

Effects of Shading Strategy and Orientation on Energy Performance of School Building

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Abstract: Excess solar gain in buildings affects the building's energy performance; however an optimal choice of overhangs and fins can tackle this issue to a remarkable extent. This study analyzes various alternatives of overhangs and fins attached to south, west and east facades of an elementary school building in Los Angeles, to select the best shading strategy in terms of energy performance. By considering 'no-overhang-no-fin' as the base case, three configurations such as overhang without fin, fin without overhang, and with overhang, were studied to assess the energy consumption. The simulations of all the tested alternatives were performed by eQUEST software program. The observations reveal that the overhangs and fins, and their proper positioning and orientation have significant impact on the building's energy performance. With respect to the baseline, a saving of up to 13.62 % in the annual electric energy consumption and 12.5 % in total energy cost (electricity + fuel) have been predicted by the use of overhangs with fins on south, west and east facades.

Keywords: Energy performance; Facade; Overhangs; Fins; Annual energy cost.

1. Introduction

Solar heat gain inside buildings is caused by solar radiation through transparent surfaces such as windows or skylights, or through opaque surfaces such as walls or roofs (Balcomb, 1992). Excess solar gain results in high cooling energy consumption in warm, sunny climates, while in cold and temperate climates winter sun entering south-facing windows contribute to passive solar heating. Also, in nearly all climates controlling and diffusing natural illumination could improve daylighting (Prowler, 2014). Proper design and choice of shading devices are crucial in ensuring the desirable energy performance and indoor comfort conditions of a building. The dramatic pace of developments in the building construction industry and the associated energy and environmental concerns have prompted researchers in exploring fenestration and

shading systems for optimal control of solar gains and daylighting. Appropriate combination of overhangs and fins would be promising in attenuating the excessive solar radiation into buildings, and simulation tools play an important role in taking decision during early design phase that could help in improving the thermal performance of buildings (Ali & Ahmed, 2012). This issue has attracted many researchers, and knowledge on this subject is abundant. A review by Dubois (1997) indicated the significance of using computer programs to assess energy use and comfort in buildings equipped with shading devices, and defining climate-specific shading strategies for different types of buildings.

The application of overhangs and fins on a high-rise 20-storey residential building in Hong Kong, was investigated by Bojić (2006), by using the software EnergyPlus™. It was found that the application of overhangs would reduce the electricity consumption

by up to 5.3% and side fins with overhangs would reduce the electricity consumption by up to 1.4%. Bellia et al. (2013) analyzed the influence of external solar shading devices on the energy requirements of an Italian office building, by using a building energy simulation code. The energy demands of heating, cooling and lighting, and the energy saving related to the use of solar shading devices were evaluated as a function of climate, geometrical characteristics of the shadings and the building, thermal transmittance of the building envelope and the building orientation. The shading devices could achieve annual energy saving of 8% and 20% for the coldest and warmest climates respectively. A study on residential buildings in Tehran found that appropriate overhangs or side fins in the south, west and east windows would reduce the annual energy transferred to the building and could have an energetic behavior equivalent to high performance glazing (Ebrahimpour & Maerefat, 2011).

The effect of overhangs and side-fins on building thermal comfort, visual comfort and energy consumption in the tropical climate was studied by El Sherif (2012) who simulated a typical office building by using IES-VE software. Overhangs and side-fins with various depths were assessed in different building orientations through summer and winter seasons. The shading devices were predicted to reduce solar gain by 13% to 55% and luminance level up to 9.3%, claiming a saving of 27.5% in the energy consumption.

Tzempelikos and Athienitis (2007) evaluated the impact of glazing area, shading device and shading control on the energy demand and thermal comfort of a Canadian office building, to provide guidelines on selecting glazing area and shading properties at the early design stage. The building cooling and lighting demand was calculated using a coupled lighting and thermal simulation module. An optimal balance between solar gains and internal gains was achieved, yielding a reduction of 12% in the total annual energy demand. This study was extended to select the facade and envelope options for the Engineering building of Concordia University in Montreal (Tzempelikos et al., 2007), and it was predicted that an optimum combination of glazing, automated shading devices and controllable electric lighting systems could achieve a saving of 36% in peak cooling load.

