Sustainable Architecture Under the Timeline Frame: Case Study of Fujairah in UAE

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Abstract. There is a significant link between thermal comfort and energy performance, since creating comfortable temperatures requires thermal energy. The tighter the tolerances of temperature demanded the more energy consumed. It is therefore important to understand the implications of relaxing those tolerances and what passive strategies are available as alternatives to mechanical temperature control. This study attempts to investigate the impact of passive environmental strategies on built form using a simulation of an existing residential building. The house is located in Al Bithna/Fujairah. The simulation was conducted using IES-VE software. The results show a reduction and savings when implementing different passive strategies. This begins with increasing window size and is followed by changing glazing type and finally adding a shading device to the base model. The aim of this study is to understand sustainability evolution in residential houses in the UAE across different time frames. The document will delve in the past to check the characteristics of old houses in the UAE and their attempts to maintain comfort and sustainability. Turning to the present, a case study is selected to which different passive design strategies are applied and a recommendation of what the future will look like in terms of sustainable residential houses is developed. The study concludes with a look at the impact of combined strategies to see the impact of different variables such as average day lighting, solar gain and cooling sensible load.

Keywords: Passive design · Arid · Design strategies · Timeline
UAE · IES

1 Introduction

In 2014, Ban Ki-moon stated that climate change was a hot issue for our times, affecting lives and producing high cost implications everywhere. The world is witnessing high levels of emission of CO_2 (Fig. 1), which is having an effect on climate change. These high emission levels are due to human activities which are mostly related to energy consumption. Hammad and Abu-Hijleh [7] stated that buildings consuming 40% of the total world energy and almost 70% of sulfur oxides and 50% of carbon dioxide emissions come from that sector. In the UAE, the second highest consuming sector for energy is the residential sector (Fig. 2). The country is heavily targeting sustainable development science which has proved that there is a strong relationship between energy performance and thermal comfort. This means that there

S. Fırat et al. (eds.), *Proceedings of 3rd International Sustainable Buildings Symposium (ISBS 2017)*, Lecture Notes in Civil Engineering 7,
https://doi.org/10.1007/978-3-319-64349-6_11

are stricter demands on temperatures that relate to the consumption of energy. It is very important to know the consequences of those temperatures and related passive strategies are available as alternatives to mechanical temperature control.

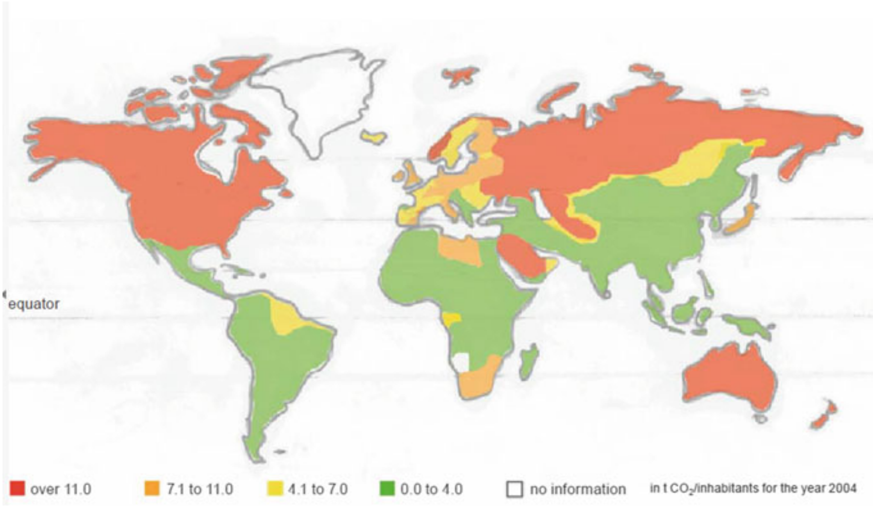


Fig. 1. CO_2 emissions distribution levels per capita. *Source* World Population for the Year 2004

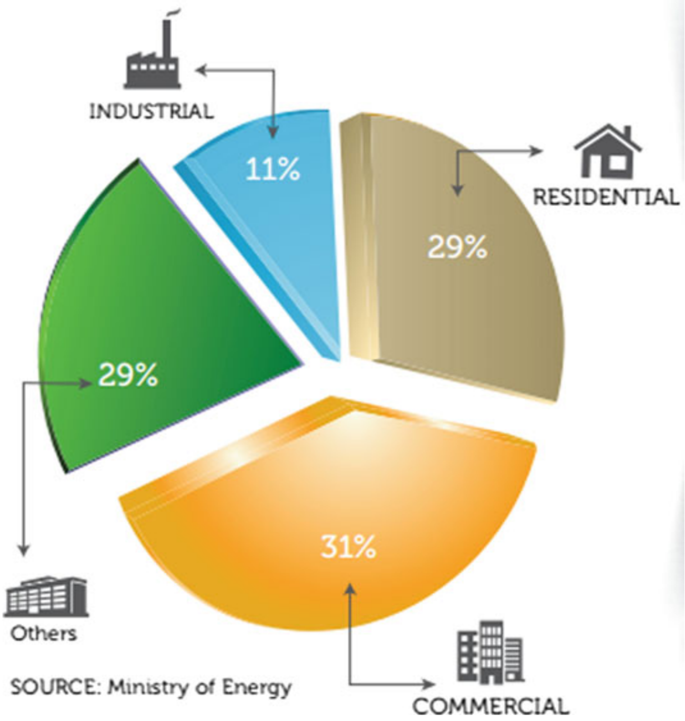


Fig. 2. UAE electricity consumption 2013. *Source* Ministry of Energy, 2013

1.1 Climatic Data

Fujairah is located on the following coordinates: latitude 25.10 North and longitude 56.33 East. It has an area of approximately 1166 km^2 (Fig. 3).

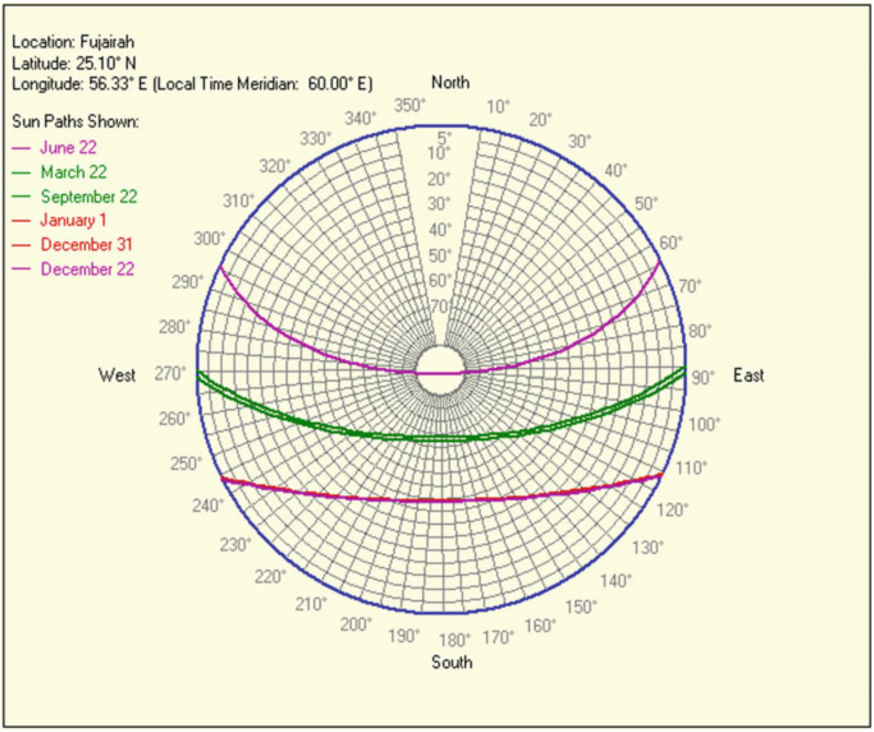


Fig. 3. Location of Fujairah. *Source* IES-VE software 2016 Daily/monthly

Temperature
Fujairah's weather is hot throughout the year. Summer is between April to October and temperatures gradually rise to an average of 43 °C between July and October (Fig. 4).

