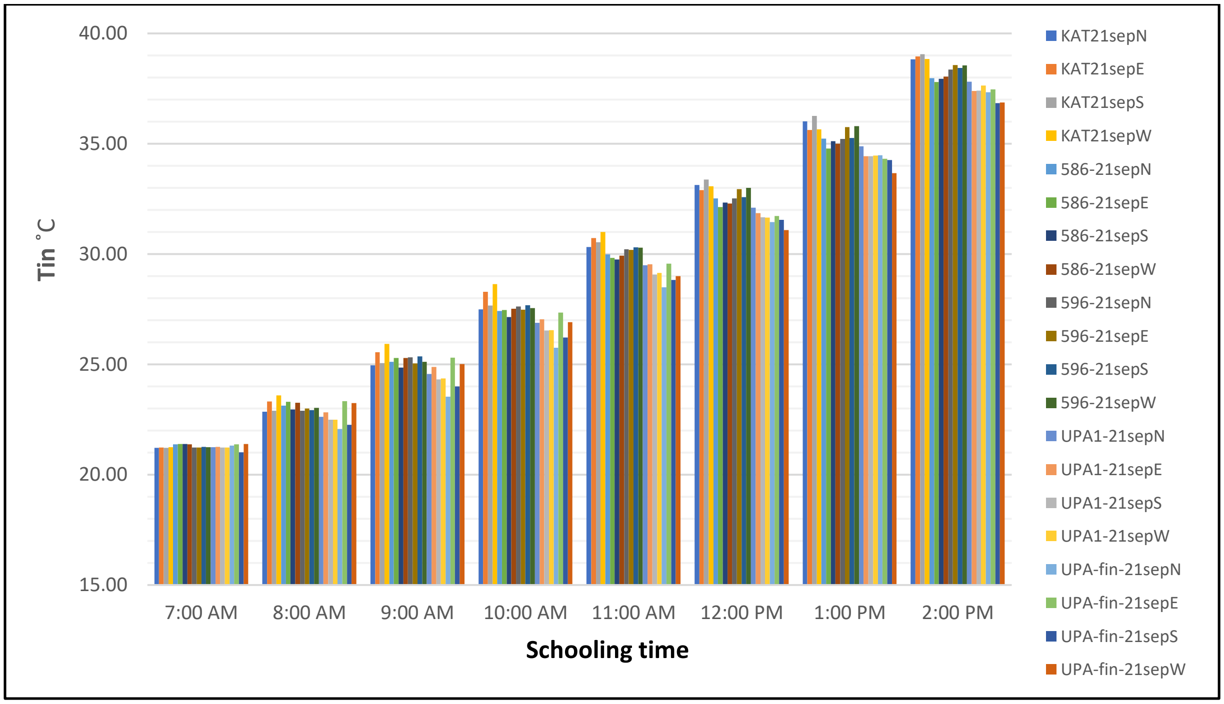


Figure 5. 23: The T_{in} for all the schools in the four main orientations on 21st of September.

Table 5. 24: The T_{in} for all the schools in the four main orientations on 21st of March.

School name	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	Average
KAT21marN	17.75	18.98	20.78	23.16	25.93	28.76	31.51	34.20	25.13
KAT21marE	17.75	19.31	21.46	24.03	26.50	28.71	31.03	34.19	25.37
KAT21marS	17.75	19.02	20.89	23.33	26.15	29.01	31.77	34.44	25.29
KAT21marW	17.75	19.58	21.85	24.42	26.83	28.93	31.12	34.15	25.58
586-21marN	17.92	19.30	20.99	23.12	25.64	28.19	30.73	33.36	24.91
586-21marE	17.98	19.53	21.25	23.26	25.57	27.87	30.27	33.12	24.86
586-21marS	17.92	19.10	20.70	22.82	25.36	27.96	30.57	33.29	24.71
586-21marW	17.92	19.41	21.19	23.25	25.62	27.99	30.45	33.35	24.90
596-21marN	17.79	19.08	21.16	23.37	25.93	28.27	30.66	33.64	24.99
596-21marE	17.78	19.15	20.92	23.19	25.84	28.58	31.25	33.98	25.09
596-21marS	17.80	19.10	21.20	23.42	26.02	28.33	30.71	33.69	25.03
596-21marW	17.79	19.15	20.98	23.25	25.92	28.66	31.30	33.98	25.13
UPA1-21marN	17.89	18.80	20.45	22.62	25.16	27.78	30.41	33.22	24.54
UPA1-21marE	17.90	19.03	20.82	22.83	25.26	27.59	29.95	32.75	24.51
UPA1-21marS	17.89	18.68	20.20	22.26	24.73	27.32	29.94	32.78	24.22
UPA1-21marW	17.89	18.67	20.27	22.28	24.81	27.34	29.94	32.97	24.27
UPA-fin-21marN	17.95	18.23	19.35	21.34	24.00	26.95	29.92	32.70	23.80
UPA-fin-21marE	17.94	19.44	21.25	23.13	25.29	27.45	29.76	32.73	24.62
UPA-fin-21marS	17.95	18.74	20.14	22.15	24.66	27.34	29.98	32.45	24.18
UPA-fin-21marW	17.97	19.46	20.98	22.71	24.74	26.82	29.11	32.13	24.24

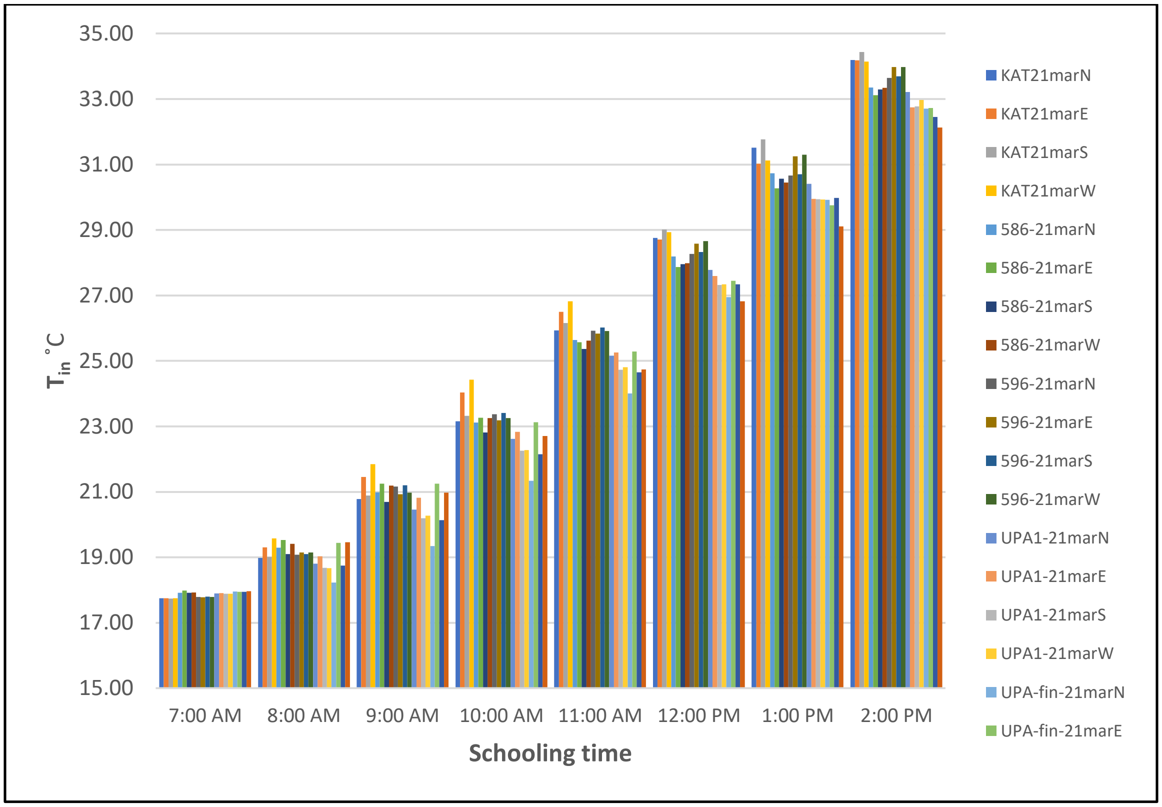


Figure 5. 24: The T_{in} for all the schools in the four main orientations on 21st of March.

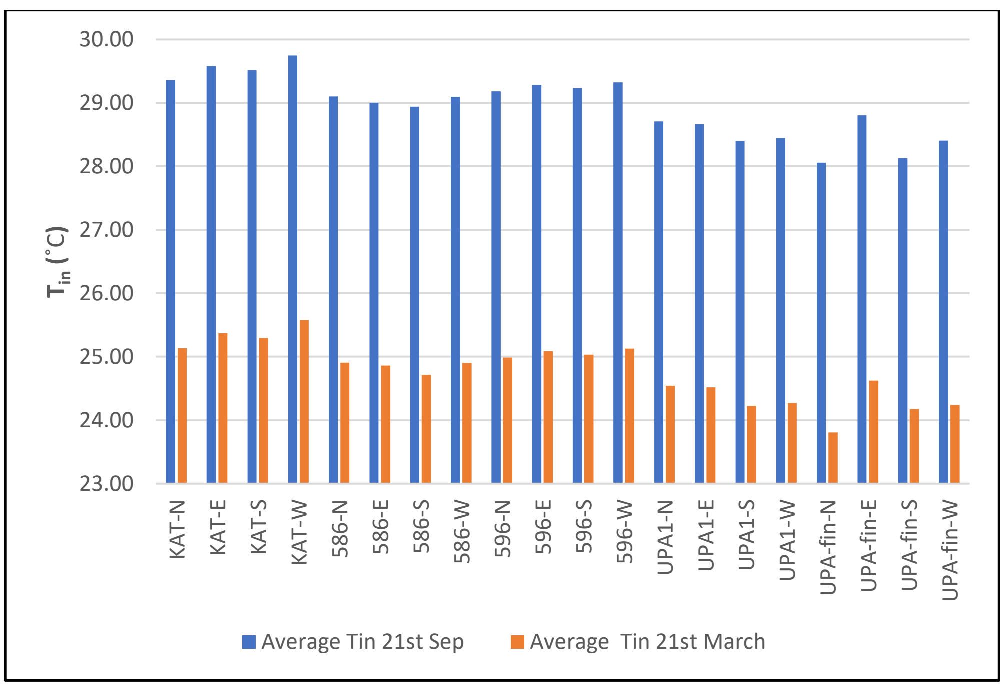


Figure 5. 25: The Average T_{in} for all the schools in the four main orientations.

5.5.1 Orientation and school type

The orientation effect on the Schools T_{in} vary according to the school type and its courtyards forms and arrangements (table 5.25), as per the following:

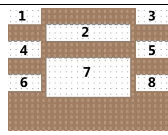
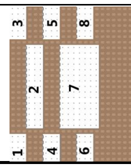
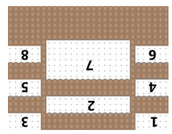
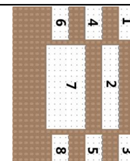
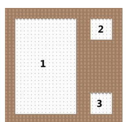
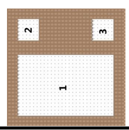
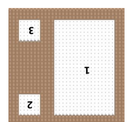
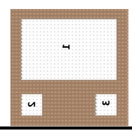
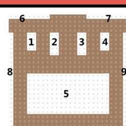
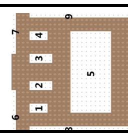
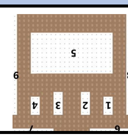
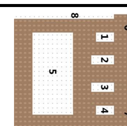
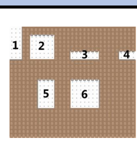
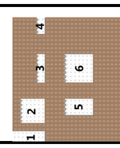
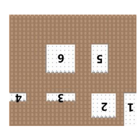
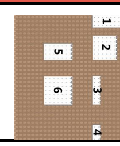
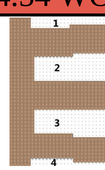
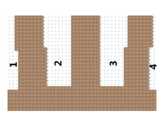
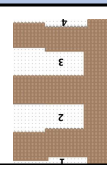
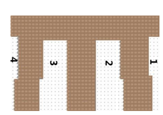
- Schools 586 and 596 have the least difference in the average T_{in} according to the orientation, which was 0.16˚C and 0.15˚C on 21st of September and 0.20˚C and 0.14˚C on 21st of March successively, and that was because they have bilateral symmetrical plans with the main large dominant closed courtyards with areas of 4,779m^2 for school 586 and 1,458m^2 for school 596. The best orientation for 586 was toward the south with a temperature of 28.94˚C, while the best orientation for 596 was toward the north with average T_{in} of 29.18˚C.
- Next in the difference of the average T_{in} was in the case of UPA1 school. This school has an asymmetrical plan with six small courtyards where the biggest one had an area of 441m^2 and the smallest one an area of 72m^2. The difference in T_{in} in relation to orientation was around 0.32˚C on 21st of September and 0.31˚C on 21st of March. The fixed height of two floors in this case has more effect on the courtyards, which are small in area compared to the previous cases. The best orientation for school UPA1 was toward the south with average T_{in} around 28.40˚C on 21st of September and 24.22˚C on 21st of March.
- KAT school follows in the difference in the average T_{in}. It has eight courtyards of different types, including closed and semi-opened. The area of the largest courtyard is about 954 m^2. The best orientation for school KAT is toward the north with T_{in} of 29.36˚C which was -0.39˚C less than the worst orientation to the west with T_{in} of 29.75˚C. The difference in KAT school was higher than the schools 596, 586 and UPA1, as KAT school has bilateral symmetry, like schools 586 and 596, but with semi-opened courtyards on two opposite sides, which surely affected the thermal performance of the building.
- The highest difference for the indoor air temperature according to orientation was found in the case of UPA-fin, as the difference was about 0.75˚C on 21st of September and 0.82 on 21st of March between the best orientation to the north and the worst case was observed toward the east. The highest difference in the case of UPA-fin can be explained because even this school has a bilateral symmetry plan, but it has two dominant semi-opened courtyards each with an area of 1341m^2. In the best scenario for UPA-fin toward the north with average T_{in} 28.06˚C the courtyards were opened in the east side and closed in the

west side, which blocked the hot air temperature coming from the north west. Moreover, the south façade of the building was shorter than the west one, which means less heat gain from the sun. In addition, three walls will produce shade inside the courtyards and outside the building at noon. On the other hand, the worst case was orientated to the east, which means that the opened sides of the two semi-opened courtyards are accessible to hot air coming from the north west from the north sides. Moreover, the south façade length is double the best scenario and that means more heat gain from the sun, especially at noon. Lastly only one wall (south wall) cast shade inside the courtyards in this case, agreed with Hyde (2000) as he explained the importance of the orientation on the courtyard's performance as it defines the shaded ranges, airflow direction, and thus the ventilation system.

In conclusion and according to the previous discussions, the schools can be arranged from best to worst thermal performance as the following: UPA-fin→N, UPA1→S,586→S, 596→N and finally KAT→N. Thus, the best school type among all the other schools in all directions on both dates of simulation was UPA-fin to the north with the lowest T_{in} amount of 28.06˚C on 21st September and 23.80˚C on 21st of March. The difference between the best case UPA-fin→N was about -1.7, -1.3, -1.0,-0.7 and -0.75 on 21st of September, and -1.78, -1.33, -1.11, -0.74 and -0.82 on 21st of March than the worst scenarios for KAT, 596, 586, UPA1 and UPA-fin, respectively.

School UPA-fin to the north was observed as the best case, which agreed with Al-Hafith et al. (2017) and Edwards (2006) as they stated that in the hot areas, it is better to have a rectangular courtyard extended to the west-east direction to make the courtyard more efficient in reducing the building's temperature. Moreover, UPA-fin to the north is oriented in a way that reduced the access of the hot northwest wind, which agreed with Kochnelson (2002) as he stated that the courtyard should be designed in a way that decreases the thermal gain and encourages the breeze, and at the same time prevents the dusty hot wind. Yaşa and Ok (2014) in their study about the courtyards, argued that the courtyard should be located in the east-west direction as a start point, and then increasing the east and west walls height for better performance. Thus, the effect of the orientation will be more effective with higher walls due to the extra amount of cast shadow.

Table 5. 25: T_{in} for all the schools in all directions.

Average T_{in}	North direction	East direction	South direction	West direction	Difference between best and worst orientation ˚C
KAT					
T_{in} -21st sep	29.36 BO	29.58	29.51	29.75 WO	0.39
T_{in} -21st mar	25.13 BO	25.37	25.29	25.58	0.45
586					
T_{in} -21st sep	29.10 WO	29.00	28.94 BO	29.09	0.16
T_{in} -21st mar	24.91 WO	24.86	24.71 BO	24.90	0.20
596					
T_{in} -21st sep	29.18 BO	29.28	29.23	29.33 WO	0.15
T_{in} -21st mar	24.99 BO	25.09	25.03	25.13 WO	0.14
UPA1					
T_{in} -21st sep	28.71 WO	28.66	28.40 BO	28.44	0.31
T_{in} -21st mar	24.54 WO	24.51	24.22 BO	24.27	0.32
UPA-fin					
T_{in} -21st sep	28.06 BO	28.81 WO	28.13	28.40	0.75
T_{in} -21st mar	23.80 BO	24.62 WO	24.18	24.24	0.82

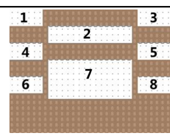
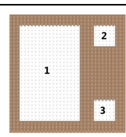
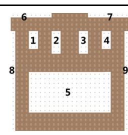
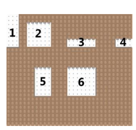
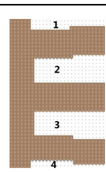
5.5.2 Orientation and CA/PA

The ratio of the courtyard area to plot area (CA/PA) of the schools were different for each type of the five schools. Comparing the ratios CA/PA for the schools and their effect on the T_{in} in relation to orientation (table 5.26) was as per the following:

- The ratios of CA/PA of the schools KAT and 586 were close as they were 0.41% and 0.49%, but school 586 presented lower T_{in} than school KAT. The school 586 to the south (lowest case) was -0.8˚C compared to school KAT to the west on 21st of September and about -0.9 on 21st of March. This can be explained due to the different types of courtyards in both cases. In school 586, the courtyards are closed and protected against the hot wind coming from the north west but in the case of the school KAT to the west there are a serious of semi-closed and semi-opened courtyards, which are opened to hot wind access, and that affected the T_{in} for the whole school building. Both schools KAT and 586 were around double the CA/PA ratio of UPA-fin school, which has CA/PA around 26%. However, school UPA-fin to the north was better in the thermal performance on the simulation dates. In the case that the CA/PA ratio is high (with a lower number of courtyards and constant height) as in the case of school 586 the SVF will be high and accordingly the thermal performance will be reduced.
- Despite the fact that the CA/PA ratio for UPA-fin and s596 are very close 26% and 29% respectively, the T_{in} of the lowest case for UPA-fin to the north was around -1.12˚C compared to the lowest case of school 596 to the north on 21st of September.
- The CA/PA ratio for the school UPA-fin was 1.4 times more than the ratio for school UPA1. Even with this difference in ratio, school UPA-fin to the north 28.06˚C (best case) was still less by -0.34˚C than school UPA1(best case) on 21st of September. Despite the fact that UPA1 in this case has less SVF for the courtyards than UPA-fin, it looks that the cooling courtyard mechanism for the small courtyards of UPA1 cannot assist that much in improving the thermal performance of its huge solid area.

In conclusion, the best CA/PA ratio of school buildings are affected by the courtyard types, areas, numbers and arrangements and it is a proportional relationship. It is not easy to define the best CA/PA ratio as long as the main plot area is not the same. In this research the best CA/PA ratio was in the middle level and about 29% (not the highest 49% and not the lowest 19%) among the other cases as in figure 5.26. However, it was clear that the amount of CA/PA ratio (with fewer courtyards and constant height) is high in the cases of schools 586, 596 and KAT, accordingly the SVF will be high and accordingly the thermal performance will be reduced. This agreed with Martinelli and Matzarakis (2017) who studied the proportions, orientation and the thermal comfort of courtyards. They concluded that the orientation of the courtyard affects the sun cast and shading duration according to the SVF, which certainly affects the thermal comfort of the courtyard. They added that the high SVF will increase the sunshine duration cast in the courtyard, and increases the outdoor air temperature, pointing to shallow ones.

Table 5. 26: Orientation and CA/PA ratio for school buildings on simulation dates.

	School type	Orientation	T_{in} 21st September	Tin 21st of March	CA/PA
1		KAT-N	29.36	25.13	41%
		KAT-E	29.58	25.37	
		KAT-S	29.51	25.29	
		KAT-W	29.75	25.58	
2		586-N	29.10	24.91	0.49%
		586-E	29.00	24.86	
		586-S	28.94	24.71	
		586-W	29.09	24.90	
3		596-N	29.18	24.99	29 %
		596-E	29.28	25.09	
		596-S	29.23	25.03	
		596-W	29.33	25.13	
4		UPAN	28.71	24.54	19%
		UPAE	28.66	24.51	
		UPAS	28.40	24.22	
		UPAW	28.44	24.27	
5		UPA-fin-N	28.06	23.80	26%
		UPA-fin-E	28.81	24.62	
		UPA-fin-S	28.13	24.18	
		UPA-fin-W	28.40	24.24	

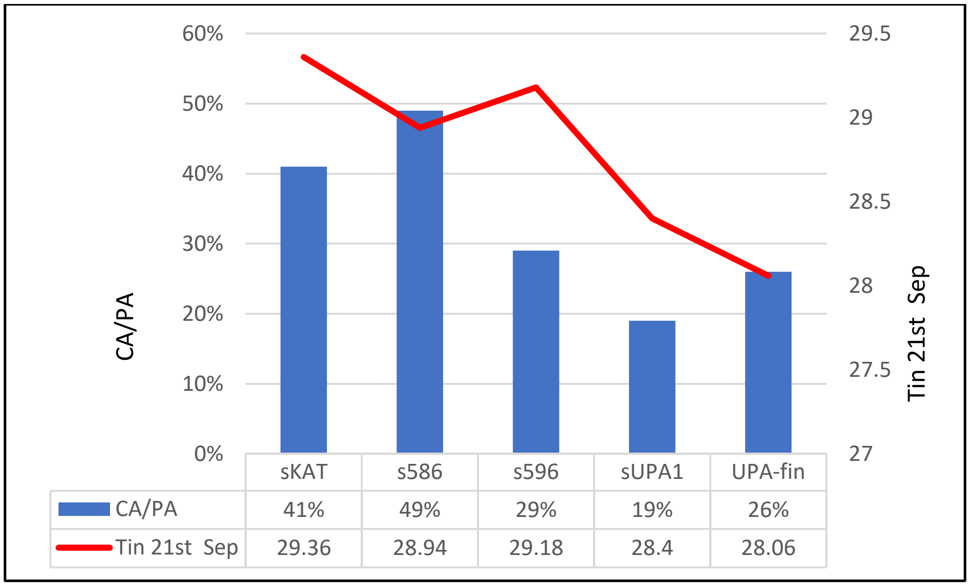


Figure 5. 26: CA/PA and T_{in} for best cases of school buildings on21st September.

5.5.3 Orientation and CA/BA

The ratio of the courtyards area to the built-up areas (CA/BA) for the five school. Comparing the ratios of the CA/BA for the schools and their effect on the T_{in} as in table 5.27, in the following some related examples related to table 5.27.

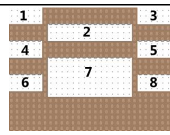
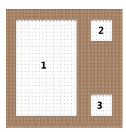
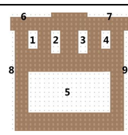
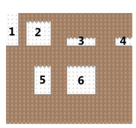
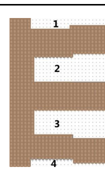
- The ratio of the courtyards area to the built-up areas of the schools UPA-fin and 596 was close as they were 40% and 48%, respectively, but the school UPA-fin offered lower average indoor air temperature than 596. UPA-fin to the north (best case) has T_{in} around 28.06˚C and that is -1.12˚C compared to school 596 to the north (best-case) which has T_{in} around 29.18˚C, this can be explained due to the different types of courtyards in both cases. The school 596 has closed courtyards unlike the school UPA-fin to the north, which has two identical semi-closed courtyards opened to the east. Schools UPA-fin and 596 were around double the CA/BA ratio of UPA1 school, which had a ratio of around 23%. Moreover, the worst-case T_{in} for school UPA1 school to the north was -0.62˚C less than the worst case for school 596 to the west even though the types of the courtyards in the two schools are similar and mostly-closed, but the less ratio was better to provide more shaded area, which will improve the T_{in} for UPA1.
- The CA/BA ratio for school 586 was around double the ratio for sUPA-fin. The indoor average temperature of the lowest case for UPA-fin to the to the north was around -1.0˚C compared

to highest case of s586 to the north. The types for the courtyards are totally different areas, types and number in both schools.

- The CA/BA ratio for school KAT was 1.7 times CA/BA ratio for school UPA-fin. Even with this difference in ratio school UPA-fin to the north (best-case) with T_{in} around 28.06˚C is -1.3˚C compared to school KAT to the north direction (best-case) which was 29.36˚C. Despite the fact that the schools UPA-fin and KAT have common types of semi-closed courtyards, the case of UPA-fin had better performance for T_{in}. That can be explained because in the case of school KAT oriented to the north, there are two sets of semi-opened courtyards, one is opened to the east direction away from the hot air (north west wind) and the other is opened from the west side and allows the flow of the north west hot air to enter the semi-opened courtyard area; accordingly, the T_{in} will be affected. On the other hand, in the case of UPA-fin to the north as the best-case the semi-opened courtyards were opened to the east side and closed from the west side, which blocked the flow of the north west hot air and improved the T_{in}.
- UPA1 has the least CA/BA ratio which was around 29% but it did not have the best thermal performance on both simulation dates in relation to any orientation. However, it was better in thermal performance than the schools with higher CA/BA ratio as in the cases of schools 586 (95%), 596 (48%) and KAT (68%).

In conclusion, the best CA/BA ratio of school buildings are affected by the courtyards types, areas, numbers and arrangements and mainly orientation, thus it is a proportional relationship. It is not easy to define the best CA/BA ratio in relation to orientation as long the main built-up area is not the same. In this research the best CA/BA ratio in the middle level as it was about 40% (not the highest 95% and not the lowest 23%) among the other cases as in figure 5.27 as an example on 21st of September, and it was for UPA-fin to the north. However, it was clear that when the amount of CA/BA ratio is high, as in the cases of schools 586 (95%), 596 (48%) and KAT (68%), the T_{in} will be high. Moreover, high CA/BA ratio with less number of courtyards and constant height will increase the SVF and decrease the thermal performance. Finally, having UPA-fin as the best CA/BA ratio of 40% in all orientations agreed with Soflaei, Shokouhian and Mofidi Shemirani (2016) as they stated that in the traditional courtyards (good thermal performance) have CA/BA ranges between 18-44%, and agreed with Tablada (2013) as he stated that it is recommended that the CA/BA ratio >25% to have better thermal performance for the building. Moreover, meets the findings of Martinelli and Matzarakis (2017) who studied the proportions, orientation and the thermal comfort of courtyards. They concluded that the orientation of the courtyard affects the sun cast and shading duration according to the SVF, which certainly affects the thermal comfort of the courtyard. They added that the high SVF will increase the sunshine duration cast in the courtyard, and increase the outdoor air temperature, pointing to shallow ones.

Table 5. 27: Orientation and CA/BA ratio for school buildings on simulation dates.

	School type	Orientation	T_{in} 21st September	Tin 21st of March	CA/BA
1		KAT-N	29.36	25.13	68%
		KAT-E	29.58	25.37	
		KAT-S	29.51	25.29	
		KAT-W	29.75	25.58	
2		586-N	29.10	24.91	95%
		586-E	29.00	24.86	
		586-S	28.94	24.71	
		586-W	29.09	24.90	
3		596-N	29.18	24.99	48 %
		596-E	29.28	25.09	
		596-S	29.23	25.03	
		596-W	29.33	25.13	
4		UPAN	28.71	24.54	23%
		UPAE	28.66	24.51	
		UPAS	28.40	24.22	
		UPAW	28.44	24.27	
5		UPA-fin-N	28.06	23.80	40%
		UPA-fin-E	28.81	24.62	
		UPA-fin-S	28.13	24.18	
		UPA-fin-W	28.40	24.24	

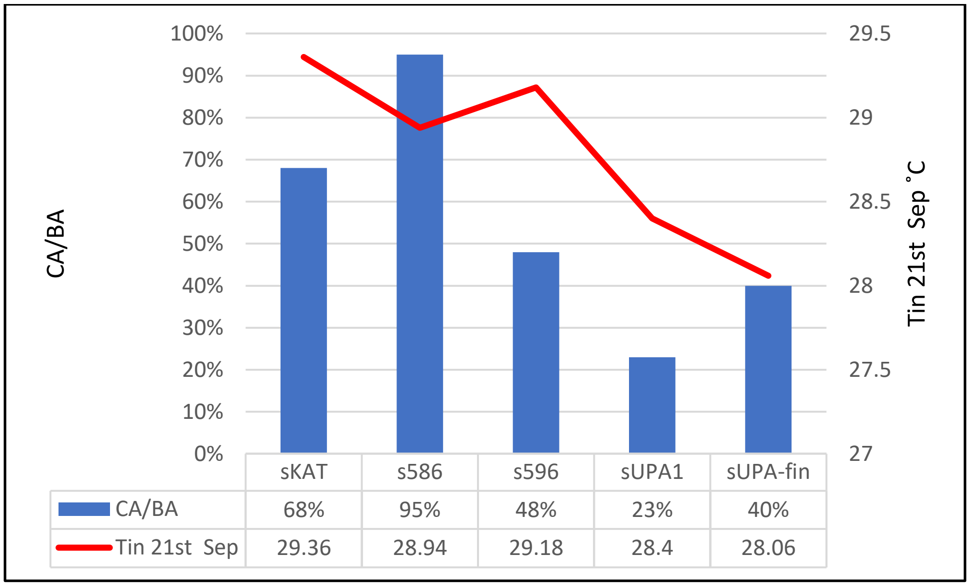


Figure 5. 27: CA/BA and T_{in} for best cases of school buildings on21st September.

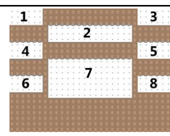
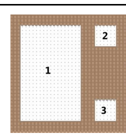
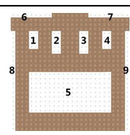
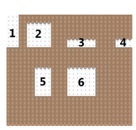
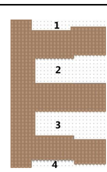
5.5.4 Orientation and courtyard ratio

According to the simulation results, it was clear that the types and number of courtyards differ in each type of the school buildings. Moreover, the ratios width to length (W/L) of the courtyards controlled the orientation effects. Table 5.28 illustrates the different W/L ratios for the dominant courtyards in each school building. Despite the fact that the W/L ratio of the main courtyards in schools KAT and 596 was around 1:2 and they were the highest in the average T_{in}, however, the performance of the courtyards in relation to their orientation were not the same. That can be explained due to the difference within the types and the areas of the courtyards in both schools. The school 586 has a ratio 1:1.6 for the main courtyard, and it is slightly better than schools KAT and 596 in the average $T_{in.}$ The fourth school in the average T_{in} was UPA1 and this school has square and rectangular courtyards, but the dominant types are square with ratio 1:1. This school performed thermally better than school 586. The fifth school with the lowest T_{in} as the best scenario was in the case of UPA-fin school with ratio 1:2.6 for two rectangular semi-opened courtyards. Thus, the best W/L ratio vary according to area of the building and have direct effect on the thermal performance in relation to orientation, and that agreed with Manioğlu and Oral (2015) insisted on the importance of the courtyard W/L ratio on its thermal performance; they defined it as a shape factor for the courtyard. They stated that the least cooling loads for a building with a floor area of

100m^2 was with a courtyard ratio of W/L = 0.2, on the other hand the least cooling loads for a building with a floor area of 200m^2 was with a courtyard ratio of W/L = 1.2, thus different areas need different W/L ratios (shape factor).

In conclusion, the school UPA-fin illustrates the best performance with an orientation to the north and with a courtyard ratio 1:2.6, as it was rectangular extended along a west-east direction and that creates more shade inside it.

Table 5. 28: Orientation and W/L ratios for school buildings on the simulation dates.

	School type	Orientation	T_{in} 21st September	Tin 21st of March	W/L ratio
1		KAT-N	29.36	25.13	Court 7 1:2
		KAT-E	29.58	25.37	
		KAT-S	29.51	25.29	
		KAT-W	29.75	25.58	
2		586-N	29.10	24.91	Court 1 1:1.6
		586-E	29.00	24.86	
		586-S	28.94	24.71	
		586-W	29.09	24.90	
3		596-N	29.18	24.99	Court 5 1:2
		596-E	29.28	25.09	
		596-S	29.23	25.03	
		596-W	29.33	25.13	
4		UPAN	28.71	24.54	Courts 6&2 1:1
		UPAE	28.66	24.51	
		UPAS	28.40	24.22	
		UPAW	28.44	24.27	
5		UPA-fin-N	28.06	23.80	Courts 2&3 1:2.6
		UPA-fin-E	28.81	24.62	
		UPA-fin-S	28.13	24.18	
		UPA-fin-W	28.40	24.24	

5.5.5 Orientation and Courtyard type

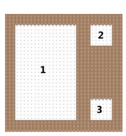
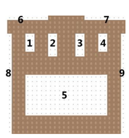
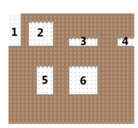
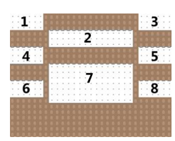
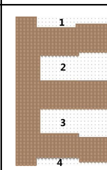
The courtyards in the schools are arranged into three groups as in table 5.29:

1- Closed courtyards (square and rectangular), like in the case of the schools 596 and 586. The performance of the school 586 was slightly better than 596 as it produced less T_{in}.

2- Mixed types of courtyards (closed and semi-opened) as in the case of the schools KAT and UPA1. The performance of the courtyards in the two schools was not the same as the school best case for UPA1 was -1.0˚C in T_{in} compared to the best case for school KAT on both simulation dates, because of the small courtyards' areas that produce more shade in relation to the constant height.

3- Semi-opened courtyards as in the case of UPA-fin with the best scenario and the least average T_{in} toward the north. This can be explained as this type of courtyard in the best scenario was oriented to the north, and thus it was closed from the west to block the hot air coming from the north west. Moreover, this courtyard has a design and ratio of 1:2.5 that produces more shade on the inner spaces of the courtyard, which reduced the T_{in} of the school building. As Feroz (2015) stated that in hot areas like Dubai the wind cannot support the cooling effect.

Table 5. 29: Types of the courtyards in the school buildings

Closed courtyards		Mixed types of courtyard (closed and semi closed)		Semi closed courtyards
				

5.6 Results of Stage one

The schools buildings orientation and T_{in} were investigated in this stage in relation to the courtyards' types, CA/PA ratios, CA/BA ratios and W/L were investigated to highlight the best case with best parameters beside highlighting the parameters and alternatives with the potential to be improved to produce an optimal school building. Results of this chapter have revealed the following:

1- The simulation of the school was conducted on 21st of September and 21st of March with the hot climate context of the UAE. The amount of solar radiation that hits the ground is high, especially in September, and that affects the performance of the courtyard strongly.

2- Changing the orientation of the school buildings in the four main directions affected their T_{in} according to change in the performance of the courtyards.

3- The best orientation for each school building was the same on the two dates of simulation on 21st of September and 21st March, despite the fact that the thermal performance for some schools are better than the others in relation to orientation. Zhang et al. (2017) investigated the thermal performance of school buildings as they found that when investigating different designs for schools in different orientations the results will show some buildings better than the others according to their orientation in relation to their design.

4- The variation in the T_{in} according to orientation was not very high as the areas of the school buildings are very huge in relation to their constant height (two stories with 8m height), thus in the cases of large area courtyards, and in relation to the constant height, the SVF was high, which surely reduced the shaded areas inside the courtyard despite the direction of the orientation, as in the case of school 586. On the other hand, school UPA1 have smaller areas for the courtyards in relation to the courtyards in the other types, thus the SVF for the courtyards of UPA1 was low but because the volume and area of the masses of the school are huge, the mechanism and the stack effect for those small courtyards could not improve the thermal performance for the total building in general. This is in agreement with Edwards (2006) who stated that the reduction in SVF increases the efficiency of the courtyard. They added that the courtyard in a building creates private solid and void spaces with different temperatures (thus difference in air density) according to shade and exposition to the sun, and that creates two types of air circulation: 1- The first air circulation between the inner courtyard space and the exterior space, both at day time and nighttime, according to winter and summer conditions; 2- The second air circulation between the inner courtyard space and inner spaces of the building. Accordingly, the courtyard architecture design and define the air circulation that can decrease the surrounding temperature beside decreasing the surface temperatures of the building and reduces the heat transfer by conduction to the indoor spaces.

5- The results of the simulation were capable of defining the best orientation for each school separately, for example on 21st of September, the best orientation for KAT school was to the north with around -0.39˚C than its worst case. The best orientation for 586 school was to the south with around -0.2˚C than its worst case. Moreover, the best orientation for 596 school was to the north with around -0.15˚C than its worst case, and the best orientation for UPA1 school was to the south with around -0.31˚C than its worst case. Finally, the best orientation for UPA-fin school was to the north with around -0.75˚C than its worst case. The variation in each case in relation to orientation depends on the school design. These results somehow meet the findings of Ghaffarianhoseini, Berardi and Ghaffarianhoseini (2015) who simulated a building with a courtyard in different orientations in the hot humid climate of Malaysia. These researchers concluded in their investigation that -0.5˚C was recorded for the north and east facing courtyards, thus the results were minor as the building heights for this building was low (one floor).

6- It was not easy to define fixed references for CA/PA ratios, CA/BA ratios and W/L for the best school buildings according to orientation, as the schools that have the same types of CA/PA ratios, CA/BA ratios and W/L ratios do not necessarily have the same performance because the arrangement of courtyards, areas of the buildings and the general designs are different.

7- Moreover, the school UPA-fin school oriented to the north recorded the best orientation for the courtyard with the lowest average T_{in} around 28.06˚C on 21st of September and 23.80˚C on 21st of March during the schooling time from 7am till 2pm.

8- The school UPA-fin oriented to the north was the best scenario and school KAT oriented to the west was the worst scenario. Accordingly, the school UPA-fin recorded -1.7˚C and -1.8˚C compared to school KAT on 21st of September and 21st of March, respectively.

9- School UPA-fin to the north as the best case agreed with Al-Hafith et al. (2017) and Edwards (2006) as they stated that in the hot areas, it is better to have a rectangular courtyard extended to the west east direction to make the courtyard more efficient in reducing the building temperature. Moreover, UPA-fin to the north is oriented in a way that reduces the access of the hot northwest wind, which agreed with Kochnelson (2002) as he stated that the courtyard should be designed in a way that decreases the thermal gain and encourages the breeze, and at the same time prevents the dusty hot wind. Yaşa and Ok (2014) in their study about courtyards, advised locating the courtyard in the east-west direction as a start point, and then increasing the east and west walls heights for better performance. Thus, the effect of the orientation will be more effective with higher walls due to the extra amount of cast shadow.

Finally, orientation effect varies according to the geometry of the building, despite the fact that sometimes the difference is clear in T_{in} while at other times it is minor. Johansson (2006) stated that the difference in temperature in relation to orientation in his study was not significant enough to be considered, while Feroz (2015) found that despite the fact the difference in temperature in relation to orientation was around 0.5K still the outdoor air temperature distribution varied in respect to changes in the orientation of the building.

Recommendation for stage two phases:

A number of strategies were suggested to improve the best case UPA-fin to the north as per the following:

1- The best case from stage one, which was school UPA-fin to the north, has W/L ratio of 1:2.6. This W/L ratio was referred to as a shape factor by Manioğlu and Oral (2015). The shape factor should be investigated to search for any possibility to improve the thermal performance. Based on that, the shape factor should be studied in other ratios more and less than the shape factor for the base case of UPA-fin 1:2.6. The suggested new shape factor ratios for investigation in stage two are 1:2, and 1:3.

2- After defining the most suitable shape factor for UPA-fin school oriented to the north, the CA/BA ratio should be investigated. The best scenario from stage one has CA/BA ratio around 40%, thus it is recommended that the school should be investigated in other CA/BA ratios with percentages more and less than the original case. The suggested CA/BA ratios of 20%, 33% and 60% should be used to find the best CA/BA ratio for this semi-opened courtyard. The suggested ratios to investigate the findings for Soflaei, Shokouhian and Mofidi Shemirani (2016) are found in the traditional courtyards (good thermal performance) have CA/BA ranges between 18-44% and Tablada (2013) as he stated that it is recommended that the CA/BA ratio >25% to achieve better thermal performance for the building.

3- In this step it is important to find ways to improve the thermal performance for the school building based on Yaşa and Ok (2014) who stated that it is expected that the energy consumption (for a building with a courtyard) will increase corresponding to the increase in the length of the courtyard; they added that in hot areas it is expected that the shaded area in the courtyard will increase when the shape of the courtyard becomes near to square, which will decrease the amount of energy required for cooling in summer. Based on that, the design of the rectangular semi-opened courtyards for the best case will be transformed to semi-opened square and it will be evaluated according to an aspect ratio and T_{in}.

4- Further improvements will be investigated based on Tablada (2013) as he recommended that buildings with wide courtyards that have a width more than 7m and have direct access to the street (as in the case of UPA-fin), to have maximum height up to 14m (3-4 floors) to achieve better thermal conditions in the courtyard and in the interior spaces. Accordingly, the UPA-fin will be investigated with a new height of 12m (three floors) by adding another floor with different designs, as all the previous investigations in this chapter involved schools with a fixed height which was two floors only with 8m height.

5- Further improvements will be implemented on the school buildings based on Kolozali and Kolozali (2016) who stated that the greenery is important in the courtyards as it casts a shadow for better thermal performance, defines the pathways, prevents the dusty air, protects the soil structure and also offers beauty for relaxation. They added that the greenery with water in the past was a special creator for morning coolness. Soflaei, Shokouhian and Mofidi Shemirani (2016) insisted on the importance of vegetation in the courtyard for its positive effect on the building's microclimate in addition to its beautiful appearance and shade. Based on that, three types of greenery in the courtyards will be investigated as per the following: trees only, grass only and finally a combination of trees and grass. A similar investigation process was used by Ghaffarianhoseini, Berardi and Ghaffarianhoseini (2015) in their research to evaluate the effect of greenery on the thermal performance of courtyards. Lee, Mayer and Chen (2016) used three scenarios of vegetation to examine the effect of the greenery (grass and trees) on the heat stress and thermal comfort. They used three scenarios beside the basic original condition for the site.

Chapter 6: Courtyard Design and Energy Consumption

6.1 Introduction:

This research adopted the courtyard as a passive design solution for school buildings in hot climates like the UAE. It includes three stages of investigation. The results of stage one (which investigated the best design school building with the best orientation) revealed that school UPA-fin to the north has the best performance, based on that this school was nominated for more improvement strategies in the courtyards' design to reach the optimal school design with best thermal performance. School UPA-fin courtyards have characteristics as the following: shape factor was W/L 1:2.6 for the two courtyards, CA/BA ratio around 40%, rectangular shape courtyards, two floors in height and finally a lack of vegetation. Accordingly, stage two will include two parts. The first part is designed to investigate a list of strategies - for the courtyards - through five phases as the following:

1- UPA-fin school oriented to the north has shape factor W/L 1:2.6, and it is recommended to investigate new shape factor ratios for it, which are 1:2 and 1:3, beside the original one 1:2.6.

2- UPA-fin school oriented to the north, as the best scenario, has CA/BA ratio 40%, and it is recommended to investigate new CA/BA ratios for it, which are 20%, 33% and 60% beside the original one at 40%.

3- UPA-fin school oriented to the north has a semi-closed rectangular outline courtyard, and it is recommended to transform the courtyard to square shape with ratio W/L 1:1.

4- UPA-fin school oriented to the north as the best scenario has two floors and a height of only 8m, thus it is recommended to investigate the thermal performance of it with three floors and a height up to 12m.

5- UPA-fin school oriented to the north has no greenery landscape, thus it is suggested to investigate the courtyard thermal performance with different scenarios that include vegetation, which are: trees only, grass only and finally a combination of trees and grass.

The second part will include an assessment for the courtyards thermal comfort (PMV) at the break time at 10am for the best cases of the previous five phases in part one.

6.2 Stage two courtyard design and thermal comfort

6.2.1 Section one: courtyard design

After choosing the best school model with best orientation that have the lowest indoor temperature, there will be further investigation for the courtyard configurations in stage two through two sections. The first section will include evaluation for different design variables to improve the thermal performance of the courtyard design through five phases, and in the second section there will be an evaluation for the thermal comfort for the best models of as evidenced via results in section one.