Alzoubi and Al-Zoubi (2010) investigated the effect of vertical and horizontal shading devices on the quality of daylight in buildings and the associated energy saving. This computer-aided study concluded that there was an optimal orientation for shading

devices to keep the internal luminance level within the acceptable range with minimum amount of solar heat gain. Vertical shading devices could simultaneously provide good daylighting and minimum heat gain in spaces. The impact of management strategies for external mobile shadings and cooling by natural ventilation was studied by van Moeseke et al. (2007) who simulated various control rules for shading and natural ventilation, and predicted that the management choices had real impact on energy and thermal comfort. For instance, for shadings, strategies based on both internal temperature and solar irradiation set points were shown to be more efficient than those based on solar irradiation or internal temperature alone. A study (Yao & Yan, 2011) on energy performance of shading devices based on incremental costs revealed the merits (with respect to incremental cost, for same energy efficiency) of movable shading devices over fixed ones for residential buildings, and wing panel shadings over baring screen ones for commercial buildings.

The effect of louver shading devices on the cooling and heating loads was analyzed by Palmero-Marrero and Oliveira (2010), for different window and louver areas, under climatic conditions of Mexico, Cairo (Egypt), Lisbon (Portugal), Madrid (Spain) and London. The integration of louver shading devices in the building was found to provide comfortable indoor thermal conditions and significant energy savings. Ali and Ahmed (2012) investigated the impact of shading devices on the thermal performance of residential buildings in Egypt. The study showed that the use of vertical fins had a reduction of 1.50C in indoor temperature for the northern, eastern, and western orientations, whereas, the combined shade and overhang reduced the temperature by 1.50C for the southern orientation. Recently, Liu and Kensek (2013) have compared three exterior window shade strategies such as block shading plus side fins, overhangs plus side fins, and louvers plus overhangs, for a building in the USC campus in Los Angeles. The simulations were run by using Design Builder software program. The energy performance was shown to be dependent on shading strategies and their orientations. The results also substantiated the fact that the type of shading depends on orientation.

However there is significant scope for research on the design, type, orientation, etc., of shading devices such as overhangs and fins, and their use in different types of buildings under various climatic conditions. In the present study, an elementary school build-

ing in Los Angeles was considered to analyze the effects of shading strategy and orientation on the annual electricity consumption and energy (electricity + fuel) cost of the building. Three shading options such as 'overhang without fin', 'fin without overhang', and 'with overhang and fin' on the south, west and east facades were studied for the annual energy consumption with respect to the baseline (without overhang and fin). The simulations of all the tested alternatives were performed by eQUEST program.

2. Methodology

2.1 Los Angeles

The city of Los Angeles (LA) is situated in a hilly region which shares its southern and western boundaries with the Pacific Ocean, while the Santa

Monica and San Gabriel Mountains are in its north and east boundaries respectively. This geographical location and the numerous valleys and canyons of the region make LA an area of diverse climatic conditions. The predominant weather is warm and humid, and the temperature is mild throughout the year. Summers are dry and sunny and most of the rainfalls occur during the winter. In addition to the smog and air pollution weather issues of the region include the hot and dusty Santa Ana winds, and the occasional flash floods causing mudslides. It has area of 469.1 square miles and population of 3,850,000. LA is located in zone 8 (of the 16 climatic zones of California) with latitude of 34° 05' N, longitude of 118° 22' W, and the corresponding solar declination angle (the angular distance of the sun north or south of the earth's equator) is approximately 220 South, 22.180 North and 7.220 South in winter, summer and spring respectively. Figures 1 to 3 show the trends of monthly average temperature, relative humidity and wind speed respectively, of LA.