Relative Humidity
The weather in Fujairah remains humid throughout the year. Relative humidity ranges from 31% which is considered comfortable to 79% which is considered humid (Fig. 5).

March is considered very dry or very humid.

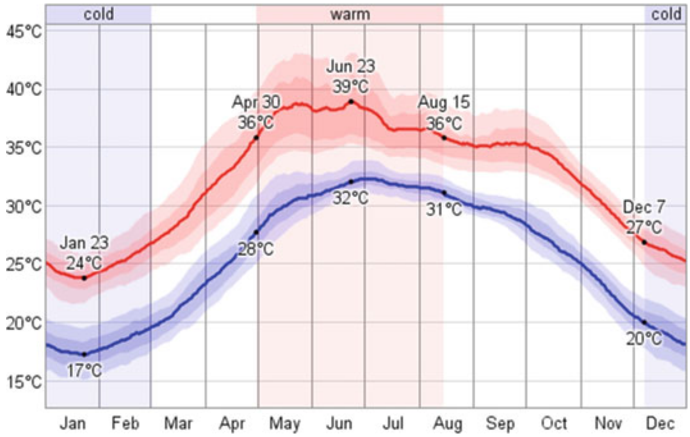


Fig. 4. Daily temperature in Fujairah. *Source* http://www.worldweatheronline.com/fujairah-weatheraverages/fujairah/ae.aspx

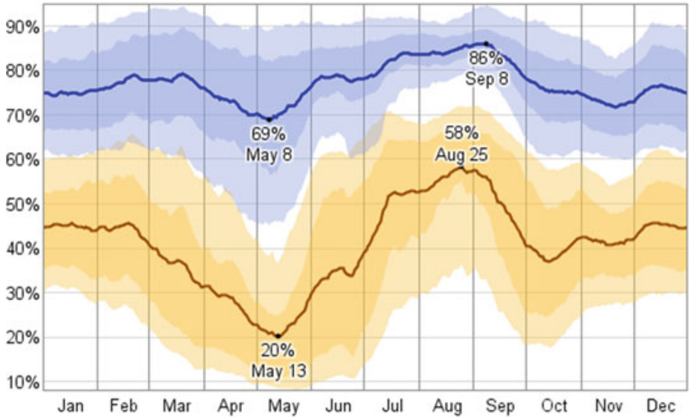


Fig. 5. Relative Humidity in Fujairah. *Source* http://www.worldweatheronline.com/fujairah-weatheraverages/Fujairah/ae.aspx

Dew Point

The most comfortable months of the year are December to February, with the rest of the year considered muggy (Fig. 6).

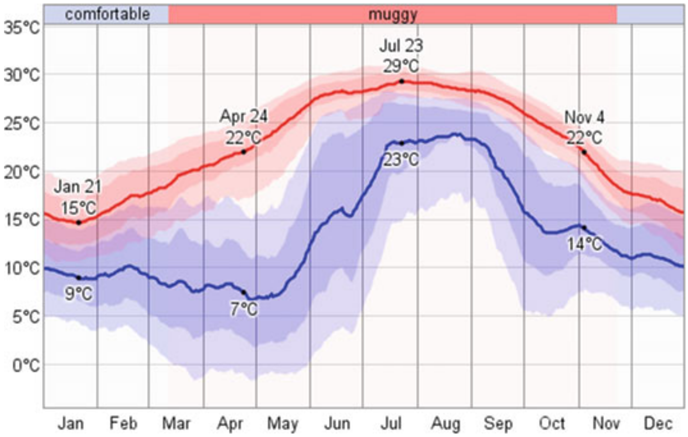


Fig. 6. Dew point in Fujairah. *Source* http://www.worldweatheronline.com/fujairah-weatheraverages/fujairah/ae.aspx

2 Literature Review

Olgyay [12] stated that there is a significant relationship between passive design strategies and the site and geographical location of a building. Designers need to be aware of orientation which will affect the amount of daylight entering the building and ventilation. It is important to begin the study with climatic data to check the shading, ventilation, thermal capacity and day lighting of the building.

Meyer [11] stated that in hot and dry climates, the main source of solar radiation is the roof, since it faces direct sun. Perusing in the literature, the following was discovered. Windows have a significant impact on daylight performance and visual comfort. Occupant comfort and performance will be associated with daylight performance, in addition to the enhancement of building energy performance.

Thermal comfort is subjective and related to glazing and shading devices characteristics. Tzempelikos et al. [15] state that it is possible to reduce the need for secondary air-conditioning by maintaining an operative temperature within the comfort zone in a good building envelope. In terms of window and glazing, the following findings are from the literature review: Wong and Istiadji [16] argue that the designer should place emphasis on window glass since this has the highest impact in terms of reducing annual consumption of energy. It is then necessary to start to add shading devices. Chi-Ming and Yao-Hong [4] show that window glass has a larger impact on energy consumption than the shading device effect does. Bessoudo et al. [3] examined the interior thermal atmosphere of a fully glazed office building with different types of shading. The use of roller and Venetian blinds showed an improvement in the inside thermal environment.

In 2010, Carmody et al. 2004 cited in Bessoudo et al., demonstrated that in a cold climate, a big window area which is facing south will have a substantial effect on enhancing interior thermal comfort for all type of windows except the double-glazed reflected type.

In terms of shading devices the following findings were taken from the literature review: Fiocchi et al. [6] state that to enhance the visual comfort and support occupant productivity, it is better to increase day light and decrease solar glare. Energy transmitted by windows varies depending on variables such as window type, side and overhang fins. Kensek et al. [8] state that few designers implement the shading devices in their projects although they offer many advantages such as minimising glare, reducing cooling load and monitoring radiation and light intensity. A study conducted by Tzempelikos and Athienitis [14], found that shading devices have great implications for the energy consumption of a building; they can make a saving of 50% of total energy consumed by cooling and can see solar and heat gain of at least 12%. In terms of shading device orientation, the following findings came from the literature review: Kim et al. [9] found that external shading devices which are horizontal have an impact on reducing cooling energy. Even a short one sees 11% less reduction in cooling energy. Chi-Ming and Yao-Hong [4] examined different types of shading devices; side fins, overhangs and box shades. They found that all these devices decrease daylight spread to interior spaces at different levels and that the maximum energy reduction effect was occurred with the box type. Palmero-Marrero and Oliveira [13] examined the position of louvers, and found that for the west and east facades vertical louvers are more suitable, while for south facades horizontal louvers have significant efficiency levels. The same results were found by Alzoubi and Al-Zoubi [1] when they studied south-facing facades with a vertical shading device.

Kim et al. [9] studied the sun path and effect of shading devices at different angles. He found that an angle of 0° has the greatest performance in terms of energy and this becomes the less at an angle of 60°. Lam and Miller [10] studied the effect of bio-shading for two years and found that overheating which occurs in the summer can be overreached from vertical living. The same impact would occur when placing a living plant within the void of double glazing to reduce energy consumption. Due to an absence of methodologies and measurements and methods to estimate the performance of the bio-shading, the study was not binding.

Vegetation can be an important influence in shading a building facade, particularly in a hot climate and this helps to improve the thermal effect and the air quality.

The American Institute of Architecture (AIA) [2] defines the best shading devices as those that reduce direct solar radiation and allow only diffused radiation to enter. A reduction in the amount of light entering a building will have the effect of reducing energy consumption. A lot of studies have looked into the effect of different design solutions for the building façade to reach an optimum design strategy.

These have included exterior and interior shading devices and different kinds of louver shading devices. The AIA also showed that in a low-rise building the natural environment can be used. Deciduous trees give great shade for the façade in all seasons and will transmit 20% solar radiation in summer. Koo et al. (2010) studied automated blind shading to gain the most advantage from daylight, reduce energy consumption from lighting and avoid glare. Chi-Ming and Yao-Hong [4] examined different kinds of shading devices—overhangs, side fins and box shades—finding that all of them reduced daylight penetration to interior spaces and that box shading has the optimum energy reduction effect.

