Comparative Study of Energy Consumption Optimization for Different Orientations of School`s Buildings in Jordan

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Abstract

This paper introduces a comparative study between energy consumption optimization of school`s sector for the basic orientations (N-S) and (E-W) and the skewed ones ((NE-SW) and (NW-SE)). In a previous research *(Al-Arja O. Awadallah T., 2015)*, the basic orientations were experimented and the Energy Use Index for energy consumption was established. The largest part of energy is consumed in classrooms; so only classrooms are addressed. To conduct numerical comparisons between the different cases and orientations; Building performance simulation (using DesignBuilder® software) *[DesignBuilder® Thermal Simulation Software, USA, accessed February 12, 2011. http://www.designbuildersoftware.com]* was used. Initially, 108 model runs were simulated for the skewed orientations, to experiment the effect of the following passive elements: (1) window to wall area ratio (WWR), (2) window panes, (3) shading devices, and (4) building envelope insulation; on energy savings when compared to the conventional base case design. Secondly, a comparative analysis was conducted to conclude the optimum design solutions for minimum energy demand respecting a thermally comfortable environment. Recommendations were given to establish a regulatory base for the minimum design criteria requirement for school building`s main façades with different skewed orientations, in order to reduce energy demand, establish Energy Use Index, and provide indoor thermal comfort, for hot arid climates.

Keywords: Energy consumption, Energy simulation, Building performance, Energy efficiency, Energy optimization, Green buildings requirements, Orientation.

1. Introduction

1.1 Background

New building envelope designs are developed to meet the client's requirements without much concern to the local climate and with no objective to conserve energy, despite the fact that orientation should be decided together with massing, early in the design process. An answer should be provided for an important issues; which building orientation makes the highest reduction in energy demand for school`s buildings in Jordan?. Preserving the valuable resources in our planet would be as a result when comfort and energy saving are important in the climate responsive design *(La Roche, P., Liggett, R., 2001).* Thermal behaviour of a building is altered when it is laid out in different orientations. Building form, window surface area, and the building orientation determine solar heat gain into the building. In this research; building orientation was used to determine relative efficiency of different base and skewed orientations in hot arid climate. One study on the effect of orientation on building thermal performance *(Al-Tamimi N. A., Fadzil S. F., Harun W. M., 2011)* shows that building orientation is a significant design consideration, mainly with regard to solar radiation and wind, and the results of the study which was conducted in Malaysia showed that East windows have more obvious effect on increasing indoor air temperature than West windows for the predominantly hot humid regions. However, in *(Brandt Andersson, Wayne Place and Ronald Kammerud, 1985)*, the study was carried out for 25 climates in the United States; it was found that in all climates, when the more extensively glazed exposure is oriented to the South; total loads are significantly lower than those in the same building oriented to the East or West. North orientation also produces lower total loads than East or West orientations in the Southern two-thirds of the U.S., and roughly equivalent loads in the Northern third. Other researches as *(S. M. A. Bekkouche, T. Benouaz, M. K. Cherier, M. Hamdani, R. M Yaiche, R. Khanniche, 2013)* studied the orientation effect of a non-air-conditioned building on its thermal performance, where the orientation effect has been analysed in terms of direct solar gain and temperature index for hot-dry climates. Restricted site and orientation optimization in Design were also studied in *(C. Ochoa and I. Capeluto ,2008),* and in *(C. Hopfe and J. Hensen, 2005).*

It is well known that thermal interaction between the internal environment of a building and the ambient conditions take place through the building envelop. Principles of good thermal design for hot arid climates require promoting solar heat gain, low window to wall ratio, and tight building envelop. Whereas the nature of urban context and surroundings, plot layout, entrance and accessibility points sometimes ignores basic bioclimatic design principles and limits energy optimization and building performance from orientation.

In Jordan, due to limited resources; school buildings do not include any kind of thermal insulation. The increase in new construction of school buildings, due to population growth resulted from forced migrations; calls for better measures considering building optimization within the framework of the original governmental schools architectural design, with energy efficient adaptations, and optimization of classrooms orientation.

In a previous research *(Al-Arja O. Awadallah T., 2015)*, the following main findings end results were found for the energy consumption amounts per meter square of area per year, for the basic two Orientations (N-S) and (E-W), for both heating and cooling demand:

1) Highest total consumed energy is represented by the case which uses high Window to Wall Ratio (WWR), single Low-E glazing, and Green Building Guide (GBG) minimum U-value requirement of 0.45 $W/m^2.K$, and no shading available (worst case scenario):
    a. For N-S oriented building is **40.36 kWh/m^2/year**.
    b. For E-W oriented building is **53.5 kWh/m^2/year**.
2) Lowest total consumed energy is represented by the case which uses low WWR, double glazing and GBG U-value requirement of 0.45 $W/m^2.K$, with adjustable shading (optimum case scenario):
    a. For N-S oriented building is **24.36 kWh/m^2/year**.
    b. For E-W oriented building is **31.05 kWh/m^2/year**.
3) Average total consumed energy is **32.0 kWh/m^2/year** for N-S case, **42.0 kWh/m^2/year** for E-W case.

1.2 Objectives

1) To introduce a comparative study between energy consumption optimization for school`s buildings of basic orientations (N-S) and (E-W) and skewed ones (NE-SW) and (NW-SE).
2) To maximise energy savings for heating and cooling in school buildings.
3) To help in establishing benchmarks for energy consumption averages for different building sectors, attached to orientation optimisation.
4) To accumulate a local data base that includes differentiations between building strategies that minimises energy consumption through the building envelope parameters, and compares Energy Use Index for the educational sector in Amman Jordan, which represents Hot Arid climate zones

2. Methodology

2.1 Overview

The typical public school –Al Baseleyah Elementary School- in Amman which was chosen as a prototype in *(Al-Arja O., Awadallah T., 2015)* was modelled; to establish the case study experiment and reach the objectives of this research. Although the public school building has all basic school requirements including libraries, offices, laboratories, classrooms and other facilities; only classrooms were addressed in this research and in (Al-Arja O., Awadallah T., 2015) research, since they consume the largest part of energy in schools. The school information and the generated model from DesignBuilder® simulator *(DesignBuilder® Thermal Simulation Software, USA, accessed February 12, 2011. http://www.designbuildersoftware.com)* are presented in Table 1.

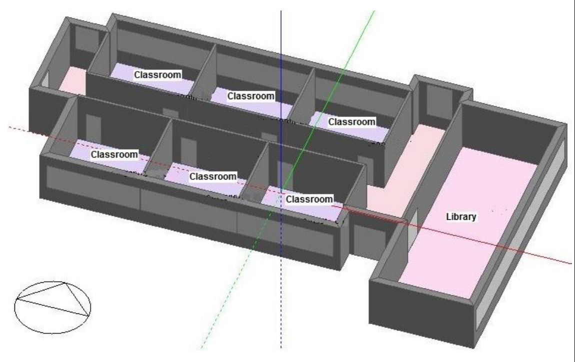
The representative sample of all schools in Jordan is used as an actual case study to represent the subject of this research. The actual case is called “base-case”. The base-case is represented in terms of: (1) general building concept: functional lay-out, orientation and so on; (2) unit size, roof spans, ceiling heights, and so on; (3) sizes, orientation and shading of openings; and (4) construction materials.