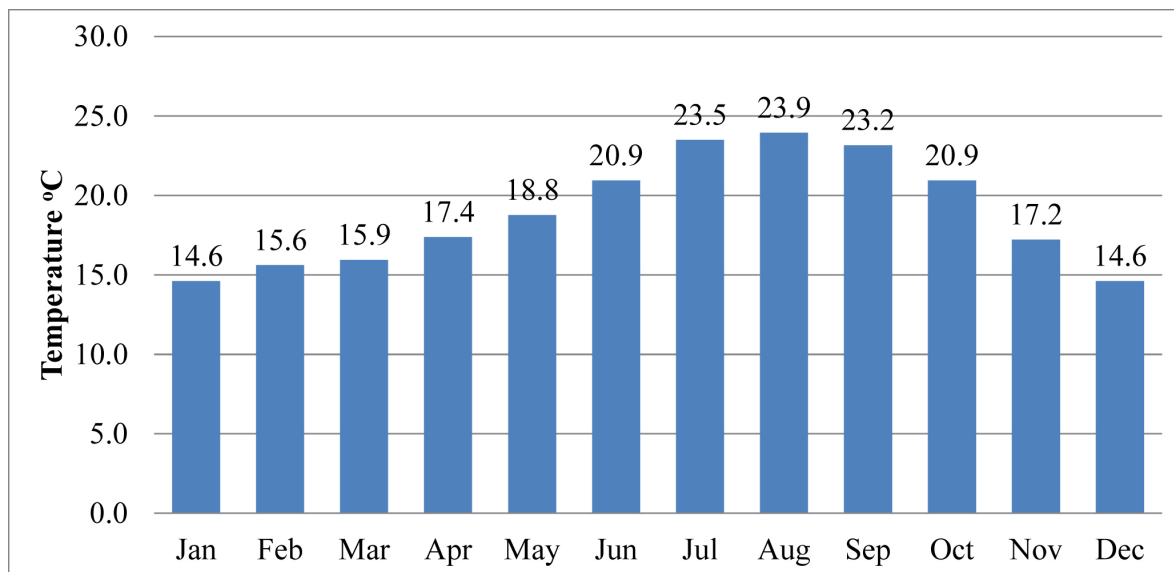


Figure 1: Average monthly temperatures of LA.

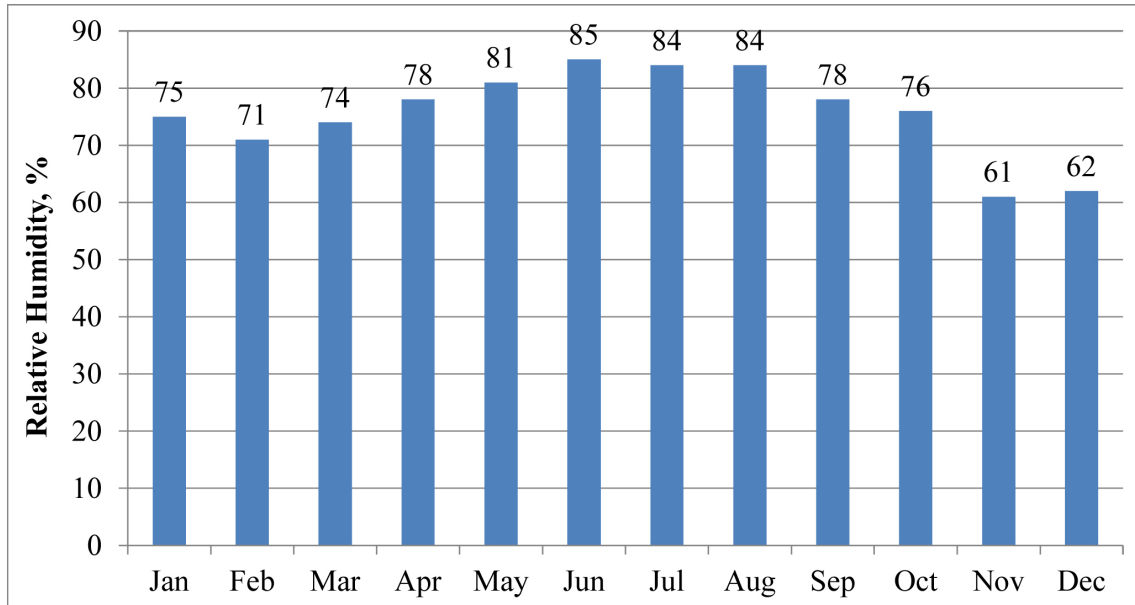


Figure 2: Average monthly relative humidity of LA.