In 2009, Palmero-Marrero conducted an investigation into the position of louvers and concludes that vertical louvers are much better for east and west façades while horizontal ones produce optimum efficiency on south façades. In addition, Ebrahimpour and Maerefat [5] examined the use of exterior devices such as overhangs and side fins for single clear glazing. The conclusion was that it is more useful for any direction of window than advanced glazing like double clear pane or low-E pane glazing. Yu et al. [17] studied residential buildings in China, finding the best performances to be better wall insulation and window shading. This can save between 11.55 and 11.31% of energy consumption by air conditioners. Before the 1970s houses in the UAE were built from palm fronds called Al Areesh and usually used in the summer. In the mountains areas houses were constructed with irregular stone and internal walls were plastered with mud. The roofs were covered with palm fronds and were flat (Fig. 7).

Fig. 7. Areesh House. *Source* https://dreaminginarabic.wordpress.com/interestingsnippets/traditional-houses/

3 Research Objectives

The aim of this study is to understand the evolution of sustainability in a UAE residential house across different time frames. The document will look in to the past to find characteristics of old houses that maintained comfort and sustainability. In the present a case study will be selected with different passive design strategies applied. Finally a recommendation of what the future will look like in terms of sustainable residential houses will be provided. The main objectives are as follows:

- Study of an existing residential house constructed by the Ministry of Public Works to understand current conditions and performance of the house.
- Study the impact of changing window sizes on the average daylight factor.

- Study the influence of changing window glazing systems on solar heat gain, total electricity used and sensible cooling load.
- Study the impact of different types of exterior shading devices on solar heat gain, total electricity used and sensible cooling load.
- Study the impact of combined strategies as a final step to their effect on different variables such as average day lighting, solar gain and sensible cooling load.

4 Methodology

This study offers a simulation using EIS-VE software to test selected design strategies to reach an optimum scenario. It then combines each optimal scenario with each design strategy to see the results to compared with findings from the literature review.

4.1 Conceptual Framework

The conceptual framework used in this study is as follow (Fig. 8).

4.2 Case Study Description

Building description:

The residential house selected is in Al Bithna, Fujairah, with a 45° N orientation (Figure shows layout of house). The residential house selected is design number 763C with the following characteristics: One storey house, 2 bedrooms with 2 bathrooms attached, 4 window types, 4 A/C, 4 water heaters, 1 Majlis with a washroom and toilet and 1 kitchen, Total area: 143.35 m^2 (Figs. 9 and 10).

Building construction material:

Windows:

- W1 170 × 145, W2 100 × 110 and W3 60 × 80
- Glass used is double 24 mm thick consisting of: (6 mm Ref. Glass H.S + 12 mm A.S + 6 mm clear low E tempered glass
- Glass Specification: U-value (W/m^2 k) 2.8

Door sizes:

- D1 180 × 220 cm, D2–D3–D5 120 × 220 cm and D4 100 × 220

Window sizes:

Wall to window ratio = 9.153158, Total area of the walls = 173.91 m^2, Total area of the windows = 19 m^2

Bill for electricity and water consumption from January 2015 to January 2016.

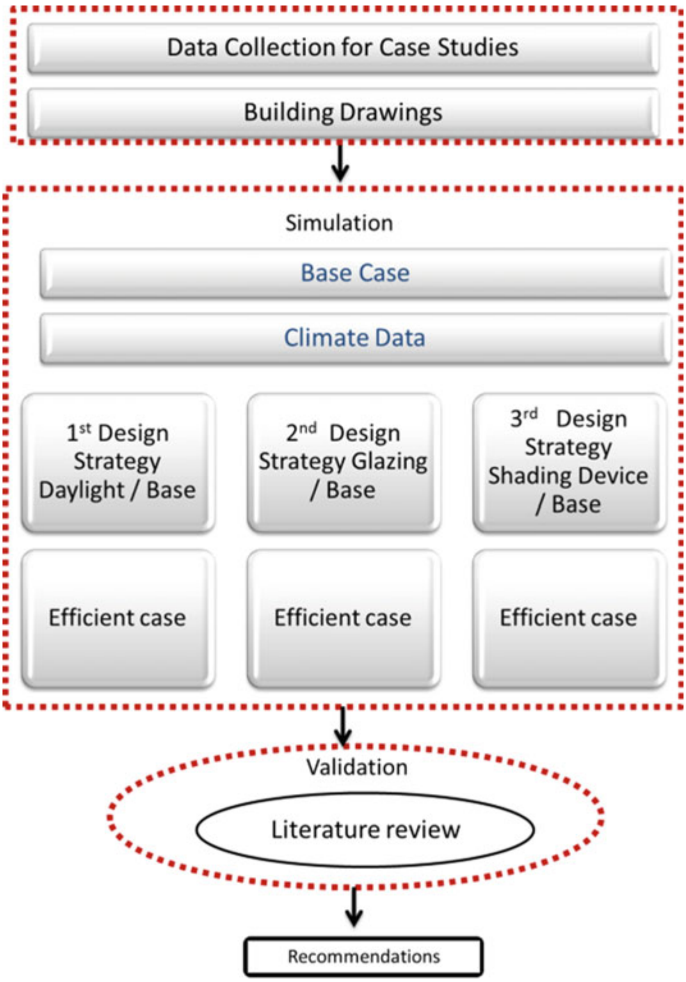


Fig. 8. Research process

Month	Electricity consumption	Water consumption
2015-01	580	11440
2015-02	595	9460
2015-03	352	6600
2015-04	905	16940
2015-05	975	12760
2015-06	1602	12760
2015-07	2190	12980
2015-08	2244	12540
2015-09	1735	12540

(continued)

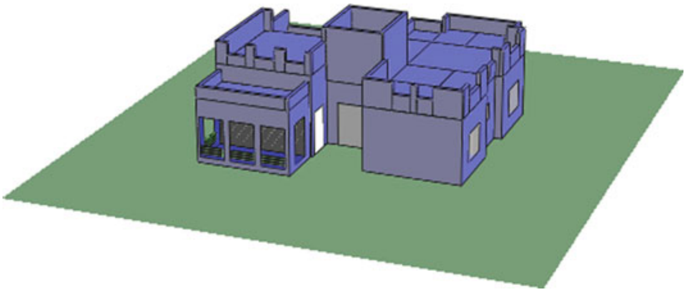


Fig. 9. Front elevation of the model

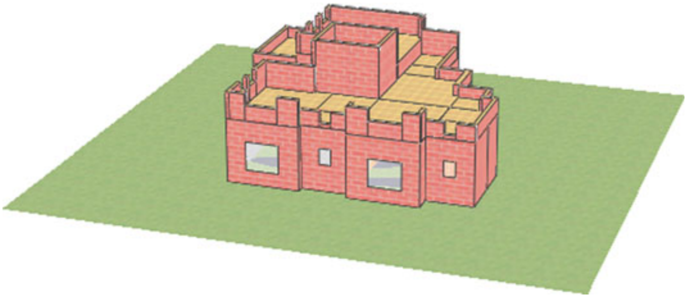


Fig. 10. Right elevation of the model

(*continued*)

Month	Electricity consumption	Water consumption
2015-10	1625	13860
2015-11	1237	10120
2015-12	595	12100
2016-01	519	8800

4.3 Assigned Scenarios

In this paper the selected strategies are:

1. Window size: the simulation will include the base model and increase window size to 15 and 20% respectively.
2. Glazing: the simulation will conducted for the base then for double and finally triple glazing.
3. Shading device: the simulation will include the base model without shading device, then with horizontal, vertical and finally combined shading device. Finally a combination of all of the above strategies will be adopted to find the optimum design.

5 Results

See Fig. 11.

