The Impact of External Shading and Windows' Glazing and Frame on Thermal Performance of Residential House in Abu-Dhabi

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دراسة حول تأثير عناصر التظليل الخارجي و زجاج وإطار النوافذ على الأداء الحراري لمنزل سكني في أبو ظبي

By

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Executive Summary:

High awareness of sustainability importance has been witnessed in the United Arab Emirates (UAE) in the last few years. Sustainable development needs have set one of the bottom lines of Abu-Dhabi vision, the capital of the UAE. Construction industry was prioritized in this vision due to the huge expanding and developments that have been carried on in the area. Estidam is the sustainability pearl rating system for Abu-Dhabi's construction. Guidelines are provided for buildings and communities. They include water and energy consumption regulations, eco-friendly materials, waste management, and insulation techniques. Construction and buildings industry are the cause of energy's massive demands in the area. Therefore, reducing energy consumption during buildings' life cycle contributes the most in CO2 emissions reduction. Sustainable principles adaptation at buildings' design stage results the best in efficient building delivery, but existing buildings are important factor in the whole energy picture and has to be highlighted. The present study significance is to enhance existing buildings' performance and at the same time improve regulators and buildings designers' ability to adopt energy efficient practices.

Cooling and air conditioning systems report 40% to 60% of annual energy consumption of buildings in the UAE. The core of this study will concentrate on cooling demands and thermal conditions as they are the biggest influence on buildings' energy consumption. Passive design strategies' effectiveness is to be analyzed and evaluated in terms of energy saving. Windows' system is one of the significant factors of buildings' thermal performance because of its direct relation to solar radiation and heat gain, Therefore, the amount of solar radiation and heat transmittance through transparent façade elements determine indoor thermal and visual conditions and thus energy demands.

The aim of this study is to improve energy performance in existing and newly designed residential buildings as part of the UAE's sustainable development. Through the determination of the most effective passive design strategies in dealing with solar radiation and heat gain through windows' system and shading devices. The start is to understand the relation between windows and solar radiation, then determine the effective parameters, examine and evaluate different windows' system and shading devices and

their impact on a case study, to find out the optimal configuration. Building design, façade characteristics, weather data, internal gain factors, systems and occupancy profiles should be considered and are all constant throughout the whole scenarios' simulation process which is needed here. Shading devices, windows' glazing and frame materials are the parameters that have changed in different scenarios. Double clear glazing with Aluminum frame and no shading devices in the existing house, are used in the reference scenario.

Windows' glazing proposed scenarios are double low-e, triple clear, and triple low-e they could reduce cooling sensible load by 3.5%, 3%, and 5%, respectively, relative to the reference scenario. PVC frame could reduce the cooling load by 1.3% in comparision with Alumium frame. Therfore, the influence of applying better windows' glazing is greater than frame materil improvement influence in terms of energy consumption reduction. Triple glazing (clear, clear, low-e) with PVC frame performed the best of windows' system scenarios. The optimal windows scenario could enhance solar heat gain by 20% while could reduce cooling sensible load by 6%.

As for shading devices (SDs) compared with the reference case applying horizontal SDs with 30cm projection to south, east, and west facing windows could reduce cooling load by 1.3% and showed better performance than vertical SDs which enhanced cooling loads by 0.9% only. Horizontal and vertical SDs combination had the best impact on cooling load and reduced it by 2.3%. In general, less solar heat gain can be achieved when greater SDs' projection applied. This has been proved in this study when the projection of SDs changed to two times the first projection amount. Changing SDs' projection from 30cm to 60cm has an improvement by around 75% with slight variation between different shading types. The optimal shading devices design is horizontal and vertical comdined scenario with 60cm projection and reduced solar heat gain by 27% and cooling sensible load by 4% when refering it to the existing case.

Optimal scenario strategies were triple low-e glazing with PVC frame and combination of horizontal and vertical shading devices with 60cm projection has achieved 41% less solar gain, and reduced cooling sensible load and annual energy consumption by 10% and 6% respectively. Also Assigned strategies influence the thermal performance accumulatively, as they do not affect each other's performance negatively. Improving windows' system had better influence than shading devices applications in terms of energy consumption and thermal condition. Nonetheless, this was not the case when examining the same scenarios on a single room of studied house. This room has different windows design and orinetation than the whole house. Thus, windows desgin and orinetation factors have to be considered case-by-case when proposing shading and windows system.

Daylight illuminance and uniformity changed as a result of applying SDs for better thermal performance. The relation between thermal and light conditions needs in-depth study for each building situation. Optimal thermal and visual performance can be achieved only by proper analysis and integration between windows system and shading devices parameters, with their relation to building design, functions, activities, climatic conditions and orientation.

Keywords: *shading devices, thermal transmittance, solar heat gain*

الملخص:

شهدت دولة الإمارات العربية المتحدة في السنوات القليلة الماضية مستوى عال من الوعي بأهمية الاستدامة. وقد عدّت احتياجات التنمية المستدامة واحدة من أهم الأسس في رؤية أبو ظبي المستقبلية، عاصمة الإمارات العربية المتحدة. أعطيت صناعة البناء الأولوية في هذه الرؤية بسبب ضخامة التوسع و التطور في المنطقة المذكورة. "استدامة" هي منظومة تقييم مستوى الاستدامة باللؤلؤة للبناء في إمارة أبو ظبي. وتزود خطوط إرشاد للأبنية والمجمعات. تشمل هذه الإرشادات أنظمة استهلاك المياه و الطاقة، واستعمال مواد بناء صديقة للبيئة، وإدارة النفايات، وتقنيات العزل الحراري. تعدّ صناعة البناء والأبنية السبب في الاستهلاك الهائل للطاقة. لذلك، فإن إنقاص استهلاك الطاقة خلال دورة حياة هذه الأبنية تساهم بكفاءة في الحد من انبعاثات ثاني أكسيد الكربون. وإن تبنّي مبادئ الاستدامة في مرحلة التصميم يضمن أفضل النتائج في أدائها، لكن المباني القائمة حالياّ هي عامل مهم أيضاَ في الصورة النهائية للطاقة المستهلكة لا يمكن تجاهلها ويجب أخذها في الحسبان. وإن أهمية الدراسة الحالية في تحسين أداء المباني القائمة وفي الوقت نفسه منح المسؤولين و مصمموا المباني القدرة على تبني أسس فعالة في ترشيد استهلاك الطاقة.

إنّ استهلاك أنظمة تكييف الهواء و تبريده للطاقة يقع بين 40٪ و 60٪ من الاستهلاك السنوي للطاقة في المباني في دولة الإمارات العربية المتحدة. تركز هذه الدراسة على احتياجات التبريد والشروط الحرارية حيث إن لها أكبر الأثرفي استهلاك الطاقة في الأبنية. سيتم تحليل وتقييم فعالية بعض استراتيجيات تصميم المباني من حيث توفير الطاقة. يعدّ نظام تصميم النوافذ واحد من العوامل الهامة للأداء الحراري للمباني بسبب علاقته المباشرة مع الإشعاع الشمسي والكسب الحراري. لذلك، فإن كمية الإشعاع الشمسي والنفاذ الحراري عبر عناصر الواجهة الشفافة تحدد ظروف الحالة الحرارية الداخلية و البصرية وبالتالي الطلب على الطاقة.

تهدف هذه الدراسة إلى تحسين أداء الطاقة في المباني السكنية القائمة والمصممة حديثاّ كجزء من التنمية المستدامة لدولة الإمارات العربية المتحدة. وسيتم عبر تعيين أفضل استراتيجيات التصميم السلبي الفعّالة مع الإشعاع الشمسي والكسب الحراري من خلال نظام النوافذ و المظلات. يكون البدء في فهم العلاقة بين النوافذ و الإشعاع الشمسي ثم تحديد العوامل المؤثرة فيها، وفحص وتقييم أنظمة مختلفة للنوافذ و المظلات من حيث تأثيرها على حالة مختارة لإيجاد النظام الأمثل. ويجب أخذ

تصميم المبنى، وخصائص الواجهات، وبيانات الطقس، وعوامل الكسب الحراري، وملامح الإشغال في الحسبان وهي كلها ثابتة في سيناريوهات عملية المحاكاة الضرورية. وقد أخذت عناصر التظليل، وزجاج النوافذ ومواد اطاراتها وسطاء متغيرة في هذه السيناريوهات المختلفة .أما السيناريو المرجعي فهو الوضع الراهن للمبنى الذي يعتمد الزجاج المزدوج الشفاف للنوافذ مع إطار من الألمنيوم بدون أي عناصر تظليل.

إن سيناريوهات زجاج النوافذ المطبّقة هي: مزدوجة مع طبقة منخفضة الانبعاثية (low-e)، وثلاثية شفافة، و ثلاثية مع طبقة منخفضة الإنبعاثية (low-e). فوجد أنها تقلل حمولات التبريد بنسب: 3.5٪، 3٪، و 5٪ على الترتيب مقارنة بالسيناريو المرجعي. أما إطار PVC فيمكن أن يقلل حمولات التبريد بنسبة 1.3٪ بالمقارنة مع إطار الألمنيوم. لذلك، فإن اختيار نوع زجاج النوافذ له تأثير أكبر من تحسين خصائص إطاراتها من حيث استهلاك الطاقة. كان سيناريو النوافذ ذات الزجاج الثلاثي (شفاف، شفاف، low-e) مع إطار PVC هو السيناريو الأمثل، إذ تمكّن من تخفيض الكسب الحراري الشمسي بنسبة 20٪ و حمولات التبريد بنسبة 6٪.

أما بالنسبة لعناصر التظليل (SDs) بالمقارنة مع الحالة المرجعية فإن تطبيق مظلات أفقية مع 30 سم بروز إلى النوافذ الموجهة الى الجنوب، والشرق، والغرب فقد خفضت حمولات التبريد بنسبة 1.3٪، وأظهرت أداء أفضل من المظلات الرأسية التي خفضت حمولات التبريد بنسبة 0.9٪ فقط. وإن تطبيق المظلات الأفقية و الرأسية معاً حققت الأداء الأفضل حيث خفضت حمولات التبريد بنسبة 2.3٪. وبشكل عام، فإن زيادة بروز عناصر التظليل يخفض الكسب الحراري الشمسي وقد ثبت هذا في هذه الدراسة عند مضاعفة بروز عناصر التظليل. تغيير بروز عناصر التظليل من 30 سم إلى 60 سم حقق تحسين بنحو 75٪ مع تغيير طفيف في نوع عناصر التظليل. كان تصميم عناصر التظليل الأمثل هو مظلات أفقية ورأسية مع 60 سم بروز التي حققت تخفيض في الكسب الشمسي بنسبة 27٪ و حمولات التبريد بنسبة 4٪ بالمقارنة مع السيناريو المرجع.

كان السيناريو الأمثل هو مع وجود النوافذ ذات الزجاج الثلاثي (شفاف، شفاف، low-e) وإطارات PVC وتركيبة من مظلات أفقيّة ورأسيّة مع بروز 60 سم. إذ حقق كسباً حرارياً شمسياً أقل بنسبة 41٪، كما خفض حمولات التبريد والاستهلاك السنوي للطاقة بنسبة 10٪ و 6٪ على التوالي. كما أثر السيناريو الأمثل تأثيراً تراكمياً في الأداء حيث أنها لا تتأثر فيما بينها سلباً. وإن

لتحسين منظومة النوافذ تأثيراً أعلى من المظلات تبعاً لاستهلاك الطاقة و الأداء الحراري. لقد وجد أن الحال مختلف عند دراسة تأثير نفس السيناريوهات على غرفة واحدة من المنزل المدروس. تحتوي هذه الغرفة على تصميم مختلف للنوافذ و توجيهها عن البيت ككل. لذلك يتعين دراسة الواجهات و توجيهها لكل حالة على حدة عند اقتراح عناصر التظليل وخصائص النوافذ.

بما أن شدة ضوء النهار وانتظامها في الداخل تتغيير نتيجة تطبيق عناصر التظليل الخارجية بهدف الوصول إلى الأداء الحراري الأفضل، فإن العلاقة بين الظروف الحرارية و الإضاءة تحتاج إلى دراسة متعمقة حسب مواصفات البناء. و يمكن تحقيق الأداء الحراري والبصري الأمثل من خلال التحليل السليم والمتكامل بين نظام النوافذ وعناصر التظليل، وعلاقتها بتصميم المبنى ووظائفه، والظروف المناخية والتوجيه بالنسبة لمسار الشمس.