This section will include investigation for the effect of courtyard design on the school building's thermal performance according to the following phases: 1- Courtyard ratios width/Length. Manioğlu and Oral (2015) insisted on the importance of the courtyard W/L ratio on its thermal performance, they defined it as shape factor for the courtyard. 2- Courtyard area to be built up area ratio CA/BA. Soflaei, Shokouhian and Mofidi Shemirani, (2016) stated that in the traditional courtyards (good thermal performance) have CA/BA ranges between 18% -44%. 3- Courtyard outline shape square and rectangular. Tabesh and Sertyesilisik (2016) stated that the geometry of the courtyard is a critical issue as the courtyard performance mainly depend on the amount of solar radiation access to it. They argued that because of the sun's location and radiation, a square courtyard is ideal in relations of energy savings. 4- Courtyard walls height Antonio and Carvalho (2015) stated that the higher the walls around the courtyard the cooler the temperature inside the courtyard, thus the reason for adjacent spaces. 5- Courtyard greenery and landscape. Safarzadeh and Bahadori (2005) mentioned that the presence of plants in the courtyard, such as trees and shrubs can considerably improve the thermal performance of the courtyard, mainly because of the shade that they produce. Taleghani, Tenpierik and van den Dobbelsteen (2014) pointed to the importance of greenery in improving of the courtyard role with respect to improving it's thermal precedence. The scale for calculating the improvement on the thermal performance of the school building is the indoor temperature T_{in},, which will be calculated by the ENVI-met software through buildings dynamics as explained before.

6.2.1.1 Phase 1: Courtyard shape factor

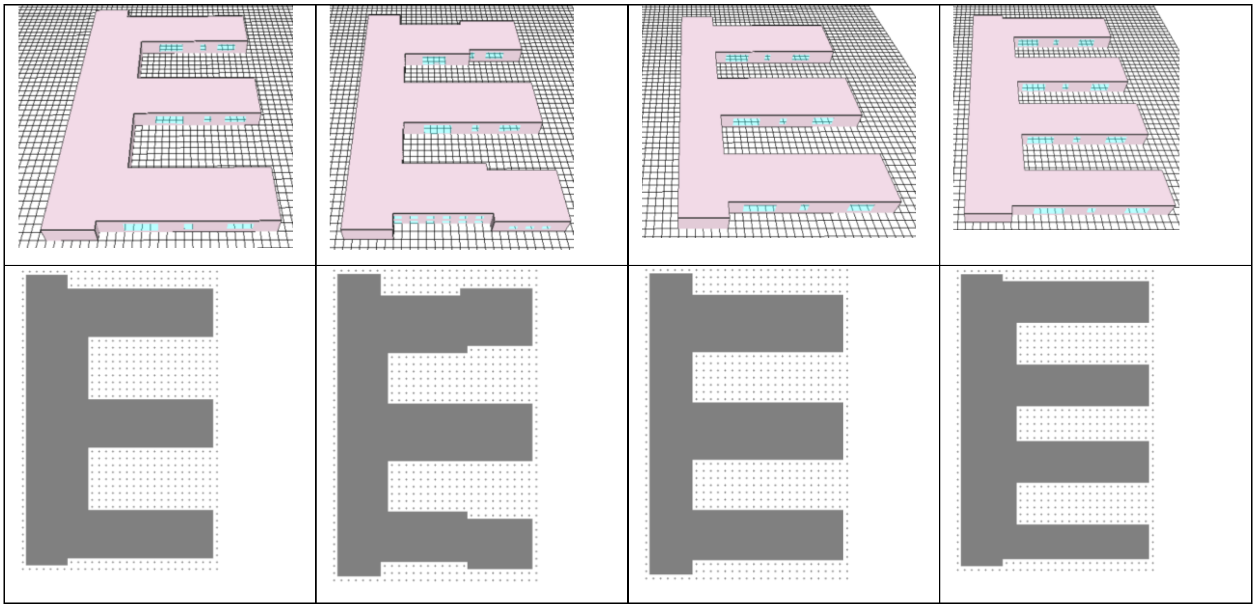
The school UPA-fin oriented to the north was the best template of the case studies which were investigated in chapter five. This school has shape factor W/L is 1: 2.6 and it will be investigated in three other W/L factors bigger and smaller than the original one, which are 1:2 and 1:3 with two courtyards and 1:3 with three courtyards to choose the best W/L factor for the school building with the best number of courtyards, (table 6.1). The simulation was conducted on two dates 21st of September and 21st of March with the same constant parameter and design conditions of stage five. One more constant parameter will be fixed, which is CA/BA will be 40%. Table (6.2) shows the four schools of UPA-fin with the suggested W/L factors to be investigated.

Table 6. 1: The investigation area of shape factor in stage two; the highlighted cells indicate the phase under investigation.

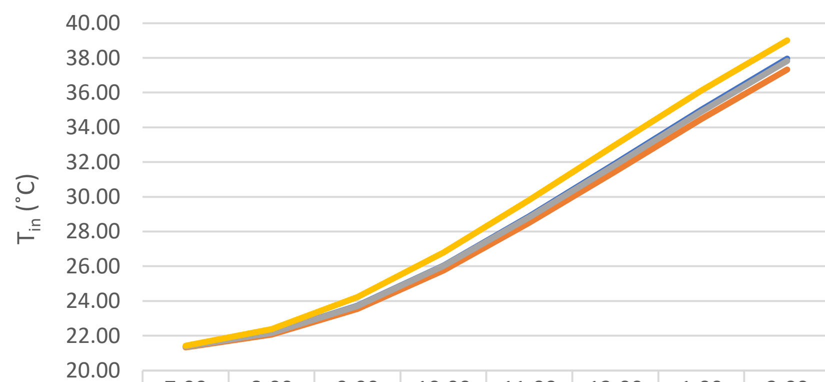
Research stages.	Investigation field	Investigated parameter	Investigating details	Software
Stage one	orientation	Orientation	North,East,West,South	ENVI-met
Stage two	design	Shape factor: W/L ratio	1:2, 1:2.6, 1:3 with 2 courtyards, 1:3 with3courryards	ENVI-met
		CA/BA	1:20, 1:33, 1:40,1:60	ENVI-met
		Courtyard outline	Rectangular, square	ENVI-met
		Courtyard walls height	2 F, 3 F/ All mass, 3 F/ East Side	ENVI-met
		Courtyard with vegetation	Trees, grass, combination of both	ENVI-met
	thermal comfort	PMV	PMV at 10 AM	ENVI-met
Stage three	Courtyard and building energy consumption	Energy consumption	Energy consumption with new microclimates from ENVI-met (specific dates)	IESve
			Energy consumption based on the built-in climate data in IESve (academic year)	IESve

Table 6. 2: shows the four schools of UPA-fin with the suggested shape factors.

CA/BA 40%, 2 courts W/L = 1:2	CA/BA 40%, 2 courts W/L = 1:2.6	CA/BA 40%, 2 courts W/L = 1:3	CA/BA 40%, 3 courts W/L =1:3

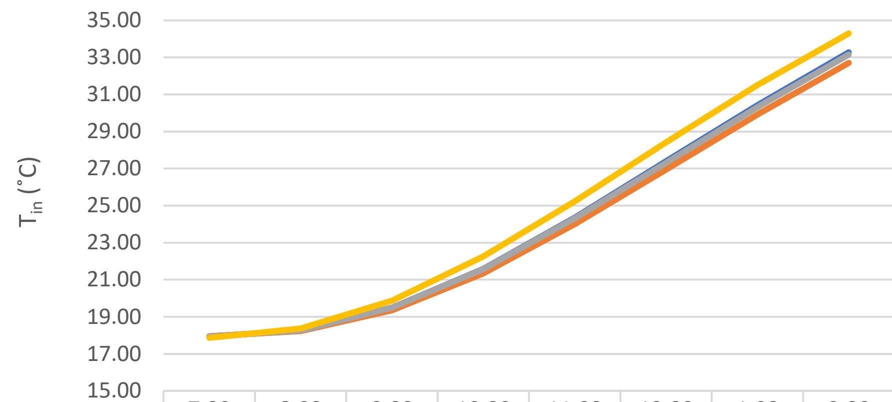


The school UPA-fin was simulated according to four shape factors ratios, which are W/L 1:2, 1:2.6, 1:3 with 2 courtyards, 1:3 with 3 courtyards with the same original CA/BA ratio 40%. The effect of the shape factor on the school building thermal performance appears on the T_{in} within the schooling time. It was clear in figure (6.1) that the different shape factors for the courtyard illustrate different T_{in} on the 21st of September, especially from 11AM-2PM more than morning time. The simulation on the 21st of March shows difference as well as in figure (6.2).



	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM
2 courts, W/L 1:2	21.37	22.17	23.73	26.04	28.88	31.92	35.00	37.95
2 courts, W/L 1:2.6	21.33	22.07	23.54	25.76	28.50	31.46	34.48	37.33
2 courts, W/L 1:3	21.37	22.17	23.72	26.01	28.83	31.84	34.89	37.83
3 courts, W/L 1:3	21.42	22.39	24.22	26.79	29.82	32.99	36.12	39.01
Max Tin (C˚) difference	0.09	0.32	0.68	1.03	1.32	1.53	1.64	1.67

Figure 6. 1: Hourly T_{in} for School UPA-fin on 21st September within schooling time with different shape factors.

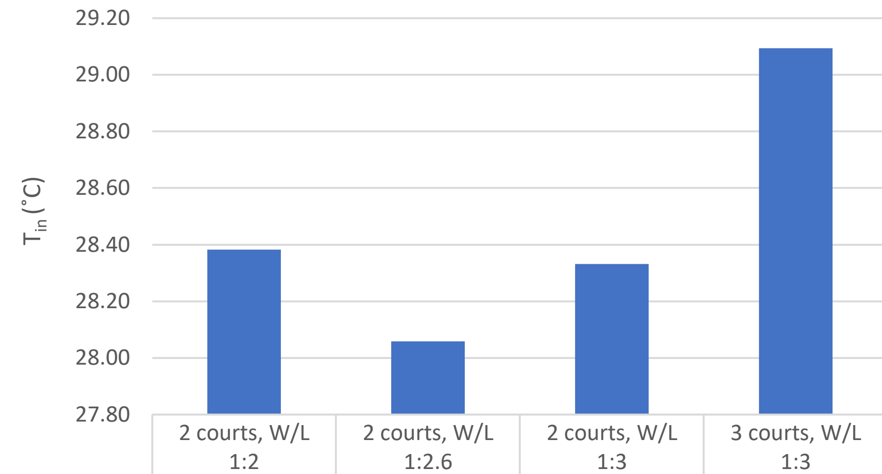


	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM
2 courts, W/L = 1:2	17.93	18.27	19.49	21.59	24.35	27.39	30.43	33.28
2 courts, W/L 1:2.6	17.95	18.23	19.35	21.34	24.00	26.95	29.92	32.70
2 courts, W/L 1:3	17.93	18.27	19.49	21.57	24.31	27.31	30.32	33.15
3 courts, W/L 1:3	17.86	18.37	19.87	22.25	25.24	28.42	31.52	34.30
Max Tin (C˚) difference	0.07	0.15	0.53	0.91	1.24	1.48	1.60	1.59

Figure 6. 2: Hourly T_{in} for School UPA-fin on 21st March within schooling time with different shape factors.

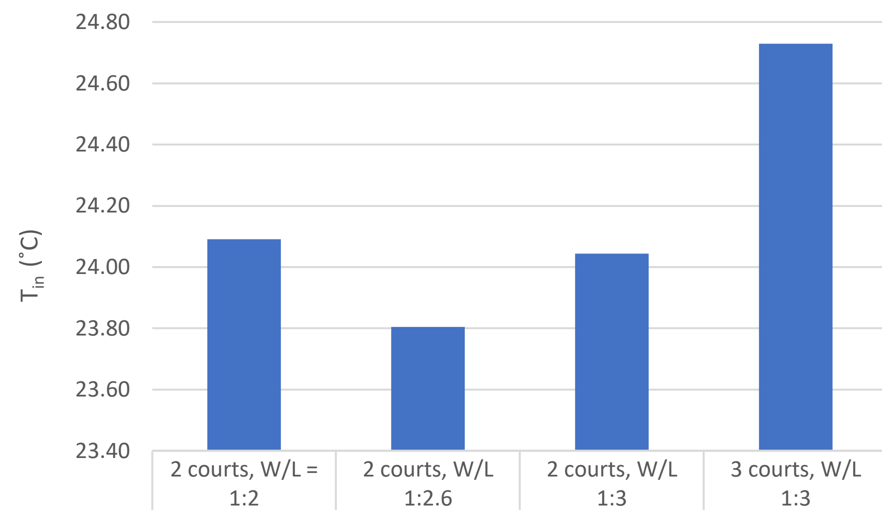
Figure (6.3) demonstrates the average T_{in} with different shape factor ratios for School UPA-fin on 21st September within the schooling time. The investigation of the shape factor indicated that the school UPA-fin with W/L factor 1:2.6 had the best thermal performance among the others with least average T_{in} with amount around 28.06 ˚C, and that is 1.03 ˚C less than the poorest case shape factor ratio W/L 1:3 with three courtyards. This can be explained due to the change in the amount of received solar radiation on the exterior walls, as the poorest case with factor ratio W/L 1:3 with three courtyards has more exterior walls exposed to exterior climate with thinner masses, unlike the best case with W/L 1:2.6 which has 30% less in the exposed walls with thicker masses. El-Deeb, Sherif and El-Zafarany (2014) stated that the more exposed surfaces of the building in relation to the air-conditioned spaces volume increases the inner temperature, thus the thicker masses of the buildings around the courtyard have better performance than the thinner ones.

Similarly, on 21st of March, the simulation results indicated that the school UPA-fin with shape factor ratio W/L 1:2.6 had the best performance among the others with average T_{in} 23.80 as in figure (6.4). Moreover, the school UPA-fin with W/L factor 1:2.6 is 0.93 ˚C less than the poorest case shape factor ratio W/L 1:3 with three courtyards.



	2 courts, W/L 1:2	2 courts, W/L 1:2.6	2 courts, W/L 1:3	3 courts, W/L 1:3
Average Tin	28.38	28.06	28.33	29.09

Figure 6. 3: Average T_{in} for School UPA-fin on 21st September within schooling time with different shape factors.



	2 courts, W/L = 1:2	2 courts, W/L 1:2.6	2 courts, W/L 1:3	3 courts, W/L 1:3
Average Tin	24.09	23.80	24.04	24.73

Figure 6. 4: Average T_{in} for School UPA-fin on 21st March within schooling time with different shape factors.

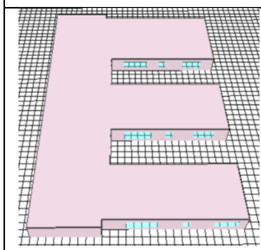
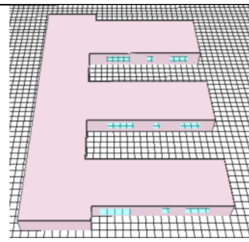
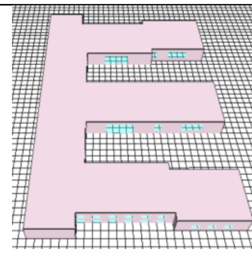
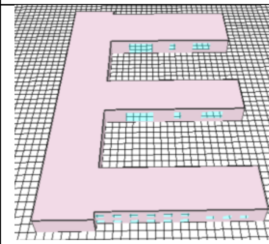
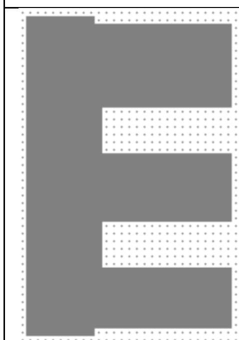
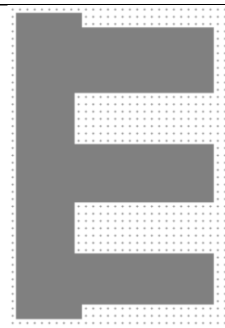
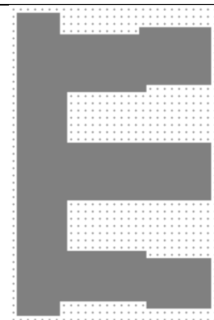
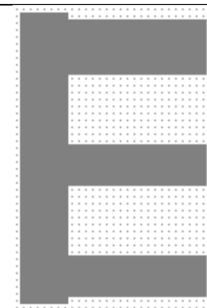
6.2.1.2 Phase 2: Courtyard area to build up area ratio (CA/BA)

Based on the previous phase, there was less potential in improving the performance of the courtyards for the school UPA-fin with the same CA/BA 40%, thus Phase two was concerned about investigating CA/BA for UPA-fin oriented to the north to improve the thermal performance of the building. UPA-fin has CA/BA ratio around 40% and it will be investigated in three other CA/BA ratios bigger and smaller than the original ratio (table 6.3) CA/BA of 20%, 33% and 60%. The simulation was conducted on two dates 21st of September and 21st of March with the same constant parameter and design conditions of stage five. Table (6.4) shows the four schools of UPA-fin with the suggested CA/BA ratios to be investigated.

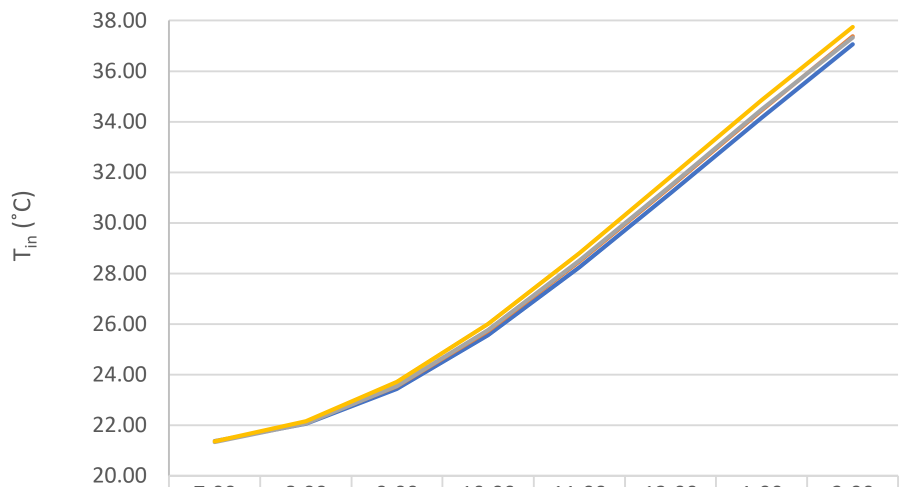
Table 6. 3: The investigation area of CA/BA ratio in stage two

Research stages.	Investigation field	Investigated parameter	Investigating details	Software
Stage one	orientation	Orientation	North,East,West,South	ENVI-met
Stage two	design	Shape factor: W/L ratio	1:2, 1:2.6, 1:3 with 2 courtyards, 1:3 with3courryards	ENVI-met
		CA/BA	1:20, 1:33, 1:40,1:60	ENVI-met
		Courtyard outline and aspect ratio	Rectangular, square	ENVI-met
		Courtyard walls height	2 F, 3 F/ All mass, 3 F/ East Side	ENVI-met
		Courtyard with vegetation	Trees, grass, combination of both	ENVI-met
	thermal comfort	PMV	PMV at 10 AM	ENVI-met
Stage three	Courtyard and building energy consumption	Energy consumption	Energy consumption with new microclimates from ENVI-met (specific dates)	IESve
			Energy consumption based on the built-in climate data in IESve (academic year)	IESve

Table 6. 4: shows the four schools of UPA-fin with the suggested CA/BA ratios.

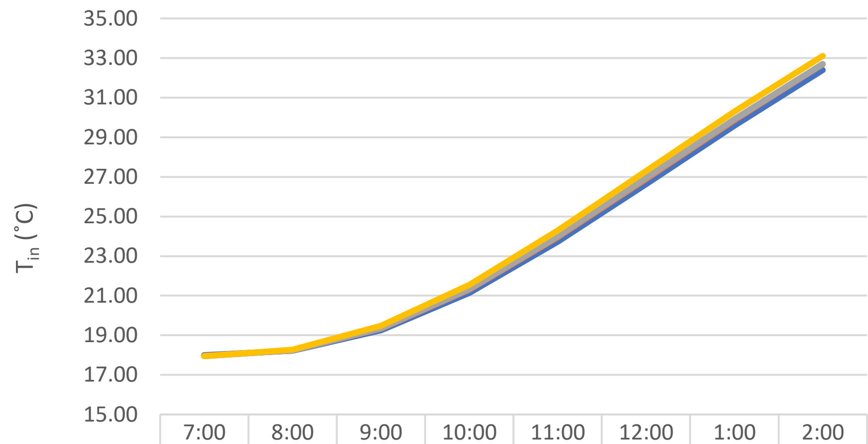
CA/BA 20%	CA/BA 33%	CA/BA 40%	CA/BA 60%
			
			

The school UPA-fin was simulated according to different CA/BA ratios, which are 20%,33%, 60% beside the original one from the previous phase 40%. The effect of the CA/BA ratio on the school building thermal performance appears on the T_{in} within the schooling time. It was clear in figure (6.5) that the different CA/BA ratios for the courtyards illustrate different T_{in} on the 21st of September, especially from 11AM-2PM which is more than in the morning time. The simulation on the 21st of March shows difference as well as in figure (6.6).



	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM
CA/BA 20%	21.37	22.05	23.43	25.56	28.24	31.16	34.16	37.07
CA/BA 33%	21.36	22.09	23.54	25.73	28.47	31.42	34.45	37.37
CA/BA 40%	21.33	22.07	23.54	25.76	28.50	31.46	34.48	37.33
CA/BA 60%	21.36	22.16	23.71	26.00	28.81	31.81	34.85	37.75
Max Tin (C˚) difference	0.05	0.11	0.28	0.45	0.57	0.65	0.70	0.68

Figure 6. 5: Hourly T_{in} for School UPA-fin on 21st September within schooling time with different CA/BA ratios.



	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM
CA/BA 20%	18.00	18.23	19.25	21.14	23.73	26.63	29.58	32.40
CA/BA 33%	17.97	18.24	19.34	21.31	23.95	26.89	29.87	32.70
CA/BA40%	17.95	18.23	19.35	21.34	24.00	26.95	29.92	32.70
CA/BA 60%	17.94	18.27	19.48	21.56	24.29	27.29	30.30	33.11
Max Tin (C˚) difference	0.06	0.05	0.23	0.41	0.56	0.66	0.71	0.71

Figure 6. 6 : Hourly T_{in} for School UPA-fin on 21st March within schooling time with different CA/BA ratios.

Figure (6.7) demonstrates the average Tin with different CA/BA ratio for School UPA-fin on 21st September within the schooling time. The investigation of the CA/BA ratio indicated that the school UPA-fin with CA/BA ratio 20% had the best thermal performance among the others with least average T_{in} with amount around 27.88 ˚C, and that is 0.43 ˚C less than the poorest case of CA/BA ratio 60%. That can be explained due to the change in the amount of received solar radiation on the exterior walls, as the poorest case with CA/BA ratio 60% has more exterior walls exposed to exterior climate with thinner masses, unlike the best case with CA/BA ratio 20 % which has less exposed walls with thicker masses. This agrees with the findings of El-Deeb, Sherif and El-Zafarany (2014) who mentioned that inner temperature of the building increases when the exposed surfaces of the building increases in relation to the air-conditioned spaces volume. Based on that, the thicker masses of the buildings around the courtyard have better performance than the thinner ones.

Similarly, on 21st of March, the simulation results indicated that the school UPA-fin CA/BA ratio 20% had the best performance among the others with average T_{in} 23.62 ˚C and that is 0.41 ˚C less than the poorest case of CA/BA ratio 60% as in figure (6.8).

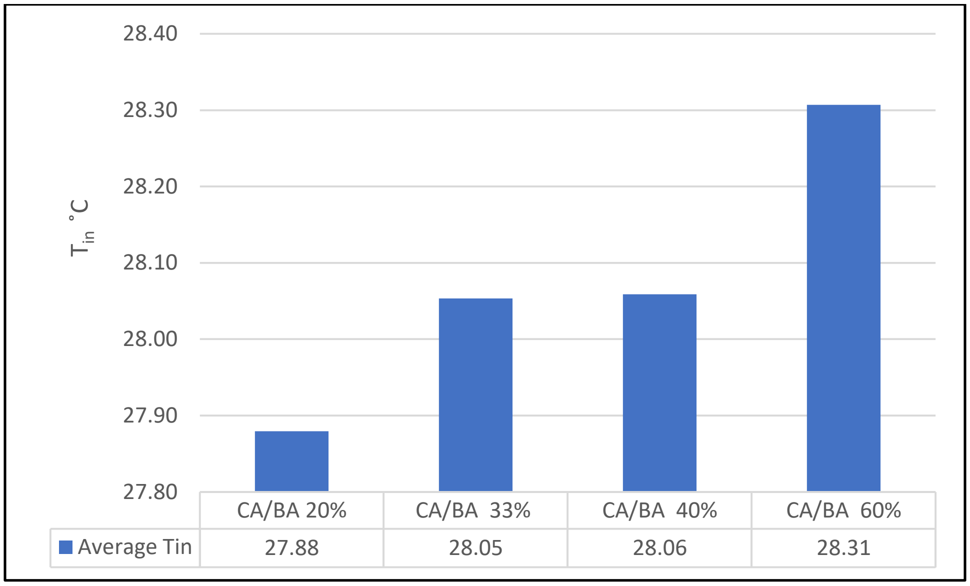


Figure 6. 7: Average T_{in} for School UPA-fin on 21st September within schooling time with different CA/BA ratios.

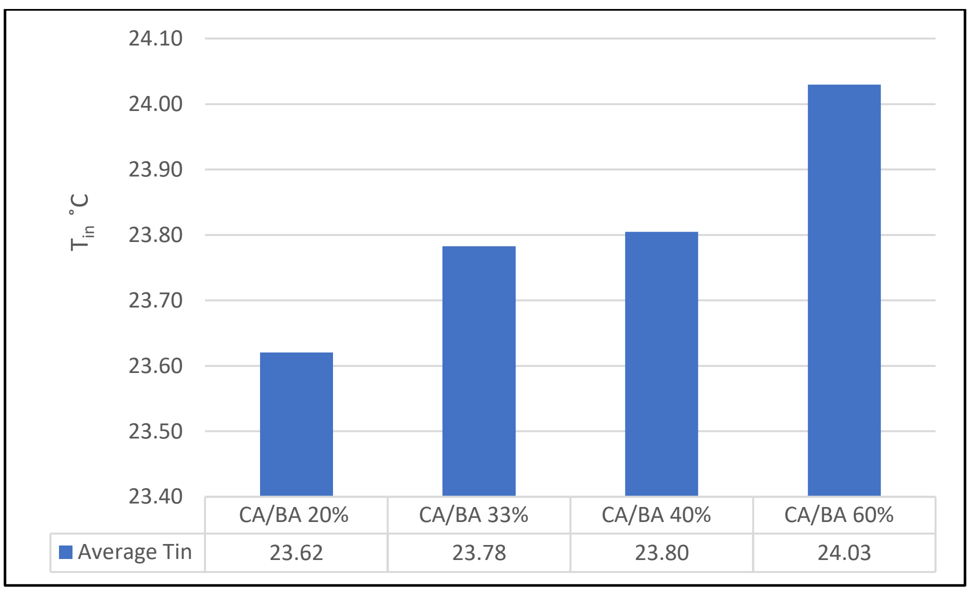


Figure 6. 8: Average T_{in} for School UPA-fin on 21st March within schooling time with different CA/BA ratios.

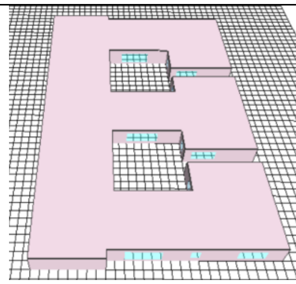
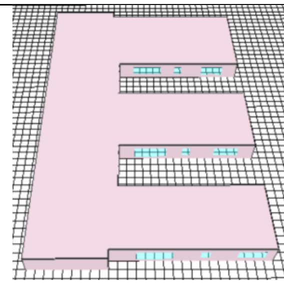
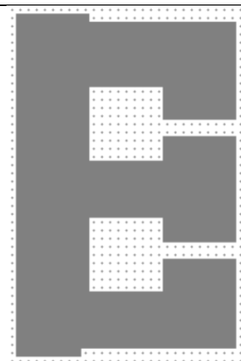
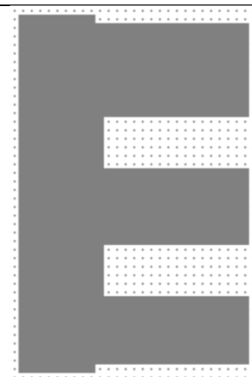
6.2.1.3 Phase 3: Courtyard outline

The best case from the previous phase was UPA-fin school oriented to the north, which has a semi closed rectangular outline courtyard, and it is recommended to transform the courtyard to square shape with ratio 1:1 (table 6.5). Based on that, the courtyard will be investigated in the new outline shape, which is a square with ratio W/L 1 to 1 to improve the thermal performance of the building. The simulation was conducted on two dates (21^{st} of September and 21^{st} of March), with the same constant parameter and design conditions of stage five and with CA/BA ratio 20%Table (6.6) shows the two schools of UPA-fin with the suggested square form to be investigated.

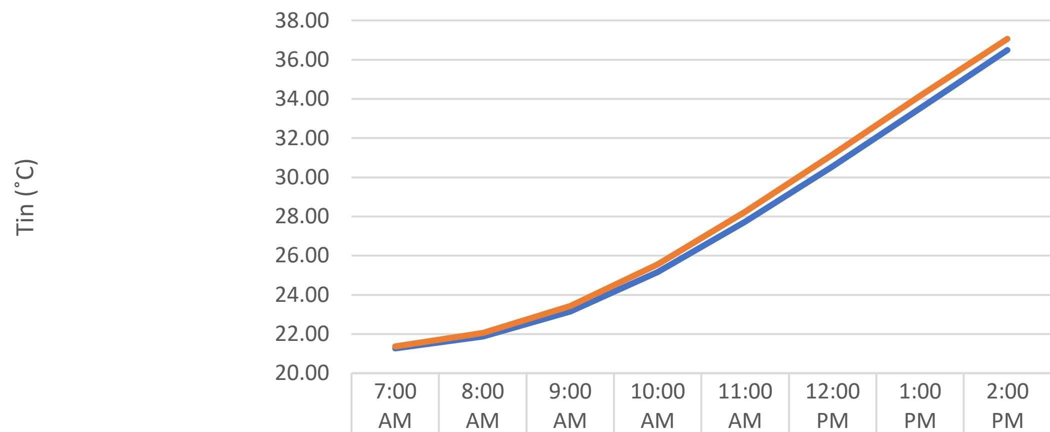
Table 6. 5: The investigation of courtyard outline.

Research stages.	Investigation field	Investigated parameter	Investigating details	Software
Stage one	orientation	Orientation	North,East,West,South	ENVI-met
Stage two	design	Shape factor: W/L ratio	1:2, 1:2.6, 1:3 with 2 courtyards, 1:3 with3courryards	ENVI-met
		CA/BA	1:20, 1:33, 1:40,1:60	ENVI-met
		Courtyard outline	Rectangular, square	ENVI-met
		Courtyard walls height	2 F, 3 F/ All mass, 3 F/ East Side	ENVI-met
		Courtyard with vegetation	Trees, grass, combination of both	ENVI-met
	thermal comfort	PMV	PMV at 10 AM	ENVI-met
Stage three	Courtyard and building energy consumption	Energy consumption	Energy consumption with new microclimates from ENVI-met (specific dates)	IESve
			Energy consumption based on the built-in climate data in IESve (academic year)	IESve

Table 6. 6: School UPA-fin with different outline shapes square and rectangular.

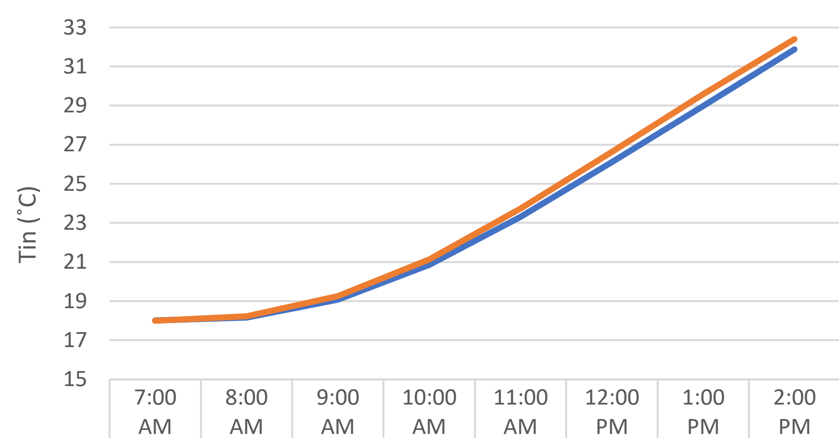
Square shape outline	Rectangular shape outline
	
	

The school UPA-fin was simulated with a new outline shape, which is square beside the original one from the previous shape which was rectangular. For both cases, the CA/BA ratio is maintained at 20%. The effect of the square shape of the courtyard on the school building thermal performance appears on the T_{in} within the schooling time. It was clear in figure (6.9) that the square shape of the courtyard illustrate different T_{in} on the 21st of September, especially from 11AM-2PM which is more than the morning time. The simulation on the 21st of March shows difference as well as in figure (6.10).



	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM
Square shape outline	21.27	21.87	23.15	25.16	27.73	30.55	33.52	36.50
Rectangular shape outline	21.37	22.05	23.43	25.56	28.24	31.16	34.16	37.07
Max Tin (C˚) difference	0.10	0.18	0.28	0.39	0.51	0.61	0.64	0.57

Figure 6. 9: Average T_{in} for School UPA-fin on 21st September within schooling time with different outline shapes (square and rectangular).



	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM
Square outline	18.01	18.15	19.08	20.85	23.31	26.1	28.99	31.88
Rectangulaer outline	18	18.23	19.25	21.14	23.73	26.63	29.58	32.4
Max Tin (C˚) difference	0.01	0.08	0.17	0.29	0.42	0.53	0.59	0.52

Figure 6. 10: Hourly T_{in} for School UPA-fin on 21st March within schooling time with different outline shapes (square and rectangular).

Figure (6.11) demonstrates that the average T_{in} with different outline shapes (square and rectangular) for School UPA-fin on 21st September within the schooling time. The investigation indicated that the school with square courtyard had better thermal performance than the rectangular one. The school with square courtyard had average T_{in} around 27.47 ˚C, and that is 0.41 ˚C less than the average T_{in} for the same school with rectangular shape. Yaşa and Ok (2014) stated that it is expected that the energy consumption for a building with a courtyard will increase in correspondence and this is determined by the length of the courtyard., They added, that in hot areas, it is expected that the shaded area in the courtyard will increase, when the shape of the courtyard becomes near to square, and that will decrease the amount of energy required for cooling in summer as the T_{in} decreases.

Similarly, on 21st of March as the simulation results indicated that the school UPA-fin square courtyard had better thermal performance than the rectangular one. Tin 23.30 ˚C and that is 0.32˚C less than the one with rectangular outline as in figure (6.12).

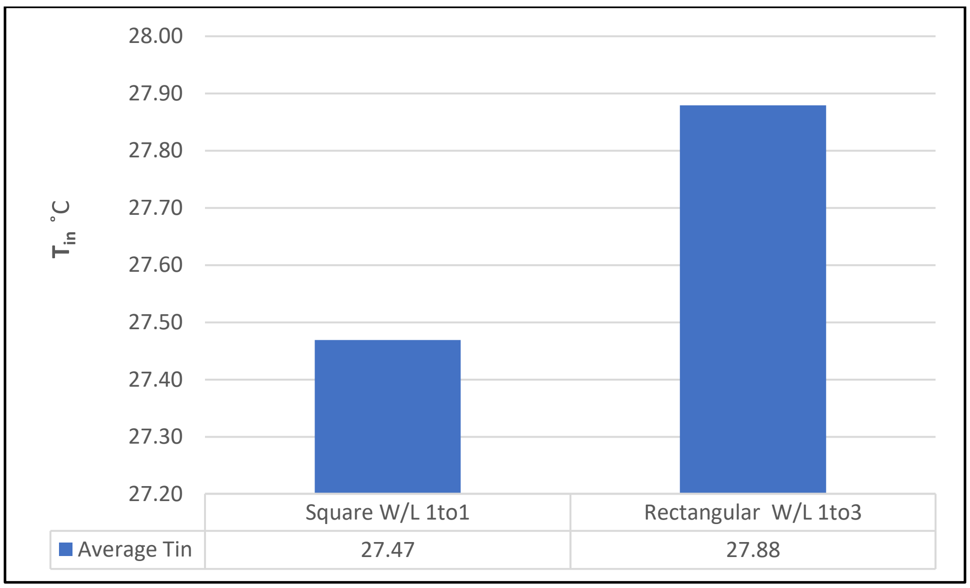


Figure 6. 11: Average T_{in} for School UPA-fin on 21st September within schooling time with different outline shapes (square and rectangular).

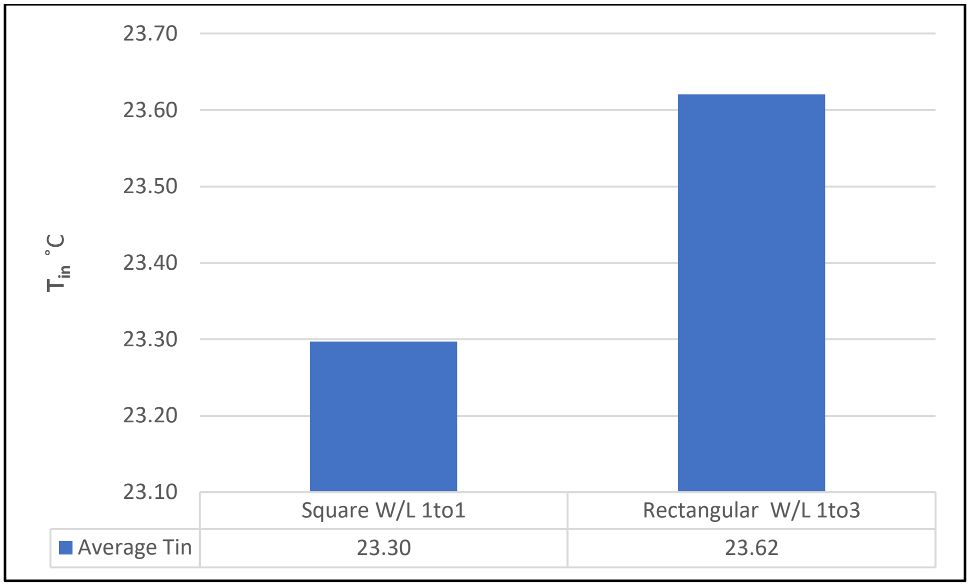


Figure 6. 12: Average T_{in} for School UPA-fin on 21st March within schooling time with different outline shapes (square and rectangular).

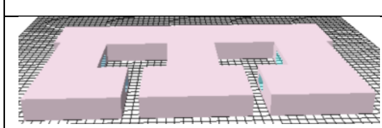
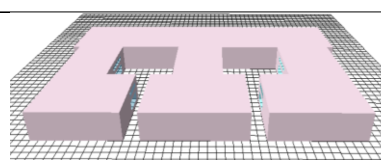
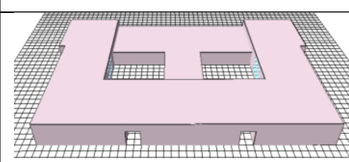
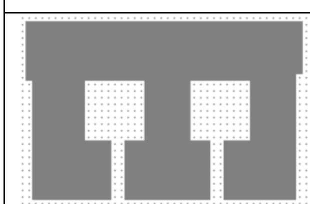
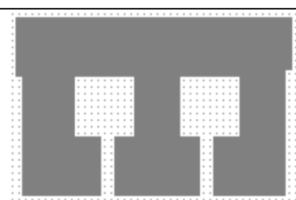
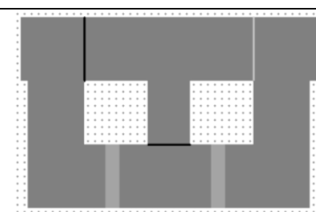
6.2.1.4 Phase 4: Courtyard height

The best case from the previous phase was UPA-fin school oriented to the north which has semi closed square outline courtyard, and it has two floors height with 8m. It is recommended to investigate the courtyard performance with three floors height (table 6.7). Based on that, the courtyard will be investigated with 12m height for the masses around the courtyard, but in two different configurations. In the first configuration the school will have repeated third floor exactly like the first and second floors and it is named 3F in all mass, while in the second configuration the school has three floors for the masses on the east, north and south sides and it is named as 3F east mass, as the east mass is the largest one. The simulation was conducted on two dates 21st of September and 21st of March, with the same constant parameter and design conditions of stage five and with CA/BA ratio 20% and square outline. Table (6.8) shows the two schools of UPA-fin with the suggested configurations of the new height.

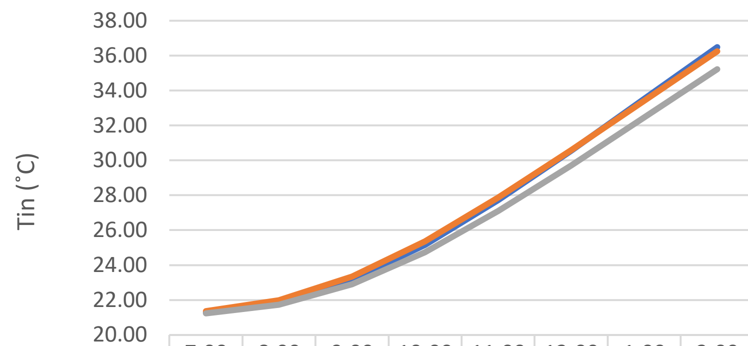
Table 6. 7: The investigation of school UPA-fin with the configuration of the new height.

Research stages.	Investigation field	Investigated parameter	Investigating details	Software
Stage one	orientation	Orientation	North,East,West,South	ENVI-met
Stage two	design	Shape factor: W/L ratio	1:2, 1:2.6, 1:3 with 2 courtyards, 1:3 with3courryards	ENVI-met
		CA/BA	1:20, 1:33, 1:40,1:60	ENVI-met
		Courtyard outline	Rectangular, square	ENVI-met
		Courtyard walls height	2 F, 3 F/ All mass, 3 F/ East Side	ENVI-met
		Courtyard with vegetation	Trees, grass, combination of both	ENVI-met
	thermal comfort	PMV	PMV at 10 AM	ENVI-met
Stage three	Courtyard and building energy consumption	Energy consumption	Energy consumption with new microclimates from ENVI-met (specific dates)	IESve
			Energy consumption based on the built-in climate data in IESve (academic year)	IESve

Table 6. 8: shows the three schools of UPA-fin with the different configurations related to height.

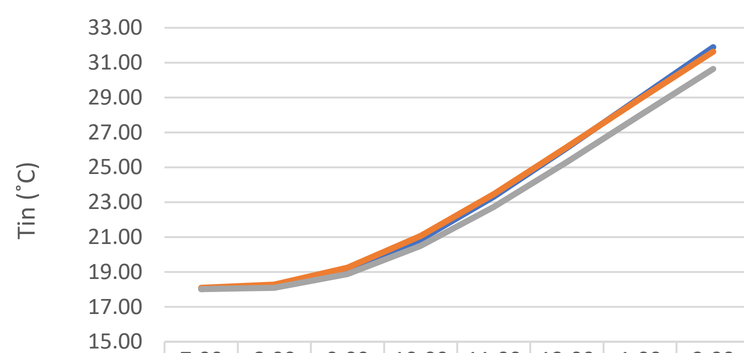
2F	3F all mass	3F east mass
		
		

The school UPA-fin was simulated with two configurations of the new height (12m) beside the original one from the previous phase which was 2 floors height (8m). The effect of the higher masses on the school building thermal performance appears on the T_{in} within the schooling time. It was clear in figure (6.13) that the 3 floors schools with higher masses around the courtyards illustrate different T_{in} on the 21st of September especially from 11AM-2PM more than the morning time. The simulation on the 21st of March shows difference as well as in figure (6.14).



	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM
2 F	21.27	21.87	23.15	25.16	27.73	30.55	33.52	36.50
3 F all mass	21.37	21.99	23.34	25.36	27.87	30.59	33.42	36.25
3 F East mass	21.22	21.73	22.90	24.74	27.10	29.70	32.45	35.23
Max Tin (C˚) difference	0.14	0.25	0.44	0.63	0.78	0.89	1.06	1.27

Figure 6. 13: Average T_{in} for School UPA-fin on 21st September within schooling time with different configurations related to height.



	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM
2 F	18.01	18.15	19.08	20.85	23.31	26.10	28.99	31.88
3 F all mass	18.09	18.27	19.25	21.06	23.46	26.16	28.91	31.63
3 F East mass	18.01	18.09	18.88	20.49	22.73	25.3	27.97	30.64
Max Tin (C˚) difference	0.08	0.18	0.37	0.57	0.73	0.86	1.02	1.24

Figure 6. 14: Hourly T_{in} for School UPA-fin on 21st March within schooling time with different configurations related to height.

Figure (6.15) demonstrates that the average T_{in} with different height configurations for School UPA-fin on 21st September within the schooling time. The investigation indicated that the school with 3F east mass had better thermal performance than the others. The school with 3F east mass had average T_{in} around 26.88 ˚C, and that is 0.59 ˚C less than the average T_{in} for the same school with two floors only.

Similar, on 21st of March as the simulation results indicated that the school UPA-fin square courtyard with 3F east mass had better thermal performance than the others with T_{in} 22.76 ˚C and that is 0.54˚C less than the one with 2F as in figure (6.16). Moreover, it was clear that the 3F all masses case had the highest T_{in} on both simulation dates, thus it was better to vary the masses heights around the courtyard to improve the stack effect inside the courtyard that helps in modifying the T_{in} of the building. This is in agreement with the work of Soflaei, Shokouhian and Mofidi Shemirani, (2016) which stated that the walls around the courtyard better to have different heights, they recommend having higher walls from the north and the south to reduce the heat gain from the solar radiation by making those walls higher.