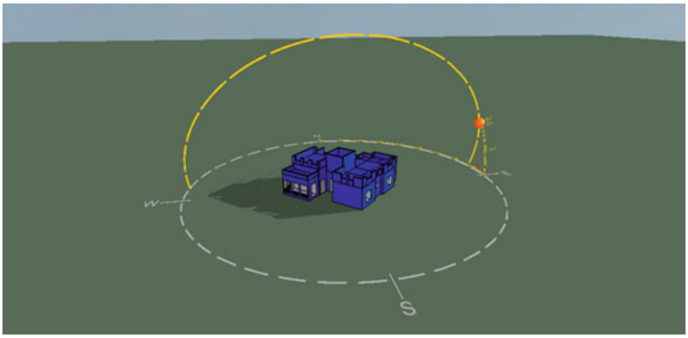


Fig. 11. Base Sun cast simulation

5.1 First Design Strategy: Increasing Window Area

This strategy involves an increase (15–20%) of window area for the Majlis, Bedroom 1 and Bedroom 2 and we will see the impact of the daylight factor. Note that the Majlis is on the northern side of the house and the bedrooms are located on the south side (Figs. 12, 13 and 14).

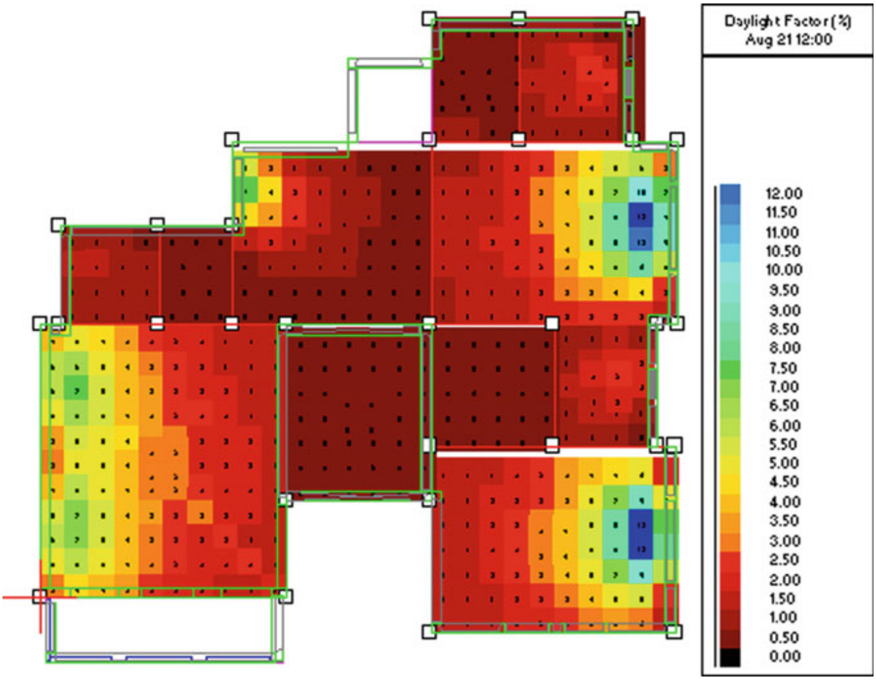


Fig. 12. Average daylight factor for the base model in August

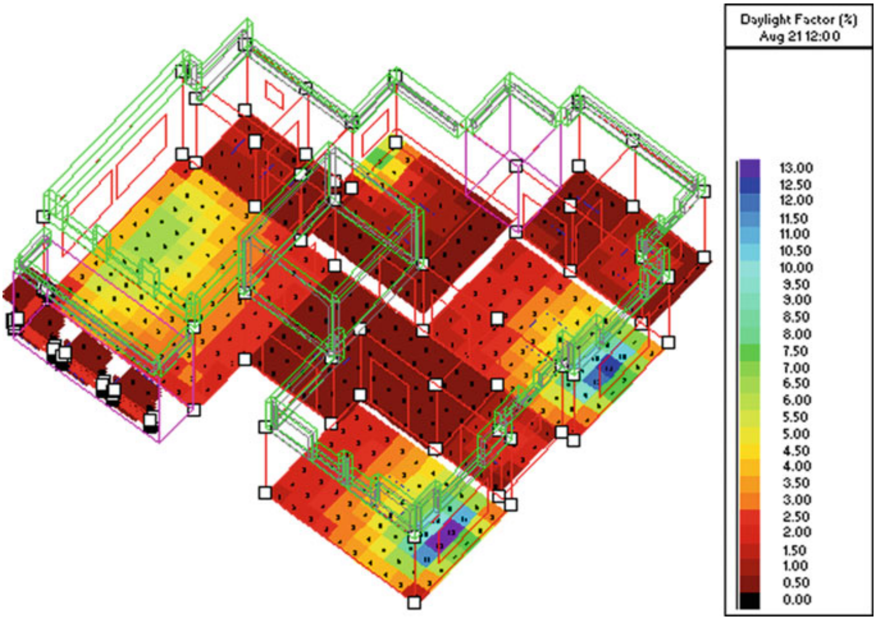


Fig. 13. Average daylight factor after increasing the window size up to 15%

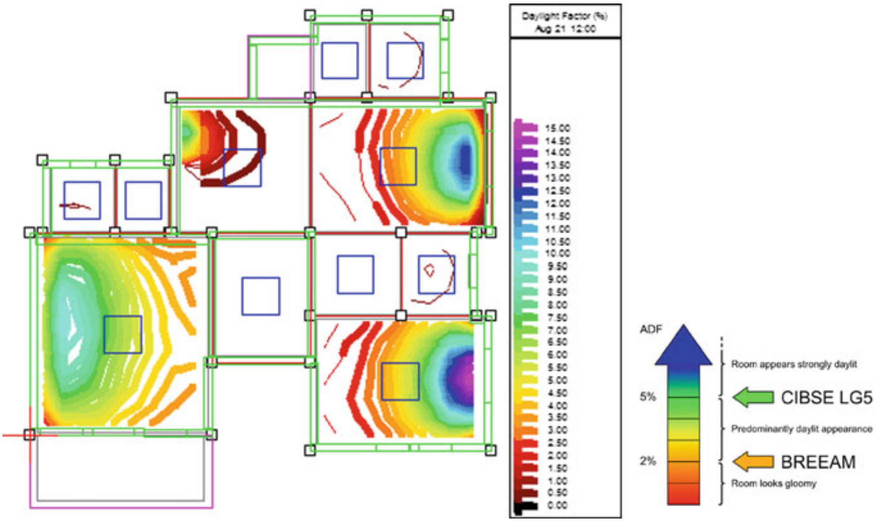
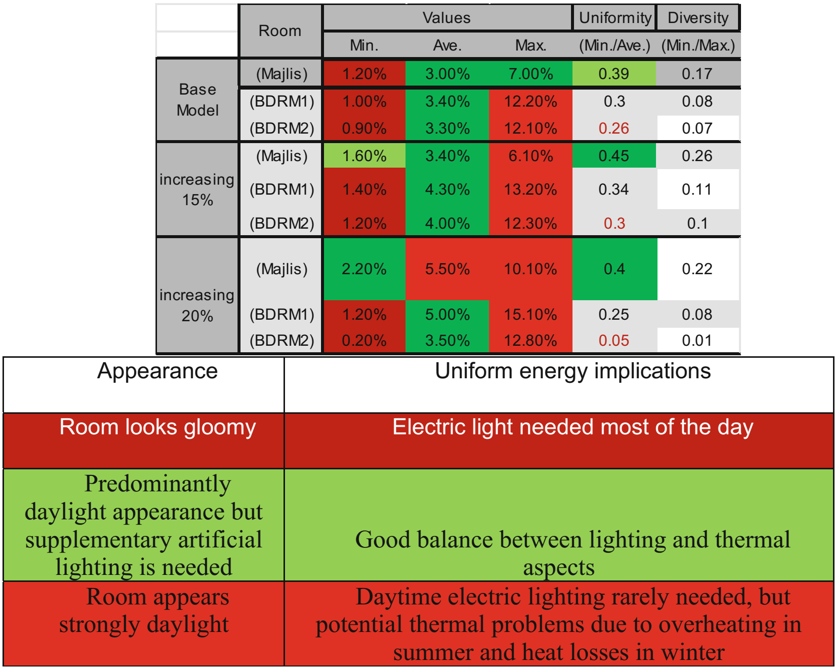


Fig. 14. Average daylight factor after increasing the window size to 20%

According to an assessment method for sustainable buildings (BREEAM): 2.08 is the ratio between DFmin/DFmean (uniformity) and should at least be 0.4 or the minimum point daylight factor should be at least 0.8%. (ADF in kitchen 2% and all living rooms should achieve a minimum ADF of at least 1.5%). According to the pearl design system used in Abu Dhabi, a residential unit should have a 2% minimum daylight factor or 200 lx daylight level for 20% of the living space floor area. Increased window size increases the average daylight factor and, in both cases, complied with BREEAM and Pearl specifications (Table 1).