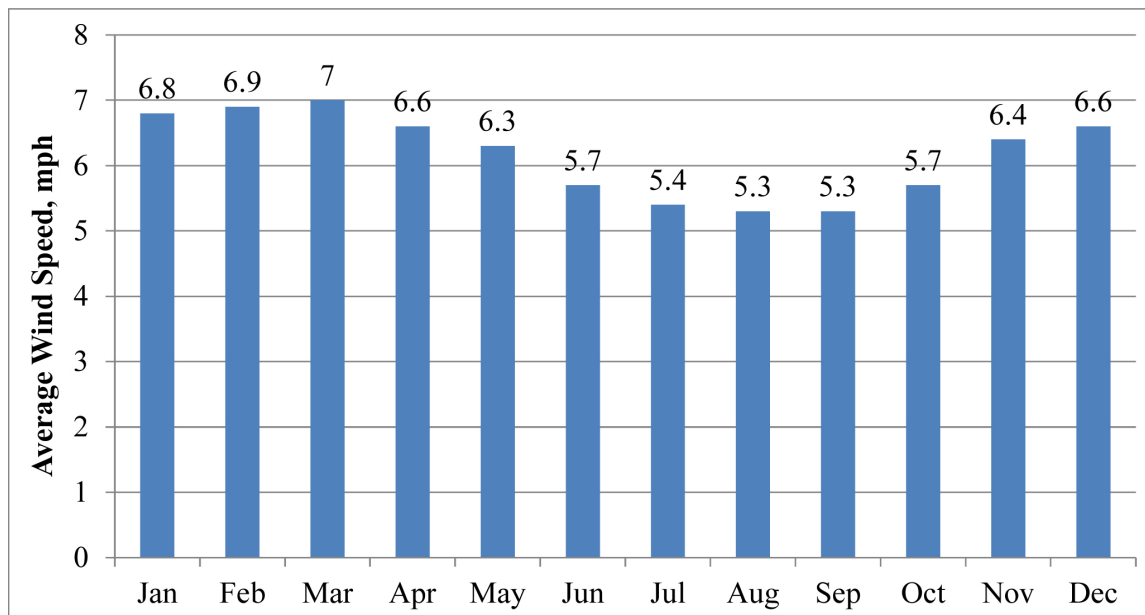


Figure 3: Average monthly wind speed of LA.

2.2 eQUEST Software Program

The eQUEST software employs enhanced DOE-2.2-derived building energy use simulation program, and provides accurate results by combining a building creation wizard, an energy efficiency measure (EEM) wizard and a graphical results display module. The building creation wizard creates the building model and DOE-2.2 performs an hourly simulation of the building based on walls, windows, glass, people, plug loads, and ventilation. DOE-2.2 also simulates the performance of fans, pumps, chillers, boilers, and other energy-consuming devices. The software offers energy cost estimating, day-lighting and lighting system control and automatic implementation of energy efficiency measures (“eQUEST... the QUick Energy Simulation Tool,” n.d.).

2.3 Tested Cases

An elementary school building in LA was selected for the study. The building has single floor, with 12 classrooms and 300 occupants. In the tests, the south and west-east façades were provided with no shading, overhangs, fins, and overhangs and fins, and the energy consumption of the building was measured in each case. Out of the 8 cases (Table 1), Case 1 (no shading) was the baseline. North façade was avoided in the study, since this orientation was found to have only nominal role in controlling the daylight; similar finding was also reported in previous work (Tzempelikos and Athienitis, 2007). However as south façade is well-known for its relatively greater impact, this was treated separately. The building specifications required for the eQUEST simulation are provided in Table 2, and the three-dimensional (3D) simulation model is shown in Figure 4. The material properties were set according to the existing situation.

Table 1: Test Cases

Case	South Facade	West & East Facades
1	No shading	No shading
2	Overhangs	-
3	Fins	-
4	Overhangs and fins	-
5	-	Overhangs
6	-	Fins
7	-	Overhangs and fins
8	Overhangs and fins	Overhangs and fins

Table 2: Building Specifications

Item	Specifications
Type	Elementary school (single floor)
Number of occupants	300 (in 12 classrooms)
Area	683 m ²
Height	Total-3.66m; Floor to ceiling- 2.7m
Frame Type	Aluminum without a thermal break, operable window
Window	Glass and aluminum frame window; Clear argon filled double pane low-e squared in aluminum frame (U = 0.63 SHGC = 0.34 T _{vis} = 0.60) Window: height = 1.22m, width = 0.61m×no. of panes. Window area: 33% of the total envelope area, as recommended by ASHRAE
Overhang and fins	Overhang = 50-60 cm from wall; fin height = 1.22m; fin width = 40cm.
Insulation	Super insulation to 2 times current code
Walls	Stucco, 5 cm + polystyrene on 20 cm hollow concrete block , exposed or plaster board
Roof	Clay or concrete tiles, natural ventilated attic, slopped roof
Floor	Slab on grade ceramic
Infiltration and ether stripping	Add sealed ducts(4.4 SLA) required in title 24 package D, inspected and blower tested
Ventilation	Natural ventilation cooling or economizer or night flush fan cooling Large whole house fan (up to 20.0 ACH as needed)
Heating	Furnace or heat pump
	Best available furnace, condensation furnace(97% AFUE, annual fuel utilization efficiency
Cooling	Air conditioner or heat pump
	Best available air conditioner, split system (16.5SEER,seasonal energy efficiency
Lighting power density	0.1 watts/ sq.m (average)
Illumination level	0.027 cm-candle