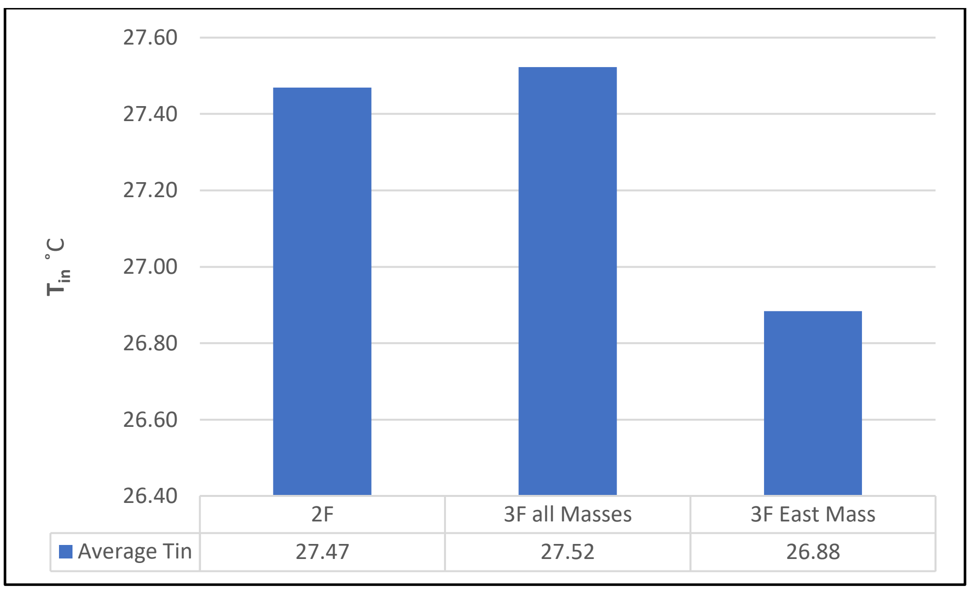


Figure 6. 15: Average T_{in} for School UPA-fin on 21st September within schooling time with different configurations related to height.

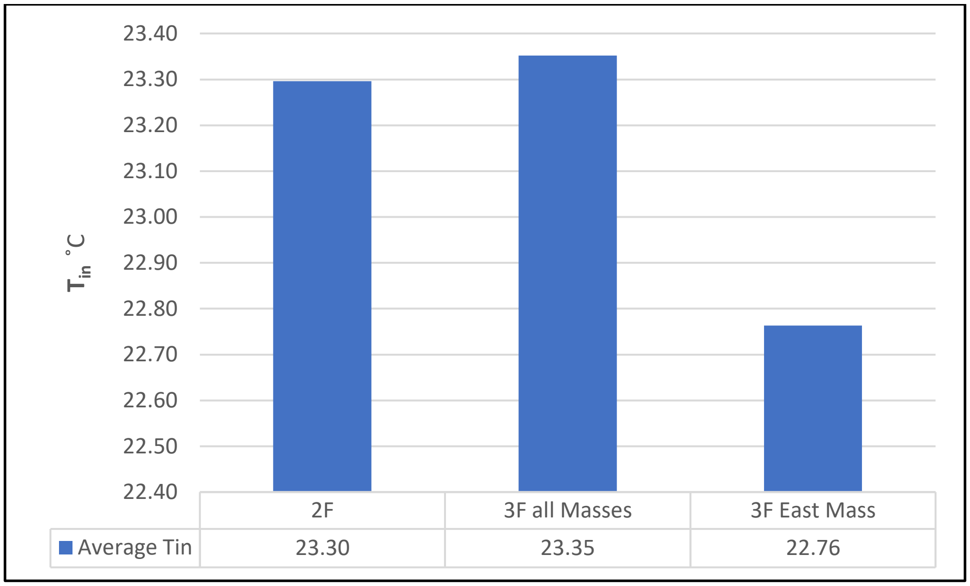


Figure 6. 16: Average T_{in} for School UPA-fin on 21st March within schooling time with different configurations related to height.

Table (6.9) illistarates vertical section through one of the courtyards for two cases of the school building, with different height configration at 121.5m on XZ axis on 21st of September within the ENVI-met domain. The two cases are 2F and 3F east mass (best case). The figures in the table (6.9) illistarates different types of air circulation and air tempearture in the courtyard according to the masses heights variations. In the case 3F east mass the open side of the courtyard from the east transformed to void for ventilation between the masses, which created better air circulation, and that agreed with Tablada (2013) and Tablada, et al. (2009) as they stated that even single side ventilation can provide colder thermal conditions for the building especially for the ground floor, if they added that cross ventilation will increase the speed of the air in the courtyard and will produce better thermal conditions in the warm areas despite the fact that the outdoor air temperature is very high.

Table 6. 9: Sections illustrate the outdoor temperature and the wind regimes at 10.00 AM.

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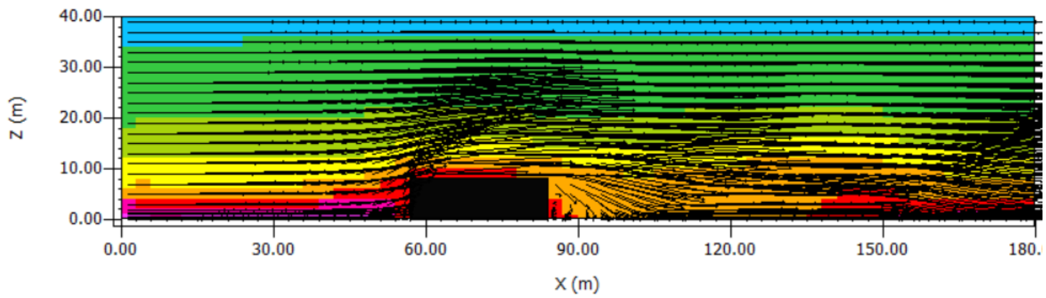
<tr><th>Section</th><th>Key</th></tr>
<tr><td>

School UPA 2F</td>
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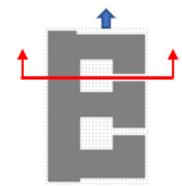
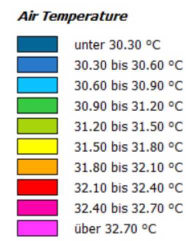

Wind direction
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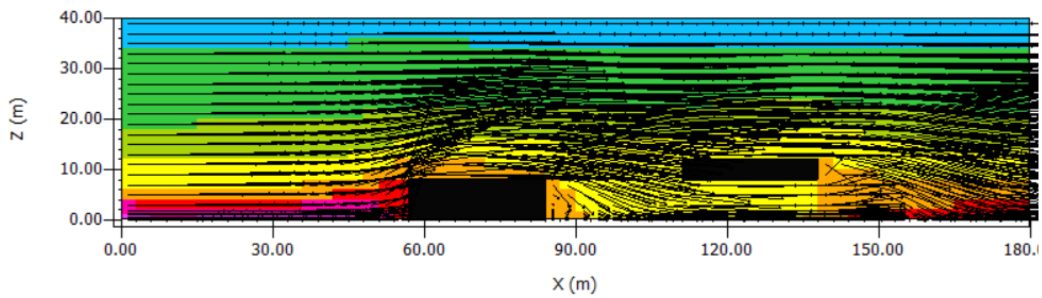
<tr><td>

School UPA 3F east mass</td></tr>
</table>

6.2.1.5 Phase 5: Courtyard with vegetation

The best case from the previous phase was UPA-fin school oriented to the north which has square outline courtyard and 3F east mass with 12m height, and it is recommended to investigate the courtyard performance with vegetation (Table 6.10). Based on that the courtyard will be investigated with different scenarios that include different vegetation configurations: trees only, grass only and finally combination of trees and grass. The simulations will be conducted on two dates 21st of September and 21st of March, with the same constant parameter and design conditions of stage five and with CA/BA ratio 20% and square outline 3F east mass with 12m.The suggested cases for the schools of UPA-fin with vegetation (table 6.11) and table (6.12) are as the following:

1- The first case includes grass only, the percentage of the area covered with grass was around 86% and the rest which is about 14% is concrete tile, that represent basic paved pathways that connect one of the school fingers finger of the school with the open sides of the courtyards, these pathways are required for equipment's movements.

2- The second case includes trees only, the percentage of the area covered by trees was around 30% and the rest was concrete tile. Maryland's Department of Education (2012) stated that the trees are better to be located at least 3-5m away from the courtyard walls, in order not to damage the foundations of the walls and to allow the light to access to the interior spaces. Thus, the trees were planted in the middle of the courtyard to reduce the heat gain on the center of the courtyard which is exposed the most to the solar radiation, unlike other parts of the courtyard that could be covered by shade according to the time of the day. When arranging the plants in the middle of the courtyard, away from the wall by 6m they covered around 30% of the courtyard. The total number of trees was around 25, all of them were deciduous trees with height 12m and width 9m (ENVI-met software).3- The third case includes a mixture of trees and grass, the percentage of trees was around 30% in the middle, and the percentage of grass was around 56% and the rest of the courtyard was around 14% and it was kept as concrete tile. The cases in this study were defined after investigating different previous studies like: Lee, Mayer and Chen (2016) who adopted three scenarios for vegetation to examine the effect of the greenery (grass and trees) on the heat stress and thermal comfort .

The scenarios were as the following: one with trees, one with grass, one without trees and grass beside the original one with trees and grass. They found that the trees have better effect on the thermal conditions than just grass. Ghaffarianhoseini, Berardi and Ghaffarianhoseini (2015) studied the effect of vegetation on the courtyards thermal performance in hot climate, they adopted different scenarios of vegetation including courtyards 75% covered by trees, 50% covered by trees, 25% covered by trees and finally 100% covered by grass, but they didn't investigate the effect of combining grass and trees in the courtyard. They concluded that covering the courtyard with greenery, mainly trees from 0 to 50% improves the thermal conditions in the courtyard most of the daytime excluding the time from 12:00 AM-3:00 PM.

Table 6. 10: The investigation of configurations of the school building with the configuration of the new height.

Research stages.	Investigation field	Investigated parameter	Investigating details	Software
Stage one	orientation	Orientation	North,East,West,South	ENVI-met
Stage two	design	Shape factor: W/L ratio	1:2, 1:2.6, 1:3 with 2 courtyards, 1:3 with3courryards	ENVI-met
		CA/BA	1:20, 1:33, 1:40,1:60	ENVI-met
		Courtyard outline	Rectangular, square	ENVI-met
		Courtyard walls height	2 F, 3 F/ All mass, 3 F/ East Side	ENVI-met
		Courtyard with vegetation	Trees, grass, combination of both	ENVI-met
	thermal comfort	PMV	PMV at 10 AM	ENVI-met
Stage three	Courtyard and building energy consumption	Energy consumption	Energy consumption with new microclimates from ENVI-met (specific dates)	IESve
			Energy consumption based on the built-in climate data in IESve (academic year)	IESve

Table 6. 11: The three cases of using vegetation in the school courtyards.

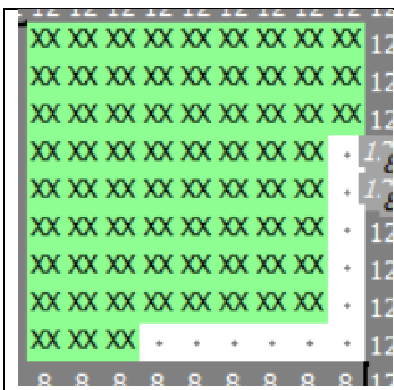
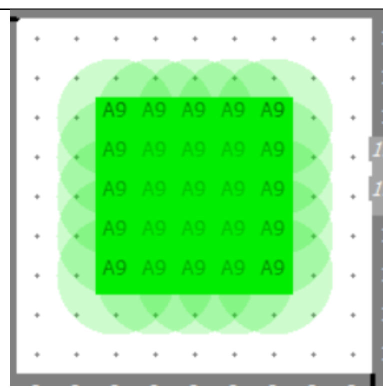
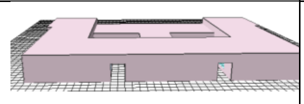
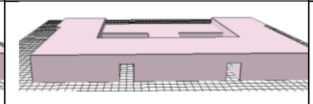
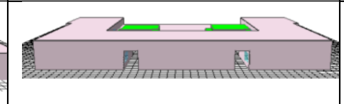
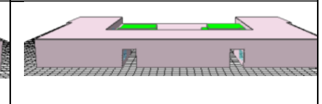
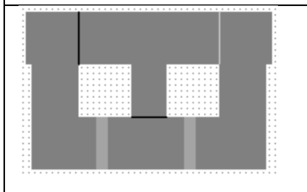
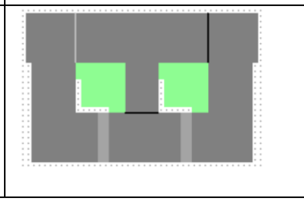
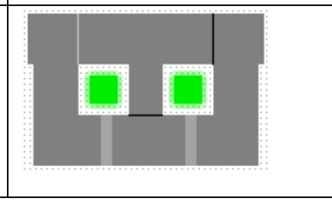
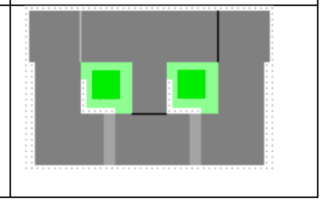
		
Case one : 86% of the courtyard covered by grass	Case two : 30% of the courtyard covered by trees	Case three : 30% of the courtyard covered by trees and 56% by grass

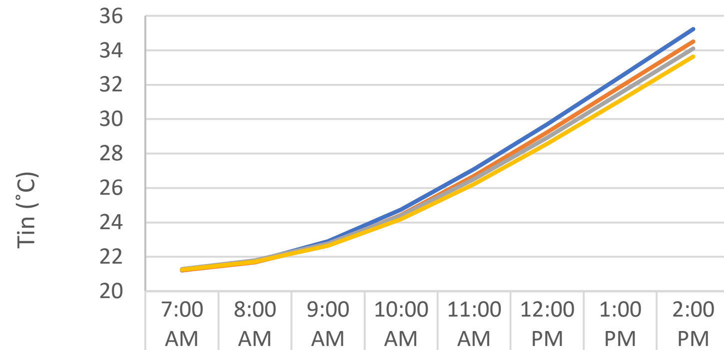
Table 6. 12: The four schools of UPA-fin with the suggested scenarios with vegetation.

Without vegetation	With grass	With trees	With grass& trees
			
			

The trees which were used in this stage were deciduous trees according to Abanomi and Jones (2005) who investigated the landscape effect on the thermal performance of a school building in Riyadh. They sated that landscape is an important element in schools in hot areas, as it helps in improving the microclimate of the building, as well as helps in cooling the inner spaces by reducing the heat gain. They recommended to use deciduous trees in schools, as they provide shade in summer and allow the sun access in winter. Moreover, these trees give the feeling of seasons for the students. The deciduous trees have foliage albedo around 0.18 as in figure (6.17) (ENVI-met software)..

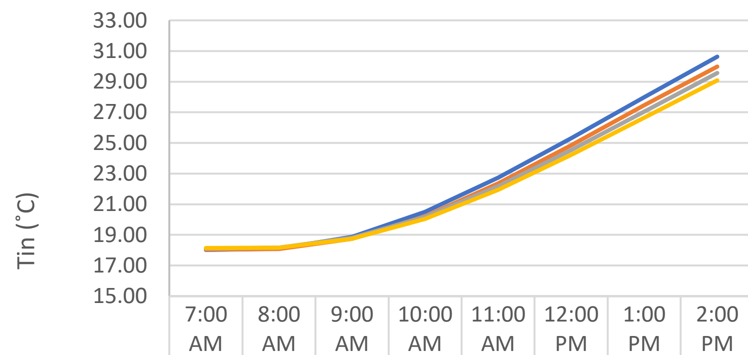
Figure 6. 17: The suggested deciduous trees in the courtyards (ENVI-met software).

The school UPA-fin was simulated with three scenarios that include vegetation beside the original one from the previous phase which was 3F east mass (12m) without vegetation. The effect of the vegetation on the school building thermal performance appears on the T_{in} within the schooling time. It was clear in figure (6.18) that the scenarios with vegetation in the courtyards illustrate different T_{in} on the 21st of September especially from 11AM-2PM more than morning time. The simulation on the 21st of March shows difference as well as in figure (6.19). The trees were located mostly in the middle as Maryland's Department of Education (2012) stated that trees are better located at least 3-4.5m feet away from the courtyard walls.



	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM
Without vegetation	21.22	21.73	22.9	24.74	27.1	29.7	32.45	35.23
With grass	21.21	21.67	22.71	24.43	26.70	29.24	31.88	34.51
With trees	21.30	21.78	22.78	24.39	26.52	28.93	31.50	34.11
With grass& trees	21.25	21.71	22.65	24.19	26.24	28.58	31.08	33.65
Max Tin (C˚) difference	0.09	0.11	0.25	0.55	0.86	1.12	1.37	1.58

Figure 6. 18: Hourly T_{in} for School UPA-fin on 21st September within schooling time with different scenarios with and without vegetation.



	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM
Without vegetation	18.01	18.09	18.88	20.49	22.73	25.30	27.97	30.64
With grass	18.03	18.07	18.74	20.21	22.36	24.85	27.45	29.98
With trees	18.10	18.16	18.81	20.17	22.17	24.53	27.04	29.56
With grass& trees	18.13	18.17	18.75	20.04	21.94	24.22	26.64	29.08
Max Tin (C˚) difference	0.12	0.10	0.14	0.45	0.79	1.08	1.33	1.56

Figure 6. 19: Hourly T_{in} for School UPA-fin on 21st March within schooling time with different scenarios with and without vegetation.

Figure (6.20) demonstrates that the average T_{in} with the new scenarios with vegetation for School UPA-fin on 21st September within the schooling time. The investigation indicated that the school with 3F east mass with grass and trees had better thermal performance than the others with average T_{in} around 26.17 ˚C, and that is 0.71 ˚C less than the average T_{in} for the one without vegetation. Similar, on 21st of March as the simulation results indicated that the school UPA-fin square courtyard with 3F east mass with grass and trees had better thermal performance than the others with T_{in} 22.12 ˚C and that is 0.64˚C less than the one without vegetation as in figure (6.21). Moreover, it was clear that the other cases with vegetation either grass or trees had better performance than the one without vegetation.

Based on the results of part one of stage two related to courtyard design, it was found that school UPA-fin square courtyard with 3F east mass with grass and trees includes the best courtyards design with best thermal performance according to the modified design parameters.

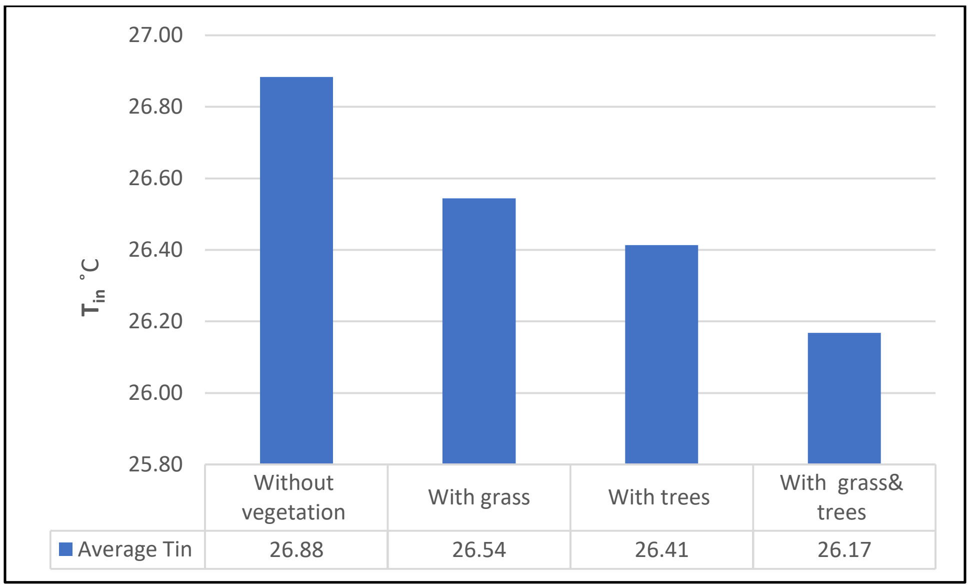


Figure 6. 20: Average T_{in} for School UPA-fin on 21st September within schooling time with different scenarios with and without vegetation.

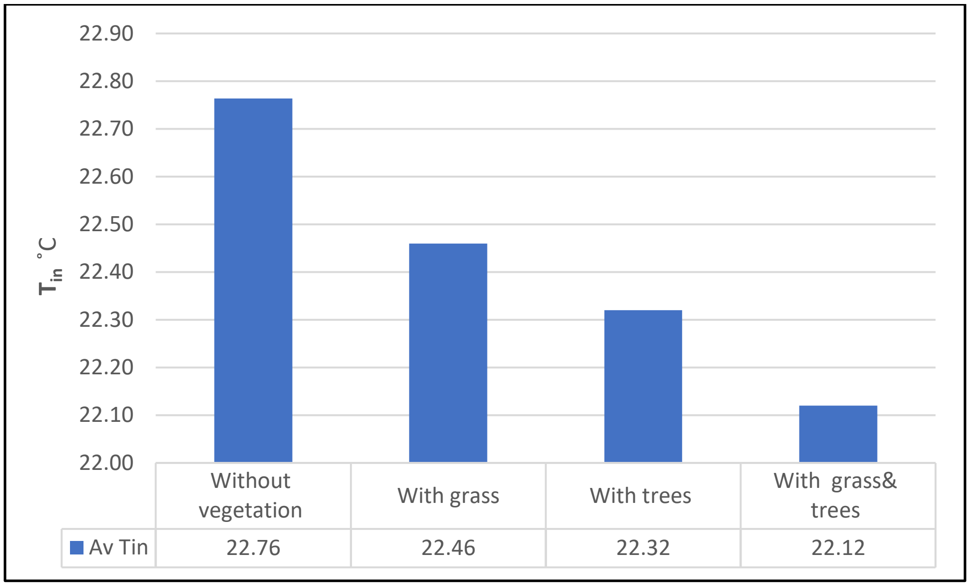


Figure 6. 21: Average T_{in} for School UPA-fin on 21st March within schooling time with different scenarios with and without vegetation.

6.2.2 Courtyard and thermal comfort

Part two of stage two includes evaluation for the courtyards' thermal comfort improvement in the Predicted Mean Vote (PMV) within the school courtyard, which is expected to positively affect the students' satisfaction toward the school building by providing enjoyable area for school socialization and the psychological and physical health especially in the break time

The thermal comfort of the courtyard will be investigated in this section for the best five models of the five phases of part one of stage two at the break time at 10:00 AM. The investigation of the PMV will be to evaluate the level of improvement in the outdoor thermal comfort in the courtyard, parallel to the indoor thermal improvements in each phase (table 6.13).

Table 6. 13: The investigation of school UPA-fin with the configuration of the new height.

Research stages.	Investigation field	Investigated parameter	Investigating details	Software
Stage one	orientation	Orientation	North,East,West,South	ENVI-met
Stage two	design	Shape factor: W/L ratio	1:2, 1:2.6, 1:3 with 2 courtyards, 1:3 with3courryards	ENVI-met
		CA/BA	1:20, 1:33, 1:40,1:60	ENVI-met
		Courtyard outline	Rectangular, square	ENVI-met
		Courtyard walls height	2 F, 3 F/ All mass, 3 F/ East Side	ENVI-met
		Courtyard with vegetation	Trees, grass, combination of both	ENVI-met
	thermal comfort	PMV	PMV at 10 AM	ENVI-met
Stage three	Courtyard and building energy consumption	Energy consumption	Energy consumption with new microclimates from ENVI-met (specific dates)	IESve
			Energy consumption based on the built-in climate data in IESve (academic year)	IESve

The thermal comfort is the state of awareness that reflects the satisfaction of the mind toward thermal atmosphere. Thus, it is an individual experience that is guided by the interactive issues beside the biological and psychological matters (Nikolopoulou & Steemers, 2003). Thermal comfort can be defined by the Predicted Mean Vote (PMV), as it is related to a stable condition for heat balance for the human physique (Hussain & Oosthuizen 2012).

In the courtyard, the stack effect improves the ventilation and air circulation especially in the hot arid areas, as it takes away the heat and moisture to accomplish the thermal comfort (Koch-Nielsen 2002; Rajapaksha, Nagai & Okumiya 2003; Zakaria & Kubota 2014). Taleghani et al. (2014) investigated the thermal comfort of courtyard models with different proportions. They found that the courtyard design with least discomfort time is 50% for the courtyard with the least solar radiation.

6.2.2.1 ASHRAE thermal sensation scale

The reference for defining the thermal comfort is ASHRAE standard, which was used widely to find the PMV in many researches like Salata (2016) who mentioned it as a suitable reference to define the PMV thermal comfort inside the courtyards. ASHRAE thermal sensation scale assume that +3 hot+2 warm, +1 slightly warm, 0 neutral, -1 slightly cold, -2 cool and -3 cold (Chen and

Ng 2012), despite the fact that zero is the perfect reading, and it illustrates the thermal neutrality, but the suitable comfort zone is suggested to be within the range -0.5<PMV<+0.5 (van Hoof & Mazej. & Hensen 2010). PMV is one of the popular tools to evaluate the outdoor thermal comfort. The outdoor thermal comfort guides not only rely on the energy balance of the human body (related to the metabolism and the clothing) but also takes into account other outdoor climatological variables such as the wind speed, air temperature, humidity…etc. Thus, the outdoor thermal comfort is not easy to evaluate compared to the indoor thermal comfort, as the outdoor climatological variables have complicated ranges (Honjo 2009).

In this research the outdoor thermal comfort will be investigated for the best cases of the five phases of the courtyard design (stage two) as a secondary advantage for the school courtyard to present the capability of the optimum school courtyard in improving the its outdoor thermal conditions, beside reducing the indoor temperature of the surrounding masses. The indoor thermal comfort for the school building will not be evaluated as the air conditioning assumed to work continuously in the time of occupancy to provide the best thermal conditions for the students. ENVI-met software will be used to evaluate the outdoor thermal conditions in the courtyards. ENVI-met software extended ASHRAE scale of PMV (which basically followed Fanger experimental scale) from 7 points that lays from -3 to +3 (pointing to +3 hot, +2 warm, +1 slightly warm, 0 neutral, -1 slightly cold, -2 cool and -3 cold) to nine points scale for the thermal comfort of the outdoor areas that lays between -4 as very cold to +4 as very hot , where the theoretic range of comfort outdoor lays between -3 and +3 (Gherraz, Guechi and Benzaoui 2018) ,(Envi-met.info. 2018).

6.2.2.2 Thermal comfort input data

Biomet wizard in ENVI-met software can calculate the thermal comfort in the outdoor spaces like courtyards. Ghaffarianhoseini, Berardi and Ghaffarianhoseini (2015) used ENVI-met software to evaluate the thermal comfort in courtyards according to different parameters like orientation, heights and vegetation.

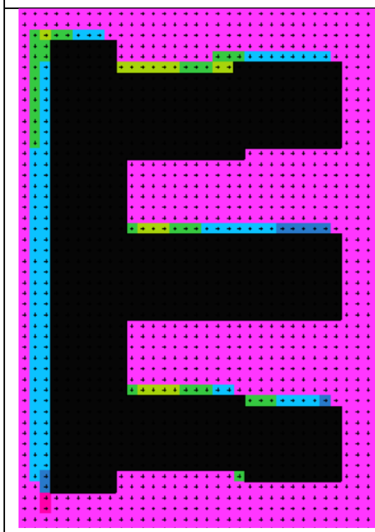
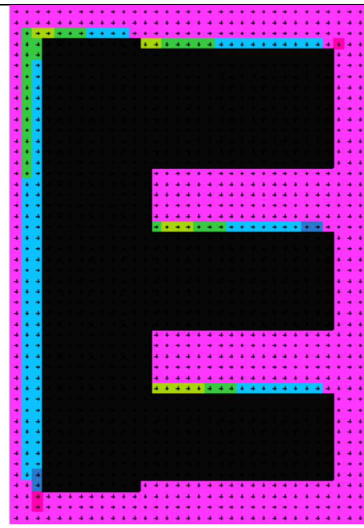
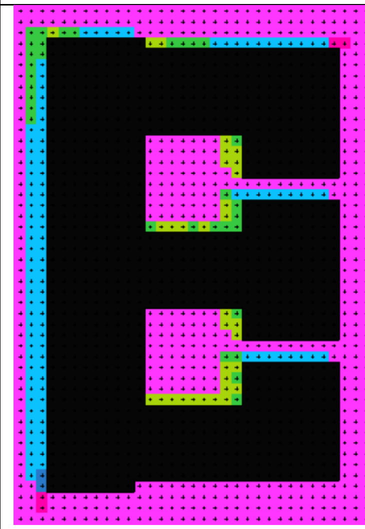
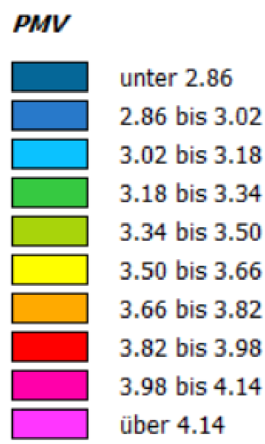
The Biomet wizard includes input data field that related to outdoor data like air temperature horizontal wind speed and the relative humidity, these data inputs already exist in the software after simulating the building and defining its microclimate.

Moreover, other input data should be defined in the Biomet wizard which are called personal human parameters. In this research the personal human parameters will be as the following:
Metabolic rate (M): "t*he rate of transformation of chemical energy into heat and mechanical work by metabolic activities within an organism, usually expressed in terms of unit area of the total body surface. In this standard, metabolic rate is expressed in met units*" (ASHRAE Standard 55-2010, 2011). In the research the metabolic rate is the average of seated, quiet person with 60 W/m2 and 1 met and walking about person with 100 W/m2 and 1.7 met, thus it will be 80 W/m2 (appendix 6.1).
The clothing insulation is "*the resistance to sensible heat transfer provided by a clothing ensemble. Expressed in clo unit*s" (ASHRAE Standard 55-2010, 2011). The clothing insulation for students' clothes includes: trousers, long-sleeve shirt beside suit jacket and that produce 0.96 clot unit for the clothing insulation (appendix 6.2).
The average age for the students 15.5 years with average weight 55kg and height 1.65m (Topics 2018).

6.2.2.3 Thermal comfort simulation

After the simulation for the best five cases of stage two (toward finding the best courtyard design) at 10:00 AM on 21st of September the results revealed that thermal comfort was improved by improving the design of the courtyard coupled with the reduction of T_{in}. Same results were noted on the simulation on 21stof March.
On the 21st of September the temperature was high and around 32.5-35 ˚C and relative humidity was around 40%. The improvements in the PMV sensation was insignificant by changing the courtyard design from phase one to phase two with CA/BA 20% according to representing colors in table (6.14). Similar situation was when changing the courtyard outline to square in phase three as the PMV was improved slightly.
Clear improvement was achieved by increasing the height to 3F and by adding vegetation. As when changing the height to 3F east mass the area with green color that indicates PMV between (3.18-3.34) as in table (6.14) was duplicated next to the inner south and east walls of the courtyards and new areas with PMV under 2.86 (warm) start to appear compared to phase three by adding vegetation.

Table 6. 14 : PMV sensation for the best cases in the five phases of stage two at 10:00AM on 21st of September.

<table>
<tr><td>1-Phase one:
Shape factor: W/L ratio 1:2.6</td><td>2- Phase two:
CA/BA ratio :20%</td><td>3- Phase three:
Courtyard outline: square</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>4- phase four: Courtyard walls height : 3F east mass</td><td>5- phase five: Courtyard with trees and grass</td><td rowspan="2">
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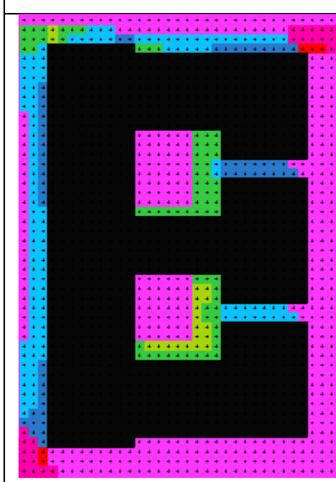
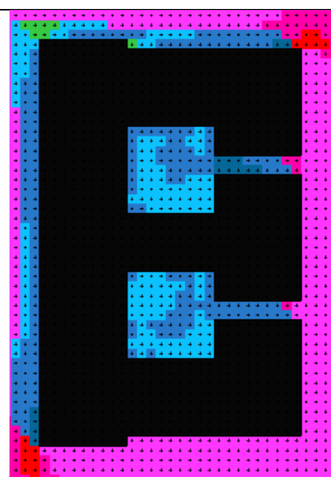
<tr><td></td><td></td></tr>
</table>

The significant improvements were in phase five by adding vegetation, as most of the courtyards area become 2.82-3.02 and below with places transformed to be warm from hot according to PMV scale, while in the first phase most of the courtyard area was above 4 (very hot) based on PMV scale.

Furthermore, table (6.15) revealed that for phase one with shape factor W/L ratio 1:2.6 the lower boundary for PMV was 3 and it covers 1% of the courtyard area while the upper boundary for PMV was 4.35 and it covers around 48% of the courtyards area on 21st of September (appendix 6.1).

On the other hand, table (6.15) revealed that for phase five with courtyards that have trees and grass the lower boundary for PMV was 2.8 and it covers 1% of the courtyards area while the upper boundary for PMV was 3.15 and it covers around 1.5% of the courtyards area (appendix 6.2). Thus, the upper boundary was lowered by 1.2 PMV in the fifth phase compared to the first phase

Table 6. 15: The upper and lower PMV boundaries for PMV on 21st of September.

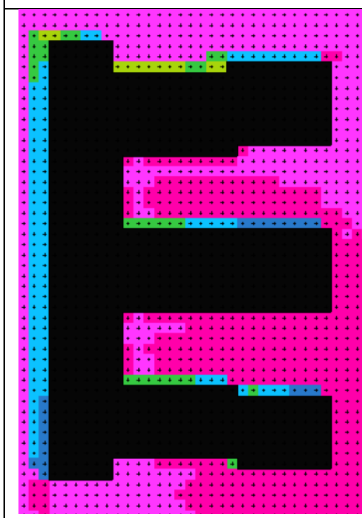
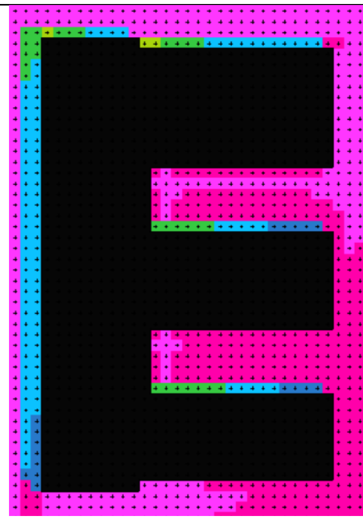
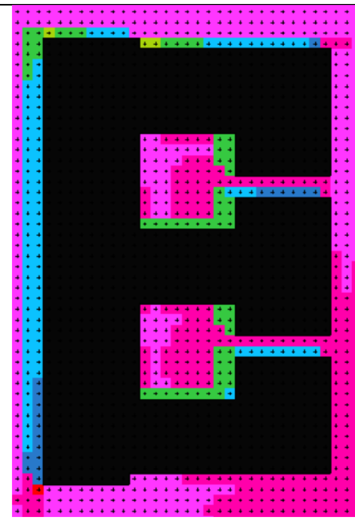
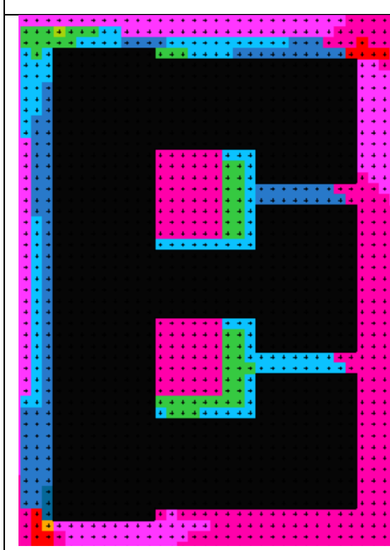
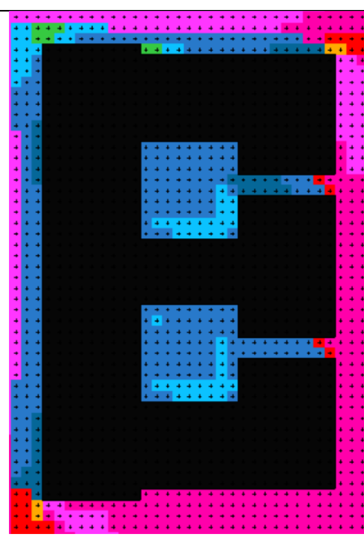
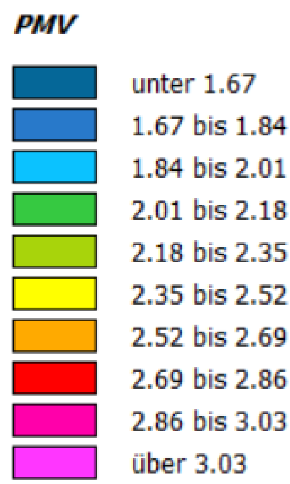
PMV readings On 21ST OF September	1-Phase one: Shape factor/L ratio 1:2.6	5- phase five: Courtyard with trees and grass	Max difference in PMV
Lower boundary for PMV	3.0 covers 1% of the courtyards area	2.8 covers 1% of the courtyards area	0.2
Upper boundary for PMV	4.35 covers 48% of the courtyards areas	3.15 covers 1.5 % of the courtyards area	1.2

On the 21st of March the temperature was still high and around 28.3-31.0 ˚C and relative humidity was around 24 %. The results of the simulation revealed that PMV sensation was slightly improved when changing the courtyard design from phase one to phase two with CA/BA 20%. Same situation with insignificant improvement on PMV happened when changing the courtyard outline to square in phase three.

Clear improvement was reached by increasing the height to 3F and by adding vegetation. As when changing the height to 3F east mass the area with green and blue color with PMV readings (1.84-2.01) and (2.01-2.18) respectively as in table (6.16) was duplicated and new areas with PMV under 1.84 (slightly warm) start to appear next to the inner south and east walls of the courtyards in relation to phase three.

The significant improvements were in phase five by adding vegetation, as most of the courtyards area become under 1.67 PMV with places transformed to be slightly warm from warm. According to PMV scale, while in the first phase, most of the courtyard area was above 2.86 (warm or hot) based on PMV scale.

Table 6. 16 : PMV sensation for the best cases in the five phases of stage two at 10:00AM on 21st of March.

1-Phase one: Shape factor:W/L ratio 1:2.6	2- Phase two: CA/BA ratio :20%	3- Phase three: Courtyard outline : square
		
4- phase four: Courtyard walls height : 3F east mass	5- phase five: Courtyard with trees and grass	
		

Furthermore, table (6.17) revealed that for phase one with shape factor W/L ratio 1:2.6 the lower boundary for PMV was 1.7 and it covers 1% of the courtyard area while the upper boundary for PMV was around 3.0 and it covers around 48% of the courtyards area (appendix 6.3).

On the other hand, table (6. 17) that for phase five with courtyards that have trees and grass the lower boundary for PMV was 1.5 and it covers 1.5% of the courtyards area while the upper boundary for PMV was 1.9 and it covers around 1.5% of the courtyards area (appendices s 6.3 & 6.4). Thus, the upper boundary was lowered by 1.1 PMV in the fifth phase compared to the first phase.

Table 6. 17: The upper and lower PMV boundaries for PMV on 21st of March.

PMV readings On 21ST OF March	1-Phase one: Shape factor/L ratio 1:2.6	5-phasefive: Courtyard with trees and grass	Max difference in PMV readings
Lower boundary for PMV	1.6 covers 1% of the courtyards area	1.5 covers 1.5% of the courtyards area	0.1
Upper boundary for PMV	3.0 covers 48% of the courtyards area	1.9 covers 1.5% of the courtyards area	1.1

6.3 Discussion of stage two:

Courtyard is considered as climate modifier. The design of the courtyard depends on different parameters that define its efficiency in improving the thermal performance for the whole building (Reynolds 2002; TERI, 2004; Almhafdy et al. 2013; Tabesh & Sertyesilisik 2016; Markus et al. 2017). Among these parameters: the courtyard shape, orientation, proportion to the built-up area, courtyard ratio height to width and sky view factor, heights of the masses around the courtyard, vegetation,….etc. Some of these parameters were investigated in the first part of stage two, including: The shape factor W/L, CA/BA ratio, courtyard shape outline, height of the courtyard walls height and vegetation in the courtyard.

6.3.1 Courtyard shape factor

This part was designed to investigate the number of courtyards and CA/BA ratio suitability for UPA-fin school before going through more improvements on the courtyards design, based on that the best case UPA-fin with CA/BA ratio 40% with two courtyards was investigated according to variations in the shape factor. The courtyard shape factor effect is connected to other parameters like the shadow index and the mass thickness around the courtyard. Sthapak and Bandyopadhyay (2014) stated that the solar shadow index (SSI) can be calculated by dividing the south wall height by N-S floor width.

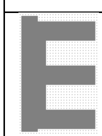
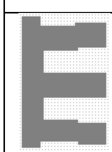
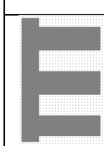
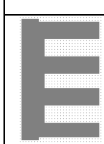
The investigation of the shape factor indicated that the school UPA-fin with shape factor ratio (W/L) 1:2.6 had the best T_{in} average among the others on both dates of simulation 21st of September and 21st of March with least average T_{in} 28.06 ˚C and 23.80 ˚C respectively. These T_{in} values for UPA-fin are less with 1.03 ˚C on the 21st of September and 0.93 ˚C on 21st of March than the poorest case with shape factor ratio W/L 1:3 with three courtyards (table 6.18). That can be explained due to the change in the amount of received solar radiation on the exterior walls, as the poorest case with factor ratio W/L 1:3 with three courtyards has more exterior walls exposed to exterior climate with thinner masses, unlike the best case with W/L 1:2.6 which has 30% less in the exposed walls with thicker masses. El-Deeb, Sherif and El-Zafarany (2014) insisted that whenever increasing the exterior surfaces of the building, the inner temperature of the spaces will increase, thus the thicker masses of the buildings around the courtyard have better performance than the thinner ones.

Moreover, UPA-fin with shape factor ratio (W/L) 1:2.6 have better performance than the one with shape factor ratio (W/L) 1:2 with less 0.34 ˚C on 21st of September and 0.29 ˚C on 21st of March. This can be explained because the school UPA-fin with shape factor ratio (W/L) 1:2.6 has SSI around 0.36 while the one with W/L 1:2 has SSI around 0.29, which produces less shade inside the courtyard. Yaşa and Ok (2014) stated that increasing the shaded area inside the courtyard decreases the needed cooling energy on the hot days. Soflaei Shokouhian and Mofidi Shemirani (2016) listed the shade cast on the courtyard ground from the surrounding walls as one of the main effects of the courtyard as passive design solution beside the shade on the southern wall of the courtyard.

Despite the fact that UPA-fin with shape factor ratio W/L 1:3 with two courtyards has SSI around 0.38, but UPA-fin with shape factor ratio W/L 1:2.6 and SSI 0.34 still has better performance than it, because it has thicker mass on the west side with amount around 21m than the one W/L 1:3 . That proves that the thicker masses effect overcome the SSI effect.

The case with three courtyards was investigated to define the best number of courtyards for this school building before going through further modifications. The results proved that two courtyards for UPA-fin school are better than three courtyards as the one with three courtyards has average T_{in} around 29.09 on 21st of September and 24.73 on 21st of March, which recorded more 1.03 ˚C and 0.93 ˚C than the best case with W/L 1:2.6, respectively, despite the fact that it has more SSI with amount 0.44. The reason behind the bad thermal performance for UPA-fin with three courtyards, it has more exposed surface to the hot climate than the one with two courtyards. El-Deeb, Sherif and El-Zafarany (2014) explained that as they stated that the more exposed surfaces of the building in relation to the air-conditioned spaces volume, increases the inner temperature.

Table 6. 18: The SSI and the thickness of masses around the courtyard in relation to the variation in the shape factor.

School	Shape factor	Number of courts	Shadow index SSI= south wall height / N-S floor width.	Surrounding mass thickness		Average T_{in} (˚C) 21st September (Difference in average T_{in} in relation to the Ref. value)	Average T_{in} (˚C) 21st March (Difference in average T_{in} in relation to the Ref. value)
				West mass	Fingers (average)		
	1:2	2	8/27=0.29	27m	21m	28.38 (+0.32)	24.09 (+0.29)
	1:2.6	2	8/22.5=0.36	21m	23m	28.06 (Ref.)	23.80 (Ref.)
	1:3	2	8/21=0.38	18m	23m	28.33 (+0.27)	24.04 (+0.24)
	1:3	3	8/18=0.44	24	17.3m	29.09 (+1.03)	24.73 (+0.93)

6.3.2 Courtyard area to build up area ratio (CA/BA)

In this phase school UPA-fin was investigated according to different CA/BA ratios, which are 20%, 33% and 60% beside the original one 40%(from the previous phase). The courtyard CA/BA ratios affects the thickness of the masses, area of the courtyards, and the SSI ratio inside them.