Table 1. Results from simulation of daylight



	Room	Values			Uniformity	Diversity
		Min.	Ave.	Max.	(Min./Ave.)	(Min./Max.)
Base Model	(Majlis)	1.20%	3.00%	7.00%	0.39	0.17
	(BDRM1)	1.00%	3.40%	12.20%	0.3	0.08
	(BDRM2)	0.90%	3.30%	12.10%	0.26	0.07
increasing 15%	(Majlis)	1.60%	3.40%	6.10%	0.45	0.26
	(BDRM1)	1.40%	4.30%	13.20%	0.34	0.11
	(BDRM2)	1.20%	4.00%	12.30%	0.3	0.1
increasing 20%	(Majlis)	2.20%	5.50%	10.10%	0.4	0.22
	(BDRM1)	1.20%	5.00%	15.10%	0.25	0.08
	(BDRM2)	0.20%	3.50%	12.80%	0.05	0.01

Appearance	Uniform energy implications
Room looks gloomy	Electric light needed most of the day
Predominantly daylight appearance but supplementary artificial lighting is needed	Good balance between lighting and thermal aspects
Room appears strongly daylight	Daytime electric lighting rarely needed, but potential thermal problems due to overheating in summer and heat losses in winter

5.2 Second Design Strategy: Different Window Glazing

The base model used single glazing; these scenarios double and triple clear glazing with the following U-value (Figs. 15, 16, 17 and 18).

As shown above using different glazing offers a reduction in cooling load by 8.63 and 13.22% for double and triple glazing respectively and in terms of saving in total electricity, 5.065 and 7.72% savings are made for double and triple glazing respectively (Table 2).

5.3 Third Design Strategy: Different Shading Devices

The existing model has no shading device, so the scenarios will be horizontal, vertical and a combined device (Figs. 19, 20, 21 and 22).

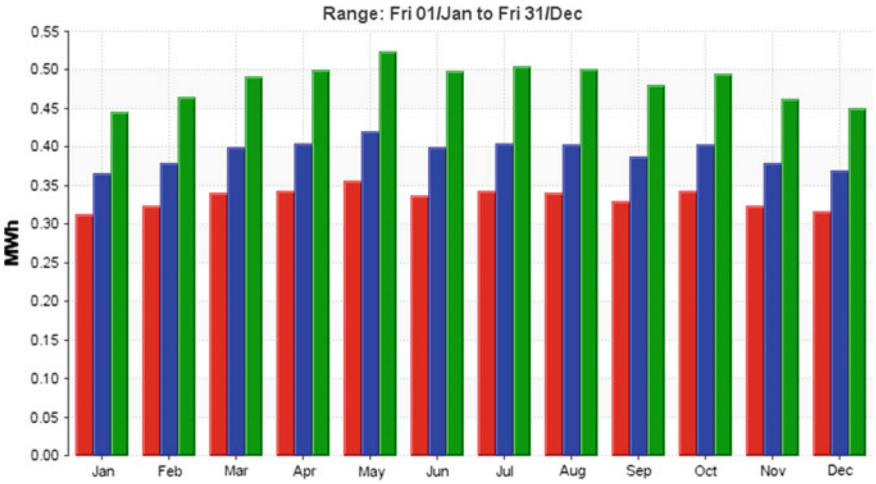


Fig. 15. Solar gain for three rooms with different glazing

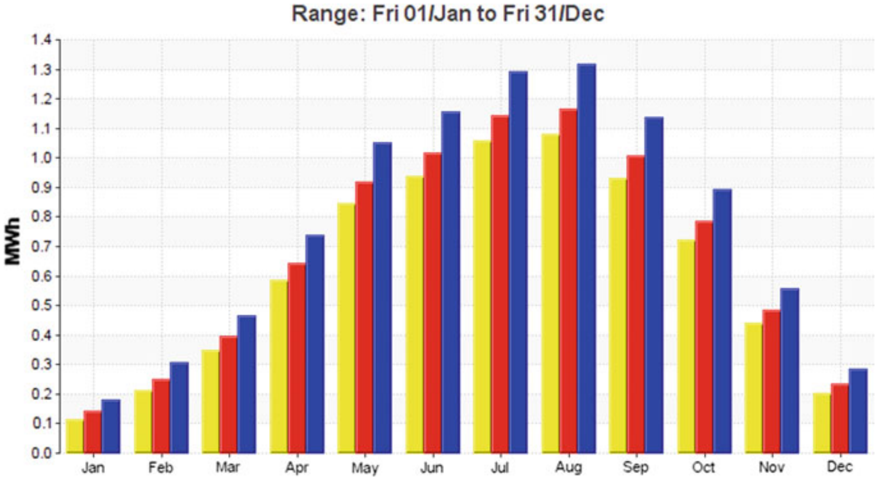


Fig. 16. Cooling plant sensible load for three rooms with different glazing

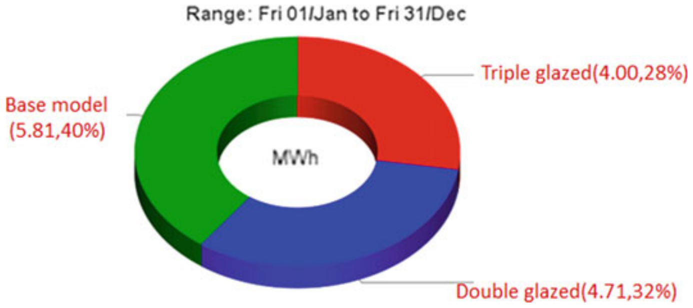
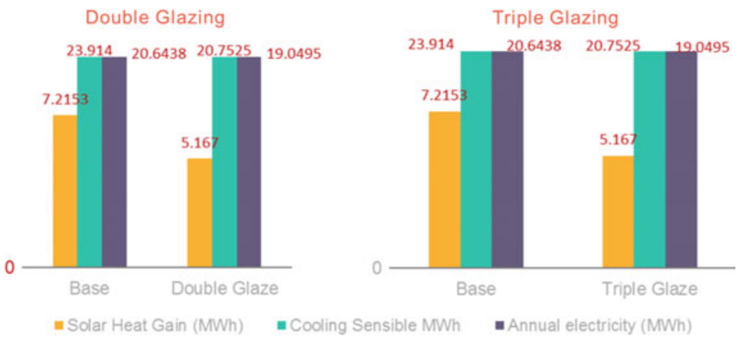


Fig. 17. Solar gain comparison for different glazing



Savings / Reduction With	Solar Heat Gain	Cooling Load	Total electricity
double glazing	16.7	8.6	5.1
triple glazing	28.3	13.2	7.7

Fig. 18. Savings and reduction for different glazing types

Table 2. The U-value of different glazing

Scenari	Variables	U-value (Glass)	U-value (net)	LT
1	6mm, clear float (Reference scenario)	5.6928	5.5979	0.89
2	Double-glazing,	2.6505	2.8598	0.89
3	Triple-glazing, clear	1.8761	2.1629	0.89

No big difference between base model and adding the horizontal device. Using a vertical device gives a predominantly daylight appearance but supplementary artificial lighting is needed. It offers a good balance between the lighting and thermal aspect. When the combined device was used, it has the same effect as the base model in March but better effects in August (Table 3).