The base case would be adjusted to a specific skewed orientation; where classrooms are on both opposite sides of that orientation. The base case should cover the skewed orientations; North East - South West (NE-SW) and North West - South East (NW-SE) orientation options.

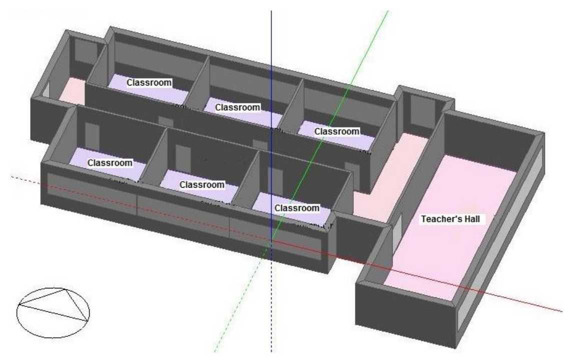
To establish the EUI, parametric case buildings were thermally modelled, in order to establish an annual heating and cooling energy consumption, in kWh/m^2. Whereas, electricity used for lighting and other uses are exempted from this study. Consequently, flexible results would be generated to be used in future studies without being affected by energy prices or type of fuel.

From the base-case, the influence of changing one parameter at a time, such as window size, is studied. This will give information on positive/ negative or strong/ weak influences, optimum dimensions, and so on. The “base-case” has gone through parametric study procedures, using the same parameters used in the study of the two basic orientations. The results from these “parametric case buildings” will be used as EUI, and will be used in the recommendations and suggestions for new building designs.

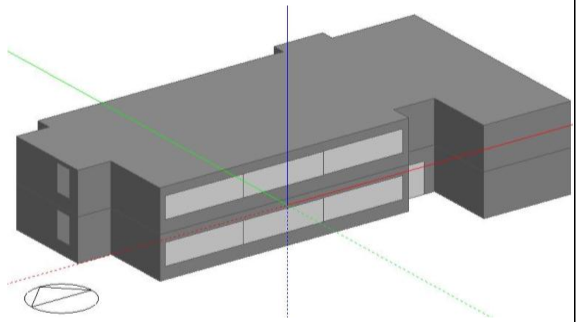
Table 1: School information and generated model from DesignBuilder® simulator.



Ground floor layout of the school Building



First floor layout of the school Building



Modelled image of school building main façade

Simulated School consists of three floors

School footprint	409 m^2
Total floor area	1224 m^2
Classrooms area	30 m^2 each

2.2 School Building Simulation Elements:

1) Volume heights, Floor, Internal slabs, and internal walls are constructed according to the *(Jordanian Construction Law 2005*), and they are constant throughout the research. Construction elements are explained in Table 2.

Table 2: Details of constant construction elements of the base-case.

Construction Element	Construction Details	Resulted U-value $W/m^2.K$
Non-insulated External Walls	20cm concrete solid block, 5cm air cavity, and 15cm concrete hollow block.	**1.323**
Non-insulated Roof	25cm reinforced slab, concrete screed and tiles	**1.163**
Windows (used mainly in public schools)	Clear single glazed	**6.121**

2) Activities, internal loads, infiltration and ventilation: Occupation of the school classrooms are considered constant and would be represented in the simulation program as explained in Table 3.

Table 3: Occupation details for the school classrooms.

Occupation period	5 weekdays from 7:00 to 15:00 hour
Occupancy rate	averaged to 20 student per classroom (0.6 persons/m^2)
Heating setpoint	18 C°,
Cooling setpoint	24 C°
Ventilation	Mixed use of natural and mechanical ventilation. - Natural ventilation is provided from simulating incoming fresh air from 20% of the window aperture. - Mechanical ventilation provides 5 l/s per person.

3) Climate data and Urban Layout: The climate of Jordan is predominately of the Mediterranean type, and classified to be of a hot arid climate, with South-West and South winds through the year. Climate data obtained from the Jordan Metrological Data; *(Jordan Climatological Data Handbook, 1998)* were formatted and applied in the simulation process, using the Excel Sheet Template for Climate data from University of Jordan Station, Amman, published in *(Al-Arja O., Awadallah T., 2015)* research. In addition, the school model runs would be simulated with the assumption of no surroundings.

2.3 Simulation Parameters:

Simulation parameters which would be studied and compared with the base-case are:

1) *Window to Wall area Ratio (WWR):* **25% WWR** and **50% WWR** will be studied; the results will be compared with the base-case and also with other parameters.

2) *Shading devices:* The base-case school has no shading devices on classroom windows, other than the 10cm shading that is given from the depth of the window. **Two** assumptions would be studied, horizontal shading of 50cm fixed overhangs with vertical shading of 50cm fixed side fins (not-adjustable) and Horizontal louvers of 10cm depth, all for both NE-SW and NW-SE oriented cases.

3) *Roof and Wall Insulation:* Un-insulated walls and roofs are typical in Jordan; disregarding codes requirements. **Two** alternative insulation related options were tested and simulated, adopting the Jordanian Energy Efficient Building (EEB) code (Jordan National Building Council, 2010), and adopting the voluntary U-value requirement from the Jordanian Green Building Guide (GBG) (Jordan National Building Council, 2013). Details of codes requirement are explained in Table 4.

Table 4: Details of codes requirement

Code	Minimum requirement of U-value W/m^2.K		Dimension thickness of added thermal insulation (cm)	
	Walls	Roofs	Walls	Roofs
EEB	0.57	0.55	5.0	4.8
GBG	0.45	0.45	6.7	6.4

4) *Window Panes:* Single pane clear glazing is used in windows for the base-case in the school building. **Two** alternative options of window pane properties would be studied and compared with the base-case and other parameters. These options are Single pane Low-E glazing and Double pane clear glazing. Properties of the window panes are illustrated in Table 5.

Table 5: Properties of the window panes

Window Panes	**U-Value (W/m^2.K)**	**Cost (JD/m^2)**
Single pane clear glazing	6.121	18
Single pane Low-E glazing	4.233	25
Double pane clear glazing	2.708	60

These parameters would be merged in all possible combinations; each case study of the two-case buildings will be represented in **54 model runs**. In total, **108 model runs** would be studied.

2.4 Basic Orientations Simulation

Both NorthEast-SouthWest and NorthWest-SouthEast oriented base cases were modelled based on the actual plans and elevations of the school layout. Base-case results for both (NE-SW) and (NW-SE) oriented building cases, showing annual heating and cooling requirements are given in Table 6. The results are also normalized per meter square area. This is due to the importance of establishing an Energy Use Index (EUI) for energy consumption for public schools in Jordan.

Table 6: Base case results, for NorthEast-SouthWest oriented building case and the NorthWest-SouthEast oriented building case, compared with the North-South oriented building case, and East-West oriented building case.