كلمات البحث: *عناصر التظليل، النفاذية الحرارية، الطاقة الشمسية المكتسبة.*

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1. Introduction:

Construction filed in the UAE in general and in Abu Dhabi, the capital, in specific are witnessing high awareness of sustainable development needs in the area, especially that UAE is one of the world most contributors to carbon dioxide emissions. The fact that green house gases are the main factor in global climate change drove Abu Dhabi government to be the first in the area to set the local sustainability assessment system; Estidama, which basically a revised version of LEED; the American assessment sustainability system, based on the local built environment conditions, resources, and culture. Estidama, basically helps buildings' professionals and stakeholders to achieve sustainable development and at the same time, it is the tool of insuring the base of sustainability requirements of any new construction project in order to help the governmental control. One to five pearl systems is the range of Estidama rating that fits basic to optimal projects in terms of sustainability.

Carbon dioxide (CO2) emissions are directly related to energy and fossil fuel consumption. Therefore, reducing energy consumption during the whole buildings' life cycle can reduce CO_2 emissions dramatically. In general, implementing and adopting sustainable principles in the first stages of buildings' design results the best in sustainable construction delivery. Residential buildings' sector, during its operation stage, consumes around 46% of the total energy consumption in the UAE based on study on energy consumption per sector in the UAE in 2005 (Radhi, 2009). Figure 1 demonstrates the study findings in a pie chart. Abu Dhabi has the largest land territory, 87% of the total area of the UAE, and the second largest population, after Dubai's population, around 2.12 million in 2011 based on Abu Dhabi statistics center.

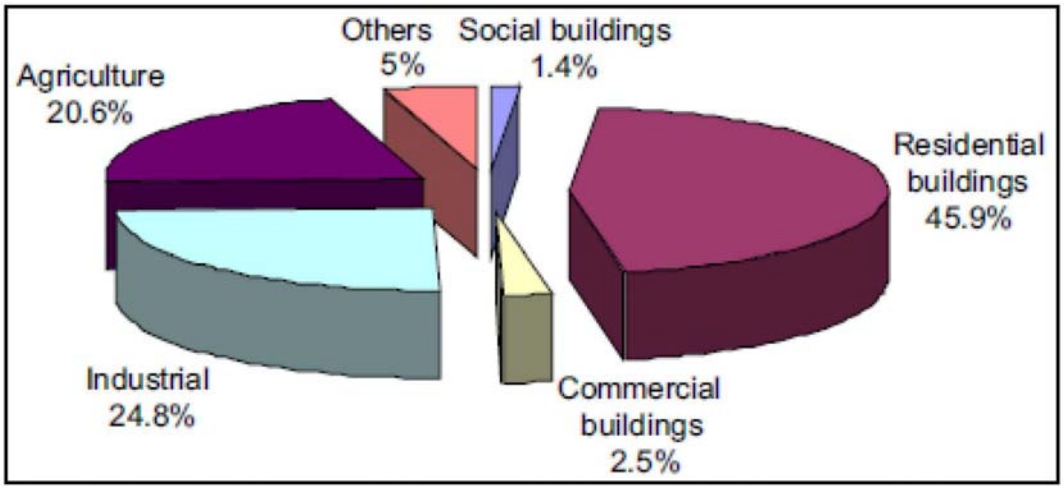


Figure 1: Energy consumption per sector in UAE, 2005 (Radhi, 2009)

Even though, there is a booming in the construction industry in Abu Dhabi where Estidama comes to play but at the same time, many of going on projects and existing buildings are not scoring even the one pearl of sustainability rating. The significance of this study is related to the passive design strategies that can be applied to existing buildings, easily, in order to enhance their energy performance. At the same time, examined strategies can be adopted by buildings' professional as a way to improve their projects level of sustainability. It is very important to provide construction stakeholders by simple and passive means that can help them save energy in terms of cooling and lighting demands, in addition to raise the awareness of energy saving by recommending effective strategies to buildings' owners, designers, and even policy makers.

Considering the tropical and semi-dry climate of Abu Dhabi and the long sunny summer period, external and internal heat gains have direct impact on cooling demands. This is basically related to buildings' envelope, function, and design and occupants practices. HVAC system report around 40% of annual energy consumption and 60% during summer peak. Therefore, dealing with solar radiation and heat gain correctly, is one of the most important methods for energy saving by passive means. Transparent parts of the façade have direct relation to air conditioning and lighting systems' demand. Figure 2 shows the relation between façade system and solar radiation and how they have direct impact on visual and thermal conditions. Basically, windows and shades systems play a significant role in solar radiation and heat allowance or prevention. This fact should be highly considered in an area with massive solar exposure, like UAE.

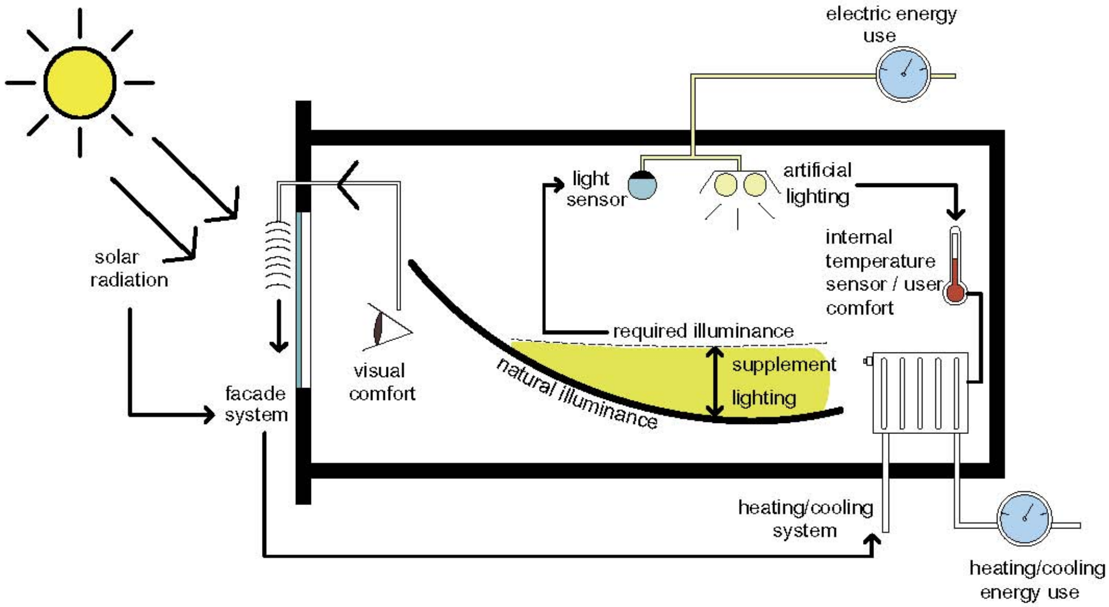


Figure 2: Influence of solar radiation on heating, cooling and lighting systems (Ochoa, 2012)

Significant impact has been stated in many literatures, to be presented in the next section, when it comes to buildings envelope characteristics and their relation to air-conditioning system demands and energy consumption. These characteristics can be divided into opaque and transparent elements. Due to the climatic conditions and geographical location of this region, transparent envelope elements have the direct relation with solar radiation and heat gain and thus they affect dramatically thermal and visual performance. Most of the reviewed studies tend to examine single factor of windows' system such as glazing, frame, or shading devices. The significance of the present study comes from the holistic approach of the passive design strategies examined for windows' glazing, frame, and shades. These strategies can be easily implemented into projects in the design stage as well.

- **Climatic Data:**

Abu Dhabi city, as part of Emirate Abu Dhabi, is basically an island on the northeastern part of the Arabian Gulf. Recently, it has expanded on the mainland creating many suburbs along with construction booming and population increase. Abu Dhabi climate is hot arid due to its location in the northern desert belt sub-region. High humidity ratios are witnessed throughout the year and especially at the coastal areas. The average monthly air temperature is above 35^{o}C during the months of June through September. Sunny clear skies are probable throughout the whole year. Figure 3 demonstrates daily dry bulb temperatures based on software weather data file. It is important to mention that from April to October monthly averages air temperature are above thermal comfort temperatures and it reaches 47^{o}C in the summer peak and drops to 5^{o}C in few hours for few days a year.

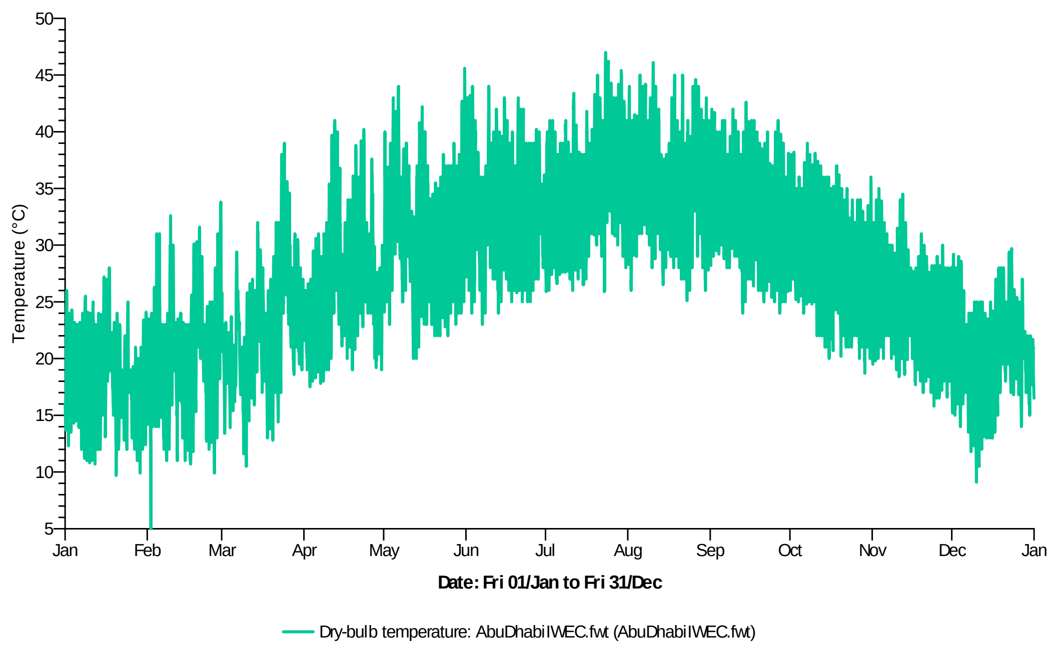


Figure 3: Daily Dry Bulb Temperatures, Abu Dhabi (IES VE2012)

Another related climatic condition to the study objectives is solar radiation. Monthly averages solar radiations' energy range between 6430 Wh/m^2 and 9286 Wh/m^2. Direct solar radiation is the most effective factor in solar heat gain through glazing and heating up the internal spaces. Direct solar radiation exceeds 0.9 KW/m2 on a daily average peak. Figure 4 illustrates direct, global, and total solar radiations monthly ranges.