5.4 Optimal Scenario

In this scenario, the optimum for each situation was applied to the base model and the following results were found (Figs. 23, 24, 25 and 26).

From the above figures and tables, it can be seen that the combined passive design strategies have a great impact on cooling loads, on solar heat gain and offer savings of 19% on total electricity costs (Table 4).

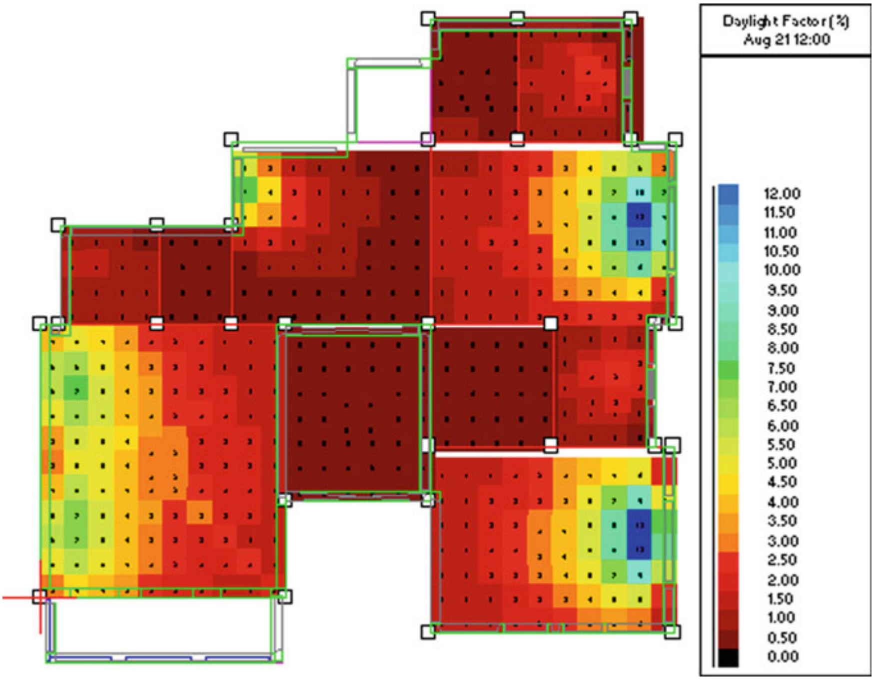


Fig. 19. Average daylight factor for the base model

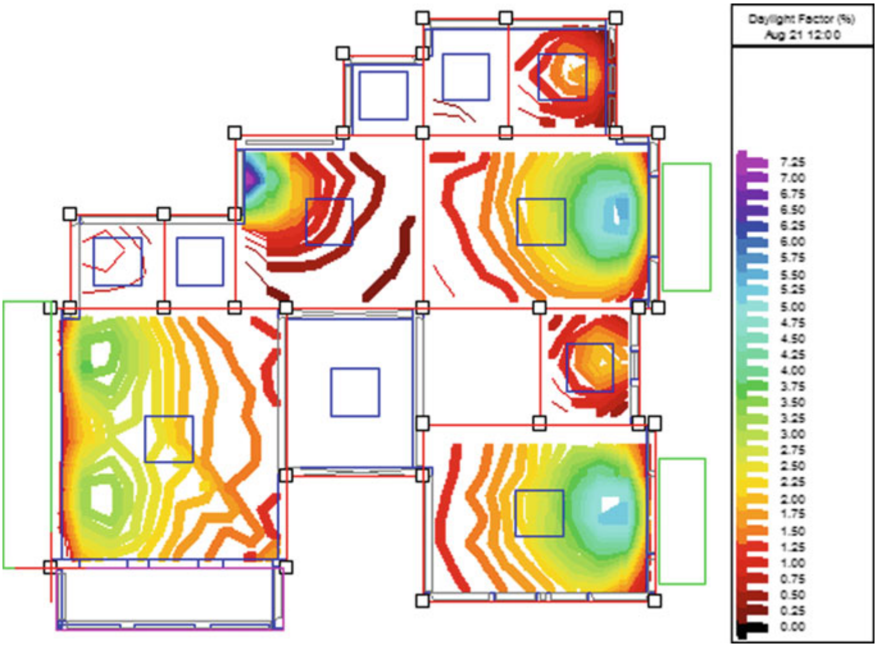


Fig. 20. Average daylight factor with a horizontal device

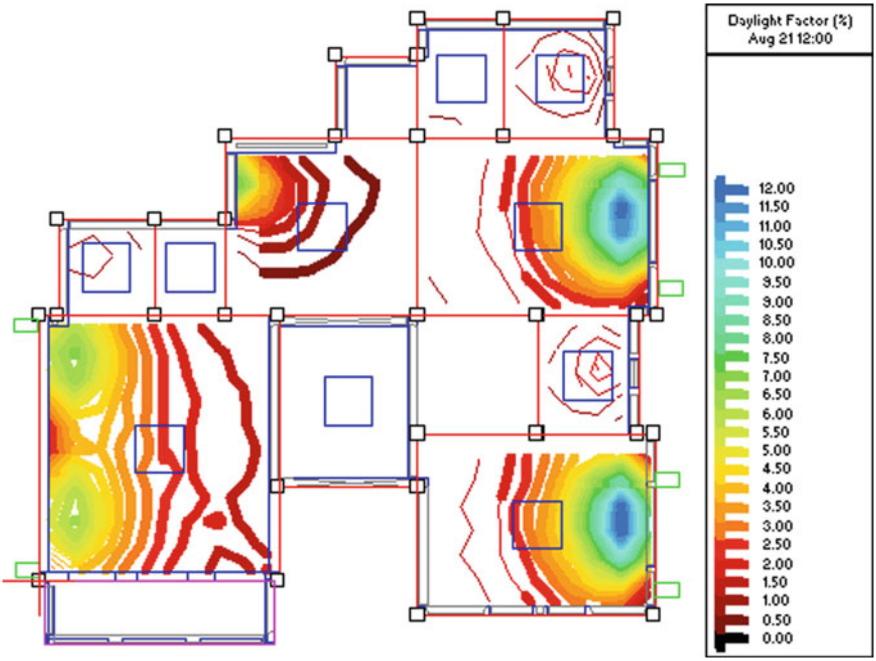


Fig. 21. Average daylight factor with a vertical device

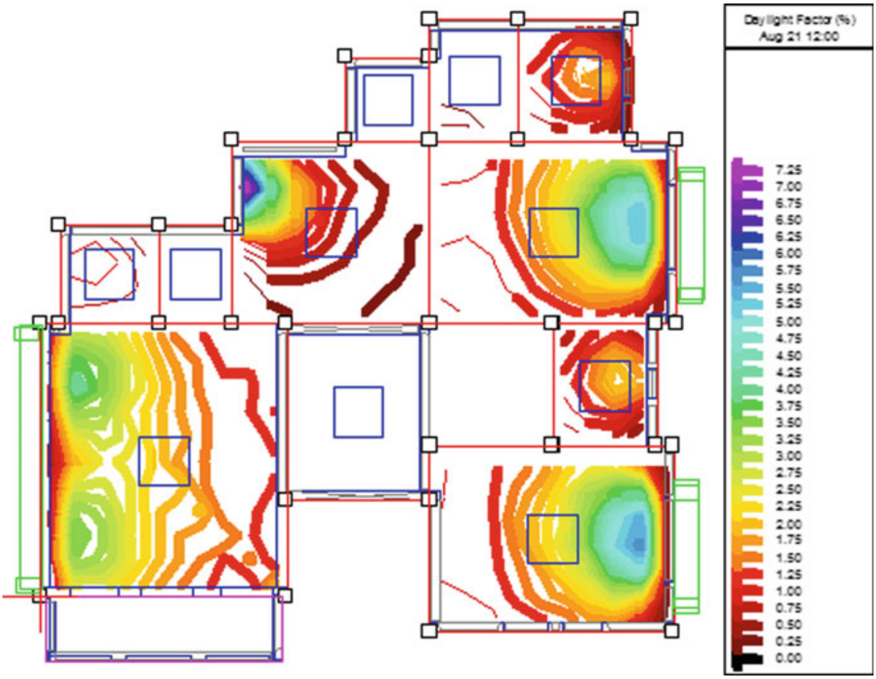
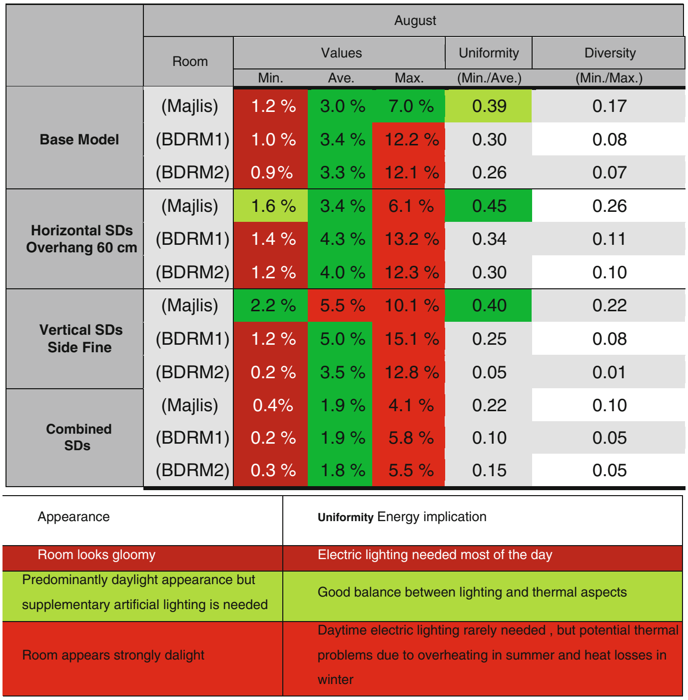


Fig. 22. Average daylight factor with a combined device

Table 3. Daylight factor for different shading devices



	August					
	Room	Values			Uniformity	Diversity
		Min.	Ave.	Max.	(Min./Ave.)	(Min./Max.)
Base Model	(Majlis)	1.2 %	3.0 %	7.0 %	0.39	0.17
	(BDRM1)	1.0 %	3.4 %	12.2 %	0.30	0.08
	(BDRM2)	0.9%	3.3 %	12.1 %	0.26	0.07
Horizontal SDs Overhang 60 cm	(Majlis)	1.6 %	3.4 %	6.1 %	0.45	0.26