Name (base case)	**Heating kWh/m^2/year**	**Cooling kWh/m^2/year**	**Total kWh/m^2/year**
NE-SW oriented school building case	8.91	39.51	48.42
NW-SE oriented school building case	9.77	39.63	49.40
Compared with:			
N-S oriented school building case	11.27	33.05	44.33
E-W oriented school building case	7.51	42.05	49.56

Performing parametric simulations on the same building, for both NorthEast-SouthWest oriented case, and the NorthWest-SouthEast oriented one; will provide comparison chances, and energy performance indicators could be delivered. Therefore, a number of model runs were simulated to compare their results with the base-case.

Parametric results showing the worst and best case scenarios with their amount of energy consumption normalised to meter square area are provided in Table 7.

Table 7: Parametric results (worst and best case scenarios), for NE-SW and NW-SE oriented building cases, compared with N-S and E-W oriented building cases.

Energy consumption rank	**Name/ parameters**					**Energy Consumption $kWh/m^2/year$**
	Case Orientation	**WWR**	**Glazing**	**U-value $W/m^2.K$**	**Shading**	
Lowest- Heating	NE-SW	50 %	Double	GBG= 0.45	None	2.50
	NW-SE	50 %	Double	GBG= 0.45	None	2.96
	N-S	50 %	Double	GBG= 0.45	None	4.08
	E-W	50 %	Double	GBG= 0.45	None	1.80
Lowest- Cooling	NE-SW	25 %	Single	GBG= 0.45	Louvers	16.64
	NW-SE	25 %	Single	GBG= 0.45	Louvers	16.58
	N-S	25 %	Double	EEB= 0.57	Louvers	17.98
	E-W	25 %	Double	None= 1.3	50 cm	25.14
Lowest- Total	NE-SW	25 %	Double	GBG= 0.45	Louvers	22.77
	NW-SE	25 %	Double	GBG= 0.45	Louvers	23.03
	N-S	25 %	Double	GBG= 0.45	Louvers	24.56
	E-W	25 %	Double	GBG= 0.45	50 cm	31.05
Highest- Heating	NE-SW	25 %	Single	None= 1.3	Louvers	14.60
	NW-SE	25 %	Single	None= 1.3	Louvers	14.89
	N-S	25%	Single	None= 1.3	Louvers	14.74
	E-W	25%	Single	None= 1.3	50 cm	10.80
Highest- Cooling	NE-SW	50 %	Single LowE	GBG= 0.45	None	44.98
	NW-SE	50 %	Single LowE	GBG= 0.45	None	48.94
	N-S	50 %	Single LowE	GBG= 0.45	None	40.36
	E-W	50 %	Single LowE	GBG= 0.45	None	51.63
Highest- Total	NE-SW	50 %	Single LowE	GBG= 0.45	None	48.94
	NW-SE	50 %	Single LowE	GBG= 0.45	None	52.08
	N-S	50 %	Single LowE	GBG= 0.45	None	44.62
	E-W	50 %	Single LowE	GBG= 0.45	None	53.50

3. Results and discussions

The following paragraphs address results and analysis for generated models, stating annual energy demand for cooling and heating only.

3.1 Effect of Shading with Window to Wall Ratio (WWR):

Figure 1(a) and 1(b) show the energy consumption needed for cooling and heating in both NE-SW and NW-SE oriented building cases:

- Variables: 1) un-shaded, shaded and louvers, 2) 25% and 50% WWR.
- Constants: 1) single clear glazing, and 2) no insulation.

The following results were found regarding energy demand:

1) For the NE-SW case:
    a. **70%** of the energy consumption is dedicated to space cooling and **30%** goes to space heating.
    b. Shading increases heating demand between **12% and 23%** for 25% WWR, and **27%** for 50% WWR
    c. Using 50cm deep shading devices decreases cooling demand by **more than 47%** compared to un-shaded cases

d. Using Horizontal louvers for shading decreases cooling demand by **more than 31%** when using 50 cm deep shading

2) For the NW-SE case:

a. **65%** of the energy consumption is dedicated to space cooling and **35%** goes to space heating.

b. Shading increases heating demand **between (10- 25)%** for 25% WWR, and **30%** for 50% WWR

c. Using 50cm deep shading devices decreases cooling demand by **more than 50%** compared to un-shaded cases

d. Using Horizontal louvers for shading decreases cooling demand by **more than 31%** when using 50 cm deep shading

(a)