The investigation indicated that the school UPA-fin with CA/BA ratio 20% had the best T_{in} average among the others on both dates of simulation 21st of September and 21st of March with least average T_{in} of 27.88˚C and 23.62˚C respectively. These T_{in} amounts for UPA-fin are less with 0.43 ˚C on the 21st of September and 0.41 ˚C on 21st of March than the poorest case with CA/BA ratio 60 % (table 6.19). That can be explained according to the relationship between the CA/BA ratio and the areas of the courtyards when the number of the courtyards and height around them are fixed. As whenever the CA/BA ratio increases the areas of the courtyards increase. For example, the poorest case has the largest CA/BA ratio with 60 % thus it has the biggest areas for the courtyards and that allows more amounts of solar radiation to hit the ground and the walls of the courtyards. Moreover, it has more exterior walls exposed to the exterior hot climate with thinner masses, unlike the best case with CA/BA ratio 20% which has less exposed walls with thicker masses, thus less indoor temperature with less cooling energy (El-Deeb, Sherif & El-Zafarany, 2014). Based on that the thicker masses of the buildings around the courtyard have better thermal performance than the thinner ones.

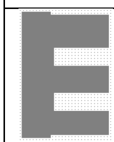
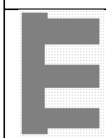
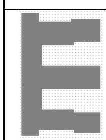
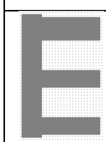
Moreover, UPA-fin with CA/BA ratio 20% has better performance than the one with CA/BA ratio 60 % because it has SSI around 0.44 while the one with CA/BA ratio 60 % has SSI around 0.27 which produces less shade inside the courtyard. Feroz (2015) stated that wider courtyards collect more heat gain as it has less shaded areas compared to the narrow ones. Yaşa and Ok (2014) specified that, increasing the shaded area inside the courtyard will improve the indoor temperature for the buildings in the hot areas, thus decreases the required cooling energy. Therefore the courtyard in the energy efficient buildings should have proper proportions beside the orientation to control the shaded area thus the heat gain, as considering the internal shaded courtyard as major contributive in producing thermal comfort (Ghaffarianhoseini, Berardi & Ghaffarianhoseini 2015). Edwards (2006) stated that the courtyard in a building creates private solid and void spaces with different temperatures according to shade and exposition to sun. Al-Hafith et al. (2017) confirmed that the shade created by the surrounding walls of the courtyard affect its microclimate, they added that, this shade changes according to the orientation, the upper width of the courtyard beside the courtyard's width to height (figure 6.22), that can agree with the simulation results of school models in this phase, as in the school model with bigger CA/BA ratio 60% the courtyard had more width, thus less shaded area, while the school model with the least CA/BA ratio which is 20% the courtyard had less width and more shaded area cast inside it.

Moreover, the courtyards with less width had less sky view factor (opining to the sky), as in the case of school model with CA/BA 20% than the ones with larger CA/BA ratio.. Kubota et al. (2014) studied the effect of the courtyards on houses in Malaysia and highlighted the effect of the sky view factor on the temperature of the air inside the courtyard. They found that the reducing the sky view factor can reduce the courtyards air temperature.

Additionally, and according to table (6.19) UPA-fin with CA/BA ratio 20 % has better performance than the one with CA/BA ratio 60 % because it has thicker mass on the west side and fingers with amount around 30m and 28 respectively. While the one with CA/BA ratio 60 % has thickness 21m for the west side and 20m as average thickness for the fingers masses.

Finally, UPA-fin with the best performance and CA/BA ratio 20 % has the ratio which lays within the range defined by Soflaei, Shokouhian and Mofidi Shemirani, (2016a) who stated that in the traditional courtyards with good thermal performance the courtyard area to the built up area should range between 18% -44%, then in later study in the same year they confirmed that the ratio of the area of the courtyard is better to have maximum amounts that ranges between 18% - 32%, however the better to be below 30%, and that according to the courtyard area ratio related to traditional buildings with good thermal performance in hot area in Iran (Soflaei, Shokouhian and Mofidi Shemirani, 2016b).

Table 6. 19: Average T_{in} and SSI for School UPA-fin within schooling time according to different CA/BA ratios.

School	CA/BA ratio	Shadow index SSI = south wall height / N-S floor Width	Surrounding mass thickness		Average T_{in} (˚C) 21st September (Difference in average T_{in} in relation to the Ref. value)	Average T_{in} (˚C) 21st March (Difference in average T_{in} in relation to the Ref. value)
			East mass	Fingers (average)		
	20%	8/18 =0.44	30 m	28m	27.88 (Ref.)	23.62 (Ref.)
	33%	8/21 =0.38	24m	24m	28.05 (+0.17)	23.78 (+0.16)
	40%	8/22.5=0.36	21m	23m	28.06 (+0.18)	23.80 (+0.18)
	60%	8/30=0.27	21m	20 m	28.31 (+0.43)	24.03 (+0.41)

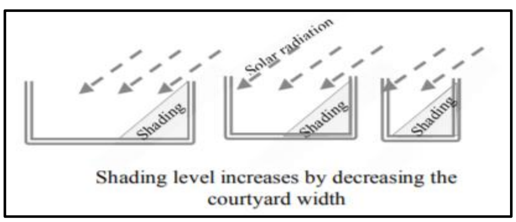


Figure 6. 22: Shade in the courtyard according to the width (Al-Hafith et al. 2017).

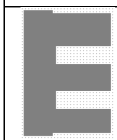
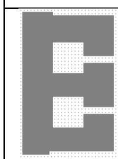
6.3.3 Courtyard outline shape

Table (6.20) demonstrates the average T_{in} with different outline shapes (square and rectangular) for School UPA-fin on 21st September and 21st of March within the schooling time. The investigation indicated that the school with square courtyard had better thermal performance than the rectangular one. The school with square courtyard had average T_{in} around 27.47 ˚C, and that is 0.41 ˚C less than the average T_{in} for the same school with rectangular shape on 21st of September. Similarly, on 21st of March as the simulation results indicated that the school UPA-fin square courtyard had better thermal performance than the rectangular one with T_{in} around 23.30 ˚C and that is 0.32˚C less than the one with rectangular outline.

Yaşa & Ok (2014) stated that it is expected that the energy consumption for a building with courtyard will increase corresponding to the increase in the length of the courtyard. They added that in hot areas, it is expected that the shaded area in the courtyard will increase when the shape of the courtyard become near to square which will decrease the amount of energy required for cooling in summer as the T_{in} decreases. Moreover, Tabesh & Sertyesilisik (2016) stated that the geometry of the courtyard is a critical issue as the courtyard performance mainly depend on the amount of solar radiation access to it. They argued that because of the sun location and radiation, a square courtyard is ideal in relations of energy request.

Additionally, the square courtyard for the school UPA-fin is better than the rectangular one because rectangular courtyard is opened from the east side, unlike square courtyard which has walls from the east side, that cast shade inside it, especially in the morning time when the school is occupied, thus the extra shaded area helps in improving the microclimate of the courtyard and the building in general. Soflaei Shokouhian and Mofidi Shemirani (2016) pointed to the shade cast on the courtyard ground from the surrounding walls beside the shade on the southern wall of the courtyard as one of the main effects of the courtyard as passive design solution. This agrees with Al-Hafith et al. (2017) who insisted that the shade created by the surrounding walls of the courtyard affect its microclimate, they added that this shade varies according to the surrounding walls.

Table 6. 20 : Average T_{in} with different shape outline on 21st September and 21st of March.

School	Courtyard outline	Average T_{in} (˚C) 21st September (Difference in average T_{in} in relation to the Ref. value)	Average T_{in} (˚C) 21st March (Difference in average T_{in} in relation to the Ref. value)
	Rectangular outline	27.88 (+0.41)	23.62 (+0.32)
	Square outline	27.47 (Ref.)	23.30 (Ref.)

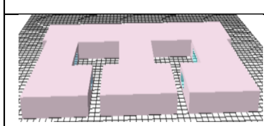
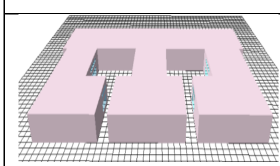
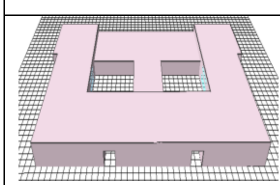
6.3.4 Courtyard height

In this phase, the school UPA-fin was simulated with two new configurations with height (12m) in addition to the original one from the previous phase which was 2 floors height (8m). This phase was designed to increase the volume of the school building to serve more students while reducing the T_{in}. Bradshaw (2010) stated that roof areas should in general be minimized by being built up in multiple stories instead of spreading out in a single story over a large site. Based on that surface to volume ratio will be decreased, thus less surfaces are exposed to the extreme weather in summer. Sharmin and Steemers (2015) who investigated different configurations for courtyards with different surface to volume ratios, they insisted that the high surface to volume ratio can increase the internal temperature of the buildings.

The investigation of the new height (12m) of the masses around the courtyards on the thermal performance of the building on 21st of September indicated that the school UPA-fin with three floors for the masses east, north and south named as 3F east mass (as the east mass is the largest one) had better indoor thermal performance than the other cases (table 6.21). The school with 3F east mass had average T_{in} around 26.88 ˚C, and that is 0.59 ˚C less than the average T_{in} for the same school with two floors only.

Similarly, on 21st of March as the simulation results indicated that the school UPA-fin square courtyard with 3F east mass had better thermal performance than the others with T_{in} 22.76 ˚C and that is 0.54˚C less than the one with 2F as in table (6.21). Moreover, it was clear that the 3F all masses case had the highest T_{in} on both simulation dates, thus it was better to vary the masses heights around the courtyard to improve the stack effect inside the courtyards and help in modifying the T_{in} of the building in general. This agreed with Soflaei, Shokouhian and Mofidi Shemirani (2016) as they stated that the walls around the courtyard better to have different height. They recommend having higher walls from the north and the south sides to reduce the heat gain from the solar radiation.

Table 6. 21: Average T_{in} on 21st of September and 21st of March according to different height configurations.

UPA-fin school	Height configurations	Average T_{in} (˚C) on 21st of September (Difference in average T_{in} in relation to the Ref. value)	Average T_{in} (˚C) on 21st of March (Difference in average T_{in} in relation to the Ref. value)
	2F	27.47 (+0.59)	23.30 (+0.54)
	3F all mass	27.52 (+0.64)	23.35 (+0.59)
	3F east mass	26.88 (Ref.)	22.76 (Ref.)

In the best case, UPA-fin 3F east mass, the third floor was located opposite to the ground and the first floors' setting, as it was located as U shape above the north east and the south sides of the school, on one hand this way provided protection from the solar radiation (in the period of schooling time (7AM-2PM) which is in the morning and noon time, when the sunrises from the east side and cast more shade in the courtyards.

On the other hand, this setting creates voids on the east side which allow access for the cross ventilation through the courtyards from one side, which eventually improved the thermal performance of the courtyard and the building in general, and reduces the accumulated thermal mass, that agreed with the following studies: Tablada, et al (2009) as they pointed to the importance of protection from the sun energy and controlling the wind circulation in the building to improve the thermal performance of the courtyards and their buildings. Zakaria and Kubota (2014) as they stated that ventilation even in single side improve the air flow and that improves the thermal performance of the courtyard the stack effect. Ok, Yasa and Özgunler (2008) advised to have voids in the masses around the courtyard to improve the wind flow and circulation in the courtyard. In this way, daytime ventilation for the courtyards improved despite the fact that the indoor spaces are closed when the temperature is high. Zakaria and Kubota (2014) advised that it is not recommended to adopt daytime ventilation for the indoor spaces in the hot humid areas, as that will open access to the hot air to access to the interior areas and rises the indoor temperature of the building.

Finally, in the best case of UPA-fin 3F east mass the average height for the masses around each courtyard is set as X with height around 10 m, while the width is 27m which lays between 10-30m (X to 3 X) for best performance according to Koch-Nielsen (2002) as he sated for best performance for the courtyard if the height of the courtyard is X it is better to have width that ranges from X to 3X to make the height of masses around the courtyard improve the building thermal comfort effectively.

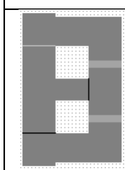
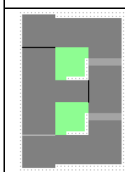
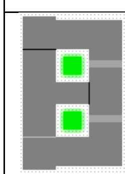
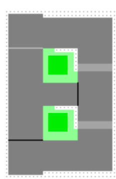
6.3.5 Courtyard and vegetation

This phase was designed to improve the thermal performance of the courtyard by adding vegetation. The simulation was conducted on two dates 21st of September and 21st of March with the same constant parameter and design conditions of stage five and with CA/BA ratio 20% and square outline 3F east mass with 12m height for the north east and south walls of the school. The simulation included different scenarios with vegetation, which are: trees only, grass only and finally combination of trees and grass. In the case of grass only, the percentage of the area covered with grass was around 86% and the rest concrete tile, while in the case of trees only, the percentage of the area covered by trees was around 30% and the rest was concrete tile. Finally, in the case of mixed trees and grass the percentage of trees around is 30% with a percentage of grass of 56% and the rest was concrete tile.

After the simulation of the different scenarios with vegetation was implemented in this research. The investigation indicated that the school with 3F east mass with grass and trees had better thermal performance than the others with average T_{in} around 26.17 ˚C, and that is 0.71 ˚C less than the average T_{in} for the one without vegetation.

Similarly, on 21st of March as the simulation results indicated that the school UPA-fin square courtyard with 3F east mass with grass and trees had better thermal performance than the others with T_{in} 22.12 ˚C and that is 0.64˚C less than the one without vegetation as in table (6.22). Moreover, it was clear that the other cases with vegetation either grass or trees had better performance than the one without vegetation. This agrees with Tsoka (2017) as he stated that plants can reduce the air temperature and improve the thermal comfort, by reducing the heat transfer to the air and by evapotranspiration. Salata et al. (2017) stated that vegetation is one of the parameters that can improve the thermal comfort and decrease the health risk for people exposed to the weather in the urban fabric. Abanomi and Jones (2005) investigated the landscape effect on the thermal performance of a school building in Riyadh. They stated that landscape is important element in schools in hot areas, it helps in improving the microclimate of the building and helps in cooling the inner spaces by reducing the heat gain.

Table 6. 22: Average T_{in} with different scenarios of vegetation on 21^{st} September and 21^{st} of March.

UPA-fin school	Scenarios for vegetation	Average T_{in} (˚C) 21^{st} of September (Difference in average T_{in} in relation to the Ref. value)	Average T_{in} (˚C) on 21^{st} of March (Difference in average T_{in} in relation to the Ref. value)
	Without vegetation	26.88 (+0.71)	22.76 (+0.64)
	With grass	26.54 (+0.37)	22.46 (+0.34)
	With trees	26.41 (+0.24)	22.32 (+0.20)
	With grass and trees	26.17 (Ref.)	22.12 (Ref.)

Moreover, it was noticed that the grass presence in the courtyards was better than having only concrete tile despite the fact that it wasn't the best scenario. Abanomi and Jones (2005) clarified that having the grass as a cover on the courtyard ground is better than concrete pavement, as the grass reflects about 0.2% from the solar radiation, while the concrete reflects around 0.4% of it. Thus, grass reduces the amount of direct solar radiation on the courtyard ground and the reflected solar radiation on the surrounding walls. Ghaffarianhoseini, Berardi and Ghaffarianhoseini (2015) mentioned that the effect of the grass in the courtyard was miner and caused about 0.13˚C reduction in the courtyard temperature at 7AM compared to the one with bare surface. He added in their research that the soil and grass can reduce the outdoor temperature with around 0.2-0.6 ˚C.

In this research, the scenario that have only trees was better in the thermal performance than the scenario with only grass. Agreed with Abanomi and Jones (2005) and Robitu et al. (2006) who stated that the effects for the trees are better than the grass on the thermal conditions. They explained that trees can reduce the temperature by shading the ground beside evaporative cooling. Same statement was from Ghaffarianhoseini, Berardi and Ghaffarianhoseini (2015) as they stated that the trees in the courtyards are more effective in enhancing the thermal conditions than the grass alone. They concluded that covering the courtyard with greenery mainly trees from 0 to 50% improves the thermal conditions in the courtyard most of the daytime.

Additionally, Feroz (2015) stated that the trees are more significant in decreasing the courtyard temperature than only grass, he found that a group of trees succeed in reducing the temperature by 0.4K compared to grass only and by 0.6 K compared to the one with no vegetation because of their shades and biotic properties, despite the fact that the trees reduce the wind speed. Thus, reducing the speed of the wind in the courtyard in the hot areas will not increase the temperature. As according to Feroz (2015) who found in his study about courtyards in Dubai that the north west courtyards which allow the north west wind to access, recorded the highest temperature and the highest wind speed. Thus, in this case the hot wind is not considered as a cooling modifier. Robitu et al. (2006) advised that to reduce the temperature of the hot air by allowing it to flow over cooling system like ponds and vegetation before entering the spaces to cool them down. Both Feroz (2015) and Robitu et al. (2006) explained that despite the fact that there is positive thermal effect for the vegetation scenarios in reducing the outdoor temperature but the quantity of this effect vary according to the characteristics of each one. Feroz (2015) added that by evapotranspiration of the water from leaves and stem and by taking the energy from the sun light and changing it to food, the vegetation can cool down the air.

6.3.6 Thermal comfort:

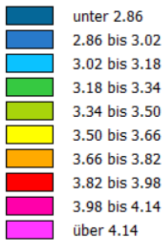
For evaluating the improvement of PMV for school UPA-fin through the process of modifying the courtyards design, there was simulation for the best five cases of stage two at 10:00 AM on 21st of September and 21st of March. The outdoor temperature on 21st of September was 32.5-35 ˚C while it was around 28.3-31.0 ˚C on 21st of March at 10 AM.

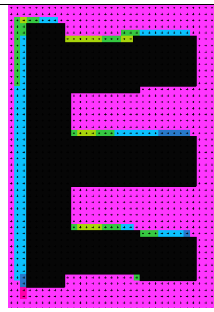
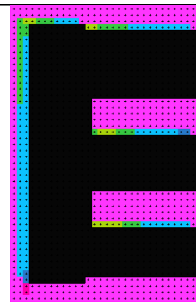
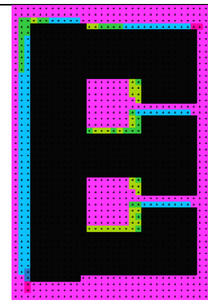
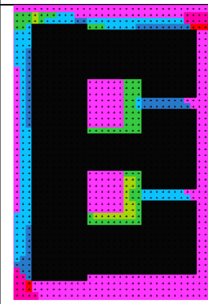
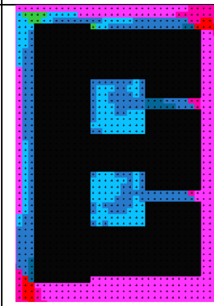
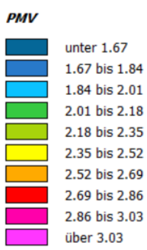
The results of the simulation revealed that the thermal comfort was improved by improving the design of the courtyard on both 21st of September and 21st of March. The improvements in the PMV sensation was insignificant by changing the courtyard design from phase one to phase two with CA/BA 20% (table 6.23). A similar situation was occurred when changing the courtyard outline to square in phase three as the PMV was improved, slightly.

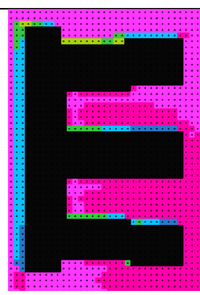
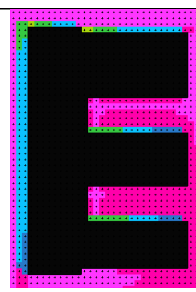
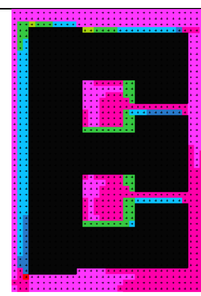
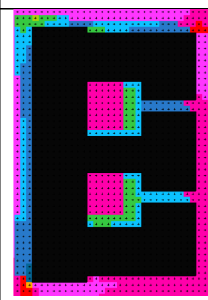
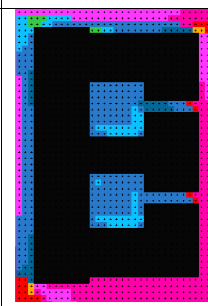
On 21st of September, the results showed that most of the courtyard spaces for phase one and two were uncomfortable with PMV amount around 4 because of the high solar radiation concentration in the courtyards. Moreover, less shaded areas due to the courtyards configurations and the low height of the surrounding masses in the first two phases caused long exposition to direct solar radiation which increased the air temperature, same results were found by Ghaffarianhoseini. , Berardi and Ghaffarianhoseini (2015) when they evaluated the thermal comfort of courtyards in hot areas of Malaysia, with area around 576m^2 and surrounded by one story masses, they explained that discomfort due to the low height of the masses around the courtyard, didn't help in avoiding the direct solar radiation.

Clear improvement was achieved in the readings of PMV for the courtyards of school UPA-fin when the height increased to 3F and when vegetation was added. When changing the height to 3F east mass the area with green color (3.18-3.34) was duplicated, especially in east and south sides of the courtyards. Moreover, new areas with PMV under 2.86 (warm) start to appear in relation to phase three on 21st of September. Ghaffarianhoseini, Berardi and Ghaffarianhoseini (2015) stated that increasing the height of the masses around the courtyards can decrease the SVF, thus blocking some the solar radiation and improving the thermal comfort. Alike situation happened on the 21st of March as UPA-fin with 3F east mass had more areas with PMV readings that ranges between (1.84-2.01) slightly warm and (2.01-2.18) warm respectively with green and blue color than the previous phases.

Table 6. 23: PMV readings for the best cases of the five phases of stage two at 10:00AM on 21st of September and 21st of March.

<table>
<tr><td>The key</td><td>Phase 1: W/L ratio 1:2.6</td><td>Phase 2: CA/BA ratio :20%</td><td>Phase 3: Courtyard square outline</td><td>Phase 4: Courtyard height : 3F east mass</td><td>Phase 5:Courtyard with Trees and grass</td></tr>
<tr><td>

PMV 21st September- 10AM</td><td>
Max PMV equals 4.35 covers 48% of the courtyards areas</td><td></td><td></td><td></td><td>
Max PMV equals 3.15 covers 1.5 % of the courtyards area</td></tr>
<tr><td>Average T_{in} on 21st of September</td><td>28.06 ˚C</td><td>27.88 ˚C</td><td>27.47 ˚C</td><td>26.88 ˚C</td><td>26.17 ˚C</td></tr>
<tr><td>

PMV 21st March -10 AM</td><td>
Max PMV equals 3.0 and covers 48% of the courtyards area</td><td></td><td></td><td></td><td>
Max PMV equals 1.9 and covers 1.5% of the courtyards area</td></tr>
<tr><td>Average T_{in} on 21st of March</td><td>23.8 ˚C</td><td>23.62 ˚C</td><td>23.3 ˚C</td><td>22.76 ˚C</td><td>22.12 ˚C</td></tr>
</table>

The significant improvements were in phase five on both dates of simulation by adding vegetation, as on the 21st of September most of the courtyards' areas become with PMV readings 2.82-3.02 and below with places transformed to be warm from hot according to PMV scale, while in the first phase most of the courtyard area was above 4 (very hot) based on PMV scale. Based on that and on 21st of September the max PMV reading for the poorest case of stage two equals 4.35 which covers 48% of the courtyards areas, while the max PMV reading for the best case of stage two (phase five) equals 3.15 and covers 1.5 % of the courtyards area with reduction about 1.2 on PMV scale .

Similar to that situation that happened on 21st of March, as significant improvements occurred in phase five by adding vegetation. Most of the courtyards places transformed from warm to be slightly warm with readings around 1.67 based on PMV scale, while in the first phase most of the courtyards' areas were between 2.86-3.03 (warm and hot) based on PMV scale. Safarzadeh and Bahadori (2005) insisted that adding vegetation will improve the outdoor thermal performance of the courtyard more than adopting design strategies alone without vegetation..Makaremiet al. (2012) advised to integrate trees and plants in the outdoor spaces to improve their thermal comfort. Ghaffarianhoseini, Berardi and Ghaffarianhoseini (2015) stated that even though the trees may reduce the wind speed and reduce the long wave radiation, trees can improve the thermal comfort more than the grass alone.

In conclusion, it was clear that whenever the design of the courtyard improved to reduce the indoor temperature, automatically the outdoor microclimate of the courtyard improved. As the best case of stage five with optimum courtyards design and with least average T_{in} was in the school UPA-fin with vegetation, and that was the same case for the best PMV performance on both dates of simulation.

Makaremiet al. (2012) stated that even though high readings for the PMV can be recorded in the courtyards in hot areas like Malaysia, still a lot of the users feel that the courtyards are thermally comfortable due to their psychosomatic adaptation. They explained that because people in hot areas are more accepting to a warm thermal atmosphere than other people in areas with lower temperature because of their expectations related to extreme hot areas like monsoon province in Malaysia.

Based on the PMV and the T_{in} investigations in stage two it was clear that there is strong connection between the outdoor thermal comfort and the indoor temperature, thus the enhancement in courtyard design produces better outdoor thermal comfort in the courtyard and reduction in the indoor average temperature.

6.4 Stage three: Energy consumption, Simulation and discussion

The simulation for energy consumption was conducted by IESve software. The models for the best case of stage one beside the best five school buildings cases of stage two were imported as 3D from sketch up and then improved by adding more details for the structural elements materials in IESve software. Then the location of the school buildings was defined in UAE to load their climates from APlocate. After that the sun cast analysis was conducted for the models to investigate the solar analysis for the shading to estimate the amount of reduction of heat gain due to the shading according to the improvements on the models in relation to the phases in stage two. The thermal analysis of cooling plant sensible load was calculated from ASHRAE wizard after modifying the weather according to the new microclimate data from ENVI-met software. The modification on the climates were to highlight the new microclimates according to the, orientation, shape factor, CA/BA ratio, outline courtyard shape, courtyard height and finally vegetation in the courtyard (according to 6.4.1 section). The modification was on the ASHRAE weather section because this application has the ability to change according to the modified weather data which is related to the new micro climates according to the peak days. Vista application was used to view the results as this application is capable of illustrating and comparing the results for all the analyses.

6.4.1 Climate and microclimate data for UPA-fin school

Understanding the influence of the micro-climate conditions which was created according to the courtyard improvements in the school building is important before calculating the energy consumption, as Cantón et al. (2014) insisted that the courtyard can create microclimate around the building which can positively affect the internal space of it. This microclimate will differ from the original country climate. Thus, the performance of the energy consumption of the school building in the IESve should be calculated according to the microclimate. "*The configuration of buildings, their location and organization form a unique microclimate at each site. A cluster of buildings, together with urban surroundings such as green areas or traffic infrastructure, form an even more complex and dynamic organism. This includes building materials, surface textures and colors that are exposed to the sun, and the design of open spaces like squares, shopping streets, gardens and roads*" (ENVI_MET 2018). Based on that there will be coupling between ENVI-met software as microclimate software and IESve as a dynamic energy software to predict the cooling energy in this research.

The recommended UPA-fin school building geometry in this research evolved after developing the courtyard characteristics, which went through two stages and tested by ENVI-met software including: orientation, CA/BA ratio, courtyard outline, courtyard height and finally vegetation. The thermal comfort in each stage was improved by reducing the indoor air temperature of the school building as it was in each stage less and better than the previous one until the fifth stage with the optimum courtyard. The reduction in the indoor temperature was because of the developments on the courtyard, and because of the new microclimates which was created according to the courtyard design at that stage, which is expected to reduce the energy consumption for the building. In order to conduct the building energy-performance analysis and highlight the energy consumption savings it was necessary to present two types of climate data for the two dates of simulation which are 21st of September and 21st of March:

1- The first type is, general climate data: the standard ASHRAE weather data for Dubai /UAE from the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). This data was gathered form the local weather stations according to observations for many years (synoptic data), this data mainly was gathered in the countryside or in the airport weather station, which might vary from air temperature in the compacted cities (Sharmin and Steemers 2015).

2- The second type is the new private microclimate data calculated by ENVI-met. Assigning the microcline date for the best models in the five stages required locating six points (receptors) in each model in critical positions around the school buildings and inside the courtyards as in table (6.24). This method was used by Sharmin and Steemers (2015) as they located points to design the new microclimate for the buildings in their research from the simulation by ENVI-met software. A weighted average calculation based on the walls area and the nearest receptors was used to calculate and design the microclimate of the school buildings in each stage (Appendices 3&4) to highlight the maximum and the minimum new temperatures for the new microclimates on both dates of simulation. It was noticed that about o.74-1.45 ˚C reduction in the air-temperature in the microclimate of the school buildings compared to the standard climate in IES-ve on 21st of September as in table (6.25) and table (6.26) and figure (6.23) and figure (6.24). Moreover, the reduction was about 0.5-1.4˚C lower on the 21st of March table (6.27) and table (6.28) and figure (6.25) and figure (6.26).

Table 6. 24: The receptor points for the UPA-fin schools used to calculate the microclimate for each case in the five phases in ENVI-met software.

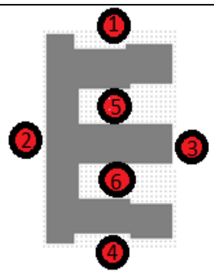
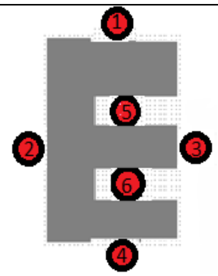
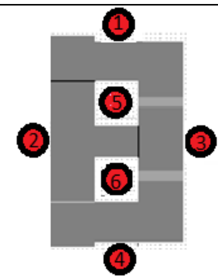
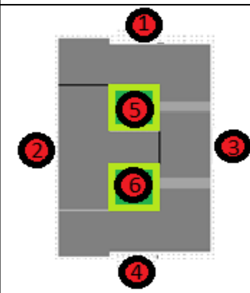
Phase 1: W/L ratio 1:2.6	Phase 2: CA/BA ratio :20%	Phase 3: Courtyard square outline	Phase 4: Courtyard height :3F east mass	Phase 5: Courtyard with trees and grass
				

Table 6. 25: Average air temperature for the micro climate for UPA-fin schools from the six receptors points on the 21st of September within schooling time.

Time	Phase 1: W/L 1:2.6	Phase 2: CA/BA ratio :20%	Phase 3: Courtyard square outline	Phase 4: Courtyard height :3F east mass	Phase 5: Courtyard with trees and grass	General climate from IES
7:00 AM	25.88	25.94	25.99	26.03	26.16	25.3
8:00 AM	28.03	28.05	28.16	28.07	28.22	28
9:00 AM	30.52	30.51	30.57	30.42	30.48	31
10:00 AM	32.12	32.07	32.08	31.90	31.87	32.5
11:00 AM	34.19	34.14	34.03	33.83	33.73	35
12:00 PM	36.08	36.01	35.80	35.59	35.46	37
1:00 PM	37.45	37.37	37.11	36.88	36.82	38.3
2:00 PM	38.26	38.18	38.10	37.90	37.55	39

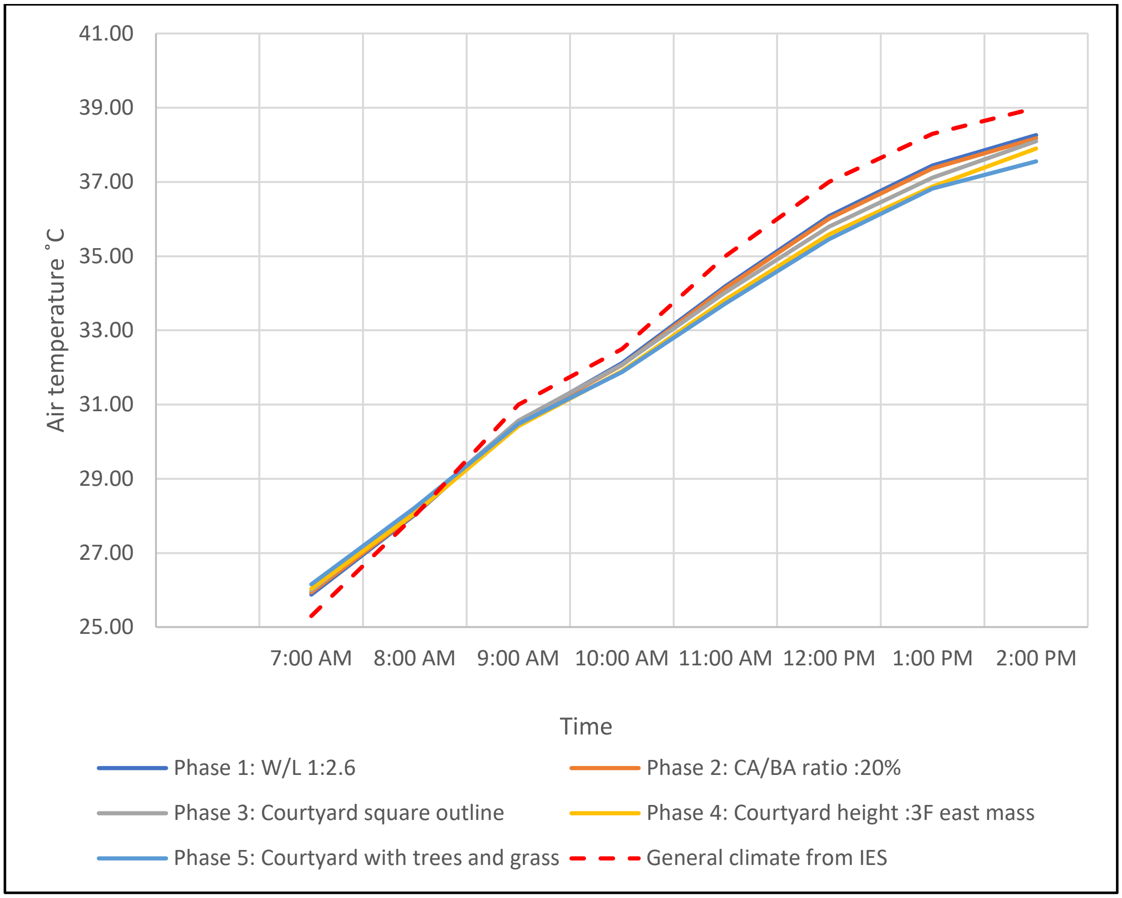


Figure 6. 23: Average air temperature from the receptor points for the UPA-fin schools and the average air temperature from IES-ve software on the 21st of September.

Table 6. 26: Comparison between max average air temperature around the schools UPA-fin with the max air temperature from the general climate from IESve on 21st of September.

School type	Max air temperature on 21st of September	Difference between max air temperature from ENVI-met and climate from IES on 21st of September (39˚C)
Phase 1: W/L ratio 1:2.6	38.26	0.74
Phase 2: CA/BA ratio :20%	38.18	0.82
Phase 3: Courtyard square outline	38.10	0.90
Phase 4: Courtyard height :3F east mass	37.90	1.10
Phase 5: Courtyard with trees and grass	37.55	1.45

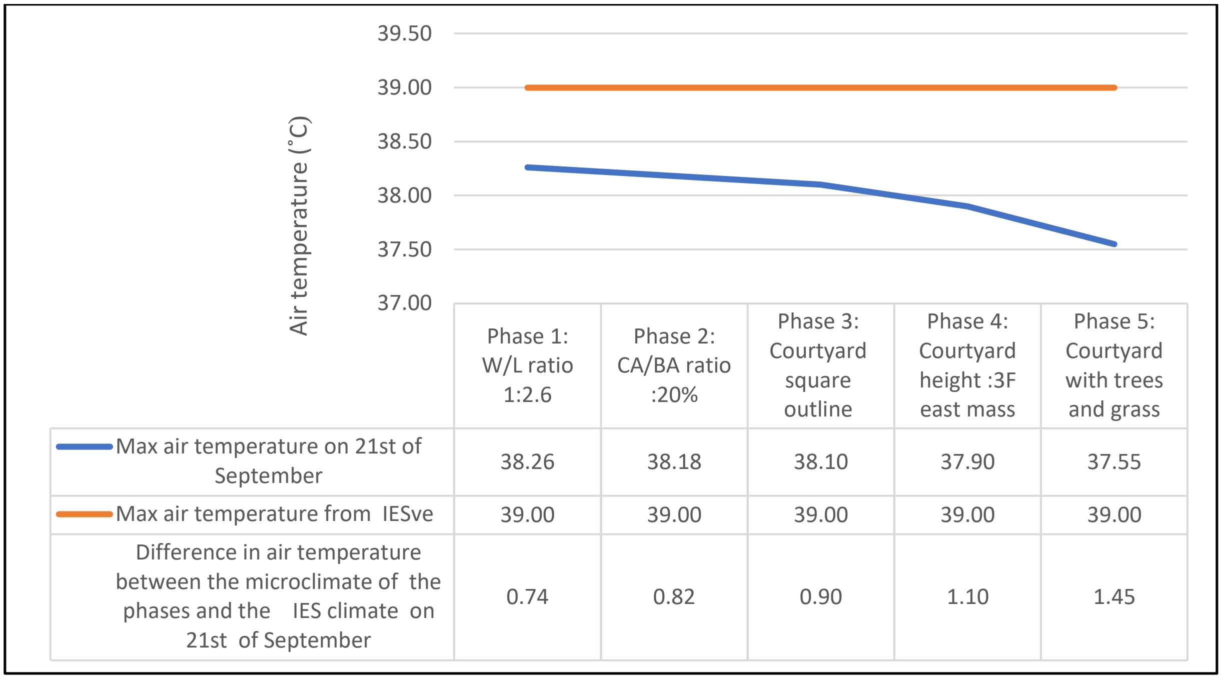


Figure 6. 24: The relationship between the max average air temperature for the schools UPA-fin from ENVI-met with the max average air temperature from the general climate from IES-ve on 21st of September.

Table 6. 27: Average air temperature for the micro climate for UPA schools from the six receptors points on the 21st of March within schooling time.

Time	Phase 1: W/L Ratio 1:2.6	Phase 2: CA/BA ratio :20%	Phase 3: Courtyard square outline	Phase 4: Courtyard height :3F east mass	Phase 5: Courtyard with trees and grass	General climate from IES
7:00 AM	18.41	18.45	18.51	18.66	18.55	17.80
8:00 AM	20.94	20.95	20.97	20.92	20.69	21.00
9:00 AM	24.57	24.58	24.50	24.33	24.13	26.00
10:00 AM	26.95	26.93	26.82	26.59	26.41	28.30
11:00 AM	29.45	29.42	29.26	29.00	28.81	31.00
12:00 PM	30.85	30.78	30.61	30.32	30.17	32.00
1:00 PM	29.27	29.08	28.99	28.68	28.61	28.30
2:00 PM	31.10	31.01	30.83	30.53	30.35	32.00

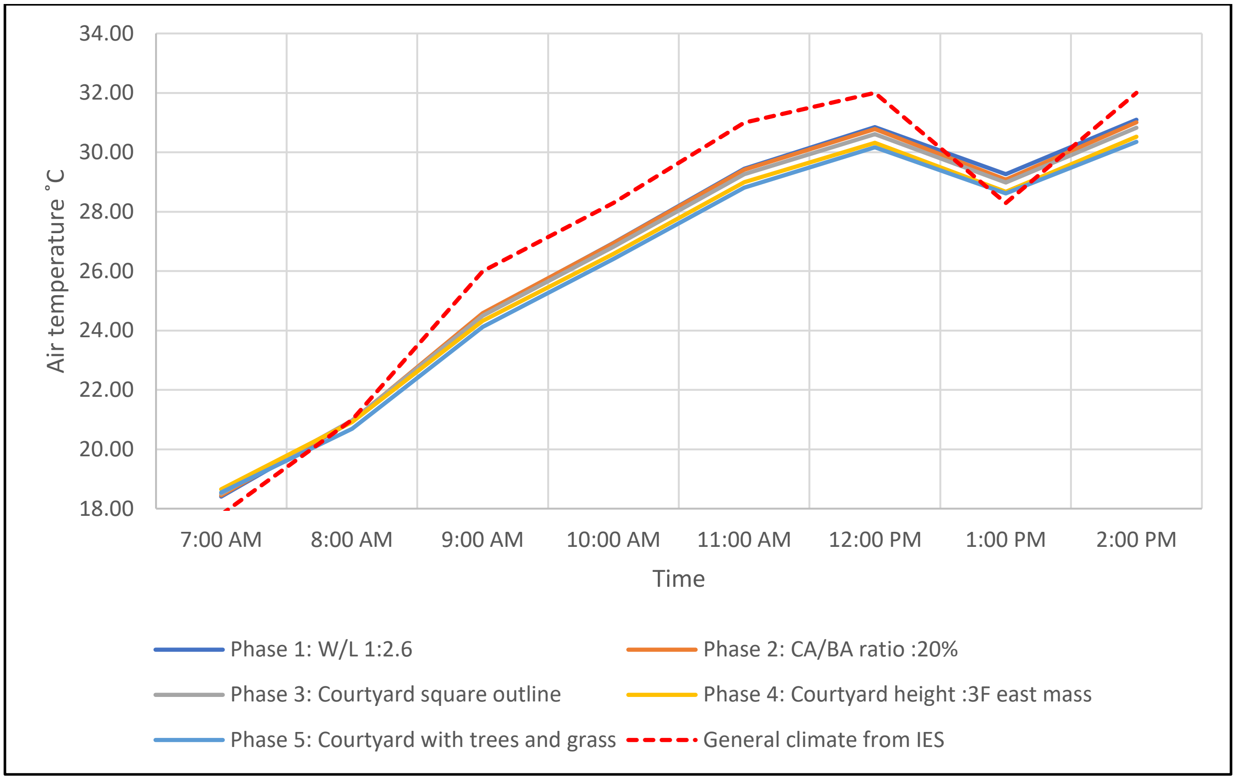


Figure 6. 25: Average air temperature from the receptor points for the UPA schools and the average air r temperature from IESve software on the 21st of March.

Table 6. 28: Difference between the max average air temperature for the UPA-fin schools on 21st of March with the max air temperature from the general climate from IESve.

School type	Max air temperature on 21st of March	Difference between max air temperature from ENVI-met and climate from IES on 21st of March (32˚C)
Phase 1: W/L ratio 1:2.6	31.5	0.5
Phase 2: CA/BA ratio :20%	31.3	0.7
Phase 3: Courtyard square outline	31.2	0.8
Phase 4: Courtyard height :3F east mass	30.9	1.1
Phase 5: Courtyard with trees and grass	30.6	1.4

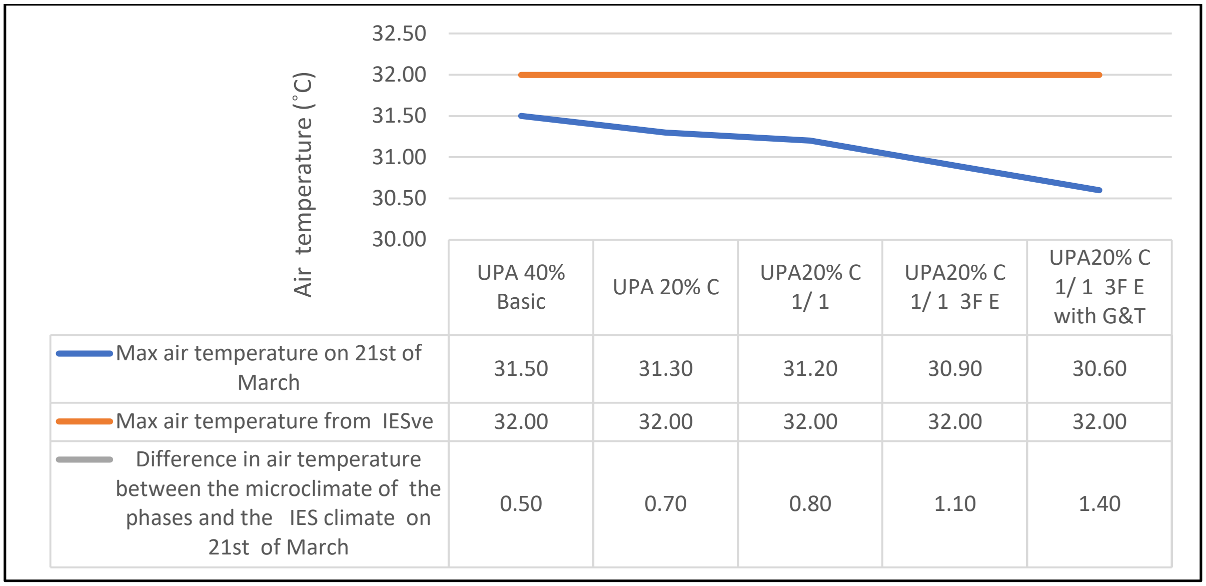


Figure 6. 26: The relationship between the max average air temperature for the UPA-fin schools with the max average air temperature from the general climate from IESve on 21st of March.

6.4.2 Modeling and construction materials in IESve

The model of the poorest case of stage one, which was school KAT to the west (table 6.29), and the best five cases for UPA-fin school buildings of stage two (table 6.30) were imported to IESve software as 3D from sketch up according to real dimensions. The worst case of stage one which was school KAT to the west direction was chosen in stage three to calculate its cooling energy to adopt it as reference point to estimate the amount of energy reduction through all the research improvements on the courtyard design and orientation for the school buildings. The best five cases for school buildings of stage two were:

- UPA-fin with W/L ratio 1:2.6 as the best case of phase one.
- UPA-fin with CA/BA ratio 20% as the best case of phase two.
- UPA-fin with square courtyard outline as the best case of phase three.
- UPA-fin with 3Floors for the east mass as the best case of phase four and.
- UPA-fin with trees and grass as the best case of phase five.