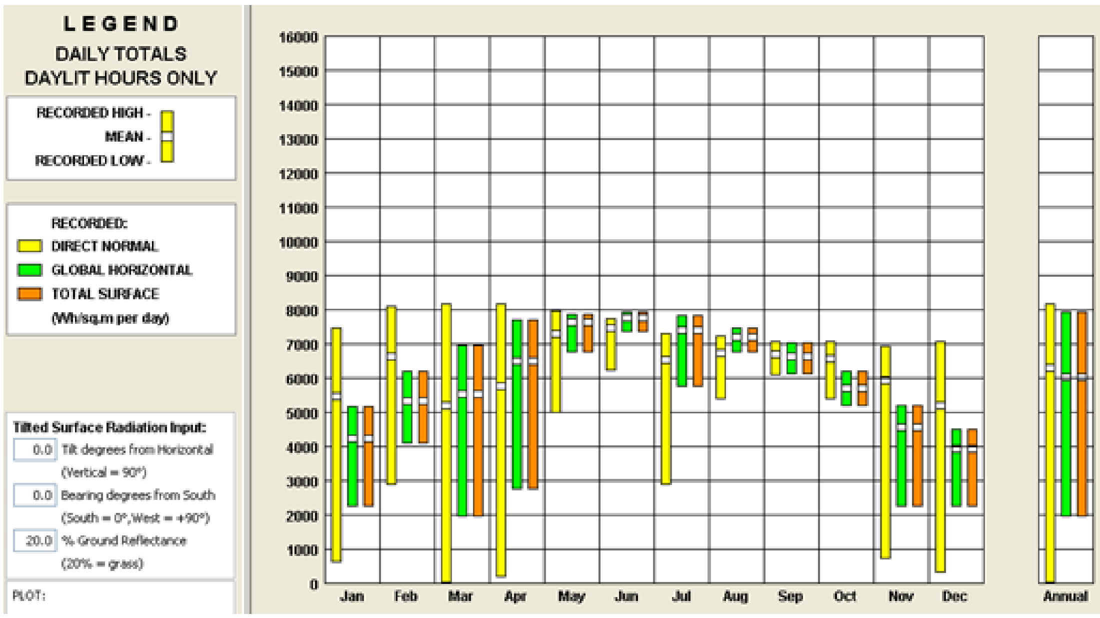


Figure 4: Monthly solar radiations' averages, Abu Dhabi (Climate Consultant)

Sky cover range has direct impact on solar radiation and heat transaction as it affects their direct impacts on buildings' envelope and internal spaces. Figure 5 shows sky cover averages in Abu Dhabi. The annual average cloud cover is less than 20% which increases the challenging solar exposure conditions in the area.

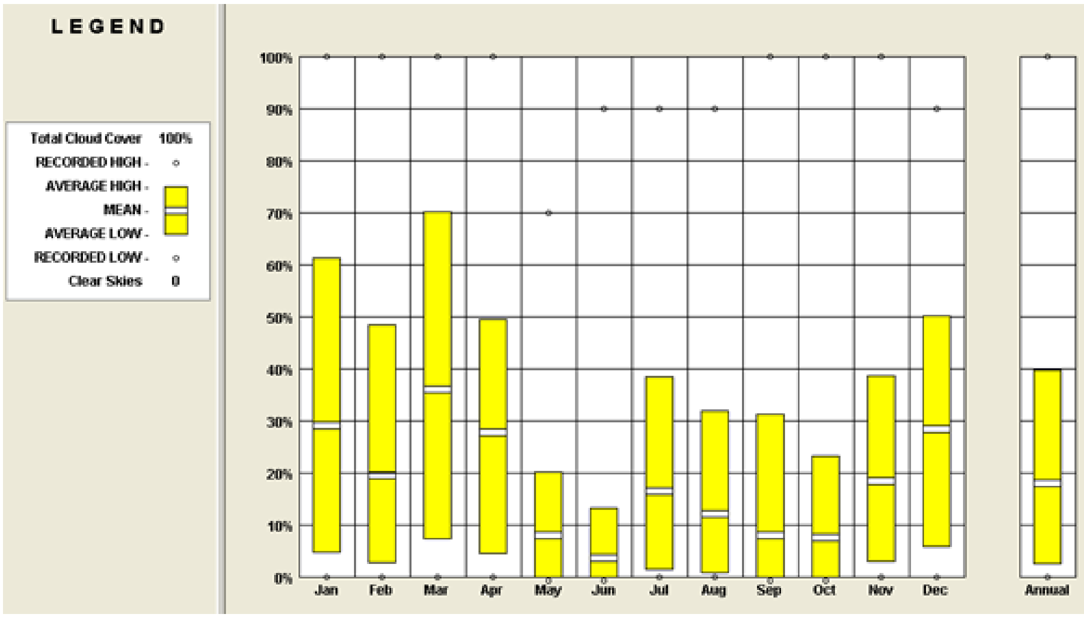


Figure 5: Monthly sky cover range in Abu Dhabi (Climate Consultant)

Therefore, examined strategies are basically concentrating on reducing solar radiation and heat gain in order to enhance indoor thermal comfort, cooling load and energy consumption. Based on Climate Consultant software, cooling and dehumidification system is essential during more than 40% of the year in buildings located in Abu Dhabi. Based on psychometric chart shown in Figure 6, the most effective passive design strategy, in Abu Dhabi climatic conditions, is shading devices for windows' system. While passive solar heat gains reduction strategies are less effective in improving thermal comfort condition than windows' shades.

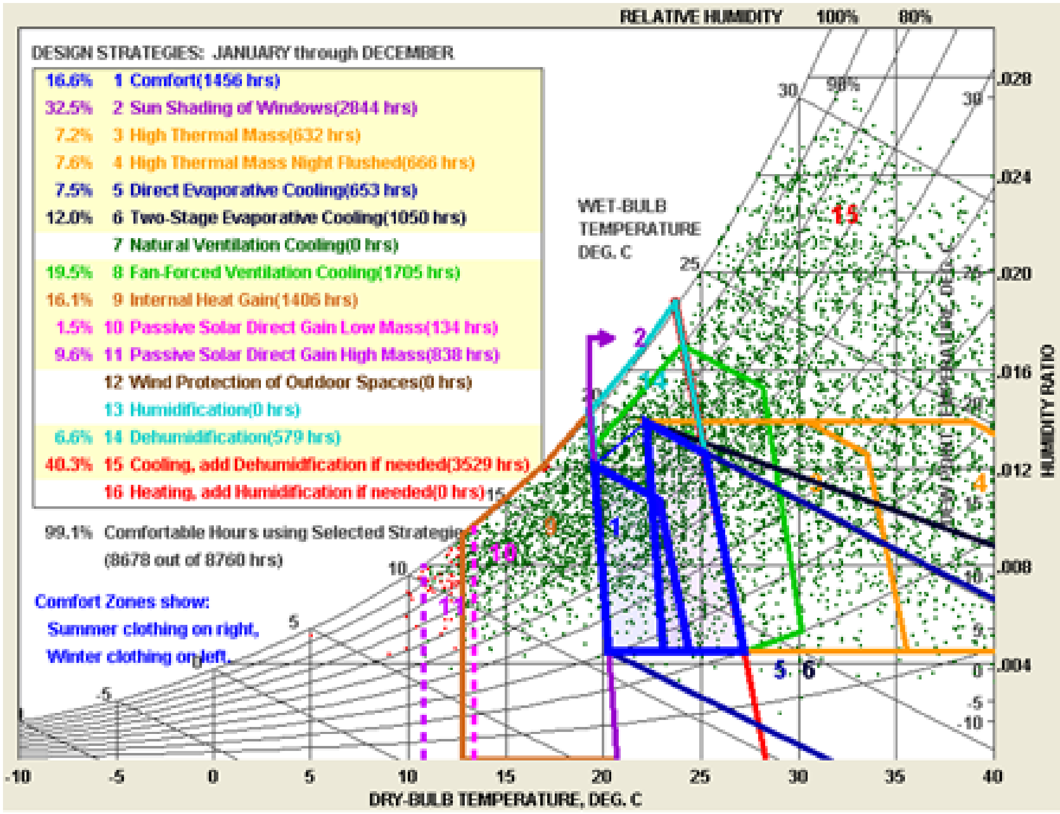


Figure 6: Psychometric chart with design strategies for Abu Dhabi (Climate Consultant)

The present study along with reviewed literature will be examining the effectiveness of windows' system materials and shading devices in terms of solar heat gain reduction and cooling load demands through simulation process and theoretical means. Moreover, it will determine the relation between strategies functionality and orientation which will help to find out the most effective strategies for buildings located in the area of study.

2. Literature Review:

According to Fiocchi et al. (2011), increasing the day lighting and decreasing the solar glare would result in enhancing the visual comfort as well as improving the occupants' productivity and thermal conditions. This gives windows system at any building the importance in terms of visual and thermal comfort. It is stated that energy transmitted through windows depends on several parameters including the type of windows, overhangs and side fins therefore selecting the optimal windows' system is a difficult task. Comprehensive literature studies have been reviewed to discuss each of shading devices and windows' system influences, individually. Additional papers have been analyzed in terms of the two architectural elements; windows and shades, impact on buildings' energy performance. The number of studies referred to in this study is 30. All of them are less than 10 years old, except two studies dated in the 1996 and 1990. These papers have been collected electronically through scientific search engines using related keywords such as; shading devices, glazing, solar heat gain, and energy performance. Peer-reviewed papers were only considered. The numbers of reviewed papers talking about shading devices and windows system are 13 and 14, respectively. 8 papers studied both shades and glazing performance and evaluate their impact on thermal conditions. Based on the above papers can be presented in the following three parts:

- **Shading Devices:**

The sun shading devices, whether they are part of the building or placed separate from the building's façade, will have an impact on daylight and ventilation, solar heat gain, and building's performance in general. Due to the key role of shading devices on solar radiation control, they are taught in all schools of architecture. Although they are useful tools for reducing glare, controlling light intensity, radiation, and minimizing cooling load, only few designers have applied them in their projects and examined their benefits in all means (Kensek et al. 1996). In a study conducted by Tzempelikos & Athienitis (2006), it has been found that shading techniques have key effects on energy consumption in any building; however, it is rarely incorporated in the initial design of the mechanical system. The study revealed that shading elements can save up to 50% of the cooling energy consumed by a building and a minimum of 12% when adapting the portions of solar and heat gains.

According to Cetiner & Ozkan, (2004), the use of solar control devices is cost efficient as they decrease energy demands dramatically when compared to the initial cost. Bojic

(2006) using computer simulation software; EnergyPlus, came to a conclusion that, applying overhangs could reduce electricity consumption by up to 5.3%. He also found that applying side fins to the building with overhangs could reduce electricity consumption by up to 1.4%. Kim et al. (2011) stated that longer horizontal external shading devices lead the cooling energy saving, followed by short one with 11% less cooling energy saving. These papers explain the variation between shading devices (SDs) and their influences based on their type and design. Moreover, the impact of applying SDs to a non-shaded building could perform the best, while this impact is less effective when improving existing SDs.

By examining three types of shading devices; horizontal, vertical, and box shades, Chi-Ming & Yao-Hong (2011) found that all SDs decrease daylight incursion to indoor spaces with variation and the use of box shading will give the maximum energy reduction effect. Palmero-Marrero (2009) studied louvers position. This study demonstrated that vertical louvers are more adaptable for east and west façades while the horizontal louvers have the ultimate efficiency on south façades. For south facing facades, vertical shading devices can provide good day lighting along with ensuring the optimal heat gain in spaces (Alzoubi & Al-Zoubi, 2009). These arguments point out that the type of SDs and orientations are the two main factors affecting their performance and optimization. In terms of SDs angle of tilt, Kim et al. (2011) argued that, angle of 0◦ has the best energy performance and it becomes the less when 60◦ of tilt and this is based on their working principles with the sun path.

Based on Collins & Harrison (2004) argument, cooling load can be considerably decreased by the use of solar shading devices. Generally, shades would reduce the SHGC and this to function efficiently when reflective materials in the shading devices are used. On the other hand, Kim & Kim (2010) stated that external shading devices are much more effective than internal shading devices, as they prevent solar radiation from entering the space and heating it up. Never the less, external shades provide better view and shading performance.

Based on these, the present study SDs variables tend to be non-tilted in all scenarios and to apply the same type and design to all building's elevations in each simulation process in order to discuss how they act differentially based on the orientation.

Shading devices (SDs) is one of the most effective passive design strategies. However, they may have negative and/ or positive impact on lighting and visual performance. Shading coefficient is the working principle of SDs and this is mainly affected by the design, sun path, and daylight accessibility (Wong & Istiadji, 2004). It is known that solar shades are efficient architectural elements that contribute to reducing the thermal loads inside a building. The efficacy of solar shades must be assessed and both thermal and visual point of view should be considered. Solar shades are able to comprehensively reduce energy needs of cooling systems. Thermal optimization process is the size of the shading devices, mainly. On the other hand, solar shades may increase energy consumptions of artificial lighting and reduce visual comfort.