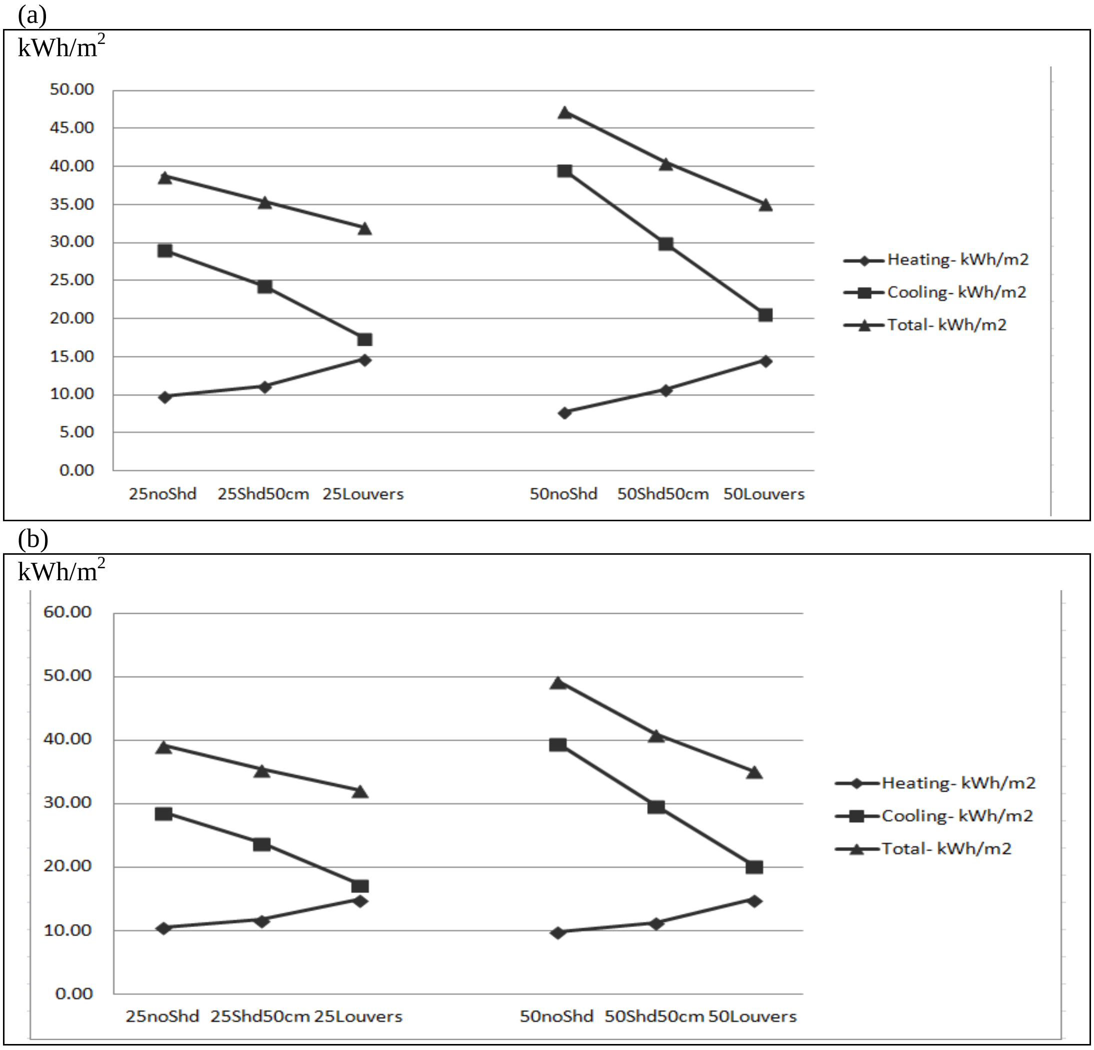


Figure 1: Heating, cooling and total energy consumption for (a) NE-SW case, (b) NW-SE case, single clear glass, with no insulation.*

*Note:**

**25noShd= 0.25 WWR, with no shading*	*50Shd50cm = 0.50WWR, with 50 cm overhang*
25Shd50cm= 0.25WWR, with 50 cm overhang	*50noShd= 0.50 WWR, with no shading*
25Louvers= 0.25 WWR, with louvers	*50Louvers= 0.50 WWR, with louvers*

It is concluded that for NE-SW and NW-SE orientations, the higher the WWR, the higher the energy demands for cooling, regardless of type of shading devices. On the other hand, higher WWRs require lower energy demand for heating. This shows that the cooling demand is important to rationalize, although it is also important to look at lowering heating loads.

When comparing these results with residential buildings, it is found that public school buildings require more energy for cooling, because of the high occupancy rate of students in classrooms, which is (0.6) person/m^2, while residential buildings have higher heating demand because of low occupancy rate, which is (0.1) person/m^2.

Moreover, for the NE-SW case, it is indicated that the higher the WWR, the more positive affect shading devices offer. Total energy consumption drops to more than **25%** when adding shading devices on large windows with 50% WWR, while total energy consumption drops by **17%** when adding shading devices on smaller windows with 25% WWR. On the other hand, for NW-SE orientated building case, the total energy consumption drops to more than **30%** when adding shading devices on large windows with 50% WWR, while total energy consumption drops by **25%** when adding shading devices on smaller windows with 25% WWR.

This concludes that for both NE-SW and NW-SE orientated building case, it is most feasible and worth putting investment (cost estimated to range between 12 to 25 JDs/m^2) in applications of horizontal fixed external shading devices on large SW and SE facing windows (with high WWR), where the positive effect on cooling demand is the highest and negative effect on the heating demand is the lowest.

3.2 Effect of U-Value with Window to Wall Ratio (WWR):

Figure 2(a) and 2(b) show the energy consumption needed for heating both NE-SW and NW-SE oriented building cases:

- Variables: 1) WWRs, 2) U-values, and 3) un-shaded, shaded, and with louvers.
- Constants: Single Low-e glazing.

The following results were found regarding energy savings when comparing between un-insulated cases and cases achieving the EEB Code minimum requirement of U-value 0.57 W/m^2.K:

1) For the NE-SW case:
   a. Heating demand is lowered by **more than 55%** for low WWR.
   b. Heating demand is lowered by **more than 48%** for high WWR.
2) For the NW-SE case:
   a. Heating demand is lowered by **more than 50%** for both low and high WWR.

The following results were found regarding energy savings when comparing between cases achieving the EEB Code minimum requirement of U-value 0.57 W/m^2.K and the GBG U-value requirement of 0.45 W/m^2.K:

1) For the NE-SW case: heating demand is lowered **by less than 13%.**
2) For the NW-SE case: heating demand is lowered **by less than 11%.**

This concludes that it is more feasible to comply only with the minimum U-value requirements of the EEB code for public schools in Jordan, this is due to the relatively low cost of a 5cm polystyrene insulation application required by the EEB (3.5 JDs/m^2), when compared to the GBG requirement of a 7cm thickness insulation ((5.0 JDs/m^2), which costs more for both NE-SW and NW-SE cases.

Moreover, figures 2(a) and 2(b) show that adding shading devices could increase heating demand as the following:

1) For NE-SW case (for all U-value assumptions)
   a. For un-insulated cases, adding 50cm horizontal shading devices increase heating demand by:
   - **13%** for low WWR, - **16%** for high WWR.
   b. For un-insulated cases, adding horizontal louvers increase heating demand by:
   - **33%** for low WWR, - **39%** for high WWR.
   c. For Insulated cases (all U-value assumptions), adding 50cm horizontal shading devices increase heating demand by:
   - **15%** for low WWR, - **18%** for high WWR.
   d. For Insulated cases (all U-value assumptions), adding horizontal louvers increase heating demand by:
   - **49%** for low WWR, - **35%** for high WWR.

2) For NW-SE case

a. For un-insulated cases, adding 50cm horizontal shading devices increase heating demand by:

- **10%** for low WWR, - **15%** for high WWR.

b. For un-insulated cases, adding horizontal louvers increase heating demand by:

- **30%** for low WWR, - **36%** for high WWR.

c. For Insulated cases (all U-value assumptions), adding 50cm horizontal shading devices increase heating demand by:

- **16%** for low WWR, - **22%** for high WWR.

d. For Insulated cases (all U-value assumptions), adding horizontal louvers increase heating demand by:

- **45%** for low WWR, - **50%** for high WWR.

This high increase in energy demand needed for heating when applying shading devices leads to the conclusion of the importance in using adjustable shading devices whenever possible, in order to save energy needed for cooling in summer, and allow solar penetration in winter to lower heating demand.