These models were chosen because they show the systematic positive effect of the courtyard design on the indoor temperature as shown by the ENVI-met results. Thus, it was important to evaluate and compare their energy consumption for cooling in the IESve as a proof of the reduction of the cooling energy according the modifications on the courtyards design phase by phase.

Table 6. 29: The poorest case of stage one school KAT to west.

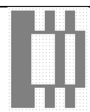
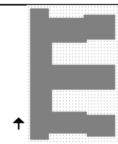
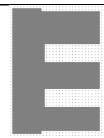
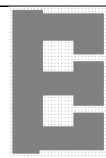
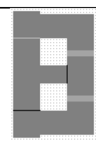
Stage One	Top view for worst case School	School investigation result	The built up area - m^2	Number of floors	Total built up area - m^2	Average T_{in} ˚C on 21st of September	Average T_{in} ˚C on 21st of March
Section one :		The poorest case School KAT to the west	3384	2	6768	29.75	25.58

Table 6. 30: The best five cases of the five phases of stage two for school UPA-fin to the north.

Stage two	Investigation field	Top view for best case	The built up area - m^2	Number of floors	Total built up area - m^2	Average Tin ˚C on 21st of September	Average Tin ˚C on 21st of March
Phase 1	Shape factor: W/L ratio 1:2.6		6750	2	13500	28.06	23.80
Phase 2	CA/BA ratio :20%		8046	2	16092	27.88	23.62
Phase 3	Courtyard outline : square		8091	2	16182	27.47	23.30
Phase 4	Courtyard walls height : 3F east mass		8415	3	22824	26.88	22.76
Phase 5	Courtyard with vegetation Trees and grass		8415	3	22824	26.17	22.12

After the models were imported to IESve, they were improved by adding more details for the construction materials for the walls, roofs, grounds and openings, which were unified for all the case studies as in tables (6.31; 6.32;6.33;6.34). Therefore, the thickness and the u values for the construction material for all school cases were unified as well. Thus, the construction materials and their properties were considered as fixed parameters. Figure (6.27) is an example for one model of the school buildings which was UPA-fin 3F east mass with vegetation with its new setting in IESve.

Table 6. 31: Construction materials for the walls in IESve.

Material	Thickness mm	Conductivity W/(m·K)	Density kg/m³	Specific Heat Capacity J/(kg·K)	Resistance m²K/W	Vapour Resistivity GN·s/(kg·m)	Category
[USPM0000] CEMENT PLASTER - SAND AGGREGATE (ASHRAE)	5.0	0.7200	1860.0	800.0	0.0069	140.000	Plaster
[EPSL] Expanded polystyrene (CIBSE)	50.0	0.0350	25.0	1400.0	1.4286	200.000	Insulating Materials
[VIBR] VERMICULITE INSULATING BRICK	200.0	0.2700	700.0	837.0	0.7407	38.000	Brick & Blockwork
[VPL] VERMICULITE PLASTERING	5.0	0.2000	720.0	837.0	0.0250	10.000	Plaster

Table 6. 32: Construction materials for the grounds in IESve.

Material	Thickness mm	Conductivity W/(m·K)	Density kg/m³	Specific Heat Capacity J/(kg·K)	Resistance m²K/W	Vapour Resistivity GN·s/(kg·m)	Category
[STD_PH1] Insulation	98.2	0.0250	700.0	1000.0	3.9280	-	Insulating Materials
[STD_CC2] Reinforced Concrete	100.0	2.3000	2300.0	1000.0	0.0435	-	Concretes
[CT] CONCRETE TILES	20.0	1.1000	2100.0	837.0	0.0182	500.000	Tiles

Table 6. 33: Construction materials for the roofs in IESve.

Material	Thickness mm	Conductivity W/(m·K)	Density kg/m³	Specific Heat Capacity J/(kg·K)	Resistance m²K/W	Vapour Resistivity GN·s/(kg·m)	Category
[STD_PHF] Insulation	5.0	0.0300	40.0	1450.0	0.1667	-	Insulating Materials
[STD_MEM] Membrane	0.1	1.0000	1100.0	1000.0	0.0001	-	Asphalts & Other Roofing
[STD_CC1] Concrete Deck	100.0	2.0000	2400.0	1000.0	0.0500	-	Concretes
[STD_US5] Plasterboard	12.5	0.2100	700.0	1000.0	0.0595	0.000	Plaster

Table 6. 34: Construction materials for the openings in IESve.

Material	Thickness mm	Conductivity W/(m·K)	Angular Dependence	Gas	Convection Coefficient W/m²·K	Resistance m²K/W	Transmittance	Outside Reflectance	Inside Reflectance	Refractive Index	Outside Emissivity	Inside Emissivity	Visible Light Specified
[CF6] CLEAR FLOAT 6MM	6.0	1.0600	Fresnel	-	-	0.0057	0.780	0.070	0.070	1.526	-	-	No

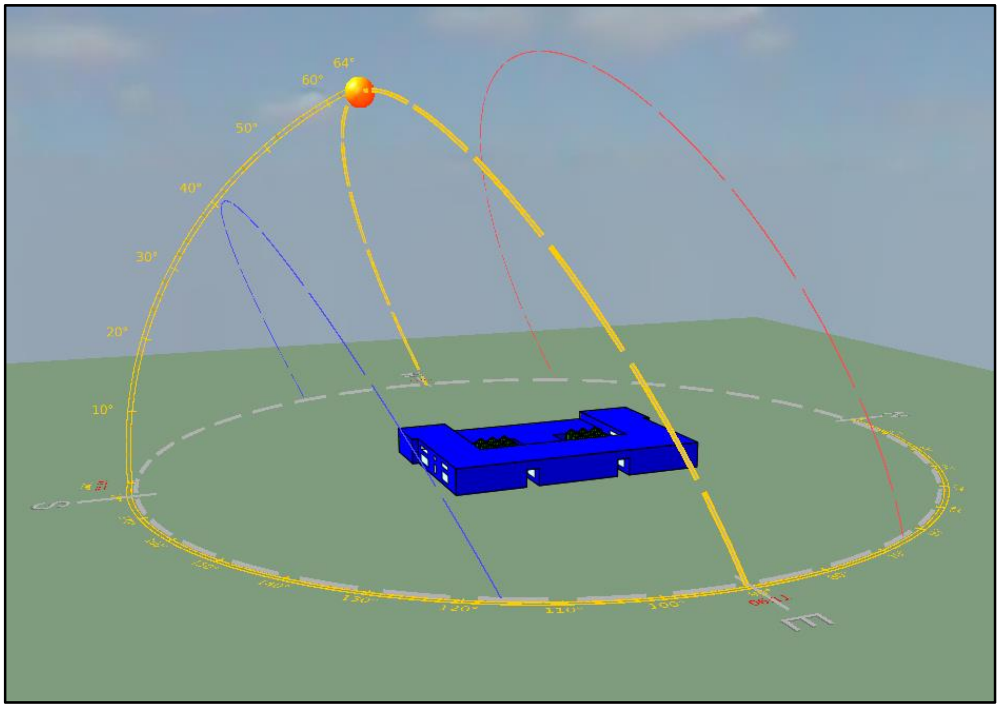


Figure 6. 27: UPA-fin 3F east mass with vegetation with its new setting in IESve on 21st of September.

6.4.3 Simulation dates and daily profile and occupancy in IESve

The simulation for the energy consumption was for two dates which are 21st on September and 21st of March are the same simulation dates in ENVI-met. The reason behind choosing these dates is that they have new microclimatic data based on the ENVI-met outcomes because of the orientation and design modifications. To calculate the energy consumption for cooling, the school buildings were assumed to be occupied within the schooling time only (7:00 AM - 2:00 PM). This usage profile was added to the IESve software as daily profile, figure (6.28). Based on that, the air conditioning system was assumed to work continuously to keep the thermal comfort suitable for the occupants according to set point temperature in the IESve which was 23 ˚C; El-Deeb, Sherif & El-Zafarany (2014) used 23 ˚C as a set point when calculating the cooling load for buildings with courtyards and buildings without courtyards.

The internal heat gain for the schools was the resultant of two sources. The first source was the florescent lighting and the second source was the students. The students' occupancy for the schools was proportional in relation to the number of classrooms in each school. Each classroom can serve 20-30 students (Daikin Applied, 2014), based on that the average number for each classroom with

25 students was adopted for the energy calculations. For example, the original school UPA-fin in the first phase has 30 classrooms, thus can serve 750 students in average and the KAT school has 24 classrooms, and it can serve 600 students in average, the number of students was calculated according to the number of estimated classrooms.

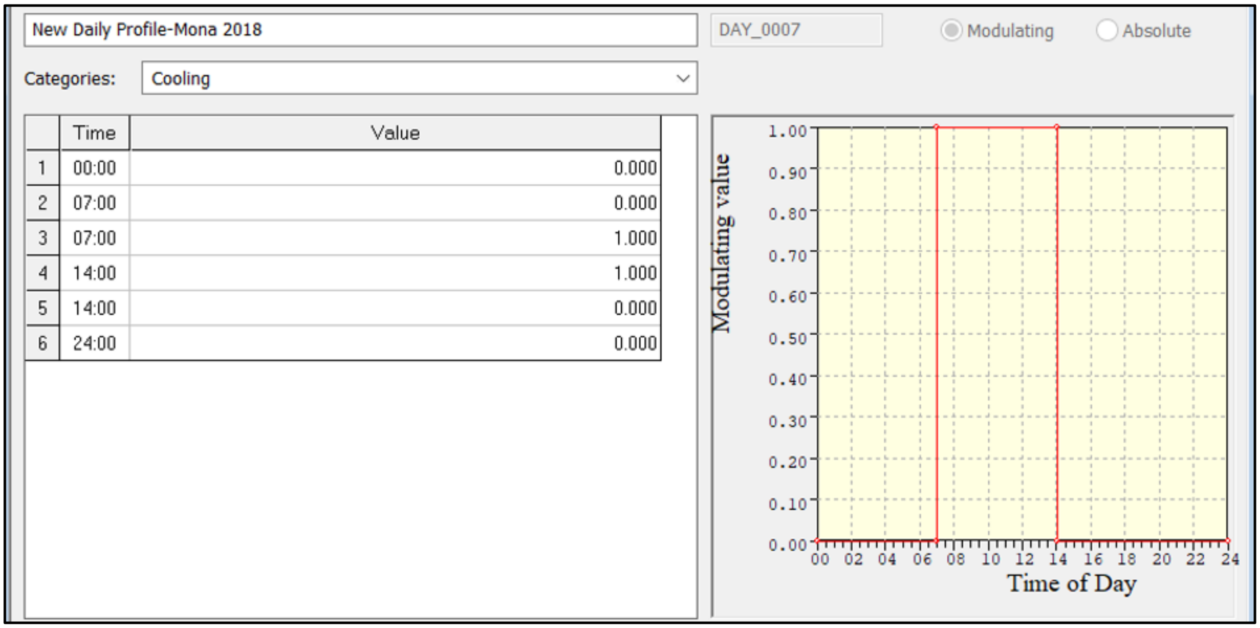


Figure 6. 28: Daily profile for cooling in IESve for the schools.

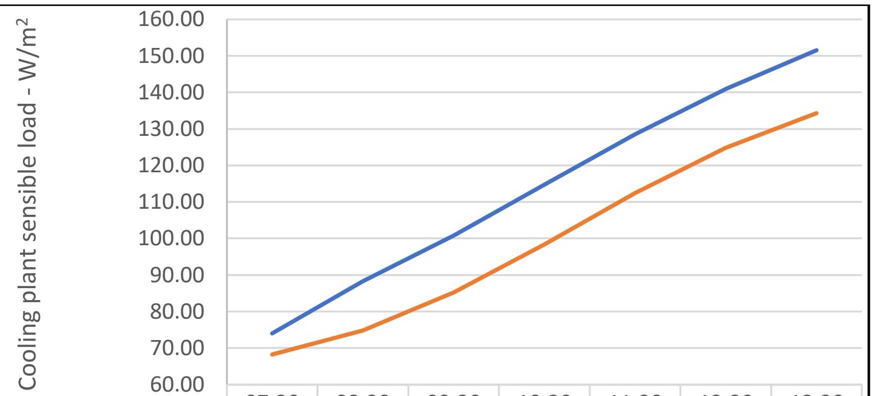
6.4.4 Energy consumption simulation (new microclimate from ENVI-met)

For evaluating the improvement in energy consumption for school UPA-fin through the process of modifying the courtyards design, there was simulation for the poorest case of the stage one and the five best cases of the five phases of stage two on 21st of September and 21st of March. The reference indication which was used for showing the energy consumption was cooling plant sensible load as "*Room cooling plant sensible load: The sum of the room cooling plant sensible loads for all rooms in the building"* according to IESve definitions guide. Many researchers used cooling plant sensible load as an indication for cooling load and Energy consumption of buildings. El-Deeb, Sherif and El-Zafarany (2014) used the cooling load as reference to evaluate the energy consumption for cooling for solid buildings and buildings with courtyards. Salameh and Taleb (2017) who used cooling plant sensible load as a sign for cooling energy consumption for a school in UAE. Sharmin and Steemers (2015) used cooling plant sensible load as W per hour to represent the reduction of in the energy use for cooling in different types of courtyard buildings.

6.4.4.1 Energy consumption and orientation

This part of energy simulation was to validate the results of stage one which investigated the courtyards types and orientation of the five case studies. The simulation results revealed that the cooling load can be reduced according to the type and the orientation of the courtyards of the school building on both dates 21st of September and 21st of March.

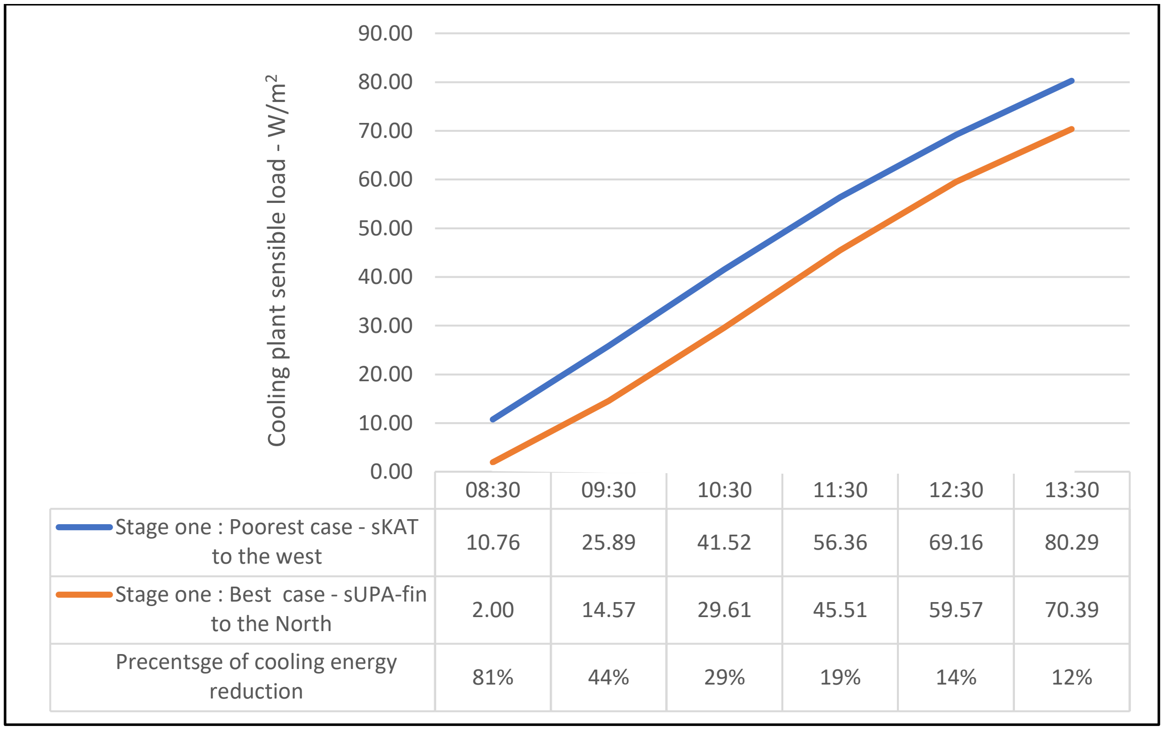
On the 21st of September (figure 6.29) the hourly cooling plant sensible load for the worst case of stage one which was KAT to the west was reduced to around 92% in the morning and to around 89% in the peak time at 1:30 PM by choosing another school which was UPA-fin to the north direction. As at the peak time, the cooling load for school KAT to the west was around 151.53W/m^2, while it was only 134.27 W/m^2 only for the school UPA-fin to the north.



	07:30	08:30	09:30	10:30	11:30	12:30	13:30
Stage one : Poorest case - sKAT to the west	74.01	88.23	100.81	114.72	128.51	140.91	151.53
Stage one : Best case - sUPA-fin to the North	68.26	74.84	85.25	98.35	112.44	124.86	134.27
Precentsge of cooling energy reduction	8%	15%	15%	14%	13%	11%	11%

Figure 6. 29: Cooling plant sensible load for the best and the poorest case of stage one on 21st of September.

On 21st of March (figure 6.30) the reduction of the cooling load varied more during the schooling time from 7:00AM-2:00 PM. The UPA-fin to the north as the best case have 19% and 88% of the cooling plant sensible load of school KAT to the west as the worst case in the morning at 8:30AM and afternoon at 1:30 PM, respectively.



	08:30	09:30	10:30	11:30	12:30	13:30
Stage one : Poorest case - sKAT to the west	10.76	25.89	41.52	56.36	69.16	80.29
Stage one : Best case - sUPA-fin to the North	2.00	14.57	29.61	45.51	59.57	70.39
Precentsge of cooling energy reduction	81%	44%	29%	19%	14%	12%

Figure 6. 30: Cooling plant sensible load for the best and the poorest case of stage one on 21st of March.

The results of the daily simulation revealed that the energy consumption was improved according to the type and orientation of the courtyards of the school building on both dates 21st of September and 21st of March. On 21st of September (figure 6.31) the daily cooling plant sensible load for the best case of stage one which was school UPA-fin to the North was only 87% of the load of the poorest case of stage one which was school KAT to the west. As UPA-fin to the north has only 698.27 Wh/m^2 cooling plant sensible load, while school KAT to the west as poorest scenario has 798.73 Wh/m^2. On 21st of March (figure 6.32) UPA-fin school has 221.65 Wh/m^2 as daily cooling plant sensible load while it was 283.99 Wh/m^2 for school KAT. This reduction in the load was only by choosing the best school type and direct it to the best orientation without any improvements in the courtyard's design.

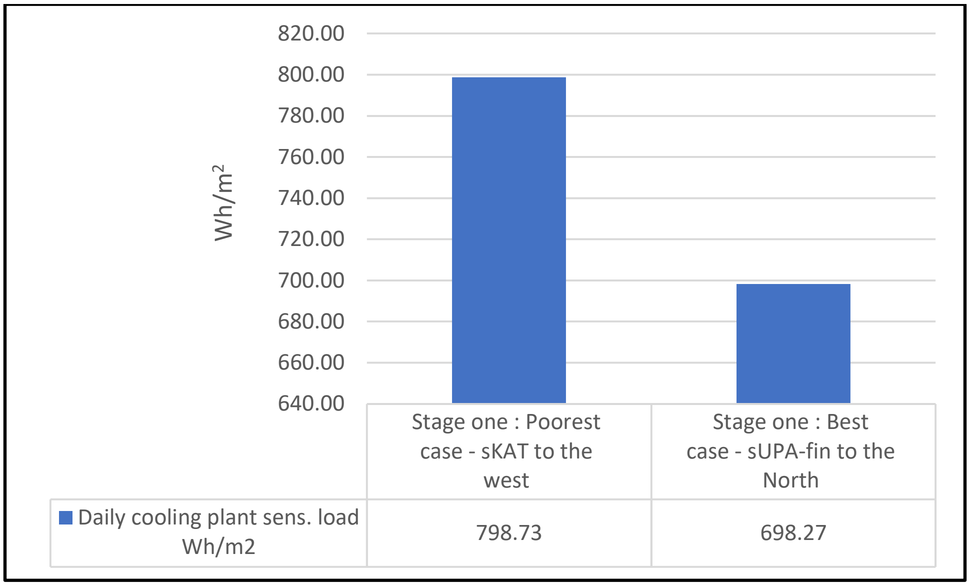


Figure 6. 31: Daily cooling plant sensible load for the best and the poorest case of stage one on 21st of September.

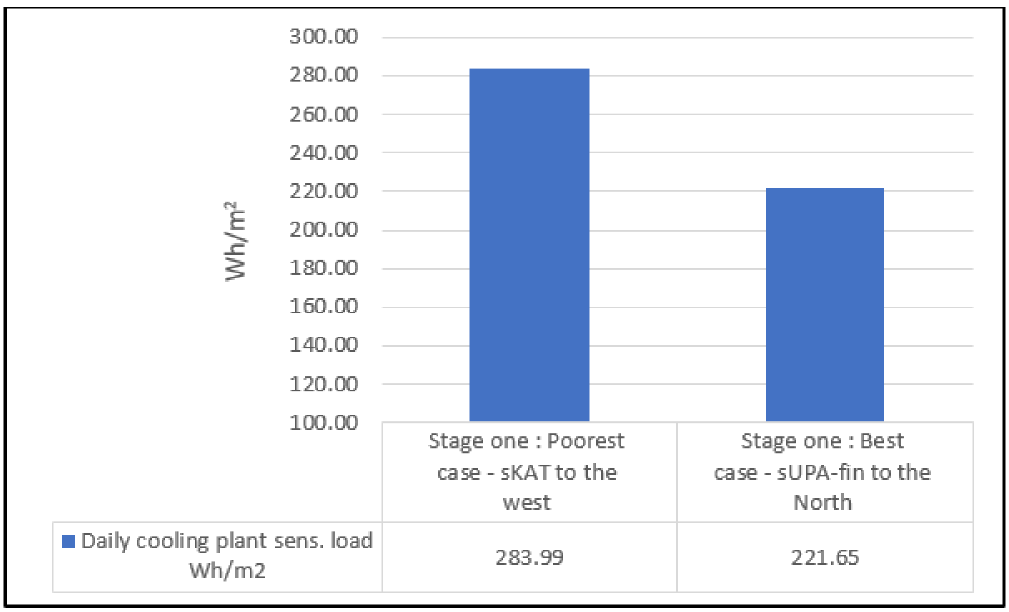


Figure 6. 32: Daily cooling plant sensible load for the best and the poorest case of stage one on 21st of March.

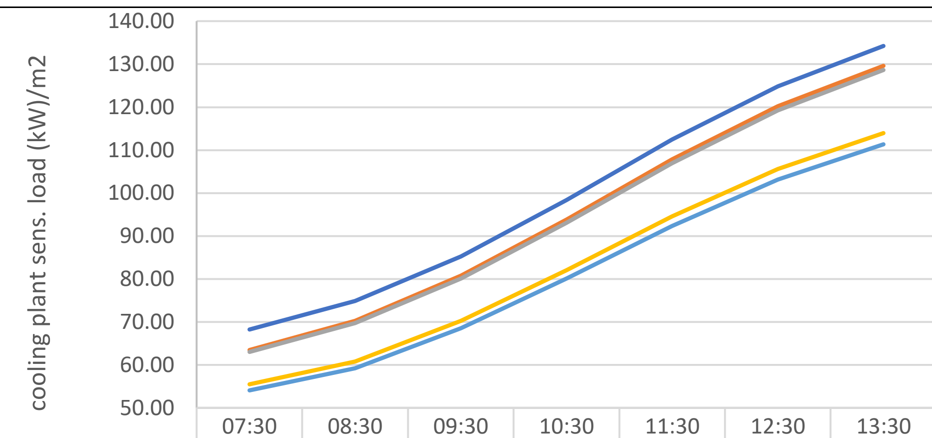
6.4.4.2 Energy consumption and courtyard design

The results of the simulation revealed that the cooling plant sensible load was decreased for school UPA-fin by improving the design of the courtyard throughout the phases of stage two on both dates 21st of September and 21st the temperature of March but in different levels.

On 21st of September as in figure (6.33) it was found that school UPA-fin in phase one has cooling plant sensible load about 134.27 W/m^2 at 1:30PM and changing the CA/BA ratio to 20% in the second phase reduced the cooling plant sensible load to 129.60 W/m^2, accordingly the cooling load was reduced to 97% according to the improvements in phase two.

Moreover, adding another floor in the school UPA-fin 3F east mass in phase four was able to reduce the hourly cooling plant sensible load to 87-88 % of the one with square outline in phase three according to the time, based on that and at the peak time the cooling plant sensible load was reduced from 128.65 W/m^2 to 113.95 W/m^2 at 1:30PM. The smallest reduction was when adding the greenery in phase five as it was about 2.3% only.

Based on the previous, the total reduction in the cooling plant sensible load was reduced to 79-83% W/m^2 by applying modifications strategies on school UPA-fin from the first phase to the fifth phase on 21st of September.

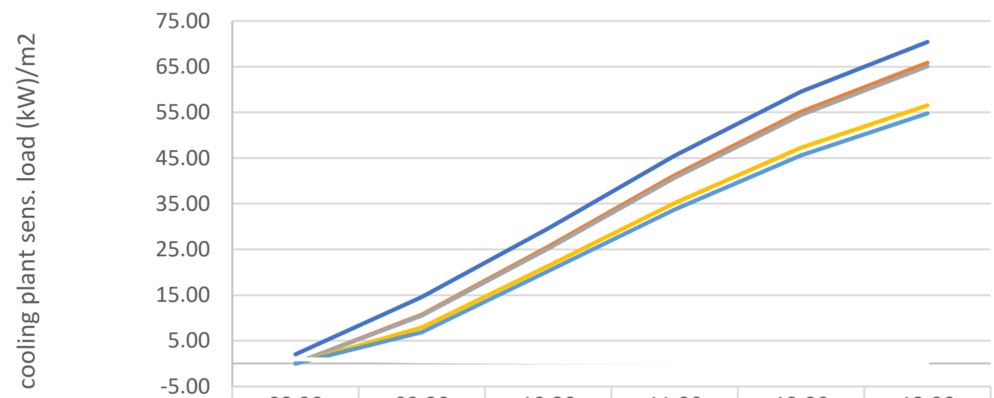


	07:30	08:30	09:30	10:30	11:30	12:30	13:30
Phase one: W/L ratio 1:2.6	68.26	74.84	85.25	98.35	112.44	124.86	134.27
Phase two: CA/BA ratio 20%	63.49	70.23	80.74	93.81	107.83	120.20	129.60
Phase three: square outline	62.99	69.73	80.12	93.07	106.97	119.25	128.65
Phase four: 3F east mass height	55.48	60.75	70.25	82.01	94.56	105.59	113.95
Phase five: with trees and grass	54.06	59.23	68.54	80.06	92.36	103.15	111.35
Precentage of reduction of cooling load in the fifth phase compared to the first phase	21%	21%	20%	19%	18%	17%	17%

Figure 6. 33: Hourly cooling plant sensible load for the best cases of the five phases of stage two on 21st of September

On 21st of March as in figure (6.34) it was found that changing the CA/BA ratio to 20% for the school UPA-fin in the second phase reduced the hourly cooling plant sensible load to 47-88% W/m^2 of the load for UPA-fin school in phase one during the schooling time. Moreover, adding another floor in the school UPA-fin 3F east mass in phase four was able to reduce the hourly cooling plant sensible load to 75-87% of the one with square outline in phase three according to the time of the schooling day. At peak time, the cooling plant sensible load was reduced from 65.10 W/m^2 to 56.57 W/m^2 at 1:30PM by adding third floor. The reduction related to adding the greenery was about 14% at 9:30AM and then it was reduced to only 5% only at noon when the temperature becomes higher to reach 32.9˚C as outdoor temperature.

The total reduction in the cooling plant sensible load was around 53% in the morning at 9:30AM and dropped to become 22% at noon at 1:30 PM, and that by applying modifications strategies on school UPA-fin from the first phase to the fifth phase on 21st of March.



	08:30	09:30	10:30	11:30	12:30	13:30
Phase one: W/L ratio 1:2.6	2.00	14.57	29.61	45.51	59.57	70.39
Phase two: CA/BA ratio 20%	0.09	10.71	25.58	41.27	55.16	65.88
Phase three: square outline	0.06	10.49	25.20	40.70	54.43	65.10
Phase four: 3F east mass height	0.00	7.93	21.40	35.17	47.26	56.57
Phase five: with trees and grass	0.00	6.88	20.25	33.75	45.62	54.75
Precentage of reduction of cooling load in the fifth phase compared to the first phase	100%	53%	32%	26%	23%	22%

Figure 6. 34: Hourly cooling plant sensible load for the best cases of the five phases of stage two on 21st of March.

On 21st of September figure (6.35) illustrates the daily cooling plant sensible load for the best cases of the five phase of stage two. Based on that, the daily cooling plant sensible load was 698.27 Wh/m^2 for UPA-fin school from phase one with W/L ratio 1:2.6, 665.91 Wh/m^2 for UPA-fin school from phase two with CA/BA ratio 20%, 660.78 Wh/m^2 for UPA-fin school from phase three with square outline, 582.59 Wh/m^2 for UPA-fin school from phase four with 3F east mass height and finally 568.76 Wh/m^2 for UPA-fin school from phase five with trees and grass. The total average reduction in the cooling plant sensible load was about 19 % by adding trees and grass to school UPA-fin in the fifth phase compared to the first phase with 1:2.6 W/L ratio.

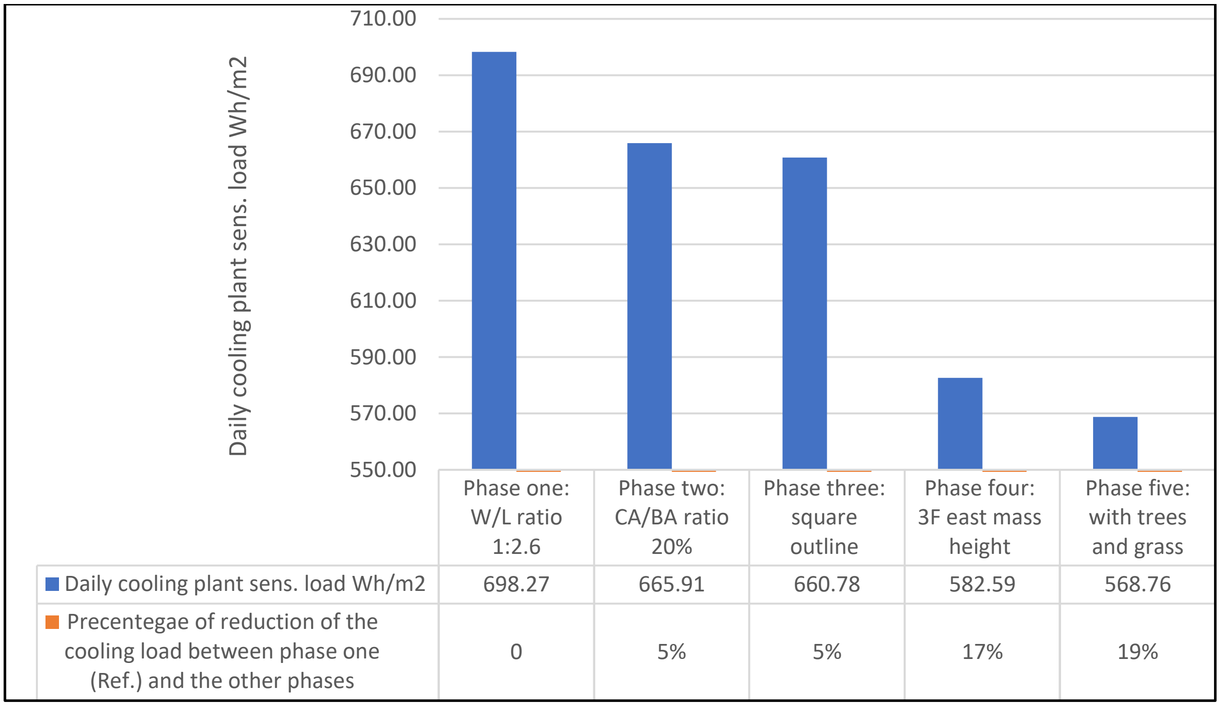
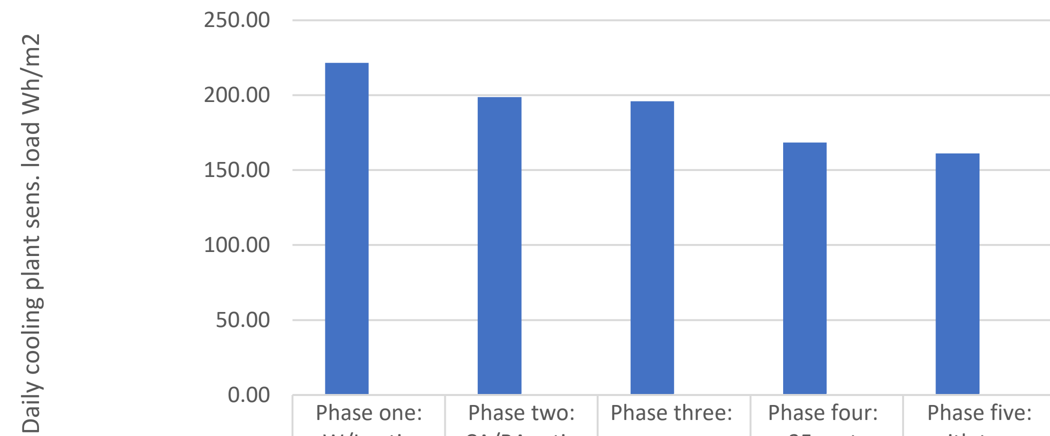


Figure 6. 35: Daily cooling plant sensible load for the best cases of the five phases of stage two on 21^{st} of September.

On 21^{st} of March similar reductions on the cooling plant sensible load parallel to the design improvements in the five stages of stage two as in figure (6.36). Based on that the cooling plant sensible load was 221.65 Wh/m^2 for UPA-fin school from phase one with W/L ratio 1:2.6, 198.70 Wh/m^2 for UPA-fin school from phase two with CA/BA ratio 20%, 195.97 Wh/m^2 for UPA-fin school from phase three with square outline, 168.33 Wh/m^2 for UPA-fin school from phase four with 3F east mass height and finally 161.24Wh/m^2 for UPA-fin school from phase five with trees and grass. The total average reduction in the cooling plant sensible load was about 27 % by adding trees and grass to school UPA-fin in the fifth phase compared to the first phase with 1:2.6 W/L ratio.



	Phase one: W/L ratio 1:2.6	Phase two: CA/BA ratio 20%	Phase three: square outline	Phase four: 3F east mass height	Phase five: with trees and grass
Daily cooling plant sens. load Wh/m2	221.65	198.70	195.97	168.33	161.24
Precentegae of reduction of the cooling load between phase one (Ref.) and the other phases	0	10%	12%	24%	27%

Figure 6. 36: Daily cooling plant sensible load for the best cases of the five phases of stage two on 21st of March.

6.4.5 Energy consumption simulation for the academic year (climate from IESve)

The second investigation for the cooling sensible load for the schools was through all the academic year by using the built-in climate in the IESve software for Dubai international airport. The investigation included three parts as the following:

1- The first part for the best and the worst orientation of the school UPA-fin (basic) from stage one in chapter five.
2- The second part investigated the cooling plant sensible load for buildings that have the same courtyard area to build up area CA/BA ratio 40% (cases of phase one of stage two) for the whole academic year.
3- The third part investigated the best cases of the first four phases of stage two from chapter six, which included:
   A. Phase one: W/L ratio 1:2.6.
   B. Phase two: CA/BA ratio 20%.
   C. Phase three: square outline courtyard.
   D. Phase four :3F for the east mass height.

The best case for the fifth stage was excluded, as it was designed based on the integration of vegetation in the courtyard, because the IESve software can’t calculate accurately the effect of the outdoor vegetation in the courtyard on the cooling sensible load, which was mentioned in the limitation section of this research.

To calculate the cooling sensible load for the academic year, the school buildings were assumed to be occupied bvy the students within the schooling time only (7:00 AM - 2:00 PM). Moreover, the yearly profile included the whole year except the winter vacation (December) and summer vacation (June, July and August) (figure 6.37). While in the weekly profile the weekend was exclude (Friday and Saturday). The daily profile for operating the air condition was designed for the 24 hours (figure 6.38). Based on that, the air conditioning system was assumed to work continuously to keep the thermal comfort suitable for the occupants according to set point temperature in the IESve which was 23 ˚C; El-Deeb, Sherif & El-Zafarany (2014) used 23 ˚C as a set point when calculating the cooling load for buildings with courtyards and buildings without courtyards.

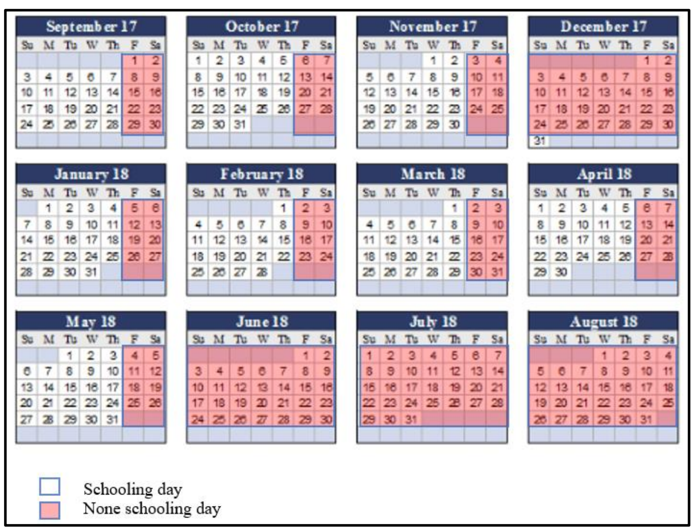


Figure 6. 37: Yearly profile for cooling in IESve for the schools with courtyards.

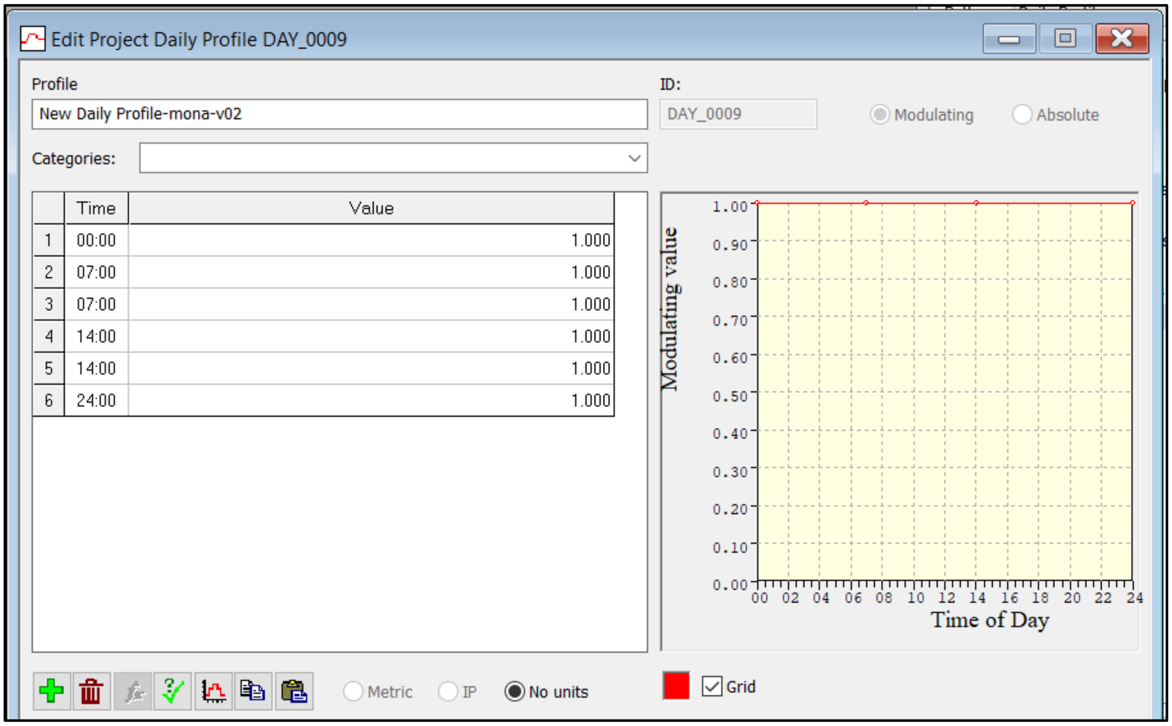
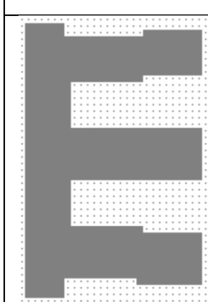
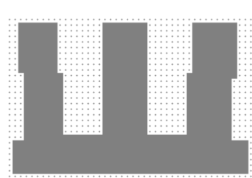


Figure 6. 38 : Daily profile for cooling in IESve for the schools with courtyards.

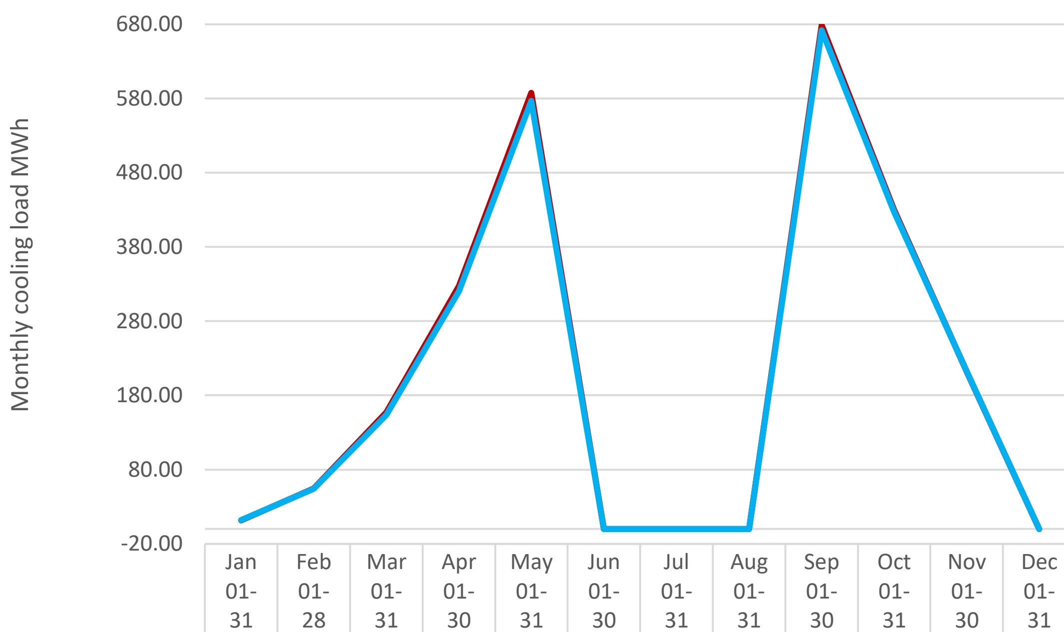
6.4.5.1 Energy consumption and orientation

In this part the cooling sensible load was calculated for the best and the worst orientation of the school UPA-fin(basic) from stage one in chapter five (table 6.35). The simulation outcomes indicated that the cooling sensible load can be reduced slightly according to the orientation of the courtyards of the school building.

Table 6. 35: The best and the poorest orientations for the school UPA-fin(basic).

Best orientation	Poorest orientation
	
UPA-fin to the north	UPA-fin to the east

The yearly cooling plant sensible load for the poorest orientation for the school UAP-fin to the east from stage one was around 2459.12 MW/h, and it was reduced by 1.2% compared to the best orientation for the school UPA-fin to the north direction, which had cooling load around 2429.93 MW/h as in figures (6.39) and (6.40), thus the yearly reduction was around 30 MW/h. This reduction in the cooling load was only by choosing the best orientation without any improvements on the courtyard's design.



	Jan 01-31	Feb 01-28	Mar 01-31	Apr 01-30	May 01-31	Jun 01-30	Jul 01-31	Aug 01-31	Sep 01-30	Oct 01-31	Nov 01-30	Dec 01-31
UPA-fin /east (Poorest orientation)	11.37	54.46	157.1	327.4	587.4	0.00	0.00	0.00	678.7	430.3	212.2	0.00
UPA-fin / north (Best orientation)	12.10	54.11	153.7	320.4	576.7	0.00	0.00	0.00	672.0	427.8	212.9	0.00

Figure 6. 39: Cooling plant sensible load for the best and the poorest orientation for school UPA-fin .