Alzoubi & Al-Zoubi (2009) stated that allowing excessive daylight in architectural spaces of buildings has negative contribution to their energy consumption. Good resolutions may include blinds and shading devices to assuage the excess amount of daylight in these spaces. An optimal orientation for shading devices is available to control the internal luminance level and to keep it within a good enough range with the least amount of solar heat gain. Thus, the evaluation of lighting performance in architectural spaces should be linked to the level of thermal condition and energy consumption in these spaces. Good daylight design incorporated with solar heat gain can lead to substantial energy saving in spaces. Therefore, the impact of SDs on daylight illuminance and uniformity will be highlighted due to its importance even though this is not under this study scope of work.

The quality of architectural spaces will also be improved by integrating the luminance levels, energy consumption rates, and visual necessities. Hammad & Abu-Hijleh (2010) studied a dynamic louvers system with a light-dimming strategy and could achieve energy savings of 34.02%, 28.57%, and 30.31% for the south, east, and west orientations, respectively. However, David et al. (2011) stated that indices need to be developed to set up an assessment method for the efficacy of solar shades against energy demand, thermal comfort and visual comfort.

- **Windows' System:**

According to Arasteh et al. (2006), site conditions analysis helps in choosing windows' type for each particular house conditions. Windows performance is also influenced by location, shades, envelope characteristics, orientation, and occupancy profile. Windows control energy use and visual comfort patterns in our buildings. Selecting the area of the window and its proportion is the main part of early design phase. Thus, the dimensions of the windows should be considered carefully as a main part of an effective design process. Currently, all the building standards and certification requirements focus on for maximum performance in multiple aspects, likewise where this study significance comes to play based on Estidama pearl rating system in Abu Dhabi.

Wong & Istiadji (2004) stated strategies to reduce solar heat gain and direct radiation penetration, these include shading devices design, low window to wall ration (WWR), low thermal allowance factor, and low SHGC. For houses in the UAE, the recommended window to wall ratio (WWR) is 15% as per green buildings regulations. In residential buildings, the choice for glazing is an effective factor as it has a direct impact on the energy consumption. The reflective glass and low emissivity (low-e) glass have proved to be more energy efficient than the clear glass. The low-e glass is characterized by lower U-value and shading coefficient (SC). Conversely, reflective glass has lower visible light transmittance when it comes to visual comfort (Bojic & Yik, 2005).

Single low-e glazing could reduce cooling electricity by 4.2% than single clear glazing while double clear glazing reduction was 3.7%. Double; clear & low-e glazing, performed the best as cooling load reduced by 6.6% based on Boji & Yik (2005) study. The same study stated that these savings vary based on orientation, type and location of the rooms. A glazing assessment of villa in Dubai was carried out by Amin & Abu-Hijleh (2012). It has been found that double low-e, triple low-e, double low-e with SD, and triple low-e with SD energy performances as 100%, 95%, 90% and 85%, respectively. On the other hand, triple glazing enhances energy consumption of houses in the UAE by 3% only compared with double glazing base case (Al-Shaali, 2013).

Windows that are optimized exclusively for visual comfort results in comprehensive energy consumption patterns. This is in line with the contribution of Mardaljevic et al. (2009) studies. Limiting the optimization of window size just to achieve low energy consumption will not meet the pre-decided visual acceptance criteria. Energy consumption and illuminance need to be considered to guarantee healthy and comfortable conditions (Ochoa et al. 2012). Another study has demonstrated the relation between thermal comfort and glazing thermal resistance and solar transmittance. Rooms applying glazing with low insulating value and high transmittance result in the maximum fluctuations of the indoor thermal environment. On the other hand, Rooms applying glazing with a higher insulating value and lower transmittance produce more comfortable conditions as they are less influenced by climatic conditions. Yet, there is a relation between transmittance of the glazing and need for primary air conditioning. Lai & Wang (2011), argued that selecting appropriate fenestration components has to strike balance between energy consumption, thermal comfort, and daylight conditions. Compromising matter or integrative approach is a contradictive situation between (Mardaljevic et al. 2009; Ochoa et al. 2012) and (Stegou-Sagia et al. 2007; Tzempelikos et al. 2010; David et al. 2011; Fiocchi et al. 2011) respectively.

The thermal performance of windows can be considerably enhanced by applying changes on frame, design and selected material (Byars & Arasteh, 1990). In general, three main types of material used in window frame are Wood, Aluminum, and un-plasticized Polyvinyl Chloride (uPVC). Each of these components has their own advantages and disadvantages. Homeowners decide on the type of material according to factors related to their lifestyle and preferences. The overall installation cost and energy efficiency material are influenced by the material of windows. It was found that the wood window frame performed better than uPVC and aluminum frames in terms of thermal and environmental conditions. The carbon footprint of uPVC window frame is almost two times higher than that of the wooden window frame while aluminum window frame is four times more than that of the wooden window frame (Sinha & Kutnar, 2012).

- **Shading vs. Glazing:**

Thermal comfort in perimeter zones is influenced by different façade components including glazing and shading properties. By considering high-quality building envelope, the operative temperatures may be maintained within the comfort zone and would eliminate the need for secondary perimeter air-conditioning (Tzempelikos et al. 2010).

To achieve the best reduction of the energy transferred into a building yearly, it is suggested to have appropriate overhangs or side fins in the south, west and east windows. Another way is having an active behavior similar to high performance glazing. It is worth mentioning that using external shading devices, horizontal or vertical, for the single clear pane glazing is more practical for any direction of window than the advanced glazing windows, like double clear pane or low-E pane glazing (Ebrahimpour & Maerefat, 2010). On the other hand, Wong & Istiadji (2004) signified that windows' glass has the utmost impact on reducing annual energy consumption while shading devices' effect comes second after the window glass. In general, it has been found that the energy saving strategies applied on the external part of buildings' envelop are the most efficient. Moreover and according to Lai & Wang (2011), applying a proper window glass performs the best in terms of reducing annual energy consumption. Window glass is followed by the shading device applications, while roofs' construction contributes the less in terms of energy-efficient advantages and benefits. Chi-Ming & Yao-Hong (2011) stated that the windows' glass has a greater effect than the shading device effect. On the other hand, Cetiner & Ozkan (2004) suggest that solar control devices have higher efficiency in terms of energy consumption and cost efficiency.

Radhi (2009) analysis showed that thermal insulation and thermal mass are efficient and useful energy design measures in residential buildings. Under different scenarios, they resulted in comprehensive reduction in energy demand and CO_2 emissions. A percentage of 13% and 15% of the total CO_2 emissions may be reduced. He stated that the window design, including window area and glazing system, are important design measurements. They would enhance the amount of energy savings considerably to around 6.8–8.1%. While shading devices help the less in reducing the CO_2 emissions of residential buildings in Al-Ain City. On the other hand, Yu et al. (2008) used eQUEST simulation software to design the exteriors of residential buildings in China. They simulated the annual energy consumption on the basis of different energy-saving designs. The best performances found to be better wall insulation and windows' shading and saved 11.55% and 11.31% of the energy consumption of air conditioners, respectively.

In summary, Windows have a positive impact on visual comfort and daylight performance. Therefore, it can enhance building energy performance and at the same time occupants comfort and performance when designed properly. On the other hand, misusing these architectural elements may results in visual and thermal discomfort in addition to extreme cooling loads and energy consumption. These negative impacts are directly related to glare and overheating problems. As for shading devices, each type of them performs differently than the others with relation to design and orientation. However, the main characteristic of all types is to control daylight and solar radiation. They tend to improve glare and overheating problems. Few studies stated the better performance of SDs than glazing in terms of thermal condition and energy consumption while most of the studies reviewed proved that windows' glazing has better impact on energy performance than SDs. However, only few studies examined this point in the UAE and the region in general. This knowledge gap is not only related to the lack of researches in this area but, indices need to be developed to set up an assessment method for the efficacy of solar shades and windows' system against energy demand, thermal comfort and visual comfort.

3. Aim and Objectives:

The aim of this study is to enhance housing projects energy performance by applying passive design strategies to existing buildings and/ or in the design stage and thus reduce residential buildings' energy consumption. Determining design strategies for transparent fenestration system of case study in the UAE that have positive impact on solar radiation and heat gain performance. Windows' glazing and frame materials are the examined variables in this study, in addition to different designs of external shading devices. The present study objectives are as follows:

- Study a sample of Abu Dhabi residential villas and understand the current energy performance factors in terms of thermal conditions.
- Examine the impact of different windows' glazing systems and frame materials on solar heat gain and cooling sensible load.
- Determine the impact of external shading devices on thermal and light performance.
- Clarify the relation between windows' system, shading devices, and building's design and orientation.
- Determine the optimal configuration of windows and shading systems for housing projects in the UAE.

4. Methodology:

Passive strategies proposed to be applied to the fenestration system in order to reduce solar heat gain and external heat transmittance. These strategies are related to windows' glazing and frame material in addition to external shading devices. The main idea of proposed scenarios is to keep external heat out from entering house's spaces and heating them up. Simulation and design software will be used as in Bojic (2006) when examined different SDs configurations and designs impact on energy consumption using simulation. Also the study of Yu et al. (2008) adopted computer simulation method for windows shading and wall insulation performances. Series of simulations by an energy analysis program, IES VE, adopted in comparative advantage of an exterior shading device in thermal performance for residential buildings by Kim et al. (2011). The impact of overhangs and side-fins on building thermal comfort, visual comfort and energy consumption in the Tropics study, by El Sherif (2012), used IES VE software and justified it because of its ability to import materials and thermal data, its popularity in the market as well as providing accurate and reliable results. Moreover, Ayyad (2011) stated that IES VE program has the ability to integrate valid weather data, having a friendly user interface, the flexibility to perform different types of simulations.

For this reason, computer simulation software will be used to model a case study house design at first, then different case scenarios will be applied and study their impacts on solar heat gain, cooling loads, and energy consumption. Computer simulation method is available, affordable, dynamic and flexible in modeling and revising, and has high accuracy in general. IES virtual environment simulation software chosen to be the main tool in this investigation based on studies reviewed in the same area of study and showed impressive findings. This software has different modules that can perform different calculations for the same model but with specific data inputs. Essentially, ModelIT, SunCast, Apache, and FlucsDL are the modules used for house modeling, solar shading analysis, thermal calculation, and daylight analysis, respectively. An existing three bedroom villa in Abu-Dhabi has been chosen as a case study for different scenarios applications.

- **Case Study Description:**

Al Raha Gardens is a mixed-use residential, commercial, leisure and retail development in Abu-Dhabi, the capital of the UAE. The vision for the development is that of a medium-sized village community with village-scale streets that afford residents the opportunity to socialize; fostering a sense of community, ownership and pride in their surroundings. The site extends over 3km adjacent to the Dubai-Abu Dhabi motorway and neighboring Al Raha Beach as shown in Figure 7. Phase one consists of 750 residences including villas and town houses planned with high density. Three bedroom villa chosen for this study because it resemble the majority of houses in this compound as it is a typical house sample of medium family size in the UAE. The houses form is compacted with maximum use of built area in order to have the minimum buildings' foot print.