	(BDRM1)	1.4 %	4.3 %	13.2 %	0.34	0.11
	(BDRM2)	1.2 %	4.0 %	12.3 %	0.30	0.10
Vertical SDs Side Fine	(Majlis)	2.2 %	5.5 %	10.1 %	0.40	0.22
	(BDRM1)	1.2 %	5.0 %	15.1 %	0.25	0.08
	(BDRM2)	0.2 %	3.5 %	12.8 %	0.05	0.01
Combined SDs	(Majlis)	0.4%	1.9 %	4.1 %	0.22	0.10
	(BDRM1)	0.2 %	1.9 %	5.8 %	0.10	0.05
	(BDRM2)	0.3 %	1.8 %	5.5 %	0.15	0.05

Appearance	**Uniformity** Energy implication
Room looks gloomy	Electric lighting needed most of the day
Predominantly daylight appearance but supplementary artificial lighting is needed	Good balance between lighting and thermal aspects
Room appears strongly dalight	Daytime electric lighting rarely needed , but potential thermal problems due to overheating in summer and heat losses in winter

6 Discussions

Passive design is proven to be related to orientation, day-light and geographical location. The results can contribute to the selection of economically efficient glass as there is a relationship between windows type, glass properties and shading device performance. The total electricity savings are largest for triple-glazing, followed by double and single.

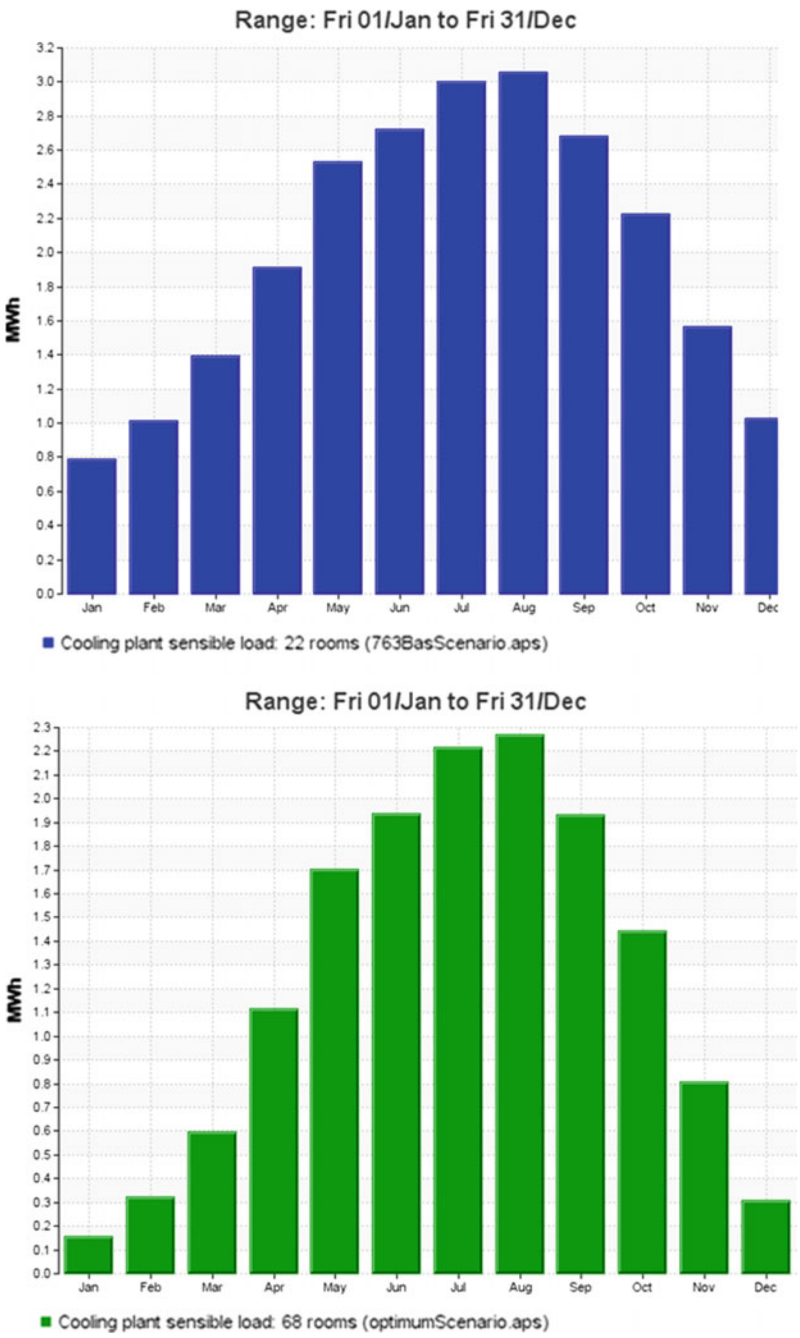
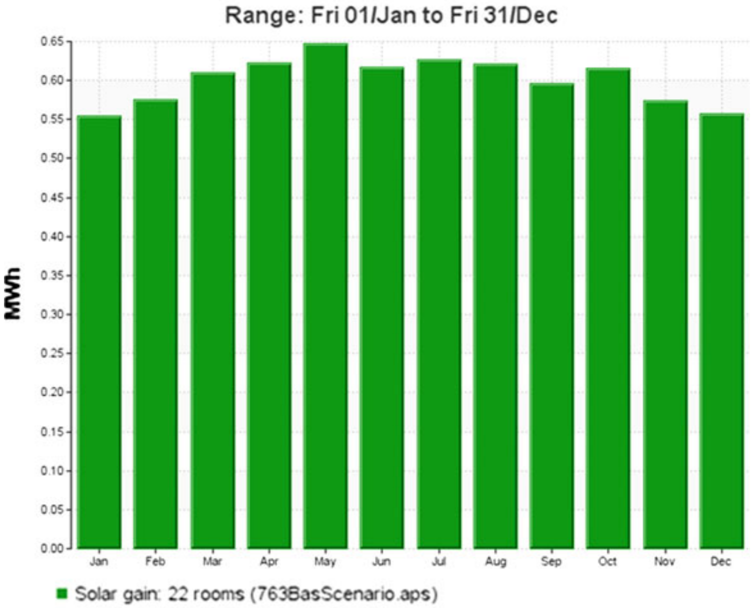