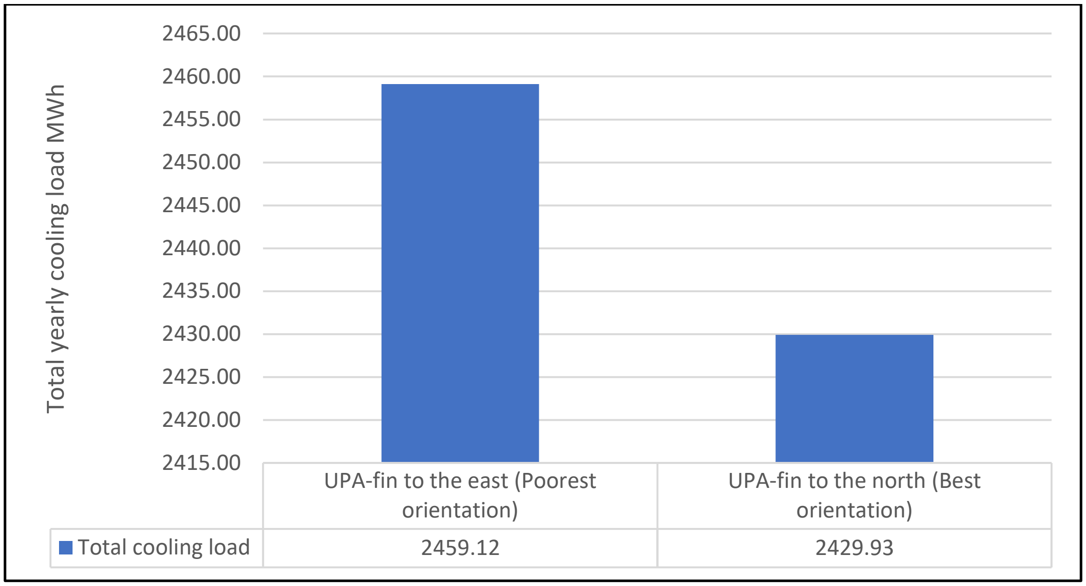
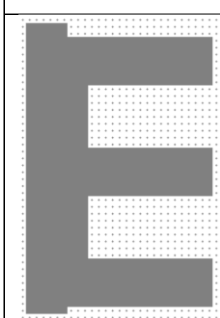
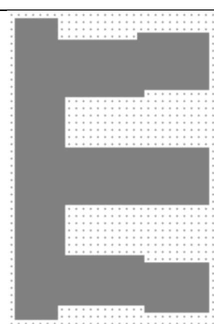
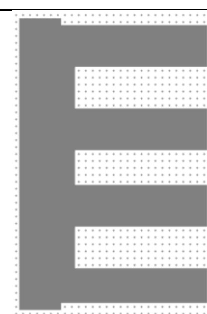


Figure 6. 40: Yearly cooling plant sensible load for the best and the poorest orientation for school UPA-fin

6.4.5.2 Energy consumption for schools with same CA/BA ratio

This part of investigation was designed to calculate the cooling sensible load for schools that have same built up area and same CA/BA ratio but with different configurations. The CA/BA ratio for these schools was around 40%. The shape factors for the investigated schools are: W/L 1:2.6, 1:2 and 1:3 with two courtyards and three courtyards (table 6.36).

Table 6. 36: Different configurations for the courtyards with the same CA/BA ratio

CA/BA 40%, 2 courts W/L = 1:2	CA/BA 40%, 2 courts W/L = 1:2.6	CA/BA 40%, 2 courts W/L = 1:3	CA/BA 40%, 3 courts W/L =1:3
			

The simulation outcomes revealed that the monthly cooling sensible load can be reduced slightly according to month and the type of configuration for the courtyard for schools with same built up area as in figure (6.41) and figure (6.42).

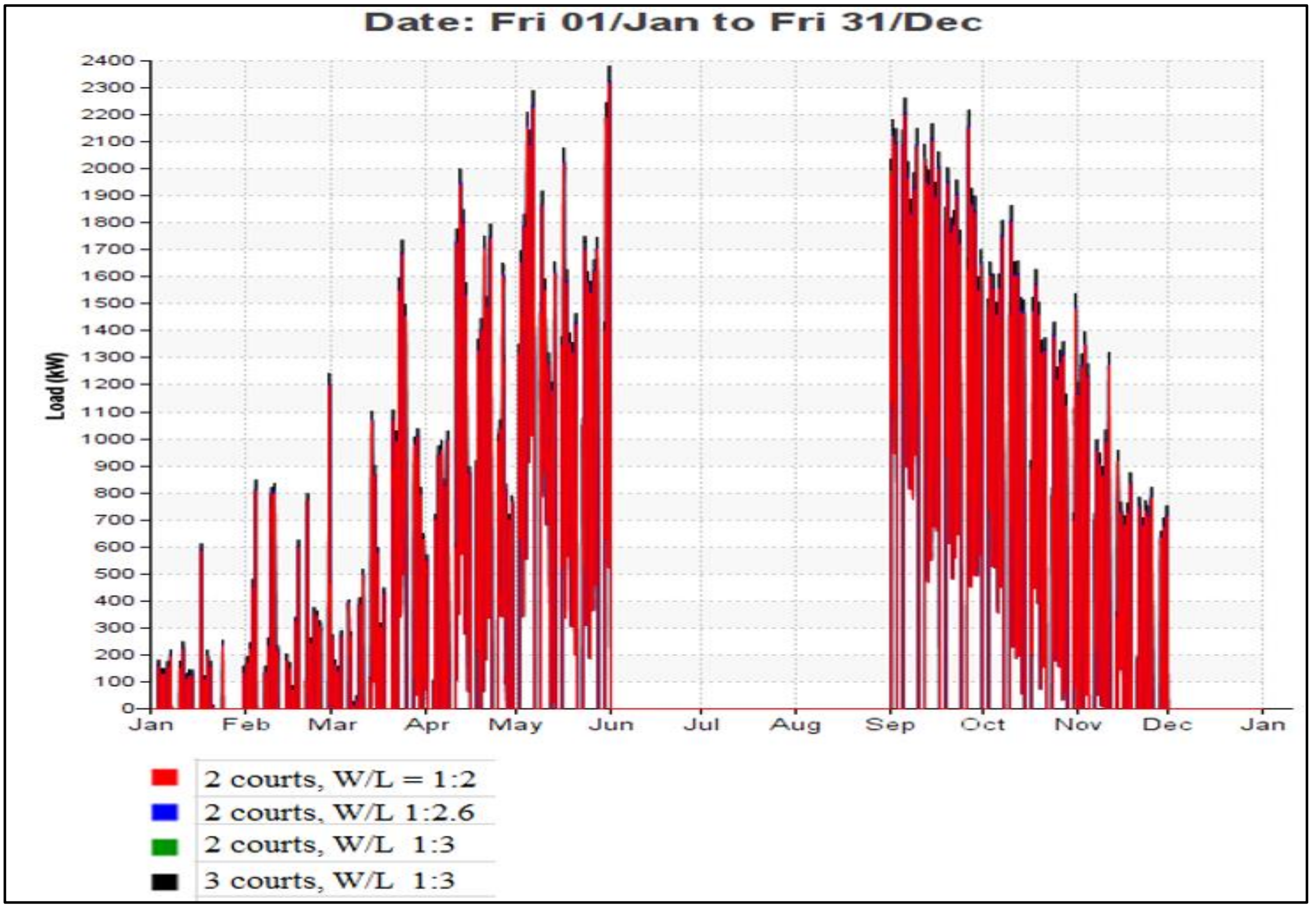
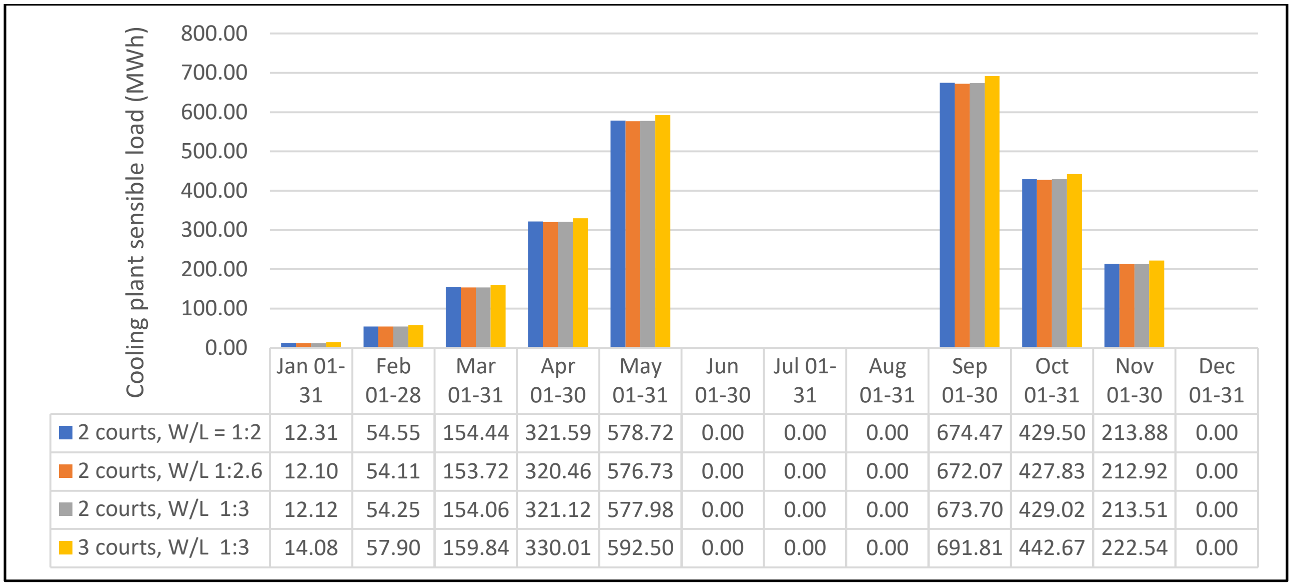


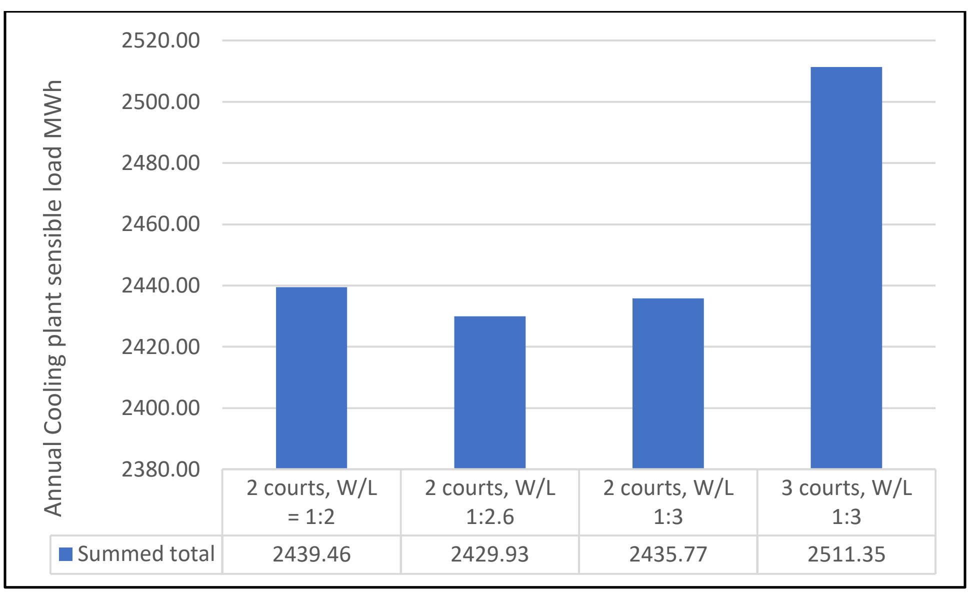
Figure 6. 41: Cooling plant sensible load MWh for schools with same built up area.



	Jan 01-31	Feb 01-28	Mar 01-31	Apr 01-30	May 01-31	Jun 01-30	Jul 01-31	Aug 01-31	Sep 01-30	Oct 01-31	Nov 01-30	Dec 01-31
2 courts, W/L = 1:2	12.31	54.55	154.44	321.59	578.72	0.00	0.00	0.00	674.47	429.50	213.88	0.00
2 courts, W/L 1:2.6	12.10	54.11	153.72	320.46	576.73	0.00	0.00	0.00	672.07	427.83	212.92	0.00
2 courts, W/L 1:3	12.12	54.25	154.06	321.12	577.98	0.00	0.00	0.00	673.70	429.02	213.51	0.00
3 courts, W/L 1:3	14.08	57.90	159.84	330.01	592.50	0.00	0.00	0.00	691.81	442.67	222.54	0.00

Figure 6. 42: Monthly Cooling plant sensible load MWh for schools with same built up area.

The annual sum for the cooling plant sensible load showed variation in the results. The least amount for the cooling load was for the school UPA-fin with shape factor W/l 1.2.6 with amount around 2429. 93 and that is less by 3.2% (around 81.43 MWh) than the poorest case which was UPA-fin school with three courts that have shape factor W/L 1:3 (figure 6.43). Moreover, the best case has reduction in the cooling load around 0.4% and 0.2% less than the schools that have two courts with shape factor W/L = 1:2 and 1:3 successively.



	2 courts, W/L = 1:2	2 courts, W/L 1:2.6	2 courts, W/L 1:3	3 courts, W/L 1:3
Summed total	2439.46	2429.93	2435.77	2511.35

Figure 6. 43: Annual Cooling plant sensible load MWh for schools with same built up area.

The highest amount for the cooling sensible load was achieved on September (previous figure 6.42). On September the least amount for the cooling load was for the school UPA-fin with shape factor W/l 1.2.6 with amount around 672.07 MWh and that is less by 3% (around 19.74MWh) than the poorest case which was UPA-fin school with three courts that have shape factor W/L 1:3 (figure 6.44. and figure 6.45).

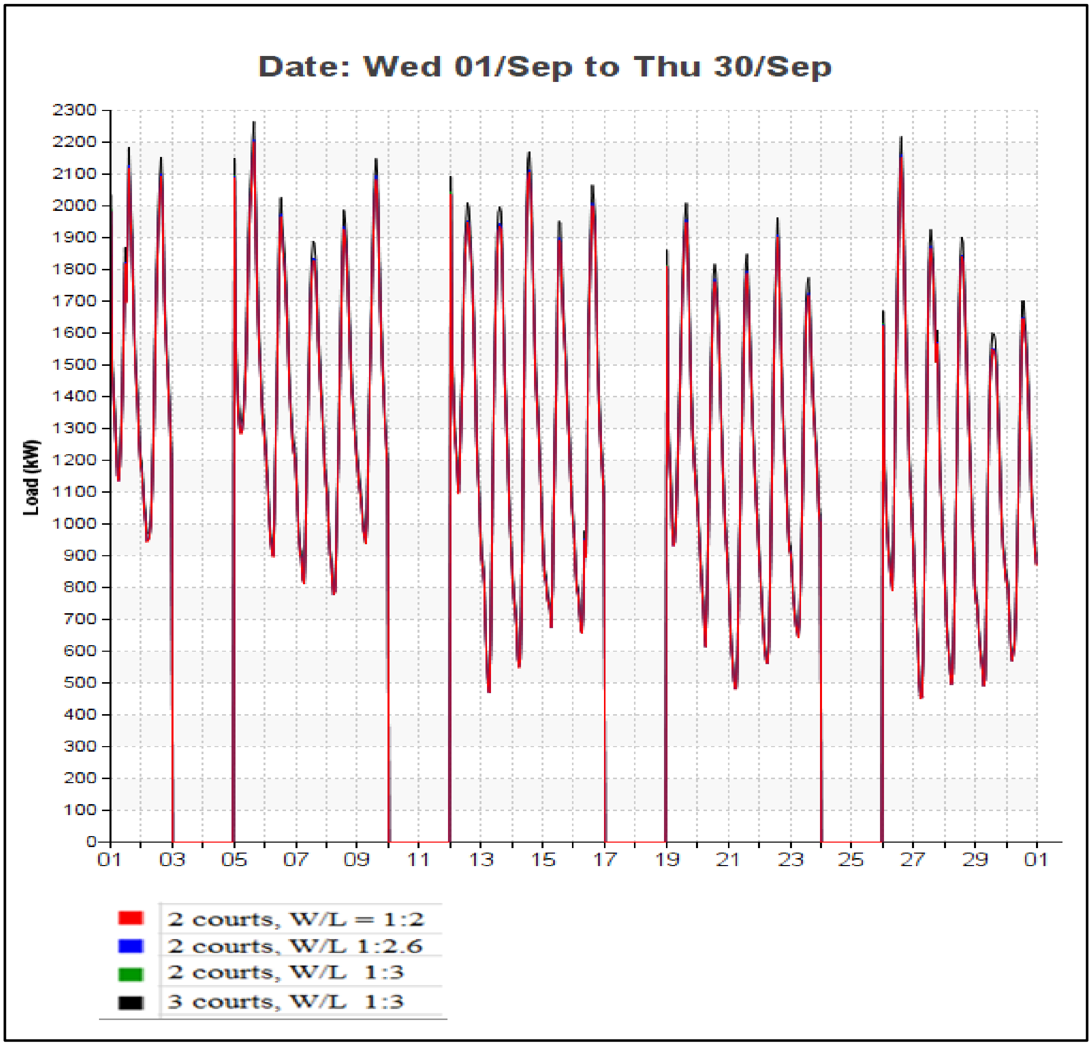


Figure 6. 44: Cooling load on September.

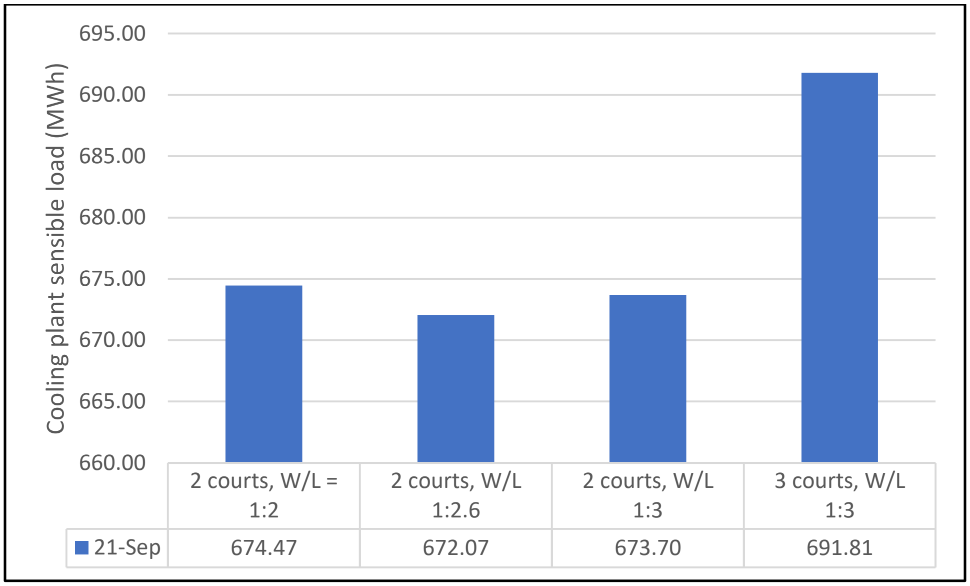


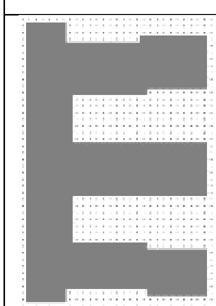
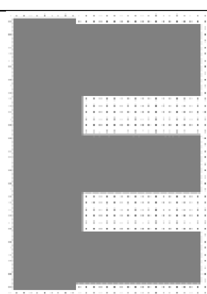
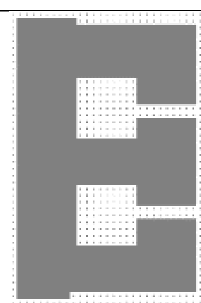
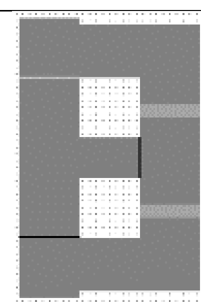
Figure 6. 45: Cooling sensible load on September.

6.4.5.3 Energy consumption and courtyard Design

This part investigated cooling plant sensible load for the best cases of the first four phases of stage two from chapter six which considered the courtyard design. The cases which were examined in this part are:

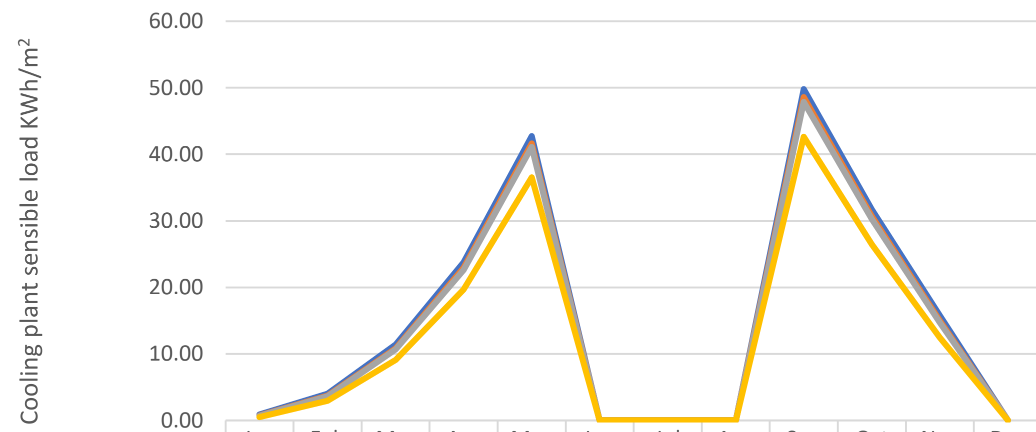
1- Phase one: W/L ratio 1:2.6.
2- Phase two: CA/BA ratio 20%.
3- Phase three: square outline courtyard.
4- Phase four :3F for the east mass height (table 6.37).

Table 6. 37: The best case for the first four phases of the courtyard design.

Phase one: W/L ratio 1:2.6	Phase two: CA/BA ratio 20%	Phase three: square outline	Phase four: 3F east mass height
			

The results of investigation the annual cooling plant sensible load for the design phases for school UPA-fin revealed that the cooling load can be reduced by improving the courtyard design (figure 6.46 and figure 6.47). Changing the CA/BA ratio to 20% for the school UPA-fin in the second phase reduced the annual cooling plant sensible load by around 3%, as the CA/BA ratio 20% created thicker masses around the courtyards, moreover it produced higher SSI ratio and that helped in increasing the shadow inside the courtyards and decreased the heat gain. In phase three the cooling load was reduced by additional 1.4% by changing the outline of the courtyards from rectangular to square. Thus, the total reduction in phase three compared to phase one was around 4.7%.

The least cooling load was achieved in phase four for the school UPA-fin 3F east mass height as it reduced the annual cooling plant sensible load by around 16.5%compared to phase one. This reduction was related to the extra shade inside the courtyards because of the added floor.



	Jan 01-31	Feb 01-28	Mar 01-31	Apr 01-30	May 01-31	Jun 01-30	Jul 01-31	Aug 01-31	Sep 01-30	Oct 01-31	Nov 01-30	Dec 01-31
Phase one: W/L ratio 1:2.6	0.90	4.01	11.39	23.74	42.72	0.00	0.00	0.00	49.78	31.69	15.77	0.00
Phase two: CA/BA ratio 20%	0.75	3.71	10.85	22.93	41.65	0.00	0.00	0.00	48.58	30.69	15.01	0.00
Phase three: square outline	0.70	3.63	10.68	22.61	41.09	0.00	0.00	0.00	47.90	30.25	14.73	0.00
Phase four: 3F east mass height	0.50	2.97	9.08	19.68	36.55	0.00	0.00	0.00	42.63	26.46	12.47	0.00

Figure 6. 46: Monthly Cooling plant sensible load KWh/m^2.

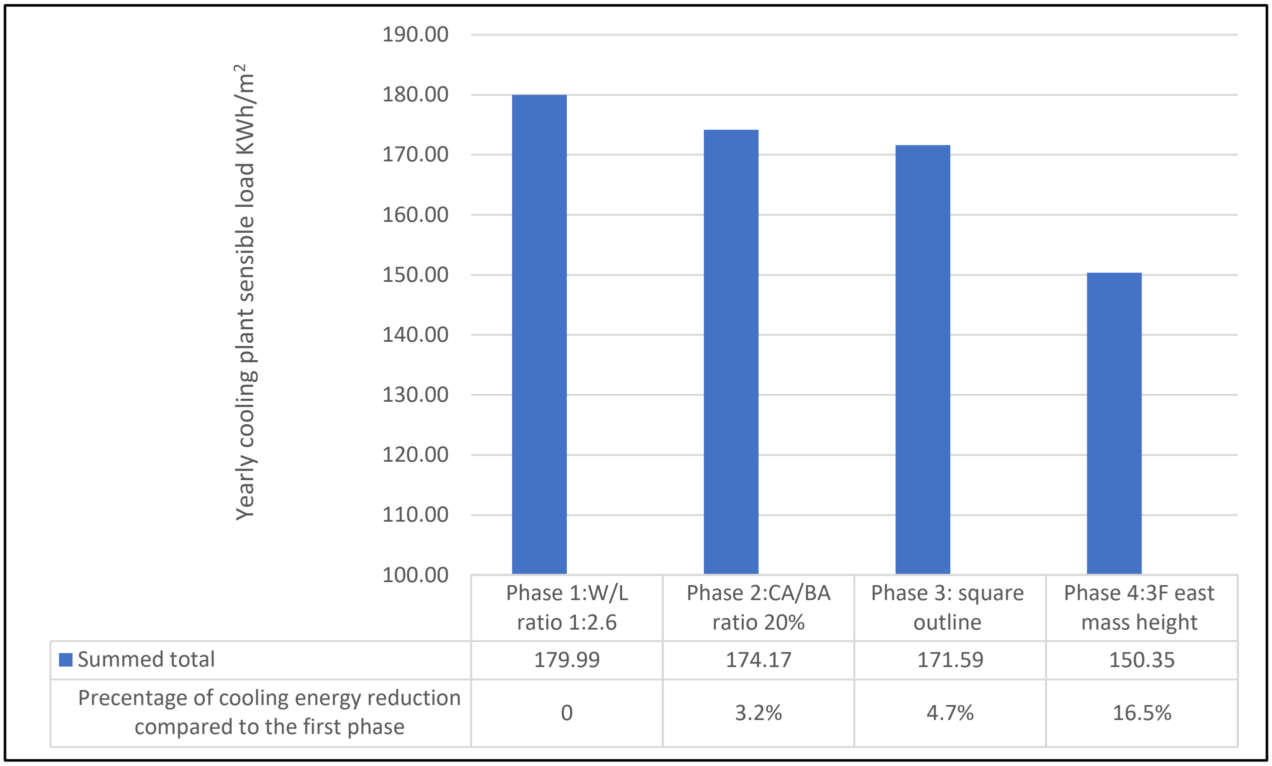


Figure 6. 47: Annual Cooling plant sensible load KWh/m^2.

6.5 Discussion of stage three

6.5.1 Energy consumption simulation (new microclimate from ENVI-met)

The results of energy calculations in stage three revealed that there was clear reduction in the hourly and daily cooling plant sensible load for school UPA-fin according to the orientation in stage one and courtyard design strategies in stage two, but this reduction varied according to the design strategy, time of the schooling day and date of simulation. Hisarligil (2013) stated that courtyards can decrease the cooling loads in summer in hot areas according to their configurations. On the 21st of September the air temperature is higher than 21st of March, and that affects the indoor temperature of the school building, based on that the air conditioning starts working earlier at 7:30 AM on 21st of September, while the air condition on 21st of March starts at 8:30AM for phase one and two, and starting from stage three the air condition starts to work from 9:30 AM, because of that high energy saving on 21st of March were in the morning time.

The highest savings in the cooling energy as in table (6.38) was in phase four by adding third floor for the UPA-fin school as it reduced the hourly cooling plant sensible load by around 12% on 21st of September and 14 % on 21st of March according to the time. This reduction can be explained mainly by the additional floor with different heights for the surrounding walls produced more shade inside the courtyards and reduced the amount of sun radiation that hits the ground of the courtyard and the adjacent walls. Moreover, adding additional floor according to the 3F east mass strategy created voids on the ground level that improved the natural outdoor ventilation for the courtyard and that helped in cooling the courtyard and the indoor spaces for the school in general, finally the additional floor reduced the exposed surfaces to the outside hot weather and reduced the heat gain. Sharmin and Steemers (2015) stated that the higher surface to volume ratio increases the cooling energy of the buildings, in their study for different buildings with different courtyards' configurations, they found that the average cooling plant sensible load for the courtyards building with small surface to volume ratio is around 0.662 kW per hour while it is for the courtyard building with higher surface to volume ratio around 0.966 kW per hour. El-Deeb, Sherif and El-Zafarany (2014) found out that the cooling load for courtyard building in hot area of Khargah was around 200 kWh/m2 for a building with 8m height while it was only around 160 kWh/m2 for the same building with 12m height, in their case there was around 20% reduction in the cooling load in relation to height.

Changing the CA/BA ratio to 20% for the school UPA-fin in the second phase reduced the cooling plant sensible load by around 5% on 21st of September and by around 10% on 21st of March, as the CA/BA ratio 20% produced thicker masses around the courtyards, moreover it produced higher SSI ratio and that helped in increasing the shadow inside the courtyards and decreased the heat gain.

The reduction in the average daily cooling sensible load because of adding vegetation in phase five was only about 2.4 % on 21st of September and around 4.2% on 21st of March. Abanomi and Jones (2005) investigated the landscape effect on the thermal performance of a school building in Riyadh, they sated that landscape is important element in schools in hot areas, it helps in improving the microclimate of the building and helps in cooling the inner spaces by reducing the heat gain. The higher savings of the energy because of the vegetation on 21st of March was due to the integrating of the vegetation that kept the T_{in} below the set point thus delayed the operation of the air condition till 9:30 AM.

The least savings were when changing the outline of the courtyard to square which resulted in around 1% on 21st of September and 1.4 % on 21st of March. This mainly occurred because of the extra shade inside the courtyards because of the added east walls that shaped the semi closed square outline for the courtyards.

The five strategies in stage two were able to reduce the daily cooling plant sensible load by 19 % on 21st of September and by 27.3 % on 21st of March.

Table 6. 38: The average daily improvements on energy consumption between the five phases of stage two on 21st of September.

	Average energy savings between phase one and two. By changing CA/BA to 20%	Average energy savings between phase two and three. By changing the courtyard outline to square	Average energy savings between phase three and four. By increasing the height to 3F east mass	Average energy savings between phase four and five By adding vegetation	Average energy savings between phase one and five with optimum courtyard design.
21st of September	4.6%	1.0%	11.8%	2.4%	19%
21st of March	10.4%	1.4%	14.1%	4.2%	27.3%

To highlight the total energy saving through all the research, there was comparison between the cooling plant sensible load for the poorest case of stage one which was school KAT to the west and the best case of stage two which was school UPA-fin with vegetation as in table (6.39), figure (6.48) and figure (6.49). The results revealed that all the research strategies in stage one succeeded in reducing the hourly cooling plant sensible by 27-32% on 21st of September and by 32-100% on 21st of March according to the hour of the schooling day as in table (6.39). Taking in consideration that the reduction with 100% related to 8:30 AM hour as the improvements in the T_{in} of the UPA-fin delayed the operation of the air condition to 9:30AM.

Table 6. 39: Comparison between the cooling plant sensible load for the poorest case of stage one school KAT to the west and the best case of stage two UPA-fin with vegetation.

	Cooling plant sensible load on 21st of March W/m2			Cooling plant sensible load on 21st of September W/m2		
Time	Stage one : Poorest case - sKAT to the west	Stage two Best case UPA-fin with vegetation	Total hourly reduction in cooling plant sensible load	Stage one : Poorest case - sKAT to the west	Stage two : Best case UPA-fin with vegetation	Total hourly reduction in cooling plant sensible load
7:30				74.01	54.06	27%
8:30	10.76	0	100%	88.23	59.23	33%
9:30	25.89	6.88	73%	100.81	68.54	32%
10:30	41.52	20.25	51%	114.72	80.06	30%
11:30	56.36	33.75	40%	128.51	92.36	28%
12:30	69.16	45.62	34%	140.91	103.15	27%
13:30	80.29	54.75	32%	151.53	111.35	27%

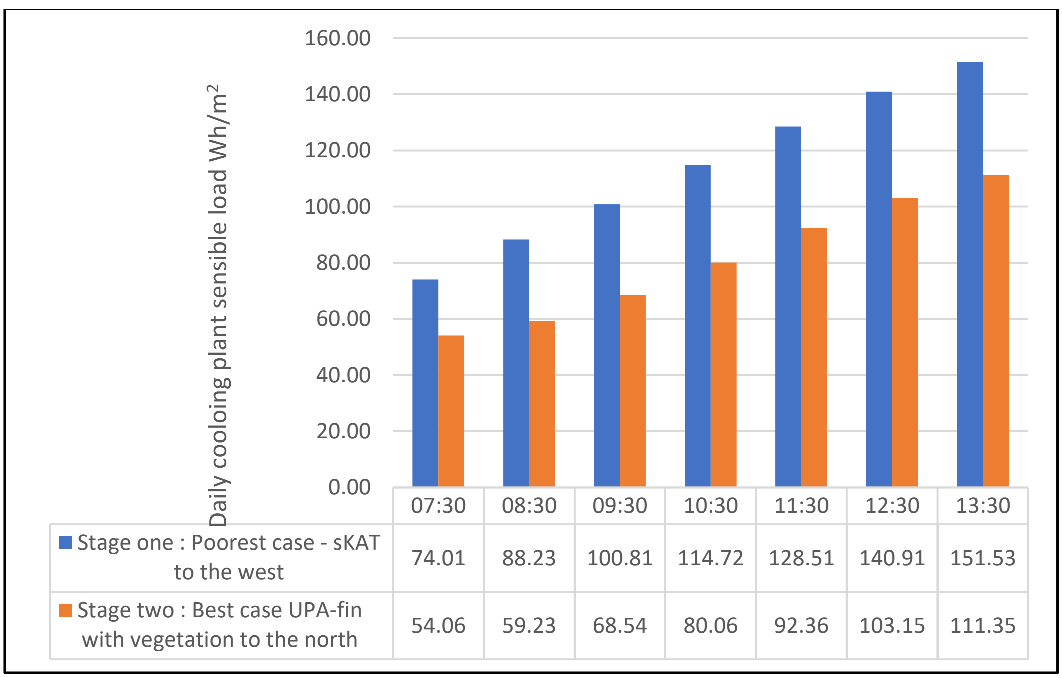


Figure 6. 48: Comparison between the cooling plant sensible load for the poorest case of stage one school KAT to the west and the best case of stage two UPA-fin with vegetation on 21st of September.

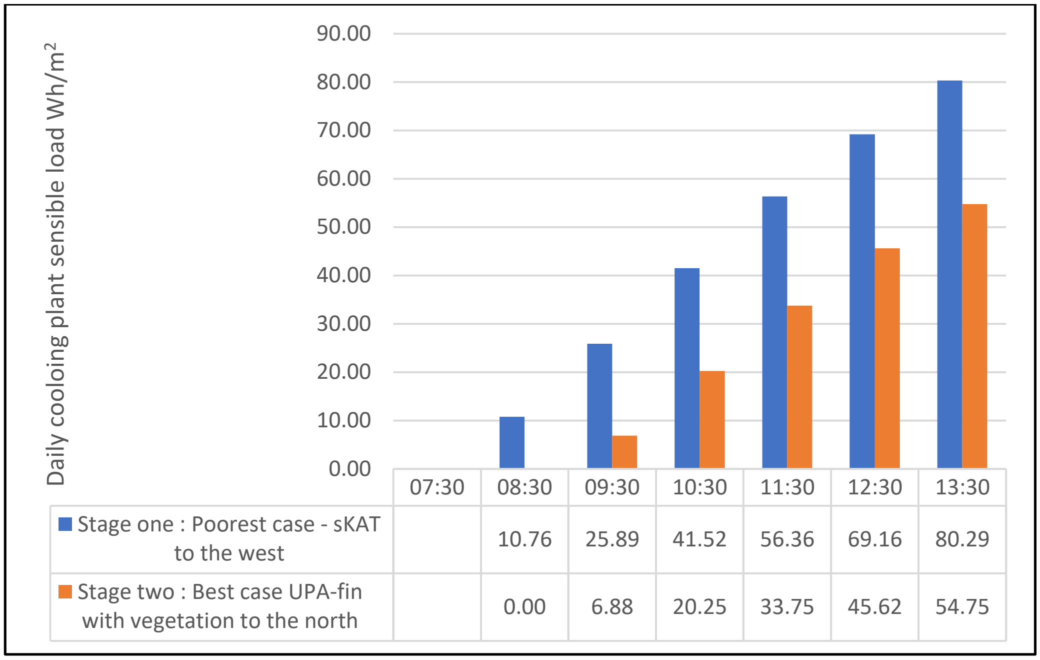


Figure 6. 49: Comparison between the cooling plant sensible load for the poorest case of stage one school KAT to the west and the best case of stage two UPA-fin with vegetation on 21st of March.

The daily reduction of the cooling plant sensible load for the poorest case of stage one which was school KAT to the west and the best case of stage two which was school UPA-fin with vegetation as in table (6.40). Figure (6.50) indicated that the research succeeded to save 29% of the daily cooling energy on 21st of September and 43% on 21st of March because of adopting courtyard as passive design solution. Taking into consideration that the courtyard should be directed to the suitable orientation to reduce the access of hot air and reduce the heat gain. Moreover, the courtyard should be well-designed to act as successful passive design strategy in the school buildings in UAE and in areas with similar climate. Thus, the passive design solutions can be effective in the energy reduction and that is with agreement with Abanomi and Jones (2005) who applied passive strategies on prototype school building in hot, arid region in Riyadh. They found that the passive strategies like thickness of the walls, infiltration control and other strategies were capable to reduce the cooling load for a classroom from 7516.03 KW as base school case to 3518.77KW as modified school case, thus the reduction was more than 50% of the cooling energy.

The courtyard in this research succeeded in reducing the energy consumption for cooling and that will have positive environmental and economic effects. On the other hand, a well-designed courtyard in the school buildings proved its capability in improving its thermal comfort (PMV), which is expected to affect positively the student satisfaction toward the school building by providing enjoyable area for school socialization and the psychological and physical health especially in the break time.

Table 6. 40: Comparison between the daily cooling plant sensible load for the poorest case of stage one school KAT to the west and the best case of stage two UPA-fin with vegetation on 21st of September.

	Stage one: Poorest case - sKAT to the west	Stage two: Best case sUPA-fin with vegetation to the north	Total reduction in the cooling plant sensible load
Daily cooling plant sensible load W/m2 on 21st of September - Wh/m2	798.73	568.76	29%
Daily cooling plant sensible load W/m2 on 21st of March - Wh/m2	283.99	161.24	43%

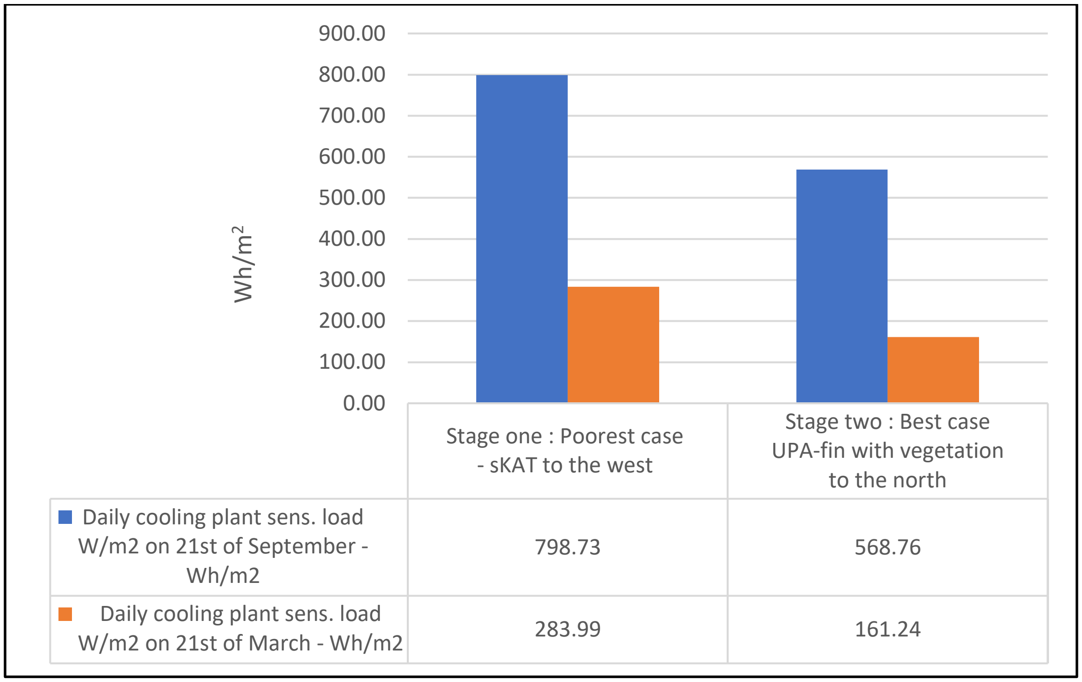


Figure 6. 50: Comparison between the daily cooling plant sensible load for the poorest case of stage one school KAT to the west and the best case of stage two UPA-fin with vegetation on 21st of September.

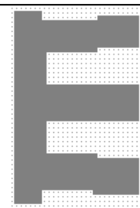
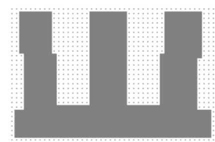
6.5.2 Energy consumption simulation for the academic year (climate from IESve)

The results of predicting the cooling sensible load for the schooling academic year and by using the built in climate from IESve revealed that there was a reduction in the monthly and yearly cooling plant sensible load for the school UPA-fin according to the courtyard orientation , configuration and courtyard design, but this reduction diverse according to the design strategy, time of the schooling year, as Hisarligil (2013) mentioned that the configuration of the courtyards can control the amount of the cooling loads.

6.6.2.1 Annual cooling sensible load and orientation

The results of the investigation of the cooling sensible load for the best and the poorest orientation for the school UPA-fin basic revealed that there was annual reduction in the cooling load around 1.2%by adopting the best orientation to the north (table 6.41) and (figure 6.51). Moreover, the highest reduction occurred in March with around 2.16%. This can be explained because the best orientation case to the north has rectangular courtyards directed east west and that reduces the amount of solar gain, and enable the courtyard to be more efficient in reducing the building temperature. Moreover, UPA-fin to the north is oriented in a way that reduces the access of the hot northwest wind and that agrees with Al-Hafith et al. (2017), Edwards (2006), Kochnelson (2002) and Yaşa and Ok (2014) .

Table 6. 41: Cooling plant sensible load MWh for the best and the poorest orientationfor the school UPA-fin

	Best orientation	Poorest orientation
School orientaion	 UPA-fin to the north	 UPA-fin to the east
Cooling plant sensible load MWh	2429.93	2459.12

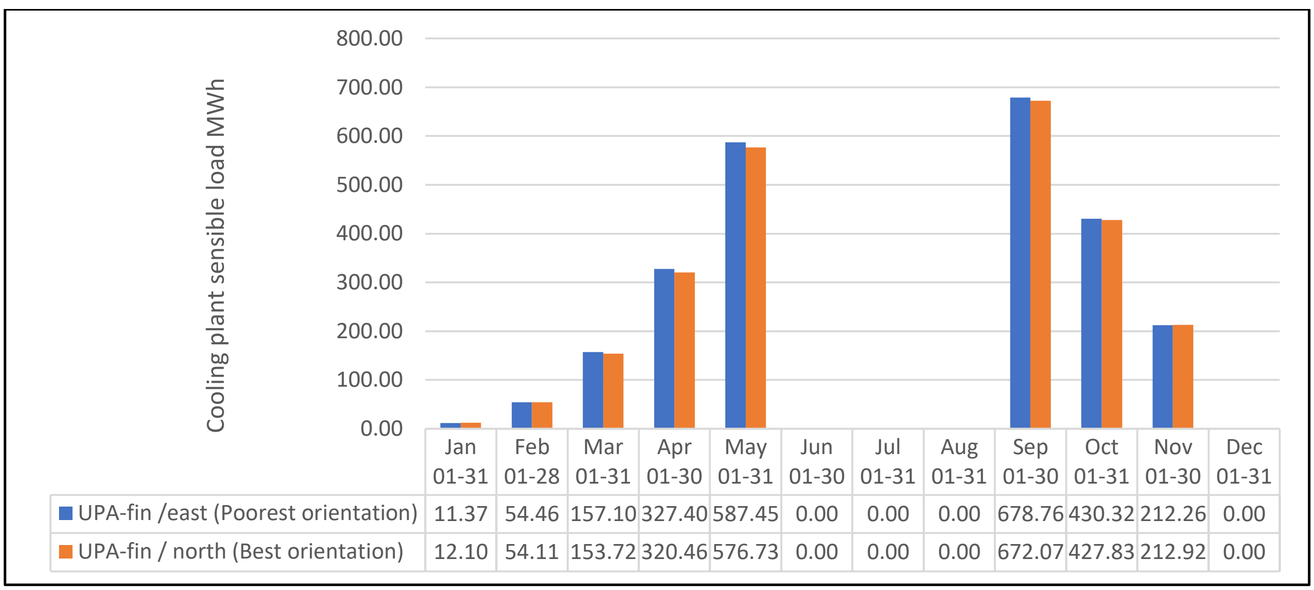
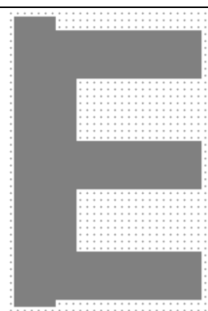
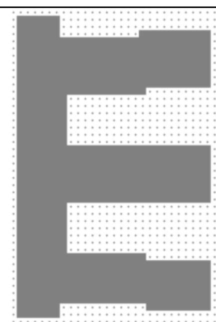
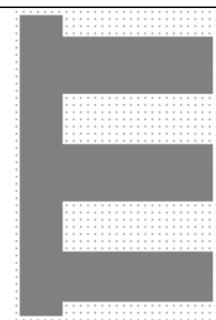


Figure 6. 51: Monthly cooling plant sensible load for the best and the poorest case of the school UPA-fin.