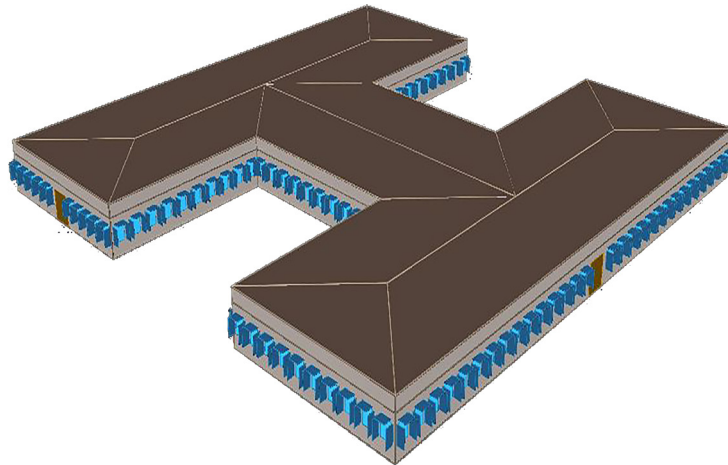


Figure 4: 3D simulation model of the building.

3. Results and Discussion

In the eQUEST simulation, the contributors of annual electricity consumption include area lighting, task lighting, space heating and cooling, refrigeration, ventilation fans, pumps and auxiliaries, water heating, exterior usage, heat rejection and miscellaneous equipment. Figure 5 shows the annual electricity consumption predicted by the present simulations, for the eight cases. The impact of shading on electricity consumption is very clear from the base case (Case 1) which has the highest consumption (101 MWh), while the combination of overhangs and fins on all the facades could yield minimum consumption (87.52 MWh), yielding a saving of 13.6%. The advantage of overhang-fin configuration was also verified by Liu and Kensek (2013). Figure 6 elucidates the

individual contributions of overhangs and fins in reducing the electricity consumption; on all the facades, the performance of overhangs is more than that of fins. It is also worth noting that the location of shading device greatly influences the solar heat gain as the shading on south façade performed well compared to east and west facades for a given shading strategy. South-facing facades receive maximum solar gain during winter, but require more energy for cooling during the summer (Ratti et al., 2005). However, as indicated by Haller (1999), properly sized overhangs on south orientations could eliminate summer solar gains and allow the desired amount of winter gains. Since LA has predominantly warm and humid weather, the south façade has contributed to increased solar gain, which could be attenuated effectively by the overhang-fin shading configuration in the present study.

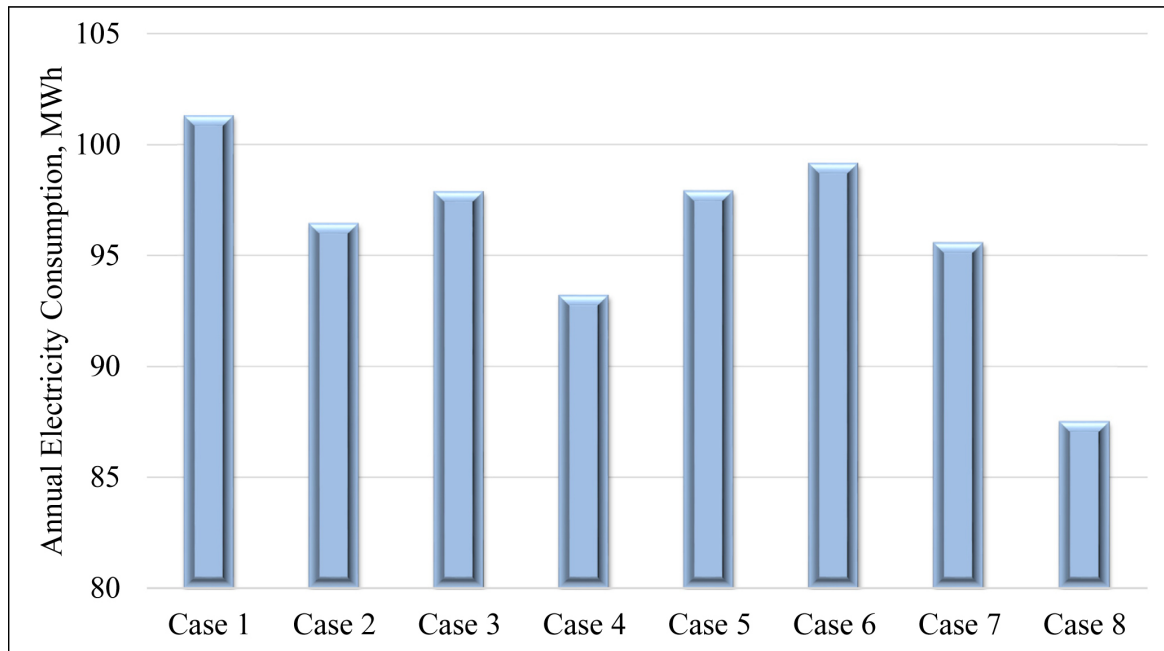


Figure 5: Annual electricity consumption.