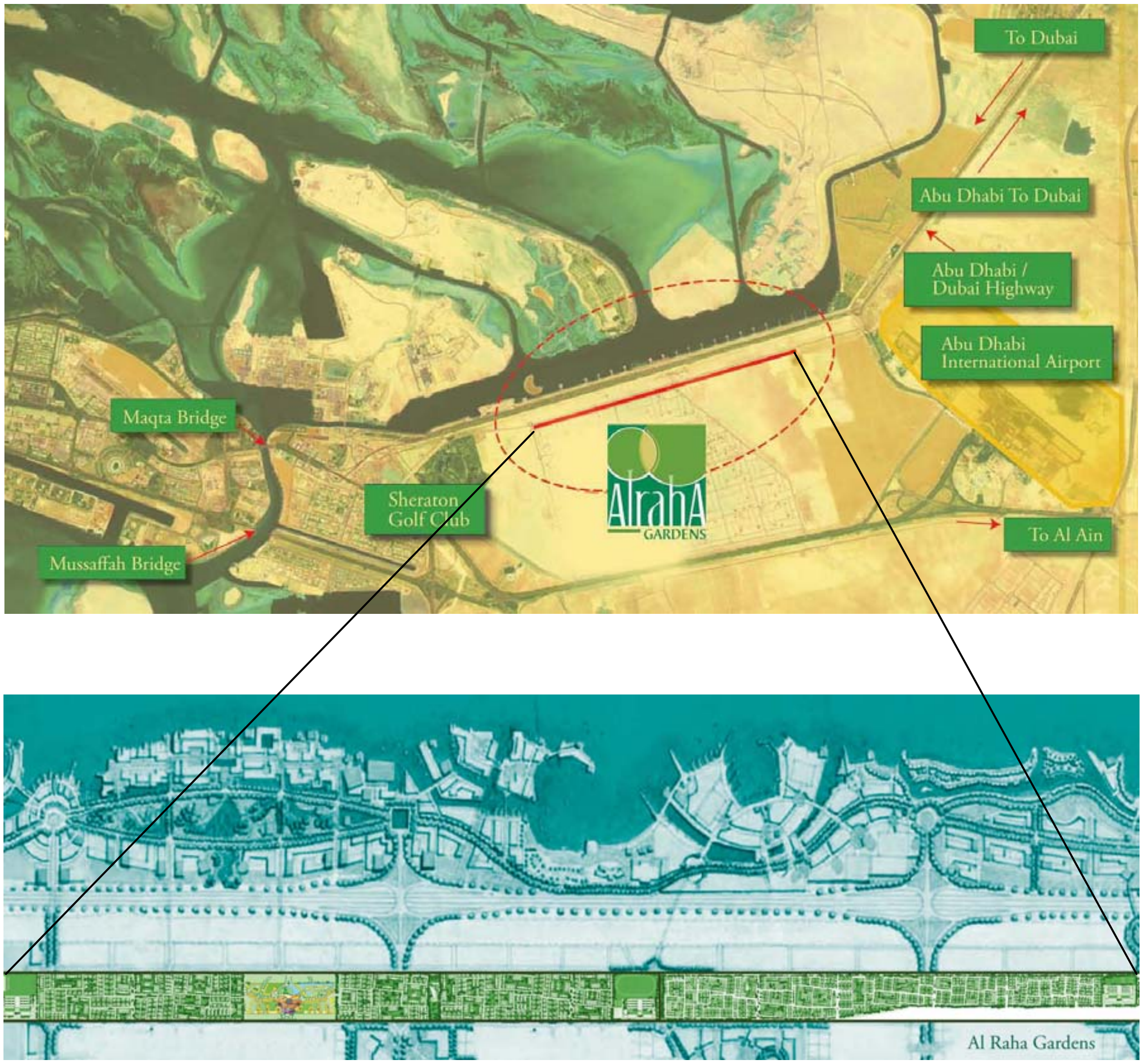


Figure 7: Project lot location, Al Raha Gardens, Abu Dhabi (Al Dar, 2012)

The villa's land plot area is 330m^2, ground floor area is 155m^2, and first floor area is 100m ^{2}. Ground floor consists of living and dining area, family room, guest bedroom, kitchen, entry, and stair case, in addition to service block next to open parking area. The average window to wall ratio of ground floor is 18%. Figure 8 demonstrates ground floor layout.

Figure 8: Case study (3BR villa ground floor plan) Al Raha Gardens, Abu Dhabi (Al Dar, 2012)

First floor consists of the master bedroom, bedroom 2, stair case, and hallway area with two balconies semi-covered by wooden pergola. Two more pergolas are applied in the garden and adjacent to the house illustrated in Figure 9 along with first floor layout. Window to wall ration of the first floor is 13% while window to floor ratio in both, ground and first floors is the same; 28%.

Figure 9: Case study (3BR villa first floor plan) Al Raha Gardens, Abu Dhabi (Al Dar, 2012)

The external walls are basically light weight concrete blocks with external rendering and internal dense plaster. Total thermal transmittance; U-value, is 0.75 W/m^2.K while roof's U-value is 0.4 W/m^2.K. Windows' glazing is double clear glass with aluminum frame. Net thermal transmittance; glazing and frame, is 3.4 W/m^2.K, solar heat gain coefficient (SHGC) is 70% and light transmittance ratio is 100%. No external shading devices applied to the current house design. Figure 10 shows a general view of the main entrance side of the house.

Figure 10: Case study (3BR villa photo) Al Raha Gardens, Abu Dhabi

- **Modeling Steps:**

The basic house design of three bedrooms in two floors villa has been modeled by ModelIT module in IES VE2012 program. The studied house details are presented in the case study description section. Weather data file of Abu Dhabi city (latitude: 24.43◦N, longitude: 54.65◦E) assigned before simulation process has started. Annual solar radiation and shading calculations of the whole building run by SunCast module and this is basically depends on Abu Dhabi's sun path throughout the year. Sun path diagram of Abu Dhabi as considered in simulation process is presented in Figure 11.

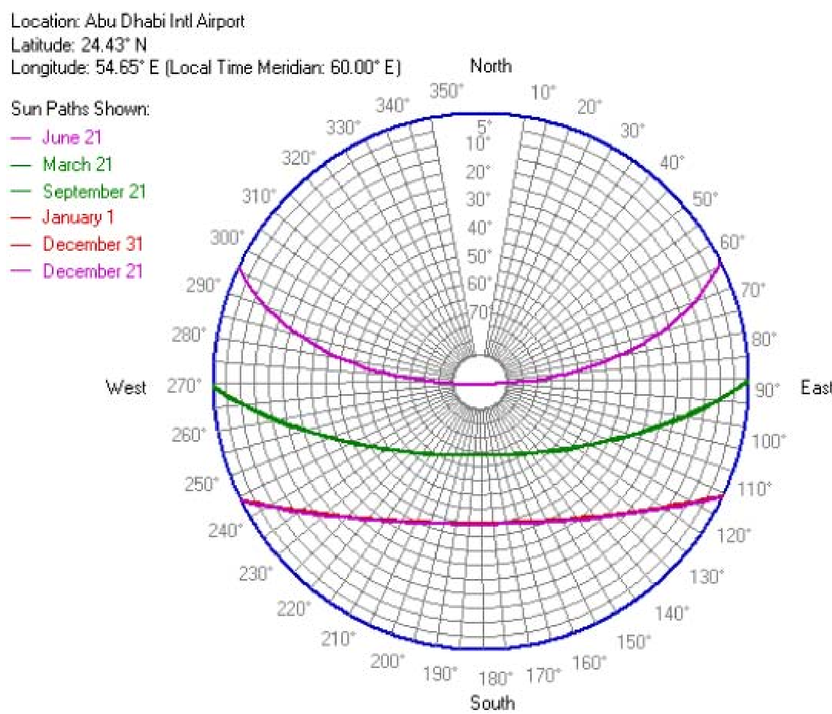


Figure 11: Sun Path diagram of Abu Dhabi, UAE (IES VE2012)

Thermal conditions inputs have been set through building template manager as follows: domestic family occupancy profile assigned for cooling system and people internal load. The assigned profile working hours during the week day are different than the weekends and Figure 12 and 13 illustrate each of them respectively. Optimal occupancy profiles proposed assuming energy saving in residents' practices.

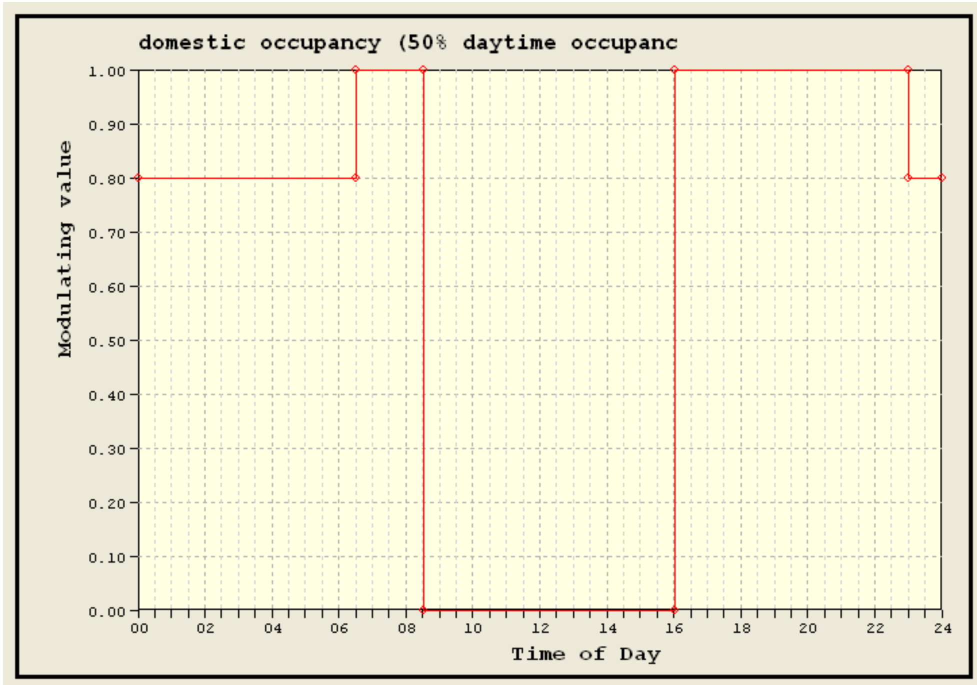


Figure 12: Domestic occupancy profile during weekdays (IES VE2012)

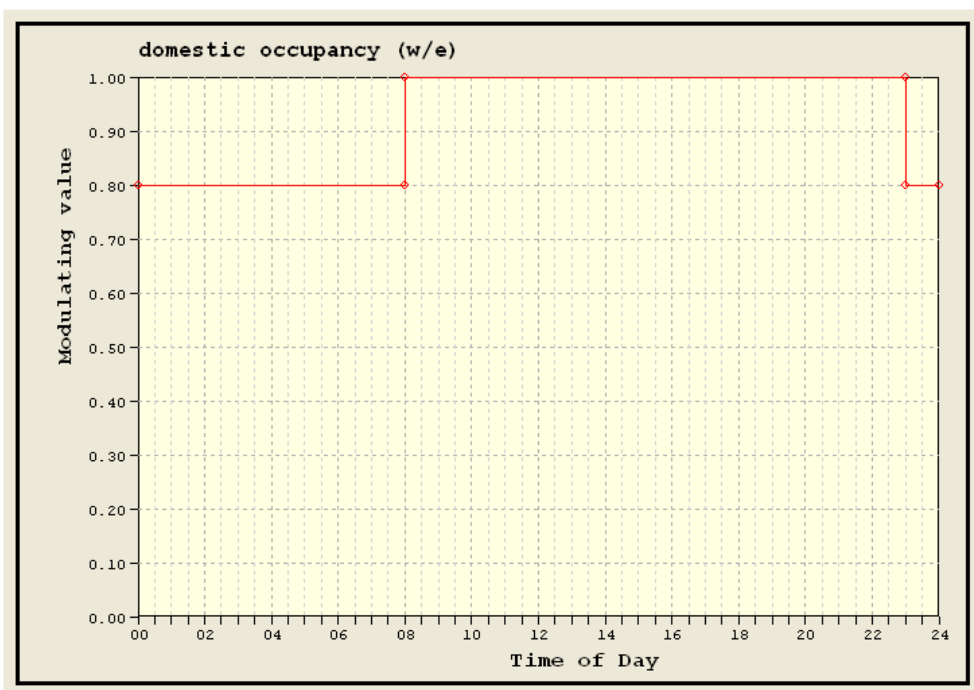


Figure 13: Domestic occupancy profile during weekends (IES VE2012)

Design temperature for cooling set-point is 23°C while no heating system considered due to the climatic conditions in the area. Climatic conditions will be explained in details in the climatic data section. Relative humidity control kept between 30% and 70%. Air change rate profile follows cooling profile with minimum flow rate of 3.0 l/s.m^2. Infiltration gain set as on continuously with external air maximum air flow 0.1 ACH. Internal gains were basically related to two factors; people (5 persons (sensible gain: 90 W/person, latent heat: 60 W/person)), and electrical lighting (fluorescent lighting with domestic lighting profile shown in Figure 14 (sensible gain: 15 W/m^2)).