6.5.2.2 Annual cooling load for schools with same CA/BA ratio.

The simulation outcomes for investigating the cooling load for schools that have courtyards with different shape factor with 40% CA/BA ratio revealed that the annual cooling sensible load can be reduced slightly according to the type of configuration and number of the courtyards (table 6.42). The best configuration was the one with least cooling load which was for the school UPA-fin with two courts that have shape factor W/L = 1:2.6 with amount around 2429. 93 and that is less by 3.2% (around 81.43 MWh) than the poorest case which was UPA-fin school with three courts that have shape factor W/L 1:3 . Moreover, the best case has reduction in the cooling load around 0.4% and 0.2% less than the schools that have two courtyards with shape factor W/L = 1:2 and 1:3 successively. That can be explained in relation to the variation in the amount of received solar radiation on the exterior walls, as the poorest case with factor ratio W/L 1:3 with three courtyards has more exterior walls exposed to exterior climate with thinner masses, unlike the best case with W/L 1:2.6 which has less exposed walls with thicker masses.

Table 6. 42: cooling sensible load for the schools with the same CA/BA ratio 40%.

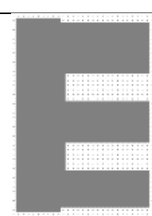
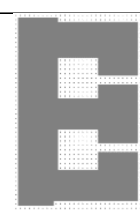
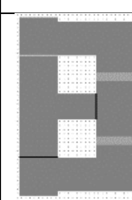
	CA/BA 40%, 2 courts W/L = 1:2	CA/BA 40%, 2 courts W/L = 1:2.6	CA/BA 40%, 2 courts W/L = 1:3	CA/BA 40%, 3 courts W/L =1:3
School configration				
Annual cooling load MWh	2439.46	2429.93	2435.77	2511.35

6.5.2.3 Annual cooling load and courtyard design.

The outcomes of investigating the annual cooling plant sensible load for the design phases for school UPA-fin revealed that the cooling load can be reduced by improving the courtyard design (table 6.43). Changing the CA/BA ratio to 20% for the school UPA-fin in the second phase reduced the annual cooling plant sensible load by around 3%, as the CA/BA ratio 20% created thicker masses around the courtyards, moreover it produced higher SSI ratio and that helped in increasing the shadow inside the courtyards and decreased the heat gain. In phase three the cooling load was reduced by additional 1.4% by changing the outline of the courtyards from rectangular to square. Thus, the total reduction in phase three compared to phase one was around 4.7%.

The least cooling load was achieved in phase four for the school UPA-fin 3F east mass height as it reduced the annual cooling plant sensible load by around 16.5% compared to phase one. This reduction was related to the extra shade inside the courtyards because of the added floor. The third floor reduced the amount of sun radiation that hits the courtyard's ground and the surrounding walls. Moreover, the additional floor on the east side of the school helped in creating voids on the ground level that enhanced the natural outdoor ventilation for the courtyard and which helped in reducing the temperature in the courtyards and the surrounding masses of the school in general, Moreover the additional floor reduced the area of the exposed surfaces to the outside hot weather and that reduced the heat gain for the masses as Sharmin and Steemers (2015) stated in their research.

Table 6. 43: Cooling sensible load for the schools according to the design phases.

	Phase one: W/L ratio 1:2.6	Phase two: CA/BA ratio 20%	Phase three: square outline	Phase four: 3F east mass height
School configration				
Annual cooling load KWh /m^2	179.99	174.17	171.59	150.35
Built Up area /m2	6750	8046	8091	8415

Moreover it was noticed that the built up area for the school UPA-fin in phase four with the least cooling load /m^2 had the largest area among the other schools (phase one to three), as it was around 8415m^2. Based on that the school UPA-fin in phase four had 20% more area than the school UPA-fin in phase one (which was around 6750m^2) yet it had less cooling. Figure (6.52) showed that when the built-up area increased through the phases of the design, the cooling load/m^2 decreased because of the increased amount of the shadow which succeeded to reduce the sun radiation that hits the courtyard's ground and the adjacent walls. Based on that the design and configuration of the courtyards in the best case of the school UPA-fin in phase four managed to reduce the cooling load /m^2 by 16.5% compared to the case in phase one despite the fact that the built up area increased.

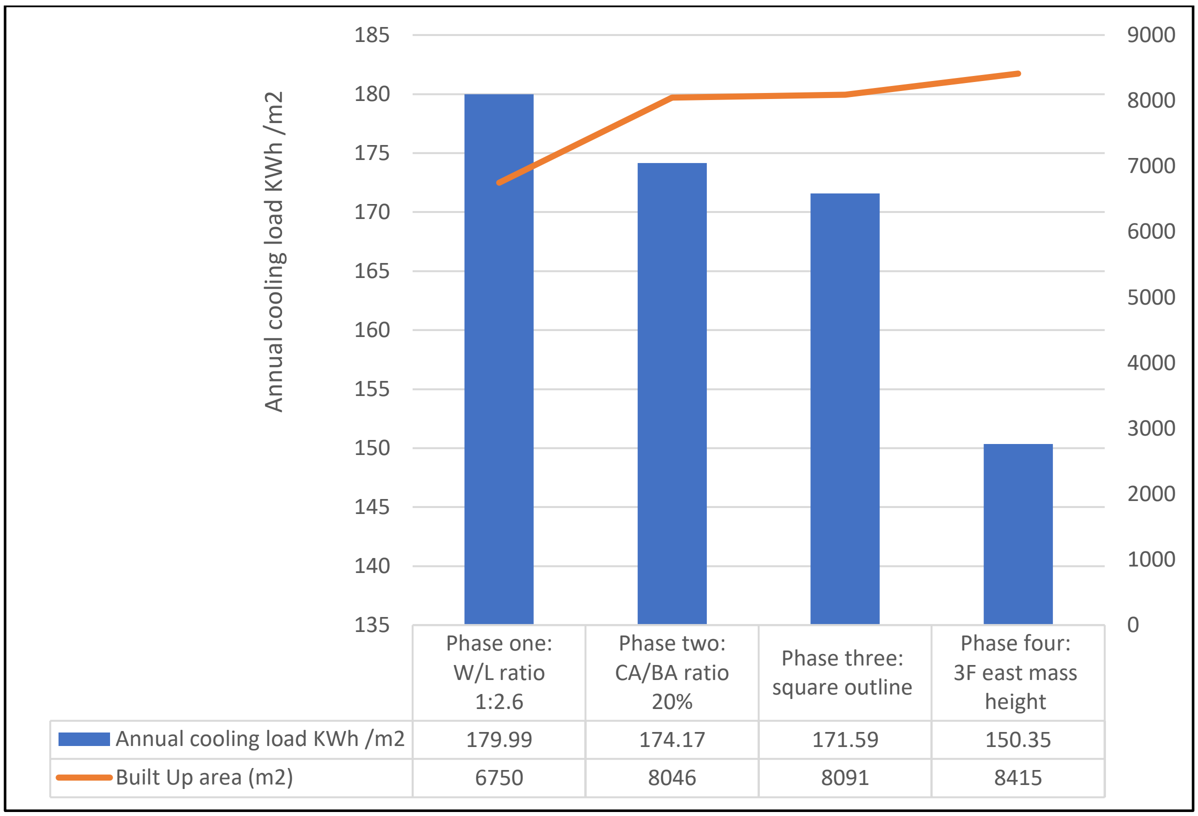


Figure 6. 52: The annual cooling load and the built-up area for the schools according to the design phases.

Finally, the research succeeded in highlighting the courtyard as a design solution in relation to the environmental pillar of sustainability which surly will affect the other two pillars of suitability the economic and social one. The courtyard as passive design solution can help in mitigating the influence of the hot climate and improve the thermal performance of the school buildings and reduces the cooling energy. Based on that, the courtyard has economic positive effects, as courtyards can decrease the energy consumption for schools, consequently the electricity bill. Moreover, the courtyard strategy can decrease the capital cost of the school buildings, as lower capacity HVAC equipment will be required. In return courtyards in school buildings, with proper proportions and sizes can save a lot from the government budget every year. In 2013, public school buildings in UAE consumed around 18.5% from the education budget which was around 16.43% of the total budget of the country on the year 2010 (Ministry of Education –UAE 2013). Moreover, the courtyard can reduce the cost for mitigating the climate and future carbon costs by improving the energy efficiency. Additionally, the improved PMV levels of the courtyards can support the social life of the students. As courtyards can improve the social interaction and the satisfaction of the students toward the school building, and that will advance their ability to study and their educational achievement. Despite the limited time that students spend in the courtyard, but that time is suitable for social interaction among them, especially if it is in the break, lunch or sport activities times and even in some science classes, if the courtyard contains plants, sand…etc. Thus, courtyards design should be developed and integrated with the contemporary concepts of design for green schools.

Chapter 7: Results, Conclusion and Recommendations

According to the literature, it was clear that few studies investigated the courtyard as a passive solution for school buildings. Furthermore, they didn't define the suitable ratios and orientation for it in the school buildings in hot areas. This research integrated a well-designed courtyard as a successful passive design strategy in school buildings in UAE to reduce the energy consumption for cooling. On the other hand, the study highlighted the thermal comfort improvement for the optimum school courtyard (PMV), which expected to affect positively the student satisfaction toward the school building by providing enjoyable area for school socialization and the psychological and physical health especially in the break time. A lot of results and findings were found to highlight the characteristics for the best courtyards for school buildings in hot areas according to the research parameters, and that to answer the questions of the research and meet the objectives.

7.1 Results and findings

The results for this research are arranged in three groups according to the related stage in the research as the following:

7.1.1 Results of stage one: Courtyard and orientation

The schools buildings orientation and T_{in} were investigated in stage one in relation to courtyards' types, CA/PA ratios CA/BA ratios and W/L to highlight the best school case beside highlighting the parameters and alternatives with potential to be improved to produce optimal school building. The simulation of the school was conducted on 21st of September and 21st of March with the hot climate context of UAE. The amount of solar radiation hits the ground in UAE is high especially in September, and that affect the performance of the courtyard strongly.

Results of this stage have revealed the following:

1- Changing the orientation of the school buildings in the four main directions affected their T_{in} according to the change in the thermal performance of the courtyards.

2- Each school had one best orientation that managed in reducing the T_{in} on both dates of simulation, for example school UPA-fin had its best orientation toward the north that made reduction in T_{in} around 0.75˚C on 21st of September and 0.82 ˚C on 21st of March compared to the worst orientation of the school UPA-fin toward the east. The orientation effect on the thermal performance for some schools is better than the others in relation to the courtyard geometry, type, area, beside courtyards arrangements and number.

3- The variation in the T_{in} according to the courtyard orientation was not very high because the areas of the school buildings are huge in relation to their constant height (two stories with 8m height), other reasons for the slight difference due to orientation are the type and the time of occupancy.

4- The results of the simulation can define the best orientation for each school of the case studies separately, for example the best orientation for KAT school was to the north with around -0.5 ˚C than its worst case to the west.

5- School UPA-fin to the north was the best case among the others, it was with rectangular courtyards that extended to the west east direction, and that made the courtyards more efficient in reducing the heat gain thus the building temperature as they have shorter east west walls .

6- The effect of orientation on the school buildings vary according to the courtyard type. Schools with semi closed courtyards were better in the thermal performance than the ones with mixed types of courtyards (closed and semi closed) and the ones with closed courtyards only. The semi closed courtyards were in the case of UPA-fin with the best scenario and the least average T_{in} toward the north. Theses courtyards were opened from the east side and closed from the west side and that blocked the hot air coming from north west.

7- School UPA-fin oriented to the north recorded the best orientation for the courtyard with average T_{in} around 28.06 ˚C during the schooling time from 7am till 14pm on the 21st of September. While school KAT recorded the highest averages for the T_{in} among the other cases. Based on that school UPA-fin to the north direction recorded -1.7 ˚C compared to school KAT to the west direction on the 21st of September and recorded -1.75 ˚C on the 21st of March. The difference between the best case UPA-fin to the north was about, -1.3 ˚C, -1.0 ˚C, and -0.7 ˚C on 21st of September, and -1.33 ˚C, -1.11 ˚C, and - 0.74 ˚C on 21st of March than the worst scenarios for 596,586 and UPA1 respectively.

8- It was not easy to define the best CA/PA ratio in relation to orientation because the main plot area for all the case studies is not the same. In this research the best CA/PA ratio was in the middle level and about 29% (not the highest 49% and not the lowest19%) among the other cases. But it was clear that if the amount of CA/PA ratio is high the SVF for the courtyards will be high and accordingly the T_{in} will be reduced slightly.

7.1.2 Results of stage two: courtyard design

1- The investigation of the shape factor indicated that the school UPA-fin with shape factor ratio (W/L) 1:2.6 had the best T_{in} average among the others on both dates of simulation 21st of September and 21st of March with least average T_{in} 28.06 ˚C and 23.80 ˚C respectively.

2- The results proved that two courtyards for UPA-fin school is better than three courtyards as the one with three courtyards has average T_{in} around 29.09 on 21st of September and 24.73 on 21st of March which recorded more 1.03 ˚C and 0.93 ˚C than the best case with W/L 1:2.6 on the previous dates respectively, and that because the one with three courtyards has more exposed surfaces to the outdoor environment.

3- The investigation of the courtyard area to build up area ratio (CA/BA) indicated that the school UPA-fin with CA/BA ratio 20% had the least T_{in} average among the others with CA/BA ratios 33%, 40% and 60% on both dates of simulation 21st of September and 21st of March with least average T_{in} 27.88˚C and 23.62˚C respectively.

4- The investigation indicated that the school UPA-fin with square courtyards had slight reduction than the rectangular ones. The school with square courtyards had average T_{in} around 27.47 ˚C, and that is 0.41 ˚C less than the average T_{in} for the same school with rectangular courtyards on 21st of September. As the square courtyards can create more shade than the rectangular ones.

5- The investigation of the new height (12m) of the masses around the courtyards on the thermal performance of the building on 21st of September and 21st of March indicated that the school UPA-fin with three floors for the masses east, north and south named as 3F east mass (as the east mass is the largest one) had better indoor thermal performance than the other cases with two and three floors, as adding third floor mainly on the east part increased the shaded area inside the courtyards and created voids around them which improved the outdoor ventilation.

6- After the investigation of different scenarios with vegetation inside the courtyards, the investigation indicated that the school with 3F east mass with grass and trees had better thermal performance than the others with average T_{in} around 26.17 ˚C, and that is 0.71 ˚C less than the average T_{in} for the one without vegetation on 21st of September.

7- The results of the simulation revealed that the thermal comfort in the courtyards was improved by improving the design of the courtyard on both dates of simulation. Moreover, significant improvements in the readings of PMV were in phase five by adding vegetation compared to phase one the basic case for the school UPA-fin.

8- In conclusion, it was clear that whenever the design of the courtyard improved and managed to reduce the indoor temperature, automatically the outdoor microclimate of the courtyard improved. As the best case of stage five with optimum courtyards design and with least average T_{in} was in the school UPA-fin with vegetation, and that was the same case for the best PMV performance on both dates of simulation. Based on that the total reduction in T_{in} on stage two due to the design strategies on the basic shape of UPA-fin was around 1.9 ˚C on 21st of September and 1.7 ˚C on 21st of March by applying the design strategies including 20% CA/BA, square courtyard, three floors on the east mass and finally adding mixture of vegetation trees and grass.

7.1.3 Results of stage three: Energy consumption

1- The results of the daily simulation revealed that the energy consumption was changed according to the type and orientation of the courtyards of the school building on both dates 21st of September and 21st of March. On 21st of September the daily cooling plant sensible load for the best case of stage one which was school UPA-fin to the North was only 87% of the load of the poorest case of stage one which was school KAT to the west. Based on that the total reduction was around 13% in cooling load.

2- After calculating the cooling load according to the modifications phases of the courtyards design in stage two, the highest savings in the cooling energy was in phase four by adding third floor for the UPA-fin school as it reduced the hourly cooling plant sensible load by around 12% on 21st of September and on 14 % on 21st of March compared to phase three for school UPA-fin with square courtyards.

3- Changing the CA/BA ratio to 20% for the school UPA-fin in the second phase reduced the cooling plant sensible load by around 5% on 21st of September and by around 10% on 21st of March, as the CA/BA ratio 20% produced thicker masses around the courtyards, moreover it produced higher SSI ratio and that helped in increasing the shadow inside the courtyards and decreased the heat gain.

4- Only about 2.4 % was the reduction by adding vegetation in stage five on 21st of September and around 4.2% on 21st of March. The landscape is important element in schools in hot areas, it helps in improving the microclimate of the building and helps in cooling the inner spaces by reducing the heat gain.

5- The least savings were when changing the outline of the courtyard to square as it was around 1% on 21st of September and 1.4 % on 21st of March, this mainly occurred because the extra shade inside the courtyards because of the added east walls that shaped the semi closed square outline for the courtyards.

6- The design strategies in the research including orientation and adopting 20% CA/BA ratio , square courtyard , three floors on the east mass and finally adding mixture of vegetation trees and grass stage two were able to reduce cooling plant sensible load by 19 % on 21st of September and by 27.3 % on 21st of March, due to the reduction in T_{in} by 1.9 ˚C on 21st of September and 1.7 ˚C on 21st of March.

7- When investigating the cooling plant sensible load for the whole academic year (with the built-in climate in the IESve) for the best orientation to north and the poorest orientation to the east for the school UPA-fin basic, the results revealed that there was annual reduction in the cooling load around 1.2%by adopting the best orientation to the north. This can be explained because in the best orientation case the rectangular courtyards are directed east west and that reduces the amount of solar gain and enable the courtyards to be more efficient in reducing the building temperature.

8- The annual simulation outcomes for investigating the cooling load for schools that have courtyards with different shape factor but with the same CA/BA ratio 40% revealed that, the annual cooling sensible load can be reduced slightly according to the type of configuration and number of the courtyards. UPA-fin with two courts that have shape factor W/L = 1:2.6 had the best configuration with the least cooling load which was around 2429. 93 and that is less by 3.2% (around 81.43 MWh) than the poorest case with three courts and with shape factor W/L 1:3. Moreover the best case has reduction in the cooling load around 0.4% and 0.2% less than the schools that have two courtyards with shape factor W/L = 1:2 and 1:3 successively. That can be explained in relation to the variation in the amount of the heat gain in relation to received solar radiation on the exterior walls.

9- The annual cooling plant sensible load for the school UPA-fin in the second phase when changing the CA/BA ratio from 40% to 20% was reduced by around 3% through the academic year, as the CA/BA ratio 20% created thicker masses around the courtyards, moreover it produced higher SSI ratio and that helped in increasing the shadow inside the courtyards and decreased the heat gain.

10- In phase three the annual cooling load through the academic year was reduced by additional 1.4% by changing the outline of the courtyards from rectangular to square.

11- The least annual cooling load was achieved in phase four by adding third floor for the school UPA-fin mainly on the east mass, as it reduced the annual cooling plant sensible load by around 12.4% compared to phase three with two floors only and around 16.5%compared to phase one UPA-fin basic. The third floor reduced the amount of sun radiation that hits the courtyard's ground and the surrounding walls. Moreover, the additional floor on the east side of the school helped in creating voids on the ground level that enhanced the natural outdoor ventilation for the courtyard and that helped in reducing the temperature in the courtyards and the surrounding masses of the school in general.

7.2 Conclusion:

The research results revealed that the optimal design of the courtyard can reduce the T_{in} for the inner spaces of the school, thus it can reduce the cooling load for the school building in general. Moreover, it can improve the thermal comfort for the outdoor areas.

The school UPA-fin oriented to the north (basic without modifications in the design) had less 1.7˚C and 1.78 ˚C in the T_{in} than the poorest case which was school KAT oriented to the west. This reduction in the indoor air temperature reduced the cooling load by12.5% on 21st of September and 21.9% on 21st of March compared to the poorest case KAT oriented to the west. Thus the type of the school design and the layout and number of the integrated courtyards affect the thermal performance of the building.

The design of the courtyard can affect the indoor temperature of the building, thus the cooling load. In this research adopting the following strategies that included 1- orientation to the north , 2-CA/BA ratio 20%, 3-square outline for the courtyards, 4-additional third floor on the east mass mainly 5- integrating vegetation in the courtyards, succeeded in reducing the T_{in} to 1.9 ˚C on 21st of September and 1.7 ˚C on 21st of March and that managed to reduce the cooling load by 19% on 21st of September and 27% on 21st of March compared to the basic UPA-fin to the north in phase one .

The investigation of the annual cooling load after adopting only four strategies that included 1-orientation, 2-CA/BA ratio 20%, 3-square outline for the courtyards, 4-additional third floor on the east mass mainly and excluding the integrating of vegetation, succeeded in reducing the cooling load by 16.5%compared to phase one UPA-fin basic to the north.

This research can conclude that courtyards are efficient passive design strategies that can improve the thermal comfort with less cooling energy inside educational buildings such as schools in UAE. Since the research was focused on UAE as an area with hot climate, the results can be used in designing green schools in other areas with similar climate.

7.3 Recommendations

7.3.1 Recommendation for designing courtyards in schools in hot areas:

1- It is important to consider the orientation of the courtyard in the school building as passive design solution, thus in hot arid areas it is not suitable to use the hot wind directly as cooling modifier, it is better to avoid its flowing directly into the courtyards of the school unless it is cooled before by other features like vegetation, then allowed to enter the courtyard as a cooling modifier.

2- In the case of having rectangular courtyards because of the architectural concepts, it is better to extended them along the west east direction to create more inner shade and reduce the amount of solar radiation because the west and east walls will be reduced compared to the north and south.

3- Courtyard orientation positive effect is connected to the number of courtyards, as it was found that the number of the courtyards should be studies according to the built-up area.

4- The CA/BA ratio is better to be around 20% for better thermal performance.

5- Designing suitable H/W ratio for the school courtyards, as if this ratio increases the thermal performance increases.

6- Controlling the width of the school's courtyards by reducing the sky view factor can reduce the courtyards air temperature and improves the thermal performance for the school building in general.

7- The shaded area in the schools' courtyards will increase when the shape of the courtyard become near to square, and that will decrease the amount of energy required for cooling in summer as the T_{in} decreases.

8- It is better to vary the masses heights when adding third floor around the courtyard by rising the height of the north, east and south walls to improve the stack effect and the shade inside the courtyards in the schooling time and help in modifying the T_{in} of the school building in general.

9- It is better to change the setting of the third floor in a way that creates voids on the east side which allow access for the cross ventilation through the courtyards from one side despite the fact that the indoor spaces are closed when the temperature is high, which eventually improves the thermal performance of the courtyard and the building in general, and reduces the accumulated thermal mass.

10- landscape is important element in schools in hot areas, it helps in improving the microclimate of the building and in cooling the inner spaces by reducing the heat gain. It is better to combine trees and grass in the schools' courtyards. Also, it is good to use deciduous trees.

11- It is not recommended to cover all the courtyard floor with concrete tile, if the school conditions don't allow planting trees, at least cover the courtyard floor with grass, as it is better than leaving it as concrete tile flooring.

7.3.2 Recommendation for future studies for the school courtyards:

This research covered many issues related to the courtyard design and orientation in the school buildings in the hot areas like UAE. However, the knowledge field of courtyards in school buildings is still open for more investigation to produce more sustainable green schools in hot areas. Based on that this research recommended paths with potential for investigation in future studies like the following:

- Shading devices the shading devices for the courtyards as these devices can help in reducing the received direct solar radiation that hits the ground of the courtyard, and decrease the indirect radiations reflected on the walls of the courtyard. The shading devices can reduce the heat gain for the whole building and help in reducing the cooling load for the indoor spaces. The shading devices should be movable and not fixed and controlled in a way that does not increase the heat stress in the courtyard.
- Arcades around the school courtyards: These Arcades can help in providing connection zone between the school courtyard and the indoor spaces. Moreover, they can decrease the direct gained heat through the walls of the courtyards and control the cooling loads especially in the peak hours.

- Insulation materials: The insulation materials will reduce the heat gain through the walls and help in cooling down the interior spaces. Thermal insulation can expressively improve the thermal comfort of a school building spaces, moreover it can separate the inner spaces from the outside harsh climate.
- Night ventilation: as because of the thermal mass the heat absorbed by the structural elements and released by night. Warm air might accumulate in the interior spaces from the internal surfaces through the night time, and that would increase the indoor air temperatures the next day and more energy will be needed to the reach the set point of the air temperature especially in the hot days. Based on that, night ventilation is required to move the heat to outside.
- The reflectance of the school building surfaces including the courtyard surfaces. The solar radiation that hit the building surfaces can be absorbed or it can be reflected. The amount of reflected radiation depends on the surface material, color, albedo ratio and the angle of the sun rays. Thus, the reflectance can affect the interior temperature and the cooling loads of the school building.

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Appendices

Chapter 2:

Appendix 2.1: The solar shadow calculations (Maryland Dep. of Education, 2012)**.**

The Solar Shadow Index

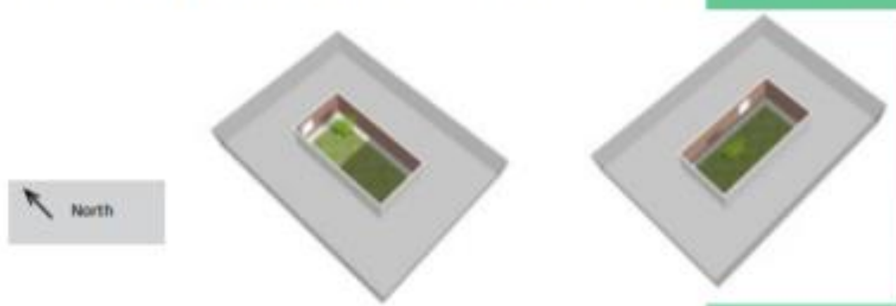
The solar shadow index measures the amount of winter sun exposure a courtyard encounters based upon the height of the walls around the courtyard, and the length of walls running in the north/south direction. "The greater the solar shadow index, the deeper the well formed by the courtyard, and the less winter sun reaches the floor or even the north"(sunniest) wall of the courtyard. (Reynolds, J. S. 2002, p. 16)

How to determine the Solar Shadow Index –

Step 1: Determine the height of the courtyard's south wall (w).
Step 2: Determine the width of the courtyard in the North/South direction (x).
Step 3: Divide the height of the wall (w) by the width of the floor (x) in the North/South direction.
w/x =Solar Shadow Index (SSI)

The lesser the value of the solar shadow index, the more indicative of light entering the courtyard in winter. This aspect of solar gain is greatly impacted by the orientation of the courtyard in the north/south direction.

Below are two sample courtyard diagrams with different orientations. Both are 25' x 50' with exterior walls of 15'-0" high. North is oriented to the upper left hand corner. Note the differences in the Solar Shadow Index (SSI).



Long walls oriented N/S
December 21 at noon
SSI = w/x = 15/50 = 0.3

Long walls oriented E/W
December 21 at noon
SSI = w/x = 15/25 = 0.6

Graphics prepared by Grimm and Parker Architects

<u>Appendix 2.2:</u> Aspect ratio in the courtyard (Maryland Dep. of Education, 2012)**.**

<u>Exposure to the Sky</u>

If a courtyard's primary reason were to bring light into the surrounding building, then the primary goal of the design of a courtyard would be to have as much exposure to the sky and sun through all seasons, as much as possible. Several factors affect the success of a courtyard's exposure to the sky and this measurement is called the aspect ratio. (Reynolds, J. S. 2002, p. 16)

The Aspect Ratio

- Determine the Aspect Ratio –

Step 1: Find the area (A) of the courtyard and the average height of the walls surrounding the courtyard (w).

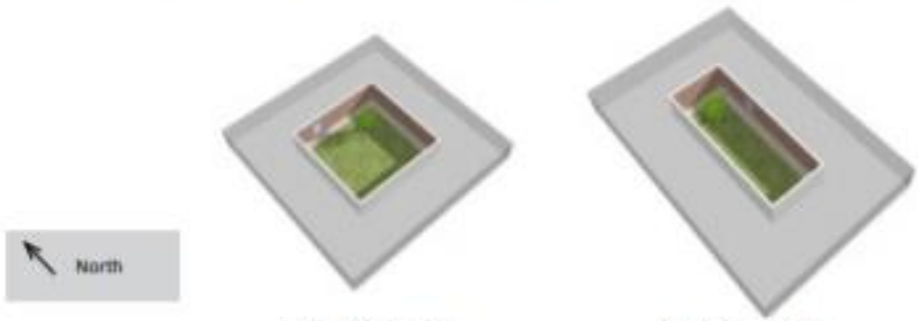
Step 2: Square the number representing the height of the walls.

$(w)^2 = W$

Step 3: Divide the area of the courtyard by the square of the height of the surrounding walls.

(A / W = the aspect ratio or AR)

A higher aspect ratio indicates a greater exposure of the courtyard to the sky.



Area = 60' x 60' = 3600
March 21 at 9 a.m.
AR = 60 x 60/15² = 16

Area = 80' x 30' = 2400
March 21 at 9 a.m.
AR = 80 x 30/15² = 10.6

Graphics prepared by Grimm and Parker Architects

Note that although the long walls of courtyard B are in the north/south direction the size of the floor perimeter has a bigger impact on the aspect ratio.

Again, this figure is an index, an <u>indicator</u> of the amount of sun exposure to the courtyard. This indicator is most helpful in the design stage using it for comparisons between several different schemes with different courtyard orientations, sizes and wall heights.

School Courtyards
Maryland State Department of Education, May 2012
24

Appendix 2.3: General rules for school building design in UAE.

Chapter 2 Licensing of Schools Article 2 The following conditions must be met in the school: First: The site should be in a suitable location for the neighborhood or region in terms of ease of transport and ensure the safety of pupils to access it. The site should be away from noise, pollution and everything that affects the educational message of the school. The necessary services are available near the site.

Second: Specifications of the Private School Building The Ministry's approval of the building plans for any private school must be obtained before it begins. It should include the following specifications:

1. Classrooms with a minimum area of 30 square meters each.
2. Management rooms and rooms for teachers to suit their numbers with their own toilets separate from student toilets.
3. Rooms for multi-purpose activities of not less than (40) square meters in proportion to the number of students.
4. Clinic consisting of two connected rooms separated by a barrier and not less than each area of (6) square meters.
5. Water cycles commensurate with the number of students and the stage so that the unit serves no more than thirty students with the separation of the boys units from the girls' units and provided that the necessary water connections are available.
6. Science and computer laboratories suitable for the stages of study and the area of each laboratory about (40) square meters to be attached to the science laboratory store for the conservation of chemicals.
7. School libraries not less than (50) square meters.
8. Mosque or chapel of not less than (30) square meters.
9. Canteen, storeroom and room for keeping exam papers.
10. The use of prefabricated wooden rooms (caravans) is forbidden and the roofs of asbestos are prohibited.
11. Each study stage shall be assigned a separate building or section and for each sex beginning from the fifth grade. An independent building with its facilities. Several sections may participate in the use of the educational facility (laboratories, activity halls) provided

that the ports do not lead to mixing between the students of different departments or between the sexes.

12. The building should be surrounded by an appropriate external wall from all sides.
13. Providing all safety devices and systems.
14. Provide ventilation and lighting, health and safety of electrical and sanitary wiring.
15. The school building shall include yards and playgrounds of at least twice the size of a total area of the classrooms, 30% of which should be shaded and floors should be in compliance with safety and security requirements.
16. Provide a guard room attached to the school building.
17. Provide adequate parking for cars and buses.
18. The width of the passages in front of the entrances shall not be less than (3) meters.

<u>Appendix 2.4:</u> Design rules for designing a courtyard in a school (Maryland Dep. of Education, 2012)**.**

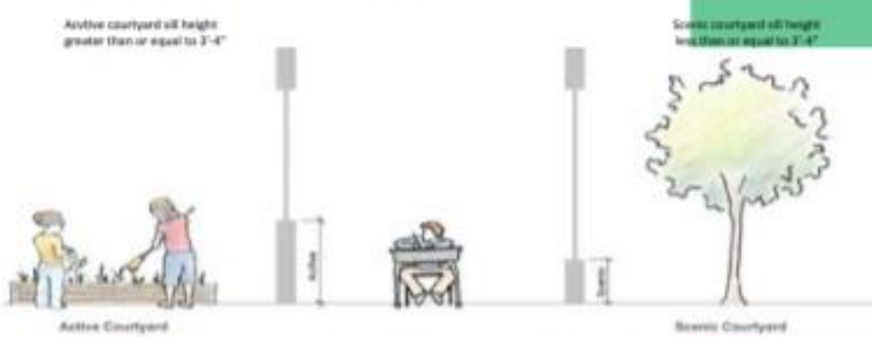
<u>Design</u>

Below is a list of architectural elements to include as the groundwork for a successful school courtyard.

"Take care of the land and the land will take care of you."
- Hugh H. Bennett
conservationist

Elements of Successful Courtyard Design
For School Buildings

- Analyze sun angles, building massing and orientation to ensure the most positive impact on the quality of light both into the courtyard and into the adjacent spaces.
- Provide for south light or place the courtyard south of the building as much as possible with appropriate shading.
- Note the direction of prevailing winds and design for protection.
- **When designing a new school building consider the noise levels expected in the courtyard.**
- Consider the access needed by both personnel and equipment to provide regular maintenance. Snow removal should be taken into account.
- Plant native species.
- Before the trees mature, shade may be provided by arbors, pergolas, fabric structures, umbrellas, etc.
- Provide GFIC exterior outlets and frost-proof hose bibs on more than one wall.
- Consider drainage patterns, porosity of the path material and its impact on storm water management. Provide good drainage, not only to collect the water, but also discharge the water to a safe place.
- Where classrooms are adjacent to active courtyards, design the window sills higher to block distractions from inside the classrooms.



- Where classrooms are adjacent to scenic courtyards, design the window sills lower for children of all ages to see out.

School Courtyards
Maryland State Department of Education, May 2012
17

Chapter 4
Appendix 4.1 : Specifications of Extech 45170 meter(Extech.com 2018).

Specifications

Range Specifications

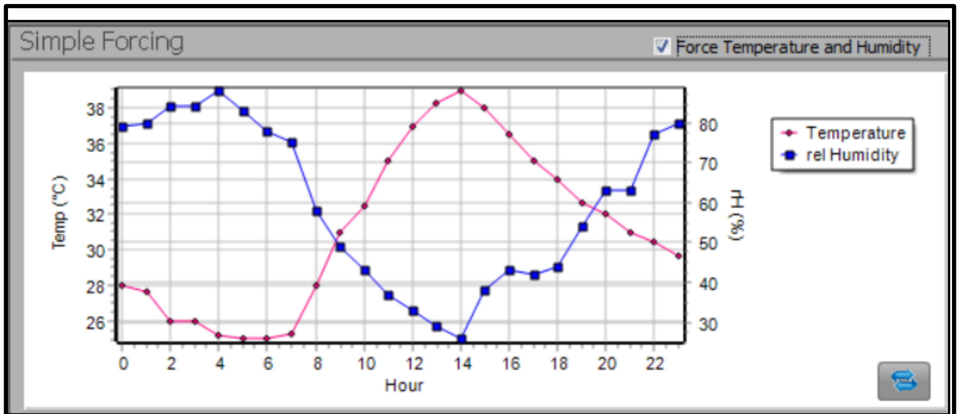
Measurement	Range	Resolution	Accuracy
MPH (Miles per hour)	0.9 to 67.0MPH	0.1MPH	≤ 3937 ft/min: ±3% F.S. > 3937 ft/min: ±4% F.S
km/hr (kilometers per hour)	1.4 to 108.0 km/h	0.1km/h	
Knots (nautical miles per hour)	0.8 to 58.3 knots	0.1knots	
m/sec (meters per second)	0.4 to 30.0 m/s	0.1 m/s	
ft/min (feet per minute)	80 to 5910 ft/min	1ft/min	
Temperature/Thermistor	32 to 122ºF (-0 to 50ºC)	0.1ºF/C	± 2.5ºF (± 1.2ºC)
Temperature /Thermocouple	-148 to 2372°F -100 to 1300°C	0.1°F 0.1°C	± (1% + 2°F) ± (1% + 1°C)
Relative Humidity	10.0 to 95.0%	0.1%	±4% RH (from 10% to 70%RH) ±4%rdg +1.2% RH (> 70% RH)
Light (Auto Ranging)	0 to 2,200 Lux	1 Lux	±5% rdg +8 digits
	1,800 to 20,000 Lux	10 Lux	
	0 to 204.0 Fc	0.1 Fc	
	170 to 1,860 Fc	1 Fc	

General Specifications

Display	4 digit (9999 count) Dual Display LCD
Sensors	Thin film capacitance humidity sensor
Min/Max	Min/Max recalls the highest/lowest reading
Data Hold	Data Hold freezes the display
Operating conditions	0 to 50ºC (32 to 122ºF) / < 80% RH
Power supply	9 Volt Battery
Dimensions / Weight	Instrument: 156 x 60 x 33mm(6.14 x 2.36 x 1.29") Vane: 24mm (1") diameter / 160 g (5.7 oz)

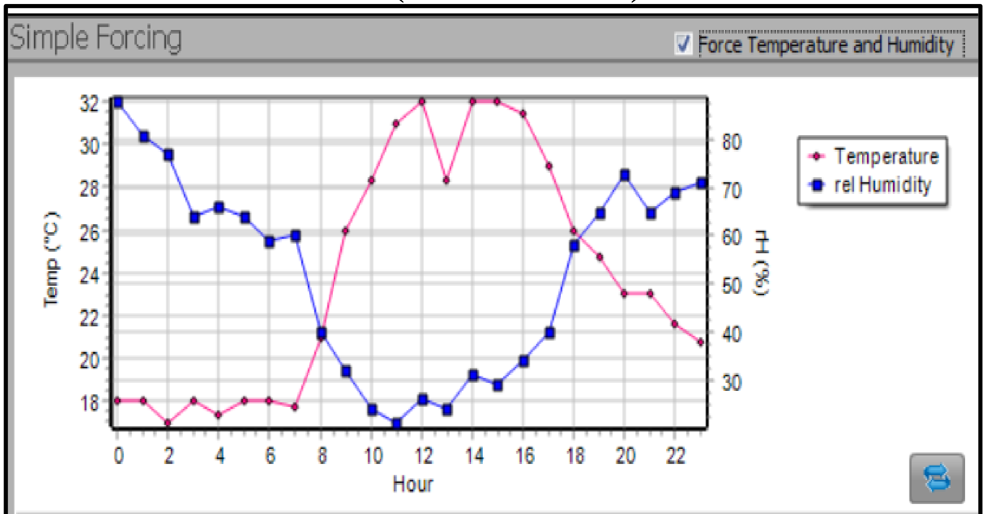
Chapter 5:

Appendix 5.1 : Air temperature and relative humidity on 21 September from forced data in ENVI-met (IES weather data).



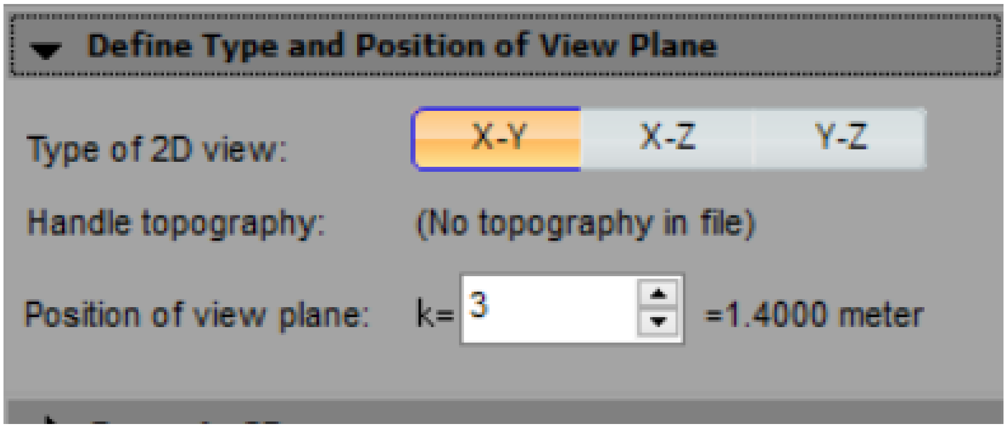
Output data directory	[SIMPLEFORCE]
  Start Simulation at Day (DD.MM.YYYY): =21.09.2016 Start Simulation at Time (HH:MM:SS): =00:00:00 Total Simulation Time in Hours: =24 Wind Speed in 10 m ab. Ground [m/s] =4 Wind Direction (0:N..90:E..180:S..270:W..) =315 Roughness Length z0 at Reference Point [m] =0.01 Initial Temperature Atmosphere [K] =304.330 Specific Humidity in 2500 m [g Water/kg air] =7.0 Relative Humidity in 2m [%] =50 % End main data .... [OUTPUTTIMING]______________________________ ________ Output interval main files (min) =60.00 Output interval text output files (min) =30.00 Include Nesting Grids in Output (0:n,1:y) =0 [TIMING]____________________________________ _ Update Surface Data each ? sec =30.00 Update Wind field each ? sec =900.00 Update Radiation and Shadows each ? sec =600.00 Update Plant Data each ? sec =600.00	Hour 00h [Temp, rH] = 301.15, 79.00 Hour 01h [Temp, rH] = 300.75, 80.00 Hour 02h [Temp, rH] = 299.15, 84.00 Hour 03h [Temp, rH] = 299.15, 84.00 Hour 04h [Temp, rH] = 298.35, 88.00 Hour 05h [Temp, rH] = 298.15, 83.00 Hour 06h [Temp, rH] = 298.15, 78.00 Hour 07h [Temp, rH] = 298.45, 75.00 Hour 08h [Temp, rH] = 301.15, 58.00 Hour 09h [Temp, rH] = 304.15, 49.00 Hour 10h [Temp, rH] = 305.65, 43.00 Hour 11h [Temp, rH] = 308.15, 37.00 Hour 12h [Temp, rH] = 310.15, 33.00 Hour 13h [Temp, rH] = 311.45, 29.00 Hour 14h [Temp, rH] = 312.15, 26.00 Hour 15h [Temp, rH] = 311.15, 38.00 Hour 16h [Temp, rH] = 309.65, 43.00 Hour 17h [Temp, rH] = 308.15, 42.00 Hour 18h [Temp, rH] = 307.15, 44.00 Hour 19h [Temp, rH] = 305.85, 54.00 Hour 20h [Temp, rH] = 305.15, 63.00 Hour 21h [Temp, rH] = 304.15, 63.00 Hour 22h [Temp, rH] = 303.65, 77.00 Hour 23h [Temp, rH] = 302.85, 80.00

Appendix 5.2: Temperature and relative humidity on 21st March From forced data in ENVI-met (IES weather data).



Output data directory	[SIMPLEFORCE]
	Hour 00h [Temp, rH] = 291.15, 88.00
	Hour 01h [Temp, rH] = 291.15, 81.00
Start Simulation at Day (DD.MM.YYYY):	Hour 02h [Temp, rH] = 290.15, 77.00
=21.03.2017	Hour 03h [Temp, rH] = 291.15, 64.00
Start Simulation at Time (HH:MM:SS): =00:00:00	Hour 04h [Temp, rH] = 290.55, 66.00
Total Simulation Time in Hours: =24	Hour 05h [Temp, rH] = 291.15, 64.00
Wind Speed in 10 m ab. Ground [m/s] =4	Hour 06h [Temp, rH] = 291.15, 59.00
Wind Direction (0:N..90:E..180:S..270:W..) =315	Hour 07h [Temp, rH] = 290.95, 60.00
Roughness Length z0 at Reference Point [m] =0.01	Hour 08h [Temp, rH] = 294.15, 40.00
Initial Temperature Atmosphere [K] =297.000	Hour 09h [Temp, rH] = 299.15, 32.00
Specific Humidity in 2500 m [g Water/kg air] =7.0	Hour 10h [Temp, rH] = 301.45, 24.00
Relative Humidity in 2m [%] =50	Hour 11h [Temp, rH] = 304.15, 21.00
% End main data	Hour 12h [Temp, rH] = 305.15, 26.00
[OUTPUTTIMING]_______________________	Hour 13h [Temp, rH] = 301.45, 24.00
Output interval main files (min) =60.00	Hour 15h [Temp, rH] = 305.15, 29.00
Output interval text output files (min) =30.00	Hour 16h [Temp, rH] = 304.55, 34.00
Include Nesting Grids in Output (0:n,1:y) =0	Hour 17h [Temp, rH] = 302.15, 40.00
[TIMING]_______________________________	Hour 18h [Temp, rH] = 299.15, 58.00
Update Surface Data each ? sec =30.00	Hour 19h [Temp, rH] = 297.85, 65.00
Update Wind field each ? sec =900.00	Hour 20h [Temp, rH] = 296.15, 73.00
Update Radiation and Shadows each ? sec =600.00	Hour 21h [Temp, rH] = 296.15, 65.00
Update Plant Data each ? sec =600.00	Hour 22h [Temp, rH] = 294.75, 69.00
	Hour 23h [Temp, rH] = 293.95, 71.00

Appendix 5.3 : Location of K plane for air temperature measurements.