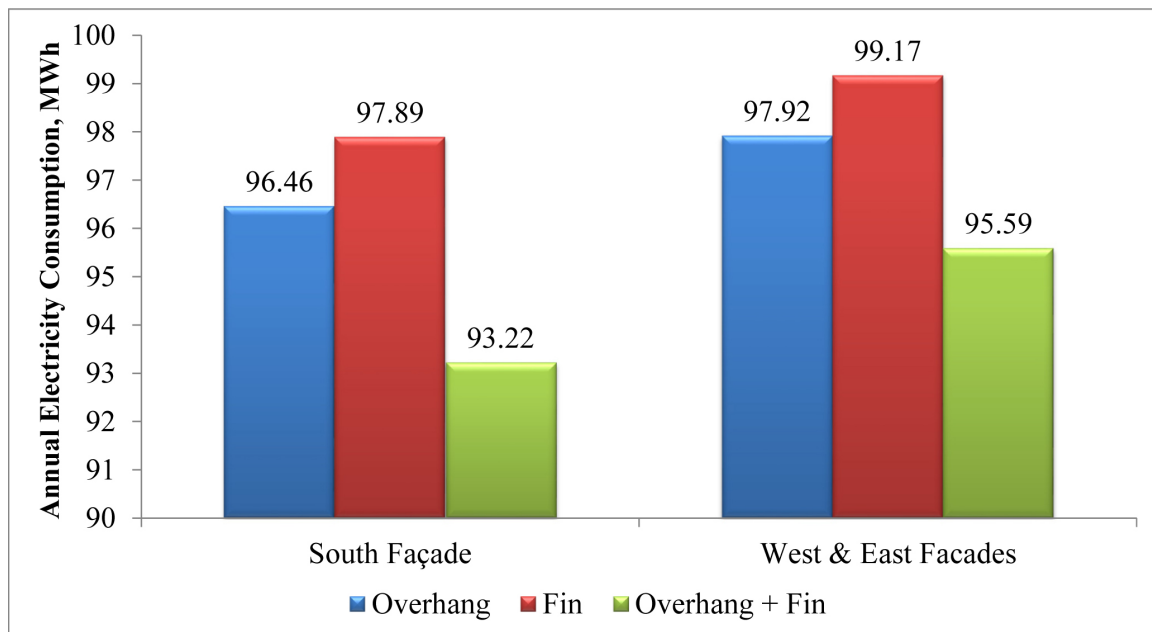


Figure 6: Individual contributions of overhangs, fins and their combination on annual electricity consumption.