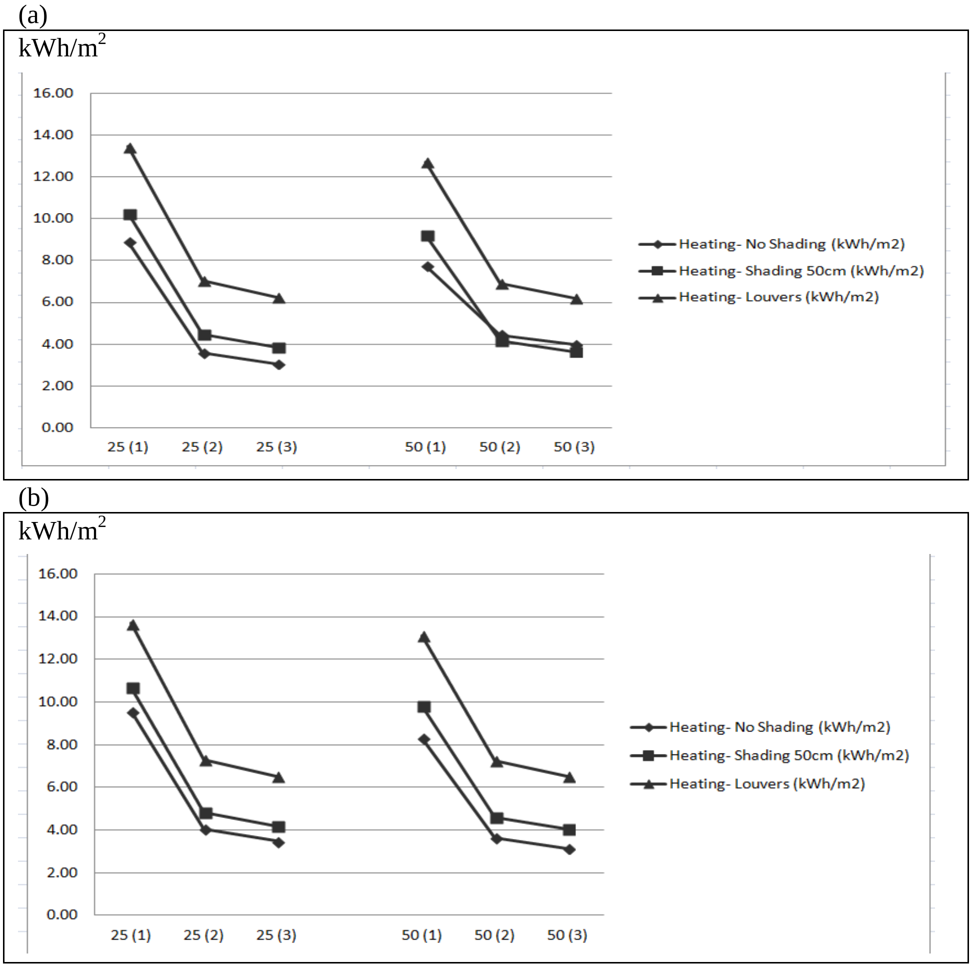


Figure 2: Heating consumption for (a) NE-SW case, (b) NW-SE case, Single Low-E Glazing, for shaded and un-shaded cases, with different U-values.*

*Note:**

25(1) = 0.25 WWR, with no insulation ;U-value of 1.8 W/m^2.k
25(2) = 0.25 WWR, according to EEB Code; U-value of 0.57 W/m^2.k
25(3) = 0.25 WWR, according to GBG U-value of 0.45 W/m^2.k
50(1) = 0.5 WWR, with no insulation; U-value of 1.8 W/m^2.k
50(2) = 0.5 WWR, according to EEB Code; U-value of 0.57 W/m^2.k
50(3) = 0.5 WWR, according to GBG U-value of 0.45 W/m^2.k

3.3 Effect of U-Value with Shading AND Window to Wall Ratio (WWR):

Figures 3(a) and 3(b) show the energy consumption needed for cooling both NE-SW and NW-SE oriented building cases:

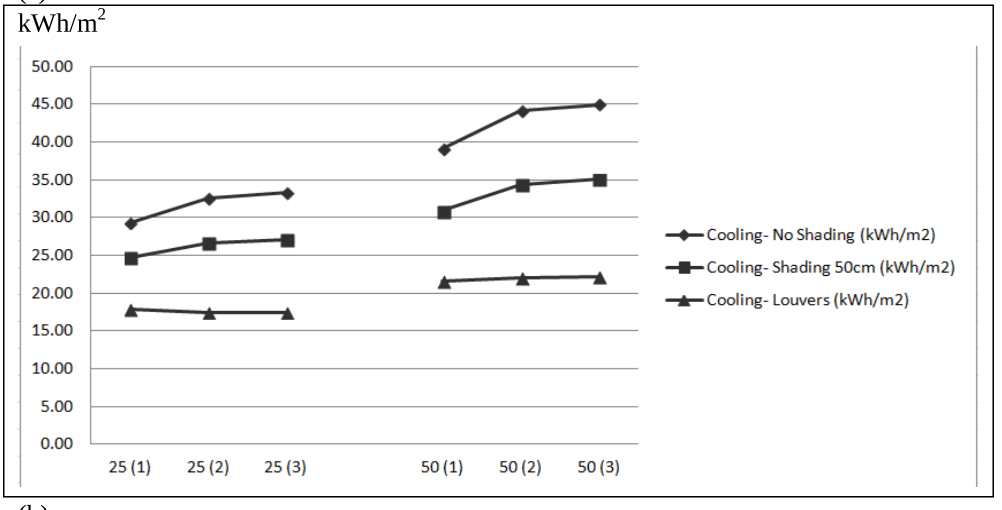
- Variables: *1)* WWRs, *2)* U-values, and *3)* un-shaded, shaded, and with louvers.
- Constants: Single Low-E glazing.

The following results were found regarding the energy savings when comparing between un-insulated cases and cases achieving the EEB Code minimum requirement of U-value 0.57 W/m^2.K, cooling demand increases as the following:

1) NE-SW: **6%** increase for Low WWR and **9%** increase for high WWR.
2) NW-SE: **10%** increase for Low WWR and **13%** increase for high WWR.

This indication does NOT eliminate the importance of complying with minimum U-value required by the EEB code.

(a)



(b)

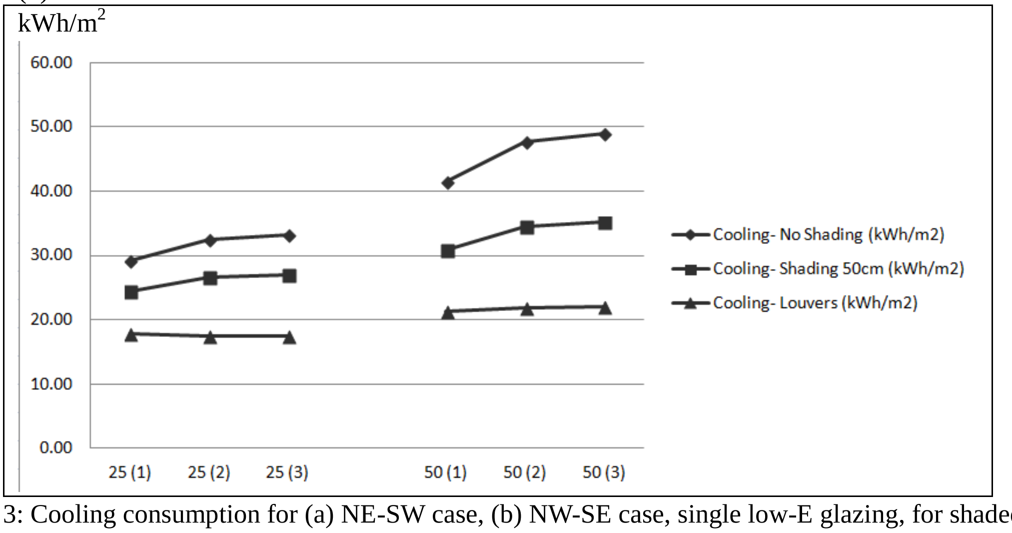


Figure 3: Cooling consumption for (a) NE-SW case, (b) NW-SE case, single low-E glazing, for shaded and un-shaded cases, with different U-values.*

*Note:**

25(1) = 0.25 WWR, with no insulation ;U-value of 1.8 W/m^2.k
25(2) = 0.25 WWR, according to EEB Code; U-value of 0.57 W/m^2.k
25(3) = 0.25 WWR, according to GBG U-value of 0.45 W/m^2.k
50(1) = 0.5 WWR, with no insulation; U-value of 1.8 W/m^2.k
50(2) = 0.5 WWR, according to EEB Code; U-value of 0.57 W/m^2.k
50(3) = 0.5 WWR, according to GBG U-value of 0.45 W/m^2.k

Moreover, for un-shaded cases, cooling consumption for low WWR is lower than cooling consumption for high WWR, and this by:

- **25%** for NE-SW case.
- **33%** for NW-SE case.