Chapter 6

Appendix 6.1 Metabolic Rates for Typical Tasks(ASHRAE Standard 55-2010, 2011)

TABLE A1 Metabolic Rates for Typical Tasks

Activity	Metabolic Rate		
	Met Units	W/m²	(Btu/h·ft²)
Resting			
Sleeping	0.7	40	(13)
Reclining	0.8	45	(15)
Seated, quiet	1.0	60	(18)
Standing, relaxed	1.2	70	(22)
Walking (on level surface)			
0.9 m/s, 3.2 km/h, 2.0 mph	2.0	115	(37)
1.2 m/s, 4.3 km/h, 2.7 mph	2.6	150	(48)
1.8 m/s, 6.8 km/h, 4.2 mph	3.8	220	(70)
Office Activities			
Reading, seated	1.0	55	(18)
Writing	1.0	60	(18)
Typing	1.1	65	(20)
Filing, seated	1.2	70	(22)
Filing, standing	1.4	80	(26)
Walking about	1.7	100	(31)
Lifting/packing	2.1	120	(39)
Driving/Flying			
Automobile	1.0–2.0	60–115	(18–37)
Aircraft, routine	1.2	70	(22)
Aircraft, instrument landing	1.8	105	(33)
Aircraft, combat	2.4	140	(44)
Heavy vehicle	3.2	185	(59)
Miscellaneous Occupational Activities			
Cooking	1.6–2.0	95–115	(29–37)
House cleaning	2.0–3.4	115–200	(37–63)
Seated, heavy limb movement	2.2	130	(41)
Machine work			
sawing (table saw)	1.8	105	(33)
light (electrical industry)	2.0–2.4	115–140	(37–44)
heavy	4.0	235	(74)
Handling 50 kg (100 lb) bags	4.0	235	(74)
Pick and shovel work	4.0–4.8	235–280	(74–88)
Miscellaneous Leisure Activities			
Dancing, social	2.4–4.4	140–255	(44–81)
Calisthenics/exercise	3.0–4.0	175–235	(55–74)
Tennis, single	3.6–4.0	210–270	(66–74)
Basketball	5.0–7.6	290–440	(90–140)
Wrestling, competitive	7.0–8.7	410–505	(130–160)

Appendix 6.2 Clothing insulation (ASHRAE Standard 55-2010, 2011)

TABLE B1

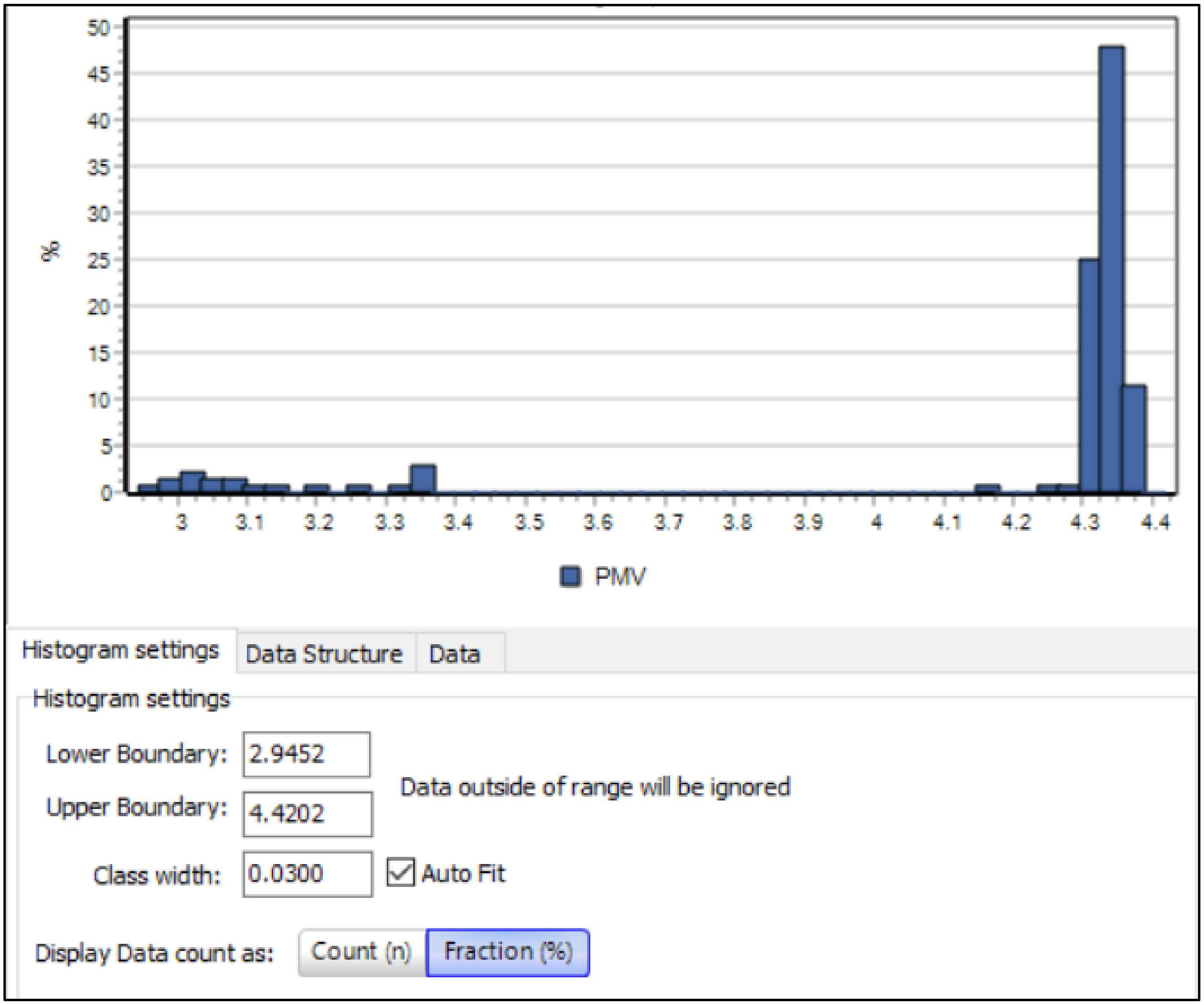
Clothing Insulation Values for Typical Ensembles*

Clothing Description	Garments Included†	I_{cl}, (clo)
Trousers	1) Trousers, short-sleeve shirt	0.57
	2) Trousers, long-sleeve shirt	0.61
	3) #2 plus suit jacket	0.96
	4) #2 plus suit jacket, vest, T-shirt	1.14
	5) #2 plus long-sleeve sweater, T-shirt	1.01
	6) #5 plus suit jacket, long underwear bottoms	1.30
Skirts/Dresses	7) Knee-length skirt, short-sleeve shirt (sandals)	0.54
	8) Knee-length skirt, long-sleeve shirt, full slip	0.67
	9) Knee-length skirt, long-sleeve shirt, half slip, long-sleeve sweater	1.10
	10) Knee-length skirt, long-sleeve shirt, half slip, suit jacket	1.04
	11) Ankle-length skirt, long-sleeve shirt, suit jacket	1.10
Shorts	12) Walking shorts, short-sleeve shirt	0.36
Overalls/Coveralls	13) Long-sleeve coveralls, T-shirt	0.72
	14) Overalls, long-sleeve shirt, T-shirt	0.89
	15) Insulated coveralls, long-sleeve thermal underwear tops and bottoms	1.37
Athletic	16) Sweat pants, long-sleeve sweatshirt	0.74
Sleepwear	17) Long-sleeve pajama tops, long pajama trousers, short 3/4 length robe (slippers, no socks)	0.96

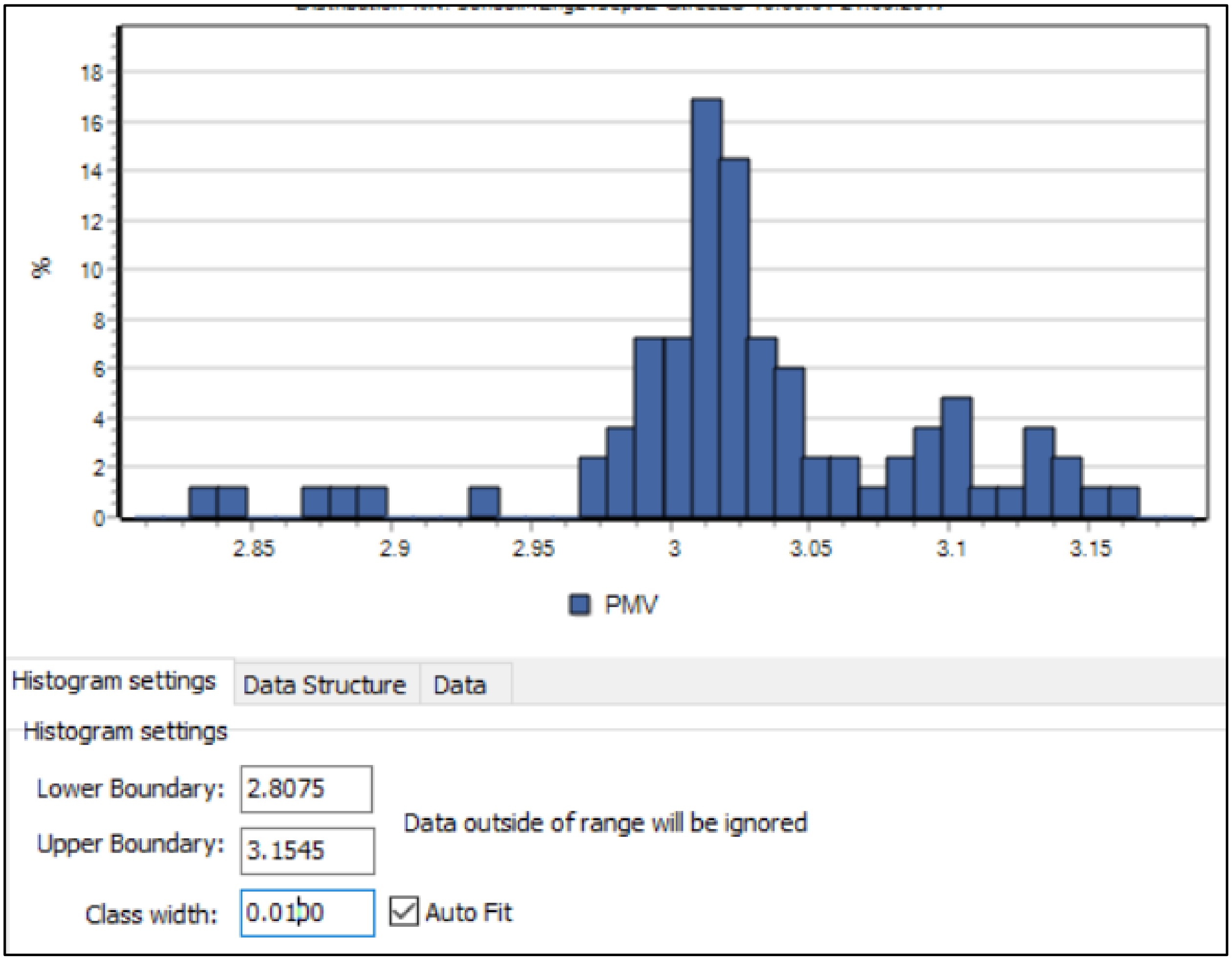
* Data are from Chapter 9 in the 2009 *ASHRAE Handbook—Fundamentals*.[3]

† All clothing ensembles, except where otherwise indicated in parentheses, include shoes, socks, and briefs or panties. All skirt/dress clothing ensembles include pantyhose and no additional socks.

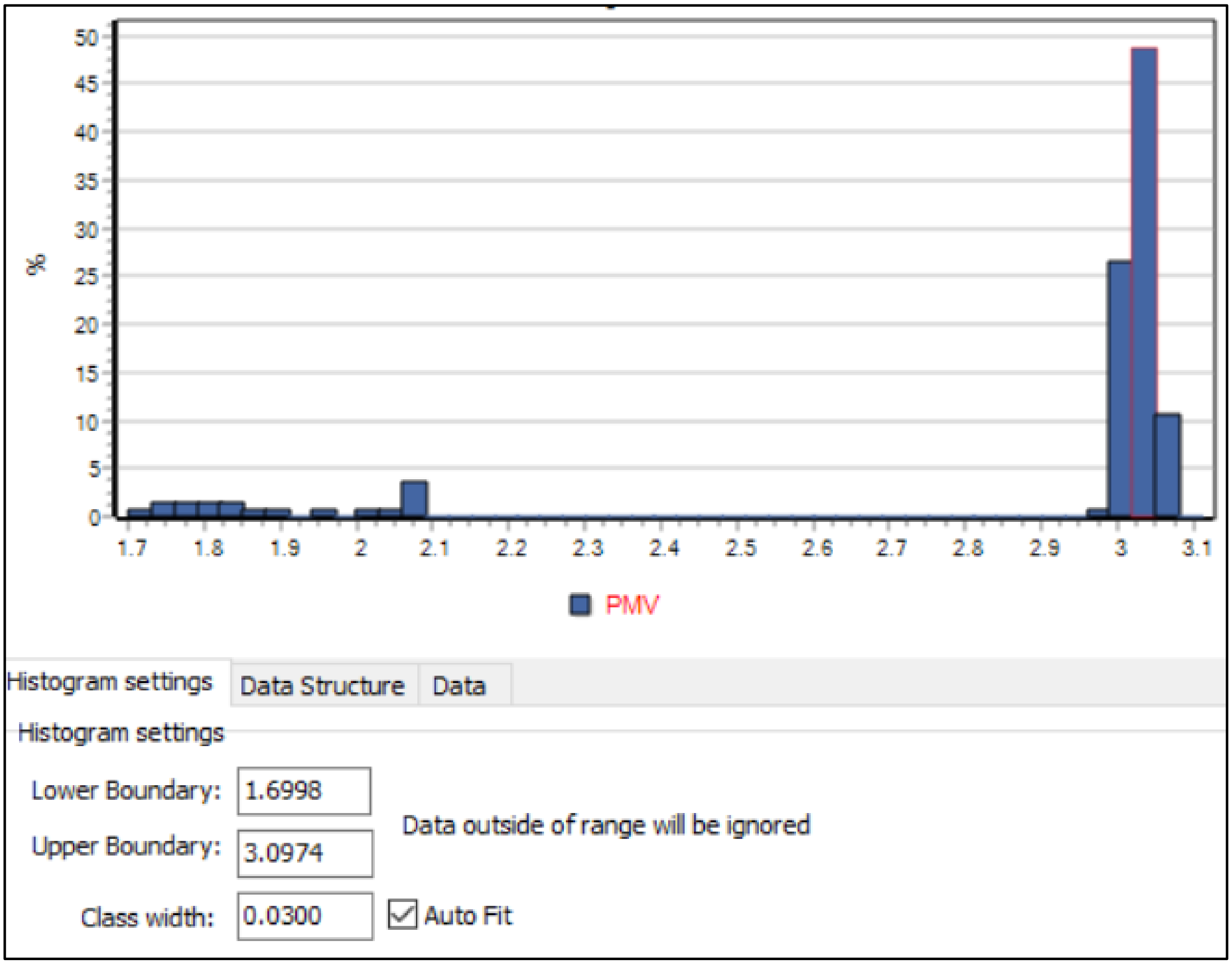
Appendix 6.3: PMV readings percentage for the first phase school model of stage two on the 21st of September .



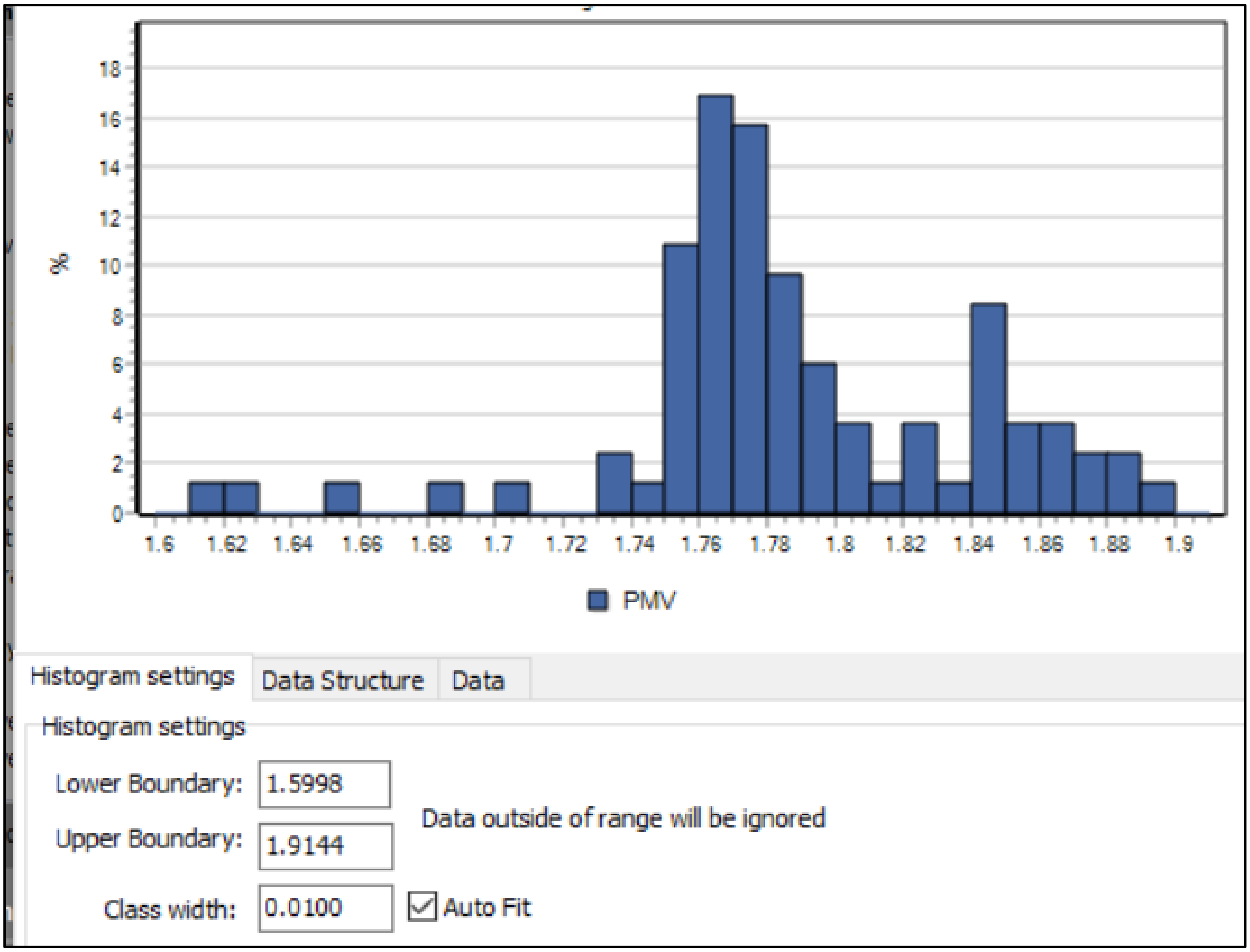
Appendix 6.4 : PMV readings percentage for the fifth phase school model of stage two on the 21st of September.



Appendix 6.5: PMV readings percentage for the first phase school model of the fifth phase of stage two on 21st of March.



Appendix 6.6: PMV readings percentage for the fifth phase school model of stage two on 21st of March .



Appendix 6.7: The receptor points for the best cases of school buildings for the main stages on 21st of September :

Air temperature for the micro climate for UPA 40% C 2F from the six receptors points

Date	Time	1 (°C)	2 (°C)	3 (°C)	4 (°C)	5 (°C)	6 (°C)	Av T (°C)
21.09.2016	1:00 AM	27.6	27.3	28.2	27.9	28.2	28.0	27.9
21.09.2016	2:00 AM	26.4	26.2	27.2	26.8	27.1	27.0	26.8
21.09.2016	3:00 AM	26.3	26.1	27.0	26.6	26.9	26.8	26.6
21.09.2016	4:00 AM	25.6	25.5	26.4	26.1	26.3	26.2	26.0
21.09.2016	5:00 AM	25.4	25.3	26.1	25.8	26.0	25.9	25.8
21.09.2016	6:00 AM	25.3	25.2	26.0	25.7	25.9	25.8	25.7
21.09.2016	7:00 AM	25.5	25.4	26.2	25.9	26.1	26.0	25.8
21.09.2016	8:00 AM	27.9	27.7	28.2	28.1	28.2	28.1	28.0
21.09.2016	9:00 AM	30.7	30.5	30.5	30.6	30.5	30.5	30.6
21.09.2016	10:00 AM	32.3	32.3	32.0	32.1	31.9	32.0	32.1
21.09.2016	11:00 AM	34.7	34.7	33.8	34.1	33.9	33.9	34.2
21.09.2016	12:00 PM	36.6	36.8	35.5	35.9	35.6	35.7	36.0
21.09.2016	1:00 PM	38.0	38.3	36.8	37.2	36.9	37.0	37.4
21.09.2016	2:00 PM	38.7	39.2	37.6	38.0	38.0	37.8	38.3
21.09.2016	3:00 PM	38.0	38.7	37.2	37.7	37.3	37.5	37.8
21.09.2016	4:00 PM	36.8	37.5	36.3	36.8	36.4	36.6	36.7
21.09.2016	5:00 PM	35.3	35.9	35.2	35.5	35.2	35.4	35.4
21.09.2016	6:00 PM	34.1	34.3	34.1	34.2	34.1	34.1	34.1
21.09.2016	7:00 PM	32.9	33.0	33.1	33.1	33.0	33.1	33.0
21.09.2016	8:00 PM	32.2	32.3	32.4	32.4	32.4	32.4	32.3
21.09.2016	9:00 PM	31.3	31.4	31.6	31.5	31.6	31.5	31.5
21.09.2016	10:00 PM	30.8	30.8	31.1	31.0	31.0	31.0	31.0
21.09.2016	11:00 PM	30.0	30.1	30.5	30.3	30.4	30.4	30.3
21.09.2016	11:59 PM	28.6	28.7	29.3	29.1	29.2	29.1	29.0

Air temperature for the micro climate for UPA 20% C 2F from the six receptors points

Date	Time	1	2	3	4	5	6	
21.09.2017	1:00 AM	27.343	27.405	28.272	27.857	28.266	28.088	27.9
21.09.2017	2:00 AM	26.163	26.312	27.253	26.826	27.171	27.029	26.8
21.09.2017	3:00 AM	26.088	26.209	27.023	26.641	26.95	26.823	26.6
21.09.2017	4:00 AM	25.448	25.602	26.46	26.068	26.357	26.243	26.0
21.09.2017	5:00 AM	25.215	25.354	26.178	25.796	26.075	25.965	25.8
21.09.2017	6:00 AM	25.167	25.286	26.07	25.701	25.972	25.865	25.7
21.09.2017	7:00 AM	25.391	25.475	26.237	25.886	26.14	26.044	25.9
21.09.2017	8:00 AM	27.847	27.747	28.298	28.127	28.204	28.188	28.1
21.09.2017	9:00 AM	30.751	30.556	30.555	30.64	30.513	30.544	30.6
21.09.2017	10:00 AM	32.493	32.32	31.974	32.176	31.927	31.979	32.1
21.09.2017	11:00 AM	34.881	34.65	33.845	34.131	33.859	33.874	34.2
21.09.2017	12:00 PM	36.882	36.674	35.541	35.917	35.607	35.617	36.0
21.09.2017	1:00 PM	38.26	38.119	36.803	37.246	36.895	36.922	37.4
21.09.2017	2:00 PM	39.018	38.946	37.568	38.077	37.693	37.744	38.2
21.09.2017	3:00 PM	38.315	38.391	37.214	37.772	37.318	37.442	37.7
21.09.2017	4:00 PM	36.988	37.146	36.3	36.834	36.363	36.537	36.7
21.09.2017	5:00 PM	35.458	35.6	35.171	35.567	35.192	35.357	35.4
21.09.2017	6:00 PM	34.199	34.221	34.053	34.191	34.057	34.118	34.1
21.09.2017	7:00 PM	32.957	32.997	33.052	33.086	33.029	33.062	33.0
21.09.2017	8:00 PM	32.209	32.242	32.385	32.368	32.358	32.369	32.3
21.09.2017	9:00 PM	31.284	31.342	31.609	31.54	31.564	31.562	31.5
21.09.2017	10:00 PM	30.748	30.803	31.101	31.011	31.056	31.043	31.0
21.09.2017	11:00 PM	30.012	30.089	30.467	30.344	30.407	30.388	30.3
21.09.2017	11:59 PM	28.558	28.699	29.284	29.088	29.177	29.152	29.0

Air temperature for the micro climate for UPA 20% C 1/1 2F from the six receptors points

Date	Time	1 (°C)	2 (°C)	3 (°C)	4 (°C)	5 (°C)	6 (°C)	Av T (°C)
21.09.2017	1:00 AM	27.348	27.404	28.209	27.855	28.272	28.105	27.9
21.09.2017	2:00 AM	26.163	26.307	27.182	26.823	27.161	27.045	26.8
21.09.2017	3:00 AM	26.087	26.203	26.959	26.638	26.941	26.835	26.6
21.09.2017	4:00 AM	25.446	25.595	26.393	26.065	26.341	26.257	26.1
21.09.2017	5:00 AM	25.214	25.348	26.114	25.795	26.06	25.979	25.8
21.09.2017	6:00 AM	25.166	25.281	26.009	25.701	25.958	25.88	25.7
21.09.2017	7:00 AM	25.39	25.471	26.188	25.885	26.124	26.052	25.9
21.09.2017	8:00 AM	27.845	27.739	28.321	28.118	28.174	28.15	28.1
21.09.2017	9:00 AM	30.748	30.548	30.609	30.627	30.484	30.472	30.6
21.09.2017	10:00 AM	32.489	32.311	32.046	32.161	31.917	31.908	32.1
21.09.2017	11:00 AM	34.874	34.639	33.917	34.111	33.883	33.819	34.2
21.09.2017	12:00 PM	36.873	36.662	35.608	35.898	35.656	35.587	36.0
21.09.2017	1:00 PM	38.248	38.104	36.866	37.226	36.956	36.912	37.3
21.09.2017	2:00 PM	39.003	38.93	37.618	38.056	37.752	37.751	38.1
21.09.2017	3:00 PM	38.299	38.374	37.254	37.749	37.357	37.461	37.7
21.09.2017	4:00 PM	36.975	37.133	36.333	36.814	36.378	36.567	36.7
21.09.2017	5:00 PM	35.449	35.594	35.199	35.553	35.187	35.382	35.4
21.09.2017	6:00 PM	34.191	34.223	34.063	34.187	34.064	34.137	34.1
21.09.2017	7:00 PM	32.95	32.998	33.051	33.084	33.028	33.081	33.0
21.09.2017	8:00 PM	32.203	32.245	32.379	32.367	32.355	32.386	32.3
21.09.2017	9:00 PM	31.28	31.345	31.597	31.54	31.555	31.58	31.5
21.09.2017	10:00 PM	30.744	30.806	31.087	31.012	31.047	31.06	31.0
21.09.2017	11:00 PM	30.01	30.091	30.448	30.345	30.395	30.406	30.3
21.09.2017	11:59 PM	28.556	28.7	29.256	29.091	29.155	29.177	29.0

Air temperature for the micro climate for UPA 3F East from the six receptors points								
Date	Time	1 (°C)	2 (°C)	3 (°C)	4 (°C)	5 (°C)	6 (°C)	Av T (°C)
21.09.2017	1:00 AM	27.603	27.585	28.291	27.884	28.461	28.081	28.0
21.09.2017	2:00 AM	26.392	26.46	27.296	26.88	27.396	27.008	26.9
21.09.2017	3:00 AM	26.289	26.34	27.054	26.687	27.146	26.805	26.8
21.09.2017	4:00 AM	25.642	25.725	26.502	26.124	26.567	26.221	26.2
21.09.2017	5:00 AM	25.403	25.473	26.216	25.851	26.275	25.946	25.9
21.09.2017	6:00 AM	25.348	25.402	26.102	25.752	26.16	25.849	25.8
21.09.2017	7:00 AM	25.557	25.586	26.262	25.91	26.29	26.017	26.0
21.09.2017	8:00 AM	27.851	27.771	28.304	28.004	28.132	28.113	28.0
21.09.2017	9:00 AM	30.578	30.484	30.534	30.503	30.32	30.451	30.5
21.09.2017	10:00 AM	32.185	32.157	31.954	32.064	31.692	31.867	32.0
21.09.2017	11:00 AM	34.469	34.418	33.808	34.042	33.621	33.794	34.0
21.09.2017	12:00 PM	36.4	36.391	35.476	35.839	35.375	35.56	35.8
21.09.2017	1:00 PM	37.735	37.799	36.689	37.17	36.676	36.882	37.1
21.09.2017	2:00 PM	38.503	38.618	37.455	37.998	37.486	37.708	37.9
21.09.2017	3:00 PM	37.853	38.072	37.096	37.691	37.127	37.397	37.5
21.09.2017	4:00 PM	36.635	36.878	36.2	36.751	36.199	36.488	36.5
21.09.2017	5:00 PM	35.241	35.422	35.102	35.491	35.069	35.314	35.3
21.09.2017	6:00 PM	34.107	34.154	34.018	34.179	34.015	34.101	34.1
21.09.2017	7:00 PM	32.92	32.969	33.037	33.093	33.036	33.046	33.0
21.09.2017	8:00 PM	32.202	32.238	32.377	32.381	32.385	32.356	32.3
21.09.2017	9:00 PM	31.304	31.354	31.617	31.567	31.623	31.55	31.5
21.09.2017	10:00 PM	30.78	30.826	31.113	31.041	31.124	31.034	31.0
21.09.2017	11:00 PM	30.06	30.119	30.491	30.384	30.497	30.378	30.3
21.09.2017	11:59 PM	28.631	28.741	29.341	29.159	29.324	29.138	29.1

Air temperature for the micro climate for UPA 3F East feom the six receptors points							
Time	1 (°C)	2 (°C)	3 (°C)	4 (°C)	5 (°C)	6 (°C)	Av T (°C)
1:00 AM	28.02	28.23	28.20	28.24	28.32	28.03	28.2
2:00 AM	26.82	27.01	27.21	27.21	27.26	26.97	27.1
3:00 AM	26.66	26.83	26.97	26.99	27.01	26.76	26.9
4:00 AM	26.03	26.18	26.42	26.41	26.43	26.18	26.3
5:00 AM	25.76	25.91	26.13	26.13	26.14	25.90	26.0
6:00 AM	25.68	25.83	26.02	26.02	26.02	25.80	25.9
7:00 AM	25.85	25.99	26.16	26.15	26.15	25.96	26.0
8:00 AM	27.91	27.95	28.10	28.02	28.05	28.06	28.0
9:00 AM	30.41	30.36	30.39	30.31	30.29	30.39	30.4
10:00 AM	31.88	31.76	31.84	31.74	31.69	31.80	31.8
11:00 AM	33.99	33.85	33.73	33.67	33.62	33.71	33.8
12:00 PM	35.86	35.70	35.48	35.46	35.46	35.55	35.6
1:00 PM	37.21	37.03	36.84	36.80	36.87	37.06	37.0
2:00 PM	37.91	37.71	37.65	37.63	37.74	37.83	37.7
3:00 PM	37.44	37.24	37.25	37.29	37.36	37.61	37.4
4:00 PM	36.32	36.12	36.16	36.34	36.23	36.45	36.3
5:00 PM	35.02	34.89	34.96	35.16	35.00	35.19	35.0
6:00 PM	33.99	33.95	33.92	34.03	33.93	34.00	34.0
7:00 PM	32.90	32.89	32.95	33.01	32.95	32.96	32.9
8:00 PM	32.21	32.23	32.29	32.33	32.30	32.28	32.3
9:00 PM	31.37	31.41	31.53	31.54	31.54	31.48	31.5
10:00 PM	30.86	30.91	31.03	31.03	31.05	30.98	31.0
11:00 PM	30.18	30.24	30.41	30.39	30.42	30.33	30.3
11:59 PM	28.83	28.91	29.26	29.19	29.23	29.10	29.1

Appendix 6.8: The receptor points for the best cases of school buildings for the main stages on 21st of March.

Air temperature for the micro climate for UPA 40% C 2F from the six receptors points								
Date	Time	1 (°C)	2 (°C)	3 (°C)	4 (°C)	5 (°C)	6 (°C)	Av T (°C)
21.03.2017	1:00 AM	18.552	18.664	19.345	19.046	19.296	19.129	19.0
21.03.2017	2:00 AM	17.698	17.831	18.588	18.252	18.511	18.34	18.2
21.03.2017	3:00 AM	18.326	18.385	18.981	18.7	18.935	18.772	18.7
21.03.2017	4:00 AM	17.871	17.952	18.612	18.303	18.542	18.38	18.3
21.03.2017	5:00 AM	18.256	18.299	18.854	18.582	18.802	18.647	18.6
21.03.2017	6:00 AM	18.258	18.296	18.849	18.576	18.792	18.639	18.6
21.03.2017	7:00 AM	18.088	18.127	18.701	18.423	18.64	18.494	18.4
21.03.2017	8:00 AM	20.835	20.685	20.976	20.939	21.066	21.093	20.9
21.03.2017	9:00 AM	25.032	24.661	24.3	24.467	24.446	24.485	24.6
21.03.2017	10:00 AM	27.553	27.217	26.609	26.834	26.717	26.794	27.0
21.03.2017	11:00 AM	30.259	29.941	28.986	29.287	29.1	29.176	29.5
21.03.2017	12:00 PM	31.612	31.463	30.327	30.723	30.415	30.562	30.8
21.03.2017	1:00 PM	29.459	29.76	28.867	29.392	28.815	29.264	29.3
21.03.2017	2:00 PM	31.788	31.816	30.528	31.042	30.605	30.828	31.1
21.03.2017	3:00 PM	31.994	32.096	30.931	31.442	30.989	31.237	31.5
21.03.2017	4:00 PM	31.471	31.61	30.634	31.124	30.683	30.943	31.1
21.03.2017	5:00 PM	29.512	29.715	29.183	29.575	29.185	29.491	29.5
21.03.2017	6:00 PM	26.744	26.876	26.867	26.966	26.814	26.973	26.9
21.03.2017	7:00 PM	25.282	25.354	25.499	25.474	25.449	25.498	25.4
21.03.2017	8:00 PM	23.708	23.8	24.126	24.018	24.07	24.068	24.0
21.03.2017	9:00 PM	23.441	23.486	23.766	23.665	23.735	23.715	23.6
21.03.2017	10:00 PM	22.236	22.317	22.735	22.576	22.686	22.641	22.5
21.03.2017	11:00 PM	21.427	21.508	21.971	21.788	21.92	21.858	21.7
21.03.2017	11:59 PM	19.121	19.288	20.041	19.742	19.938	19.843	19.7

Air temperature for the micro climate for UPA 20% C 2F from the six receptors points								
Date	Time	1 (°C)	2 (°C)	3 (°C)	4 (°C)	5 (°C)	6 (°C)	Av T (°C)
21.03.2017	1:00 AM	18.566	18.717	18.917	19.177	19.383	19.373	19.0
21.03.2017	2:00 AM	17.688	17.868	18.068	18.399	18.61	18.611	18.2
21.03.2017	3:00 AM	18.369	18.45	18.65	18.805	19.009	18.983	18.7
21.03.2017	4:00 AM	17.891	18.004	18.204	18.424	18.628	18.614	18.3
21.03.2017	5:00 AM	18.307	18.365	18.565	18.677	18.873	18.844	18.6
21.03.2017	6:00 AM	18.307	18.361	18.561	18.671	18.863	18.836	18.6
21.03.2017	7:00 AM	18.128	18.188	18.388	18.525	18.712	18.693	18.5
21.03.2017	8:00 AM	20.856	20.755	20.955	21.013	21.044	21.071	20.9
21.03.2017	9:00 AM	25.078	24.702	24.902	24.38	24.352	24.26	24.6
21.03.2017	10:00 AM	27.497	27.145	27.345	26.702	26.608	26.511	26.9
21.03.2017	11:00 AM	30.193	29.766	29.966	29.085	28.964	28.83	29.4
21.03.2017	12:00 PM	31.471	31.167	31.367	30.5	30.278	30.191	30.8
21.03.2017	1:00 PM	28.974	29.25	29.45	29.29	28.732	28.93	29.1
21.03.2017	2:00 PM	31.588	31.407	31.607	30.804	30.475	30.444	31.0
21.03.2017	3:00 PM	31.761	31.672	31.872	31.24	30.883	30.898	31.3
21.03.2017	4:00 PM	31.255	31.218	31.418	30.969	30.603	30.656	31.0
21.03.2017	5:00 PM	29.261	29.379	29.579	29.535	29.148	29.301	29.4
21.03.2017	6:00 PM	26.521	26.678	26.878	27.012	26.822	26.957	26.8
21.03.2017	7:00 PM	25.138	25.248	25.448	25.523	25.469	25.542	25.4
21.03.2017	8:00 PM	23.578	23.718	23.918	24.102	24.109	24.178	23.9
21.03.2017	9:00 PM	23.366	23.444	23.644	23.73	23.764	23.803	23.6
21.03.2017	10:00 PM	22.149	22.273	22.473	22.672	22.733	22.782	22.5
21.03.2017	11:00 PM	21.351	21.475	21.675	21.89	21.972	22.015	21.7
21.03.2017	11:59 PM	18.985	19.229	19.429	19.913	20.031	20.11	19.6

Air temperature for the micro climate for UPA 2F 1/1 from the six receptors points								
Date	Time	1 (°C)	2 (°C)	3 (°C)	4 (°C)	5 (°C)	6 (°C)	Av T (°C)
21.03.2017	1:00 AM	18.618	18.715	19.468	19.166	19.328	19.246	19.1
21.03.2017	2:00 AM	17.736	17.867	18.718	18.386	18.544	18.467	18.3
21.03.2017	3:00 AM	18.423	18.447	19.075	18.8	18.965	18.877	18.8
21.03.2017	4:00 AM	17.943	18.003	18.714	18.417	18.575	18.494	18.4
21.03.2017	5:00 AM	18.36	18.364	18.935	18.676	18.834	18.749	18.7
21.03.2017	6:00 AM	18.36	18.36	18.927	18.67	18.824	18.742	18.7
21.03.2017	7:00 AM	18.179	18.187	18.787	18.522	18.67	18.594	18.5
21.03.2017	8:00 AM	20.857	20.749	21.095	20.979	21.056	21.048	21.0
21.03.2017	9:00 AM	25.041	24.695	24.31	24.362	24.41	24.324	24.5
21.03.2017	10:00 AM	27.406	27.139	26.577	26.687	26.678	26.599	26.8
21.03.2017	11:00 AM	30.072	29.759	28.889	29.077	29.058	28.952	29.3
21.03.2017	12:00 PM	31.312	31.165	30.203	30.493	30.382	30.336	30.6
21.03.2017	1:00 PM	28.721	29.261	28.803	29.245	28.812	29.066	29.0
21.03.2017	2:00 PM	31.403	31.411	30.366	30.796	30.563	30.602	30.8
21.03.2017	3:00 PM	31.576	31.677	30.771	31.227	30.94	31.032	31.2
21.03.2017	4:00 PM	31.09	31.224	30.488	30.951	30.63	30.763	30.8
21.03.2017	5:00 PM	29.123	29.387	29.112	29.502	29.145	29.36	29.3
21.03.2017	6:00 PM	26.446	26.683	26.872	26.985	26.801	26.949	26.8
21.03.2017	7:00 PM	25.108	25.254	25.525	25.51	25.451	25.512	25.4
21.03.2017	8:00 PM	23.569	23.723	24.188	24.086	24.079	24.113	24.0
21.03.2017	9:00 PM	23.37	23.447	23.816	23.718	23.743	23.75	23.7
21.03.2017	10:00 PM	22.161	22.277	22.815	22.658	22.701	22.7	22.6
21.03.2017	11:00 PM	21.368	21.478	22.058	21.875	21.936	21.923	21.8
21.03.2017	11:59 PM	19.005	19.232	20.189	19.888	19.966	19.951	19.7

Air temperature for the micro climate for UPA 3F East from the six receptors points								
Date	Time	1 (°C)	2 (°C)	3 (°C)	4 (°C)	5 (°C)	6 (°C)	Av T (°C)
21.03.2017	1:00 AM	18.854	19.028	19.649	19.262	19.563	19.358	19.3
21.03.2017	2:00 AM	17.996	18.195	18.918	18.488	18.805	18.593	18.5
21.03.2017	3:00 AM	18.62	18.739	19.221	18.885	19.158	18.969	19.0
21.03.2017	4:00 AM	18.161	18.305	18.876	18.506	18.792	18.598	18.6
21.03.2017	5:00 AM	18.54	18.639	19.065	18.753	19.01	18.831	18.8
21.03.2017	6:00 AM	18.537	18.632	19.054	18.746	18.997	18.822	18.8
21.03.2017	7:00 AM	18.358	18.456	18.911	18.591	18.841	18.667	18.7
21.03.2017	8:00 AM	20.847	20.798	21.036	20.878	20.953	20.945	20.9
21.03.2017	9:00 AM	24.84	24.508	24.167	24.266	24.163	24.156	24.3
21.03.2017	10:00 AM	27.137	26.789	26.412	26.594	26.378	26.386	26.6
21.03.2017	11:00 AM	29.732	29.307	28.709	29.017	28.735	28.739	29.0
21.03.2017	12:00 PM	30.944	30.609	30.016	30.434	30.058	30.115	30.3
21.03.2017	1:00 PM	28.433	28.514	28.638	29.108	28.555	28.854	28.7
21.03.2017	2:00 PM	31.022	30.776	30.166	30.735	30.271	30.439	30.5
21.03.2017	3:00 PM	31.235	31.06	30.584	31.147	30.684	30.915	30.9
21.03.2017	4:00 PM	30.803	30.675	30.317	30.853	30.414	30.688	30.6
21.03.2017	5:00 PM	28.951	28.959	28.979	29.373	29.005	29.331	29.1
21.03.2017	6:00 PM	26.44	26.52	26.853	26.929	26.813	26.98	26.8
21.03.2017	7:00 PM	25.157	25.229	25.552	25.503	25.513	25.56	25.4
21.03.2017	8:00 PM	23.683	23.789	24.263	24.105	24.205	24.197	24.1
21.03.2017	9:00 PM	23.462	23.53	23.875	23.737	23.842	23.818	23.7
21.03.2017	10:00 PM	22.305	22.414	22.914	22.695	22.854	22.802	22.7
21.03.2017	11:00 PM	21.526	21.641	22.17	21.92	22.104	22.033	21.9
21.03.2017	11:59 PM	19.27	19.482	20.388	19.966	20.25	20.133	20.0

Air temperature for the micro climate for UPA 3F East with G and T from the six receptors points								
Date	Time	1 (°C)	2 (°C)	3 (°C)	4 (°C)	5 (°C)	6 (°C)	Av T (°C)
21.03.2017	1:00 AM	19.02	19.062	19.544	19.379	19.358	19.067	19.2
21.03.2017	2:00 AM	18.18	18.231	18.81	18.61	18.634	18.332	18.5
21.03.2017	3:00 AM	18.76	18.771	19.112	18.991	18.858	18.574	18.8
21.03.2017	4:00 AM	18.32	18.338	18.77	18.618	18.559	18.271	18.5
21.03.2017	5:00 AM	18.67	18.67	18.959	18.855	18.708	18.436	18.7
21.03.2017	6:00 AM	18.67	18.663	18.95	18.846	18.711	18.44	18.7
21.03.2017	7:00 AM	18.49	18.487	18.807	18.689	18.548	18.275	18.5
21.03.2017	8:00 AM	20.84	20.805	20.98	20.85	20.415	20.337	20.7
21.03.2017	9:00 AM	24.75	24.494	24.18	24.159	23.711	23.673	24.1
21.03.2017	10:00 AM	26.98	26.75	26.443	26.438	26.002	26.015	26.4
21.03.2017	11:00 AM	29.52	29.253	28.75	28.834	28.353	28.39	28.8
21.03.2017	12:00 PM	30.68	30.537	30.071	30.221	29.804	29.922	30.2
21.03.2017	1:00 PM	28.14	28.395	28.697	28.785	28.61	28.958	28.6
21.03.2017	2:00 PM	30.73	30.69	30.203	30.492	29.995	30.188	30.4
21.03.2017	3:00 PM	30.95	30.965	30.592	30.904	30.413	30.516	30.6
21.03.2017	4:00 PM	30.56	30.585	30.28	30.618	30.018	30.201	30.4
21.03.2017	5:00 PM	28.78	28.878	28.907	29.155	28.604	28.781	28.8
21.03.2017	6:00 PM	26.40	26.478	26.77	26.811	26.598	26.641	26.6
21.03.2017	7:00 PM	25.17	25.207	25.478	25.446	25.385	25.337	25.3
21.03.2017	8:00 PM	23.74	23.782	24.184	24.078	24.104	24.009	24.0
21.03.2017	9:00 PM	23.51	23.526	23.793	23.721	23.659	23.545	23.6
21.03.2017	10:00 PM	22.39	22.418	22.831	22.696	22.733	22.595	22.6
21.03.2017	11:00 PM	21.62	21.65	22.083	21.932	21.964	21.807	21.9
21.03.2017	11:59 PM	19.43	19.503	20.292	20.001	20.229	20.034	19.9