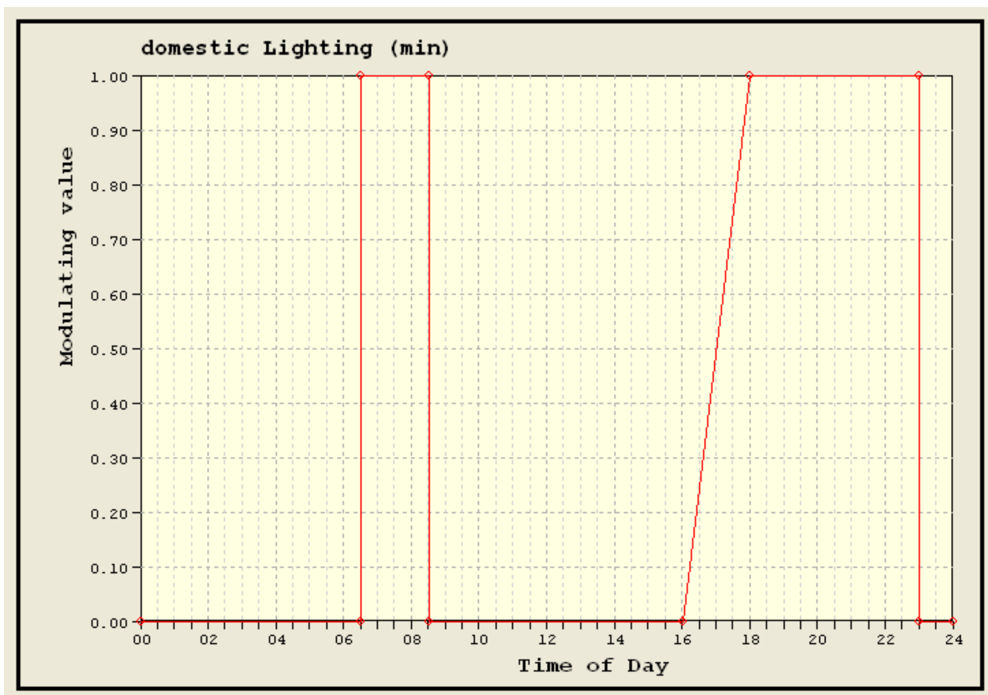


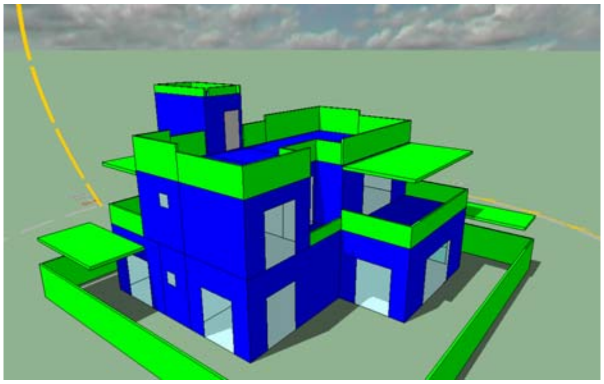
Figure 14: Domestic lighting profile (IES VE2012)

The next step was to assign construction materials as per the existing building and based on the data collect from the project main contractor. Roof construction average thermal transmittance (U-value) is 0.42 W/m^2.K, External walls' U-value is 0.75 W/m^2.K, and

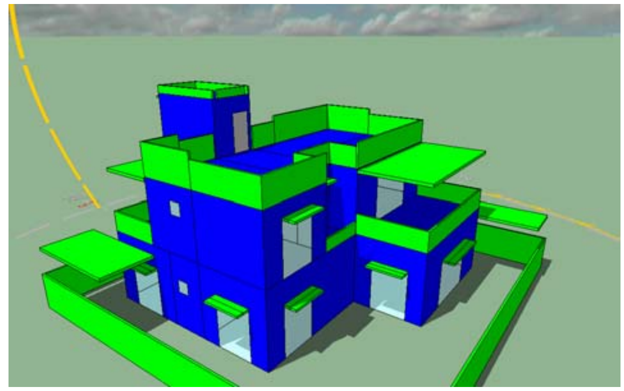
Internal ceiling and walls' U-value is 0.9 $W/m^2.K$. Windows' system in the base case is double clear glazing with Aluminum frame and with no shading devices (SDs). The net U-value is 3.4 $W/m^2.K$ and solar heat gain coefficient (SHGC) is 0.7. Apache-sim is a dynamic simulation calculated cooling load in the process of energy analysis and this was the reference scenario outputs. Using the same inputs, FlucsDL module used to examine the base case daylight performance using CIE standard overcast sky and medium quality setting in order to consider SDs applications' impact of the assigned scenarios.

- **Assigned Scenarios:**

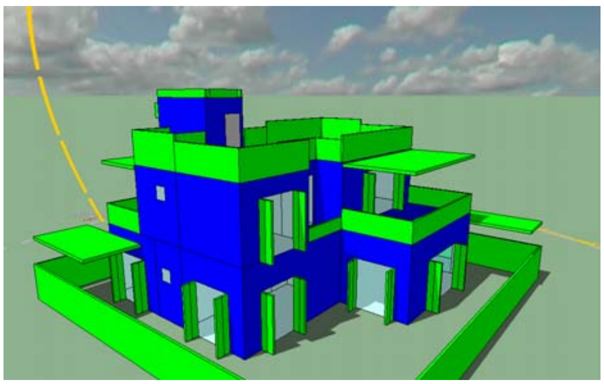
Building envelope characteristics, internal loads, interior lighting, ventilating, air conditioning, and occupancy profiles in addition to weather data are all unchanged throughout the simulation process. Windows shading condition, glazing and frame materials are the only varying parameters. The existing scenario data and design are as per the project's main contractor drawings and specifications. Walk-through and site inspection have been performed by the author of the study in order to insure collected data accuracy. A market study of UAE's most applied windows' glazing, frame materials, and shading devices' design were considered in order to propose the most appropriate scenarios to the case study. By proposing available and tested systems in the market, high acceptance and affordability to be insured for construction stakeholders and owners point of view. Economical and aesthetical designs are considered in the shading devices' designs. Horizontal, vertical, and combination of them with two different projections; 30cm and 60cm, are the scenarios assigned in term of shading devices design and their impact on thermal and daylight performance, in addition to energy consumption changes. Shading devices applied for south, east, and west facing windows based on aesthetical, technical, and functional aspects. Please refer to Figure 15 for different SDs configurations illustration.



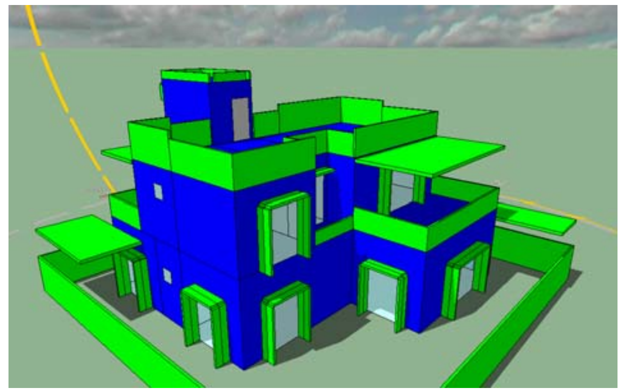
Scenario 1



Scenario 3



Scenario 5



Scenario 7

Figure 15: House's model with shading devices' scenarios 1, 3, 5, and 7 (IES VE2012)

The projections proposed will not have a significant influence on the house shape and occupants view in addition to their applicability to any windows design. Moreover, their effect on landscape spacing and occupants movements is minimal. Shading devices' materials are not examined in this study and kept unchanged basically because their material has no effect on thermal performance while they affect light performance due to reflectivity factor, but light performance is not under the present study scope of work. Kim et al. (2011) stated that, angle of 0◦ has the best energy performance and it becomes the less when 60◦ of tilt and this is based on their working principles with the sun path. Based on this, the present study SDs variables tend to be non-tilted in all scenarios and to apply the same type and design to all building's elevations in each simulation process in order to discuss how they act differentially based on the orientation.

Good daylight design incorporated with solar heat gain can lead to substantial energy saving in spaces. Therefore, the impact of SDs on daylight illuminance and uniformity will be highlighted due to its importance even though this is not under this study scope of work. As for windows' system scenarios, double clear, triple clear, double low-e, and triple low-e glazing with two different frame materials; Aluminum and PVC, are examined in terms of solar heat gain, cooling loads and energy consumption variations.

5. Results and Discussion:

The present study objectives are basically related to transparent envelope elements and their impact on solar heat gain and mechanical cooling loads which are directly related to total energy consumption. Proposed scenarios goal is to enhance the studied house thermal and energy performance without compromising the residents' satisfaction. Windows' system and shading condition are the assigned and examined scenarios. Therefore, this study tends to examine the impact of different external shading devices, windows' glazing and frame material impact on residential house energy performance. Solar heat gain, cooling sensible load, and annual energy consumption are expected to be enhanced based on these passive design applications. Solar heat gain coefficient (SHGC), thermal transmittance (U-value), and light transmittance (LT) are the variable properties when it comes to windows' system. As for shading devices (SDs), their design, projection, inclination, and finishing reflectivity are basically determine SDs performance in terms of solar radiation prevention. Windows design, size, location and orientation, are other parameter with a significant impact on the building energy consumption and occupants comfort, in terms of thermal and lighting. These parameters kept constant as per existing house design.

Reference scenario or existing case annual energy consumption is 84MWh with cooling sensible load of 104.5MWh and solar heat gain of 22.8MWh. Windows' system in the reference scenario is basically; double clear glazing with Aluminum frame and no shading devices applied. The results and discussion section to be presented in the same way as literature review section followed in order to refer and discuss critically. This way will consent to analyze windows' system and shading devices influences individually then evaluate their performances collectively. Optimal scenario to be illustrated based on the findings of this section.

5.1 Windows' System Scenarios:

Windows' system is basically the number of glass panes, type of glass, and frame material. As mentioned before, window to wall ratio (WWR) of house's ground floor is not the same as for the first floor, as mentioned in case study description section, but the average WWR of the whole house is 16%. Window to floor ratio (WFR) is constant in both floors' area; 28%. Not all house's rooms have the same opening area but these parameters kept as per the existing case study design; reference scenario. The same thing applied to openings distribution on different façade's orientation. Figure 16 demonstrates the variation in windows facing main four orientations. Based on this, east facing windows area is more than 50% of total windows area of the house.

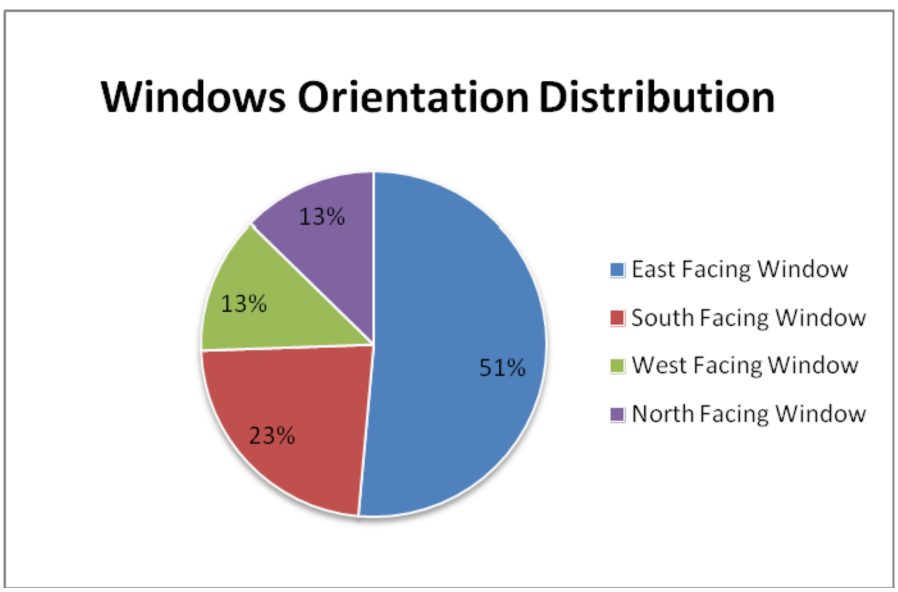


Figure 16: House windows' orientation distribution

Table 1 presents examined scenarios in terms of windows glazing and frame material. Glazing types proposed are different configurations between double and triple panes, clear and low emissivity (Low-e) glass. As for frames, only Aluminum and PVC materials proposed. These scenarios proposals are based on the mostly used and available materials in the market, thus most of construction professionals and stakeholders are familiar with these systems.