However, adding horizontal shading devices of 50cm, lowers cooling consumption as the following:

1) **16%** is saved in NE-SW with Low WWR.
2) **21%** is saved in NE-SW with High WWR.
3) **18%** is saved in NW-SE with Low WWR.
4) **27%** is saved in NW-SE with High WWR.

On the other hand, adding horizontal shading louvers lowers cooling consumption as the following:

1) **39%** is saved in NE-SW with Low WWR.
2) **45%** is saved in NE-SW with High WWR.
3) **46%** is saved in NW-SE with Low WWR.
4) **54%** is saved in NW-SE with High WWR.

This concludes it is important to apply shading devices on SW and SE facades, for high WWRs, especially horizontal louvers, in order to lower solar radiation in hot season, and consequently lower cooling demands.

3.4 Effect of Window Glazing with Shading AND Window to Wall Ratio (WWR), on Heating Demands:

Figures 4(a) and (b) show the energy consumption needed for heating both NE-SW and NW-SE oriented building cases:

- Variables: *1)* Glazing, *2)* WWRs, *3)* un-shaded, shaded, and with louvers.
- Constants: Un-insulated building envelope.

Figure 4(c) shows the percentage of savings in heating demand achieved from each glazing type compared to each other for different WWRs, for both cases. This shows that using single Low-E glazing is more feasible than using double glazed windows in NE-SW and NW-SE oriented school buildings in Amman. This is due to the relatively high energy savings achieved when using single Low-E glazing compared to clear single glazing, and the relatively lower initial costs compared to double glazing.

(a)

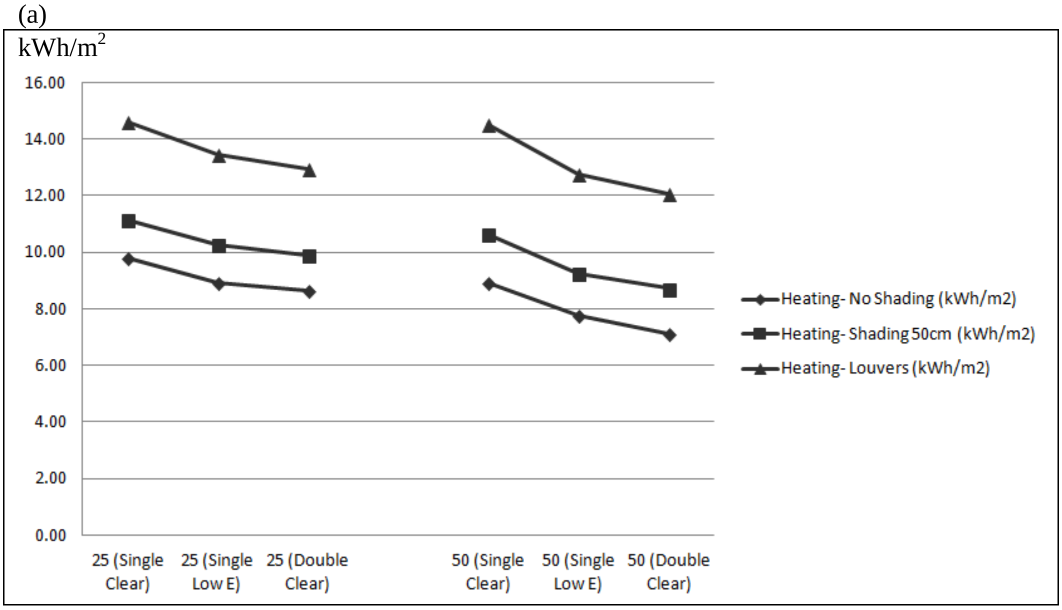


Figure 4: Heating consumption for (a) NE-SW case, (b) NW-SE case, un-insulated building envelope, different glazing types, WWRs and shading options.* *continue next page*

(b)

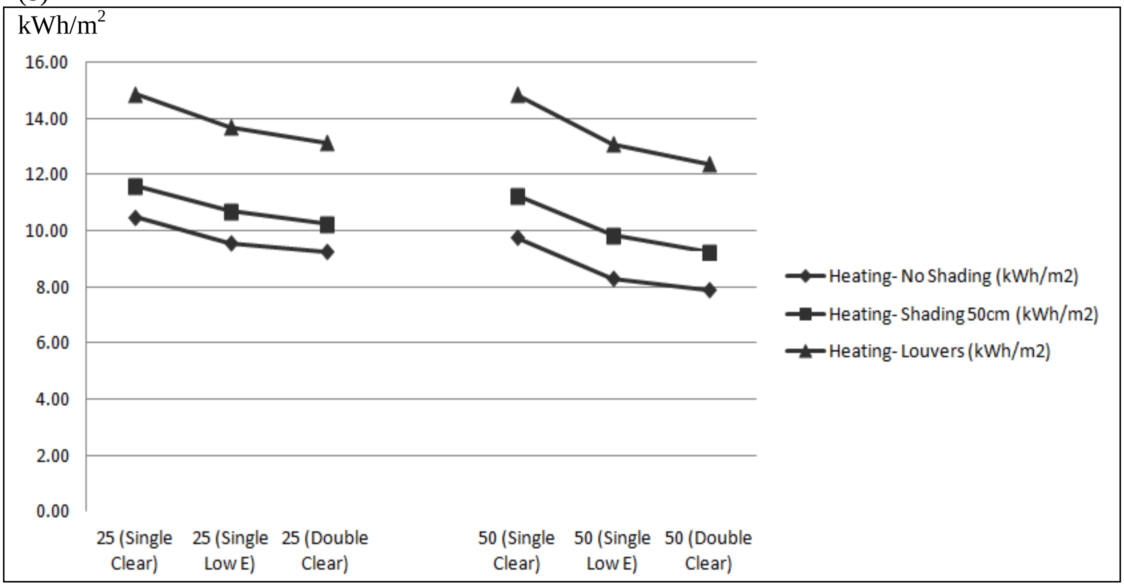
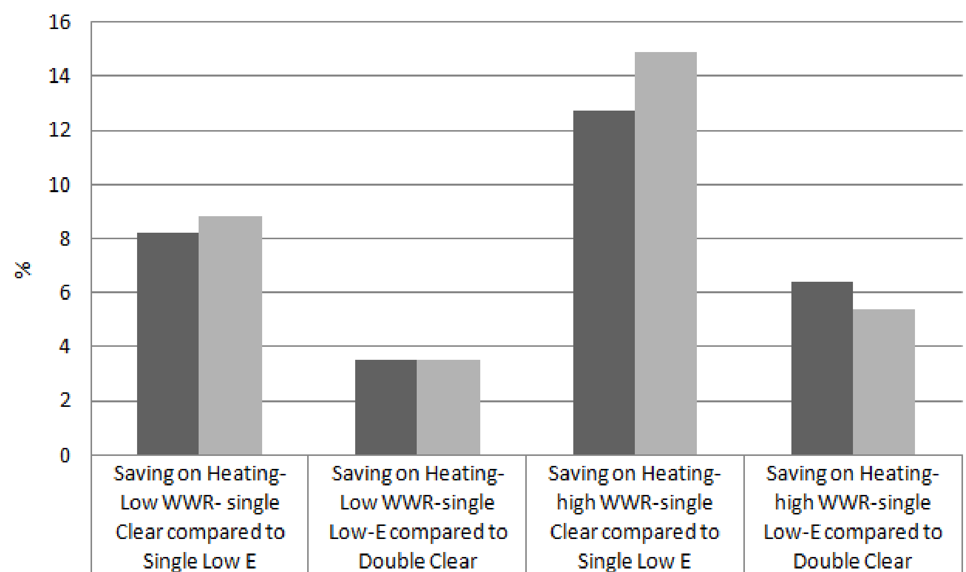