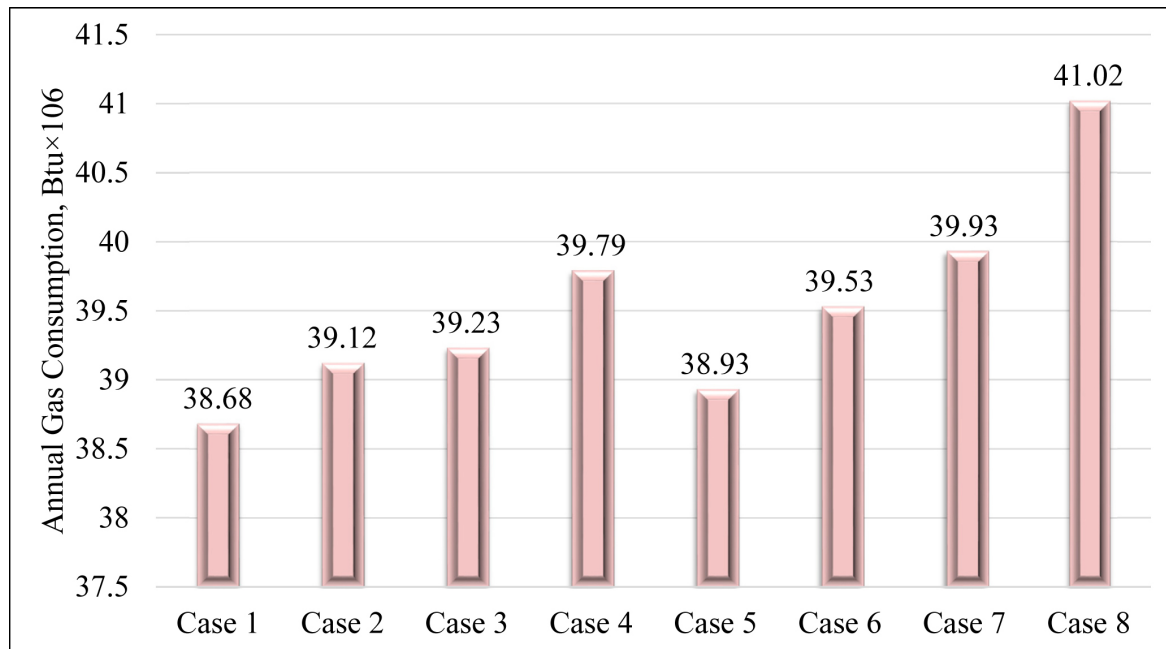


Figure 7: Annual gas consumption.

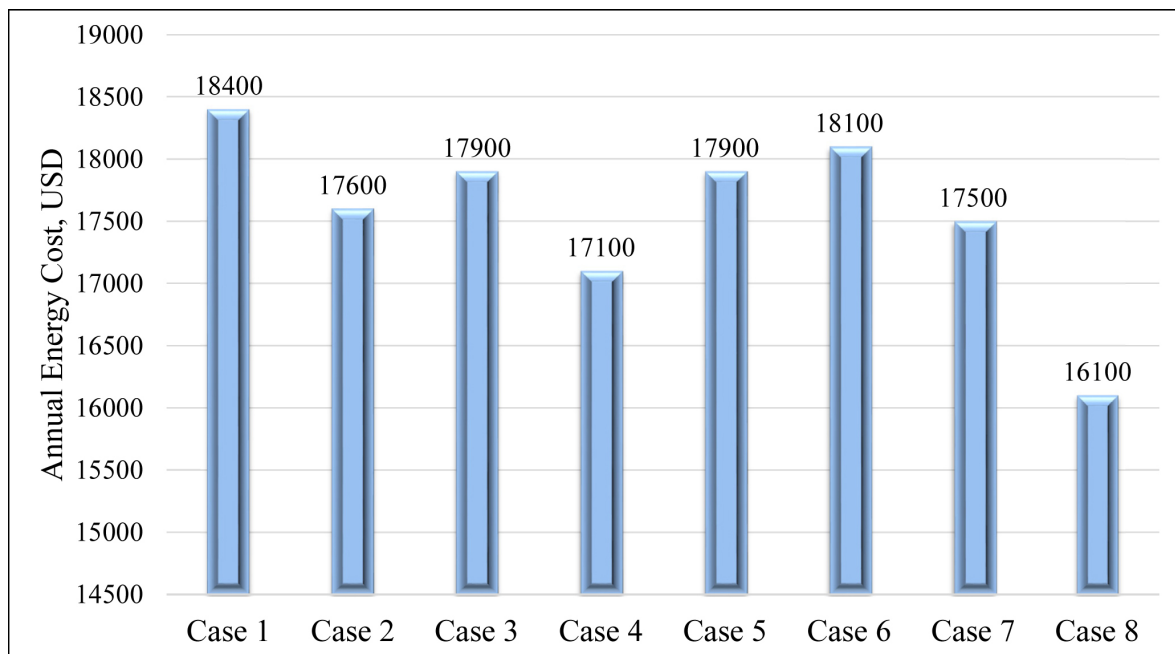


Figure 8: Annual energy (electricity + gas) cost.

Figure 7 shows the annual gas consumption for the tested cases. It is interesting to note that, even though the gas consumption is increased by the combined use of overhangs and fins, the annual cost of energy (electricity + gas) is reduced by 12.5 % compared to Case 1, as illustrated in Figure 8. This is attributed to the cheaper gas price (3 USD/gallon approx.) which constitutes only about 6% of the total energy

cost. Table 3 shows the effect of overhangs and fins on energy and fuel uses for various applications in the building. Area lighting, equipment and water heating are not influenced by shading, while ventilation pumps, and space heating and cooling, are affected. The combined use of overhangs and fins could yield electric energy savings of 20% for pumps, 20.35% for ventilation and 22 % in space cooling.

Table 3: Annual energy consumption by end use.