Table 1: Windows' system scenarios and their properties

Windows Systems' Properties						
Scenario	**Variables**	**U-value (Glass)**	**U-Value (Frame)**	**U-value (net)**	**SHGC**	**LT**
1	Double-glazing, clear with Aluminum frame (Reference scenario)	2.85	8.3	3.4	0.7	1
2	Double-glazing, Low-e with Aluminum frame	1.97	8.3	2.6	0.64	0.76
3	Triple-glazing, clear with Aluminum frame	1.89	8.3	2.53	0.61	1
4	Triple-glazing, Low-e with Aluminum frame	1.28	8.3	1.98	0.56	0.76
5	Double-glazing, clear with PVC frame	2.85	2.1	2.78	0.7	1
6	Double-glazing, Low-e with PVC frame	1.97	2.1	1.99	0.64	0.76
7	Triple-glazing, clear with PVC frame	1.89	2.1	1.9	0.61	1
8	Triple-glazing, Low-e with PVC frame	1.28	2.1	1.52	0.56	0.76

As can be noticed from table 1 that glass U-value and SHGC vary with glass type and pane numbers while light transmittance is related only to type of glass; clear or low-e. Frame material changing has a direct impact on windows system thermal transmittance. Table 2 shows the performance of windows' scenario in terms of solar heat gain, cooling load, and energy consumption. Cooling sensible load is directly proportion to windows' U-value and SHGC together. The same relation applied to annual energy demands. Based on this, the lower the U-value and SHGC are resulted in lower cooling demands.

Table 2: Windows' system scenarios and their performance

Windows Systems' Performance Summery			
Scenario	**Solar Heat Gain**	**Cooling Sensible Load**	**Annual Energy**
No.	(MWh)	(MWh)	(MWh)
1	22.89	104.56	84
2	20.58	101.98	82.7
3	19.83	101.35	82.4
4	17.93	99.32	81.3
5	22.89	103.2	83.3
6	20.58	100.56	82
7	19.86	99.92	81.6
8	18.25	98.28	80.8

The reduction in cooling load resulted from changing double clear glazing (reference case) into double (clear + low-e) is 3.5% while adding third clear pane to the double clear glazing improved cooling load by 3%. The same finding stated by Al Shaali (2013); triple glazing improves house energy consumption by 3% only**,** when compared to double glazing in the UAE houses. Triple glazing (clear + clear + low-e) reduced cooling load by 5% when compred to the reference case and by 3% when compared to double glazing (clear + low-e). The last comparision finding differ than Amin & Abu-Hijleh (2012) study of Dubai villa glazing assessment showed the change from double low-e into triple low-e impact on cooling load as 5% less.

The impact of changing frame material is clear when comparing scenario 1 with scenario 5 where the same glazing; double clear, resulted in the same heat gain while cooling load has reduced due to the frame material U-value reduction. PVC frame material could reduce cooling load by 1.3% in comparision with Alumium frame. Sinha & Kutnar (2012) found out similer result as their study stated that PVC frames showed better performance than Aluminum frames, thermally as well as environmentally. However, the influence of improving windows' glazing is better than frame materil change influence in all means; solar heat gian, cooling and energy demands reduction. In terms of windows' glazing influences, adding third pane to the double clear glass (scenario 3) showed better influence than double clear + low-e glass (scenario 2). The optimal windows' system scenario were scenario 8; the triple glazing (clear + clear + low-e) with PVC frame. Solar heat gain reduction achieved when comparing it to the reference case (scenario 1) is 20% while cooling sensiable load reduced by 6%.

5.2 Shading Devices' Scenarios:

The current status of the house is without any shading devices (SDs) for windows system. The only shades applied are the two wooden pergolas in the first floor balconies and the one in the garden adjacent to the south facing guest bedroom opening. Horizontal, vertical, and combination between horizontal and vertical shading devices are the three proposed scenarios with two different projections; 30cm and 60cm.

Table 3 shows shading devices' scenarios performance in terms of solar heat gain, cooling demands, and energy consumption. As per literature review, shading devices prevent solar radiation from heating up the internal spaces effectively and the same findings associated with the present study results. Cooling sensible loads are directly proportion to solar heat gain values when it comes to SDs performance.

Table 3: Shading devices' scenarios and their performance

Shading Devices' Performance Summery				
Scenario	**Variables**	**Solar Heat Gain (MWh)**	**Cooling Sensible Load (MWh)**	**Annual Energy (MWh)**
1	No Shading Devices (Reference Scenario)	22.89	104.5	84
2	Horizontal SDs (Overhang 30cm)	20.84	103.1	83.29
3	Horizontal SDs (Overhang 60cm)	19.29	102	82.75
4	Vertical SDs (Side Fin 30cm)	21.49	103.5	83.52
5	Vertical SDs (Side Fin 60cm)	20.42	102.8	83.16
6	Horizontal & Vertical SDs (30cm)	19.43	102.1	82.8
7	Horizontal & Vertical SDs (60cm)	16.84	100.3	81.92

Horizontal shading devices (HSDs) showed better performance than vertical shading devices (VSDs) while the combined design between horizontal and vertical shading devices (H&V SDs) performed the best in terms of solar heat gain and cooling load reductions. Third column of Table 3 shows the impact of different configurations of SDs on solar heat gain. Horizontal, vertical, and combination between them at the 30cm projection reduced solar heat gain by 9%, 6%, and 15%, respectively, when compared to the reference scenario with no SDs. Doubling SDs' projection; from 30cm to 60cm, reduced solar heat gain value by 8%, 5%, and 13% for horizontal, vertical, and the combination, respectively. It can be noted that, the combination between horizontal and vertical SDs impact on solar heat gain reduction is equal to the sum of the reduction outcome of each SD type individually.

At the projection of 30cm, HSDs, VSDs, and H&V SDs could reduce cooling load by 1.3%, 0.9%, and 2.3% respectively, while at 60cm projection the reductions' percentage became 2.4%, 1.6%, and 4% in the same arrangmnt, when reference scenario considered as base case with no SDs. The comdined design between horizontal and vertical SDs with 60cm projection is the optimal shading devices design scenario and resulted in 27% reduction in solar heat gain and 4% in cooling load. Combined SDs design is the most effective scenario due to its functionality with sun path from east to west through south orientations and this finding is simmiler to Chi-Ming & Yao-Hong (2011) finding which is; Box shading had the maximum reduction effect, more than horizontal and vertical shades.

5.3 Glazing Vs. Shading:

Even though shading devices could reduce solar heat gain more effectively than windows system did but windows system showed better performance in terms of cooling demands and energy consumption. Many other studies reviewed stated the same; the use of an appropriate window glass reduced the annual energy consumption the most, followed by the shading devices used (Wong & Istiadji, 2004; Chi-Ming & Yao-Hong, 2011; Lai &

Wang, 2011). Another study conducted on residential buildings in Al-Ain, UAE found out that thermal insulation and thermal mass are the most effective and beneficial energy design measures. The window area and glazing system provide a considerable amount of energy savings, and ranked the second. While SDs provide a limited reduction in terms of energy use (Radhi, 2009).

On contrary, Ebrahimpour & Maerefat (2010) found out that using of the most appropriate overhang or side fin is more useful for any direction of window than the advanced glazing windows. This is related to the fact that SDs' working prenciple is solar radiation penetration prevention while windows system works on two prenciples; solar radiation and heat conductivity reduction, based on low-e and U-value properties.

Family room chosen as a sample for exmaiming the same scenarios impact on its functionality. It has been chosen because it has different design charectaristic in terms of windows and orientation. It has south and east facing windows which are equal in area while south facing wall WWR is 33% and east facing wall WWR is 19%. Based on the difference in windows design and orientation between the house and Family room, a difference in performance of the same scenarios resulted. In Family room, the optimal windows' system and the optimal shading devices performed the same in terms of cooling load reduction percentage, and this differ than thier impact on the whole house where optimal windows' system performed better than optimal SDs. This result is directly related to the change in WWR and orientation. Window to wall ratio on the south facing wall of family room is higher than east facing WWR and this resulted in enhancing the SDs performance.

Therefore, windows' system and shading devices optimization has to be based on windows' design and orientation. The same finding highlighted in the literature review section based on Boji & Yik (2005) study. However, for this particular case study and as casual induction, optimal SDs design performes better than optimal windows' system for south facing windows but this is not the case for east and west facing windows.

5.4 Optimal Scenario:

Triple glazing (clear + clear + low-e panes) with PVC frame windows' system and combined horizontal and vertical shading devices with 60cm projection is the optimal scenario in terms of solar heat gain and cooling load reductions. Figure 17 shows the graphical comparison between reference and optimal scenarios' performance. Reduction percentage in solar heat gain was 41% while in cooling sensible load is 10% and annual energy consumption reduced by 6%.

The optimal case scenario impact on cooling load was positive and the total reduction in demands were almost the sum of reduction resulted of applying each of windows' system and shading devices individually. Therefore, no overlap witnessed from applying these two applications to the house' windows but there positive influences are actually accumulative.

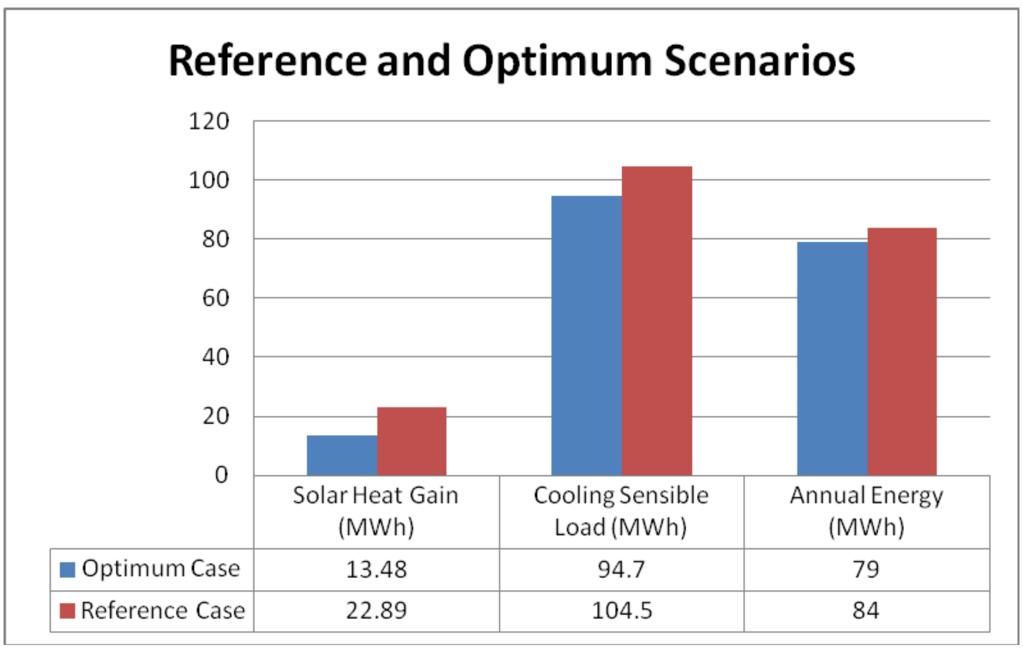


Figure 17: Reference and optimal scenarios' performance

Looking at the impacts of scenarios' application and the reduction comparison between reference and optimal scenarios in different aspects, solar heat gain reduced significantly while cooling demands and energy consumption did not improve in the same amount. Figure 18 illustrates the main heat gain factors and how they contribute differentially to indoor thermal conditions of the house. Solar heat gain contributes by 27% only and this is where fenestration system takes the important part in. Other heat gain factors are constant in this study. This explains why the enhancement in cooling load is not at the same importance as it is in solar heat gain.