Figure 4: Heating consumption for (a) NE-SW case, (b) NW-SE case, un-insulated building envelope, different glazing types, WWRs and shading options.*

*Note: **

25(Single Clear)	*= 0.25 WWR, windows with Clear Single pane glass*
25(Single Low E)	*= 0.25 WWR, windows with Low E single pane glass*
25(Double Clear)	*= 0.25 WWR, windows with Clear Double pane glass*
50(Single Clear)	*= 0.50 WWR, windows with Clear Single pane glass*
50(Single Low E)	*= 0.50 WWR, windows with Low E single pane glass*
50(Double Clear)	*= 0.50 WWR, windows with Clear Double pane glass*



	Saving on Heating-Low WWR- single Clear compared to Single Low E	Saving on Heating-Low WWR-single Low-E compared to Double Clear	Saving on Heating-high WWR-single Clear compared to Single Low E	Saving on Heating-high WWR-single Low-E compared to Double Clear
B2: Northeast- Southwest	8.2	3.5	12.7	6.4
B3: Northwest- Southeast	8.8	3.5	14.9	5.4

Figure 4 (c): Comparison between savings of heating energy of different window glazing types, for both high and low WWR, for NE-SW and NW-SE oriented school building cases in Amman.

3.5 Effect of Window Glazing with Shading AND Window to Wall Ratio (WWR), on Cooling Demands:

Figure 5 (a) and 5(b) show the energy consumption needed for cooling both NE-SW and NW-SE oriented building cases:

- Variables: *1)* Glazing, *2)* WWRs, *3)* un-shaded, shaded, and with louvers.
- Constants: Un-insulated building envelope.

It is found that regardless of glazing types, space cooling is mostly affected by the WWR and the existence of shading devices.

Whereas, when comparing low and high WWR effect, cooling demand increases for higher WWRs when compared with low WWR facades:

- By **26%**with no shading, for NE-SW case.
- By **19%** with 50cm deep shading devices, for NE-SW case.
- By **16%** with horizontal shading louvers, for NE-SW case.
- By **28%** with no shading, for NW-SE case.
- By **20%** with 50cm deep shading devices, for NW-SE case.
- By **15%** with horizontal shading louvers, for NW-SE case.

Moreover, when comparing the effect of shading device application on windows, cooling demand is lowered by the following percentages when comparing it with cooling demand for the un-shaded cases:

- **23%** for NE-SW, for High WWR, applying 50cm deep shading devices.
- **46%** for NE-SW, for High WWR, applying horizontal shading louvers.
- **16%** for NE-SW, for Low WWR, applying 50cm deep shading devices.
- **39%** for NE-SW, for Low WWR, applying horizontal shading louvers.
- **25%** for NW-SE, for High WWR, applying 50cm deep shading devices.
- **48%** for NW-SE, for High WWR, applying horizontal shading louvers.
- **16%** for NW-SE, for Low WWR, applying 50cm deep shading devices.
- **39%** for NW-SE, for Low WWR, applying horizontal shading louvers.

(a)

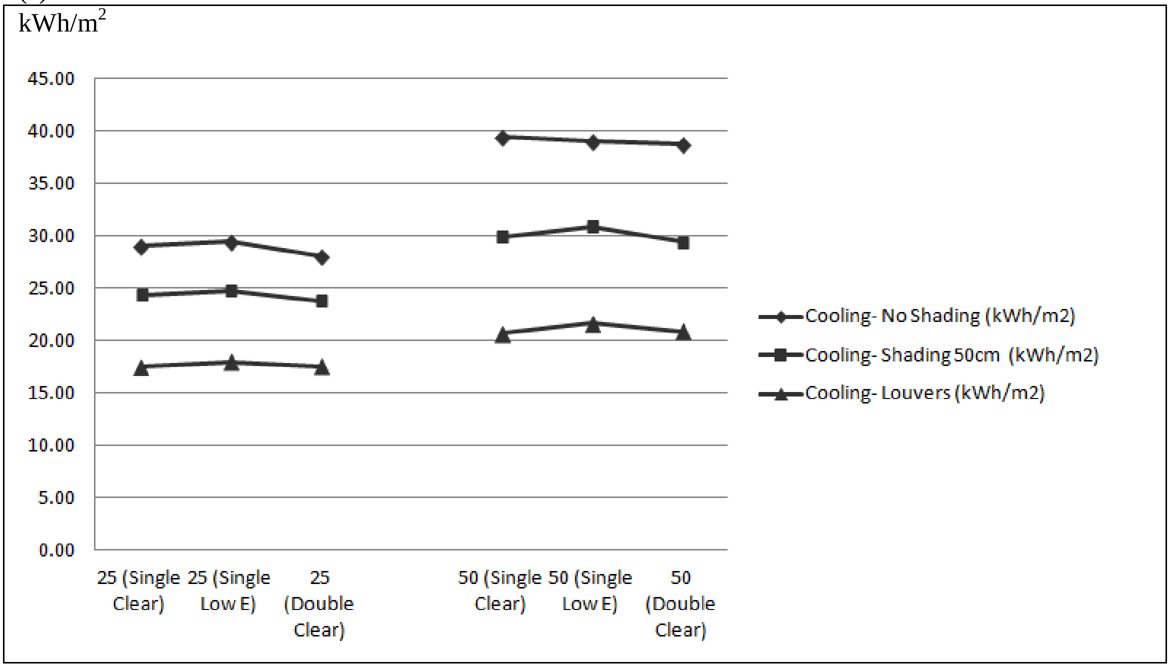


Figure 5: Cooling consumption for (a) NE-SW case, (b) NW-SE case, un-insulated building envelope, different glazing types and shading options.* *continue next page*

(b)