End Use Component	Electricity Use (MWh)		Fuel Use Btu×10⁶	
	Case 1	Case 8	Case 1	Case 8
Area lighting	22	22	-	-
Task lighting	-	-	-	-
Misc. equipment	13.8	13.8	-	-
Exterior usage	-	-	-	-
Ventilation	28.5	22.7	-	-
Pumps and misc.	10	08	-	-
Refrigeration	-	-	-	-
Space cooling	27	21	-	-
Heat rejection	-	-	-	-
Space heating	-	-	2.68	5
Heat pump suppl.	-	-	-	-
Water heating	-	-	36	36
Total	101.3	87.5	38.68	41

The accuracy of the present simulation results could be verified by comparing the baseline value with the ASHREA benchmark. From Figs. 5 and 7, the annual energy consumption (electricity + gas) of the tested building for Case 1 could be estimated as 52 kBtu/ft², by considering the total area 683 m² (Table 2). This is fairly close (91%) to the benchmark value reported in the literature (57 kBtu/ft²) (Owens et al, 2012) for elementary schools in California, without shading device.

4. Conclusion

Energy simulations were performed on a typical elementary school building in LA to study the impact of shading devices such as overhangs and fins on south, west and east facades. With no shading as the baseline, 7 alternatives were tested for energy and gas consumptions and their costs. Energy simulations were performed by eQUEST software program. It has been observed that a judicious application of shading devices could bring about significant reductions in energy consumption. The overall simulation result showed that use of overhangs and fins on all the facades of the building could achieve savings of up to 13.6% in electricity consumption compared to the base case (Case 1), and 12.5 % in the annual energy cost. It is also interesting to note that building-orientation has significant role to play, as shading devices on south façade showed better performance compared to east and west facades with the same shading devices. The present results were found to be acceptably close to the ASHRAE benchmark reported in the literature for similar building. This study could provide promising inputs for building designers in deciding the type and positioning of shading devices in the early design stage itself. For future work, similar analysis may be performed for different climatic conditions and types of buildings.

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آثار استراتيجية استخدام وتوجيه كاسرات الشمس على أداء الطاقة في مباني المدارس

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قدم للنشر في ١١/٠٢/١٤٣٥هـ؛ وقبل للنشر في ١٠/٠٥/١٤٣٦هـ

ملخص البحث. توفير الاضاءة الطبيعية في الفراغات المعمارية يؤدي الى اكتساب طاقة حرارية من شأنها ان تؤثر سلبا على أداء المبنى الحراري. وبالرغم من ذلك فإن الاختيار الامثل لنوع كاسرات الشمس سواء العمودية منها والأفقية فإنه يساهم في معالجة هذه المشكلة وبالتالي سيساهم في ترشيد استهلاك الطاقة. وتقوم هذه الدراسة على اختبار وتحليل البدائل المختلفة من كاسرات الشمس ودراسة مدى تأثير استخدامها في نوافذ الواجهة الجنوبية والواجهتين الشرقية والغربية لمبنى مدرسة ابتدائية في مدينة لوس انجلوس وذلك لتحديد أفضل استراتيجية لكسر أشعة الشمس والتي تؤدي إلى توفير استهلاك الطاقة. وقد تم مقارنة البدائل المختلفة مع الحالة التقليدية وهي عدم استخدام كاسرات الشمس بتاتا في المبنى وتشمل هذه البدائل، ثلاثة تكوينات لكاسرات الشمس والتي تشمل: كاسرات الشمس الأفقية فقط، كاسرات الشمس العمودية فقط وكاسرات الشمس العمودية والأفقية سويا وذلك لتقييم استهلاك الطاقة. أجريت المحاكاة لجميع البدائل وذلك باختبارها من قبل استخدام برنامج محاكاة استهلاك الطاقة eQUEST. وقد كشفت هذه الدراسة بأن الاستخدام الأمثل لتوجيه وموضع الكاسرات العمودية منها والأفقية له أثر كبير على ترشيد استهلاك الطاقة في المبنى. ولقد أثبتت هذه الدراسة أن المبنى المدرسي التي تستخدم فيه كاسرات الشمس يقلل من استهلاك الطاقة بنسبة تقريبيه تصل الى ١٣, ٦٢٪ من الاستهلاك السنوي للطاقة مقارنة بالمبنى المدرسي التقليدي. كما أنه يتم تقليل ما يقارب ١٢, ٥٪ من إجمالي تكلفة الطاقة السنوية والتي تشمل تكاليف (الكهرباء + وقود التدفئة) وذلك نتيجة لإستخدام كاسرات الشمس العمودية والأفقية في الواجهات الجنوبية والشرقية والغربية.

الكلمات المفتاحية: أداء الطاقة؛ واجهات المبنى. كاسرات الشمس الأفقية كاسرات الشمس العمودية، تكلفة الطاقة السنوية.