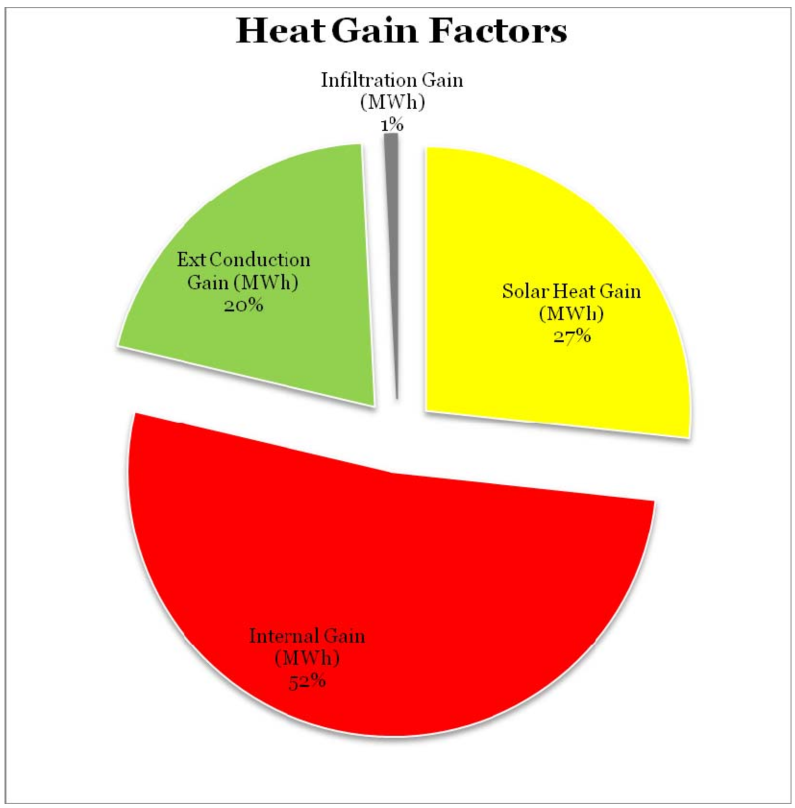


Figure 18: Heat gain factors' contribution to the House's thermal conditions

Annual energy consumption reduction percentage is less than cooling load reduction percentage is basically due to the role of other systems to take part in this study and they are basically lighting, ventilation, and dehumidification systems. Based on the reference scenario conditions, cooling demand contributs by around 65% of total energy demands. This numerical demonstration explains how findings of this study make sense.

Based on many reviewed studies, shading devices has an impact not only on solar heat gain reduction but they affect daylight performance signifcantly. However, daylight conditions are not under the present study scop of work but it is improtant to mention how daylight parameters changed accordingly. Figure 19 illustrates daylight illuminance of the ground floor in the reference case; without SDs. Daylight illuminance maximum value is 2700 lux. For example, Living room daylight factor (DF) average is 4.6%, daylight illuminance average is 563 lux, and uniformity ratio is 0.11.

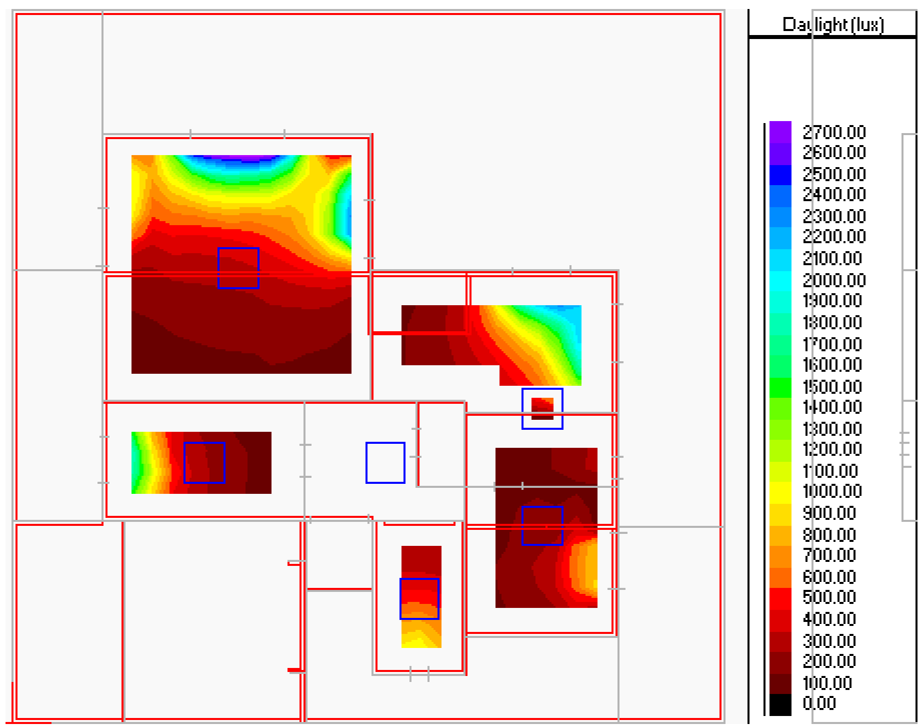


Figure 19: Reference case Daylight illuminance in the ground floor (IES VE2012)

In Figure 20 we can see that daylight illuminance maximum value is 1600 lux and Living room DF average is 2.3%, Daylight illuminance average is 281 lux, and 0.13 uniformity in the SDs optimal case. When comparing the two scenarios performance in Living room, a significant draw back witness in daylight factor and illuminance, almost 50% less. The negative influence of SDs application varies based on windows design and orientation as can be identified from the two scenarios figures of different rooms. The weakness in daylight performance happened when applied external shading devices has a direct impact on electrical light demands and therefore the total energy consumption.

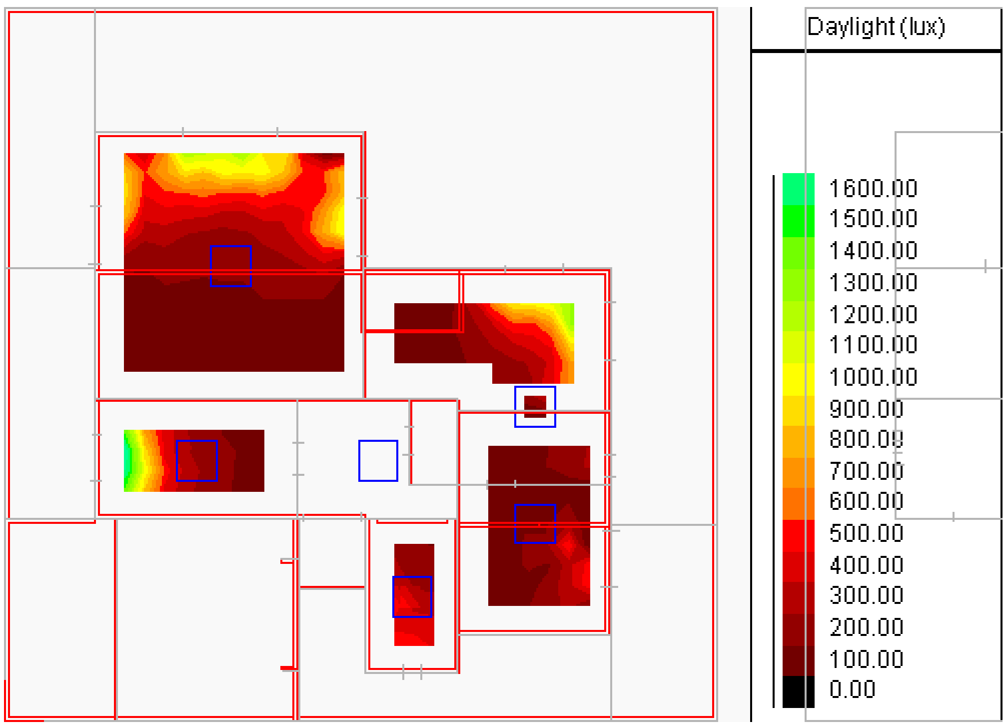


Figure 20: Optimal SDs case Daylight illuminance in the ground floor (IES VE2012)

Windows' design optimized exclusively for visual comfort produce large energy consumption patterns (Mardaljevic et al. 2009) and optimizing window size for low energy consumption only does not meet any of the predetermined visual acceptance criteria (Ochoa et al. 2012). Therefore, striking the balance between thermal and lighting conditions with relation to windows design and shading devices is a challenging task. Optimal energy consumption and visual requirements are integrative approach and they improve the quality of architectural spaces and occupants' comfort (Stegou-Sagia et al. 2007; Tzempelikos et al. 2010; David et al. 2011; Fiocchi et al. 2011). In this case where thermal and lighting performances proved to be vary from room to room and with different windows' design and orientation. It is still possible to reach the optimal performance by integrating the two systems and analyze their parameters for each area individually and then the whole picture together. A future research study is to examine the influence of studied scenarios not only on thermal and energy performance but to include light performance analysis in order to achieve the optimal energy consumption without compromising any of thermal or light comfort. This recommendation works hand by hand with presented literature of Alzoubi & Al-Zoubi (2009). Another future study recommendation in terms of glazing performance comes in line with the Mardaljevic et al. (2009) study, is to examine studied glazing scenarios impact on visual conditions of houses in the UAE.

6. Conclusion:

It is possible to reduce 10% of houses' cooling bills in the UAE by adopting simple and passive design strategies which are applicable for existing and newly designed projects. Residential buildings' energy consumption contributes by around 45% of UAE's energy consumption. The present study could reach around 6% reduction in the annual energy consumption. Therefore and based on a simple calculation, 2.7% reduction in the annual energy consumption of UAE thus, carbon dioxide emissions' reduction by around the same percentage. These numbers are actually presented to provide an efficient practice from our architecture in terms of energy and ecosystem savings. Sustainable design principles can be easy and effective at the same time and they do not have to add cost and sophistication to our architecture. But on contrary, examined scenarios can add aesthetical and cultural value as they have indirect benefits in terms of acoustical and privacy influences. The triple glazing system enhances noise insulation property while the external shading devices provide more privacy to the residents.

Based on the local climatic conditions and the geographical location of the UAE, solar radiation and heat gain are the most challenging conditions in terms of energy efficient buildings. Opaque elements of buildings' envelope are the most related to heat conduction gain while the transparent elements have a complicated relation with solar radiation, solar heat gain and heat conductivity, in addition to visual and daylight functionality. The present study concerned of thermal performance with relation to windows and shades system and how to enhance residential buildings' energy performance by improving the condition of windows' system and shading devices. A residential house in Abu-Dhabi modeled and with the help of computer simulation software; IES VE2012, energy simulation of different design scenarios applied.

Shading devices (SDs) reduced solar heat gain effectively and more than windows system did. While cooling sensible load enhanced the most by windows' system parameters; U-value and SHGC. Horizontal SDs performed better than vertical SDs while combined horizontal and vertical SDs was the best in terms of solar heat gain and energy reduction. Same windows and SDs design showed different impact on different house rooms based on their openings design and orientation. The present study scenarios varied in performance as for solar heat gain and sensible cooling load, but windows' system optimal scenario tend to be Triple glazing with low emissivity pane and PVC frame. As for external shading devices, combination between horizontal and vertical type with 60cm projection performed the best when compared to other examined scenarios.

Not like windows' system, shading devices have significant impact on daylight performance as they effect solar radiation penetration to internal spaces and lighting them up. Many design parameters control the influence of SDs on daylight illuminance, glare, and uniformity. Light condition is not one of the present study scope of work. However, daylight factor and illuminance was driven back due to optimal SDs scenario application, by around 50%, but this might have a positive impact on glare and over-heating problem. The negative influence of SDs varies based on windows' design and orientation in addition to SD's design parameters. Future studies recommendations are basically to examine the impact of studied scenarios on visual and daylight performance. Other than windows' glazing and shading devices influences on thermal conditions, light transmittance and daylight factors have to be analyzed as well. In addition to different external shading devices types and designs including tilted elements can be an area where future studies can take a place with regards to thermal and visual conditions, and energy performance.

Finally, the massive demands of cooling and air conditioning system in residential buildings in the UAE could be reduced dramatically by adopting passive and simple design strategies. The direct relation between solar radiation and heat gain through transparent envelope elements were determined. Thermal transmittance and solar heat gain coefficient properties are the main factors in windows' system performance. Therefore, improving the current status of shading and windows system in existing buildings showed significant reduction in cooling demands. However, case-by-case study and analysis is an essential part in determining the optimal configuration between external shading devices and windows' system.

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