Fig. 23. Cooling plant load (base and optimum model)

Base scenario



Optimum scenario

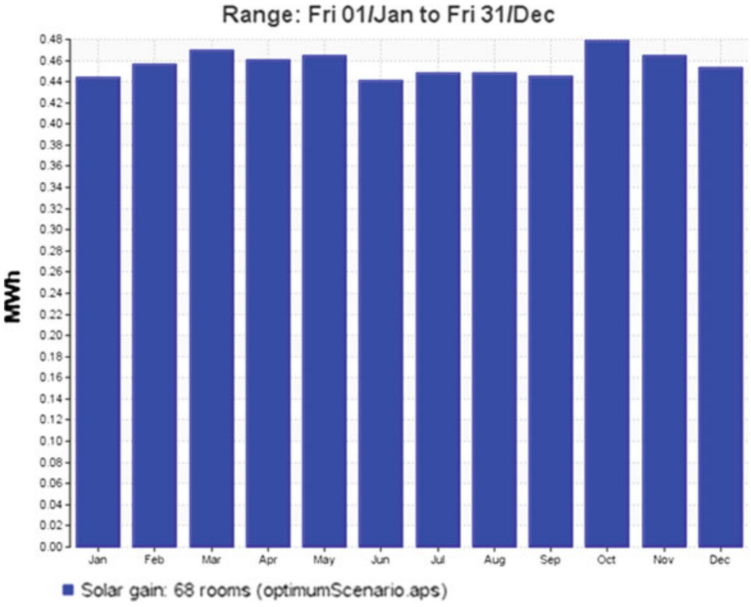


Fig. 24. Solar gain (base and optimum model)

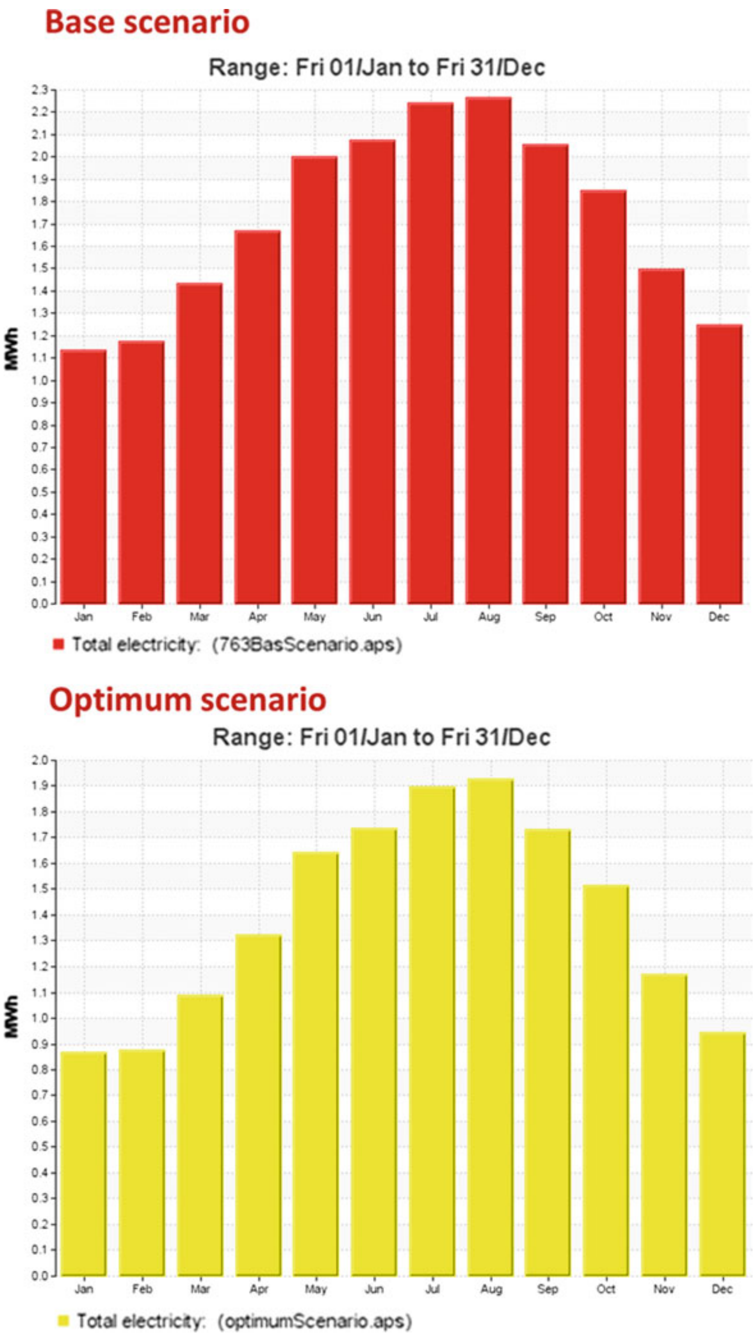


Fig. 25. Total electricity (base and optimum model)

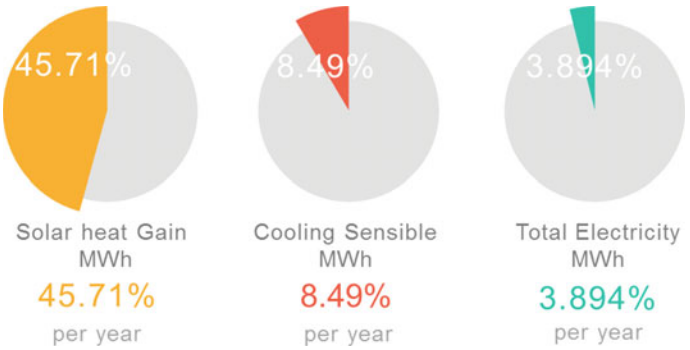


Fig. 26. Savings and reduction in solar heat gain, cooling load and total electricity (base model, optimum model)

Table 4. Average daylight factor for base and optimum scenario

Var. Name	Location	Min	Ave (%)	Max (%)	Uniformity Min/Ave	Diversity Min/Max
Base model	Majlis	Load (kW) (%)	1.7	3.5	0.22	0.11
	BDRM1	0.4	2.4	7.6	0.06	0.03
	BDRM2	0.2	2.2	7.4	0.12	0.06
Optimum scenario	Majlis	0.3	2.0	3.3	0.15	0.09
	BDRM1	0.3	3.5	10.1	0.09	0.03
	BDRM2	0.6	3.5	11.2	0.18	0.06

7 Conclusions

This study has proven that the different passive strategies which were tested in this project have huge implications for total electricity costs, solar gain and cooling loads. This is a path to achieving reductions in CO_2, leading to sustainability. As a future recommendation, different strategies could be implemented to achieve more reductions in total electricity costs. The Ministry of Public Works is targeting low emission houses to maintain sustainability.

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