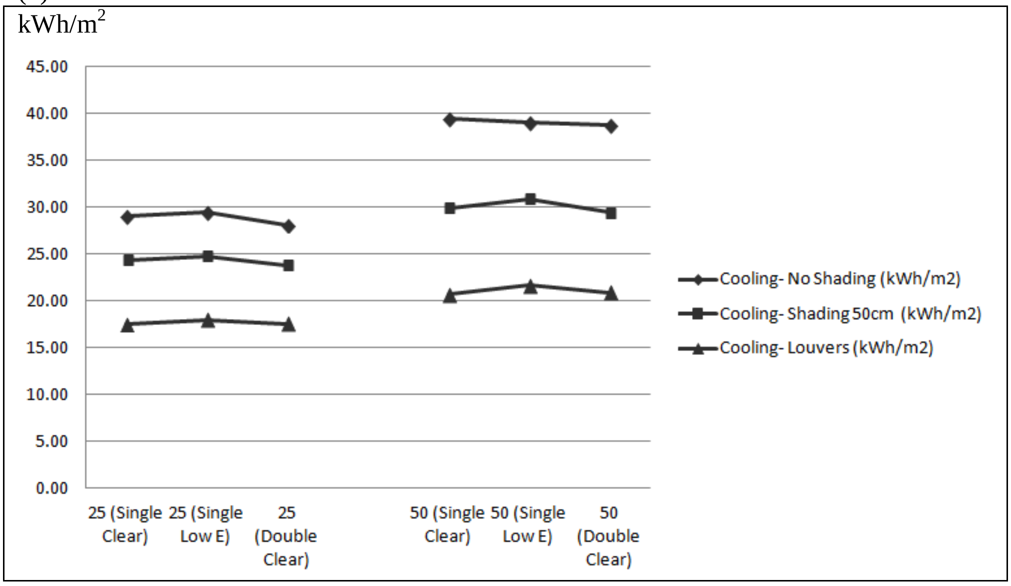


Figure 5: Cooling consumption for (a) NE-SW case, (b) NW-SE case, un-insulated building envelope, different glazing types and shading options.*

*Note: **

25(Single Clear)	*= 0.25 WWR, windows with Clear Single pane glass*
25(Single Low E)	*= 0.25 WWR, windows with Low E single pane glass*
25(Double Clear)	*= 0.25 WWR, windows with Clear Double pane glass*
50(Single Clear)	*= 0.50 WWR, windows with Clear Single pane glass*
50(Single Low E)	*= 0.50 WWR, windows with Low E single pane glass*
50(Double Clear)	*= 0.50 WWR, windows with Clear Double pane glass*

3.6 Effect of adding Adjustable Shading (the Optimum Case)

After examining results for heating and cooling demands of different cases for the two hypothetical case study skewed orientations of the building, it was found that cases requiring lower heating demand usually require relatively high cooling demands. However, cooling loads can be offset and lowered for the previously mentioned cases if adjustable - either manually or automatically- shading was used, i.e. benefit from the advantages of shading devices in summer, and can be adjusted to be opened or removed whenever shading is not needed in winter, where heating is desired. The results would form the optimum case, which has the lowest total energy consumption, provided from adjustable shading applications.

From the parametric cases simulation results of both the NE-SW and the NW-NE oriented building cases, the case which has the lowest heating demand requirement is the case that has: *1)* double clear glazing, *2)* GBG insulation requirement, *3)* no shading, and *4)* 50% for Window to Wall Ratio (WWR). When adding shading only in the summer season, the case becomes the **optimum case** for both the NE-SW and NW-SE cases.

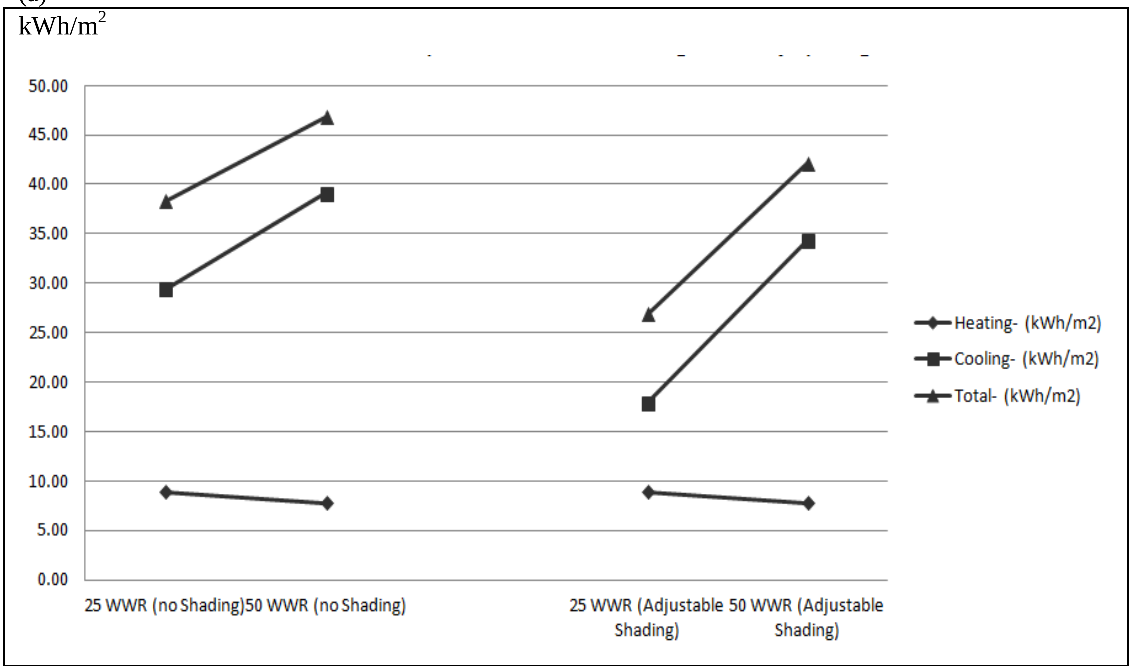
Table 8 shows the results of the optimum case for both NE-SW and NW-SE cases, and savings compared with their base cases. It also shows comparison with N-S and E-W cases studied in the research *(Al-Arja O., Awadalla T., 2015).*

Table 8: Optimum case for NE-SW and NW-SE oriented building cases, compared with N-S and E-W oriented building cases.

Case name	Heating $kWh/m^2/year$	Cooling $kWh/m^2/year$	Total $kWh/m^2/year$	Heating Saving %	Cooling Saving %	Total Saving %
Optimum NE-SW	2.50	20.92	23.42	71.94	47.05	51.63
Optimum NW-SE	2.96	20.81	23.77	69.70	47.49	51.88
Optimum N-S	4.08	22.28	26.36	63.80	32.59	40.54
Optimum E-W	1.80	37.51	39.31	76.03	10.80	20.68

Figures 6(a) and 6(b) show heating, cooling and total energy consumption when using adjustable shading devices for both orientations with single low-E glazing, where shading devices are only ON when they are needed, i.e. in the summer season. It also compares cases for energy demand with no shading on facades.

(a)



(b)

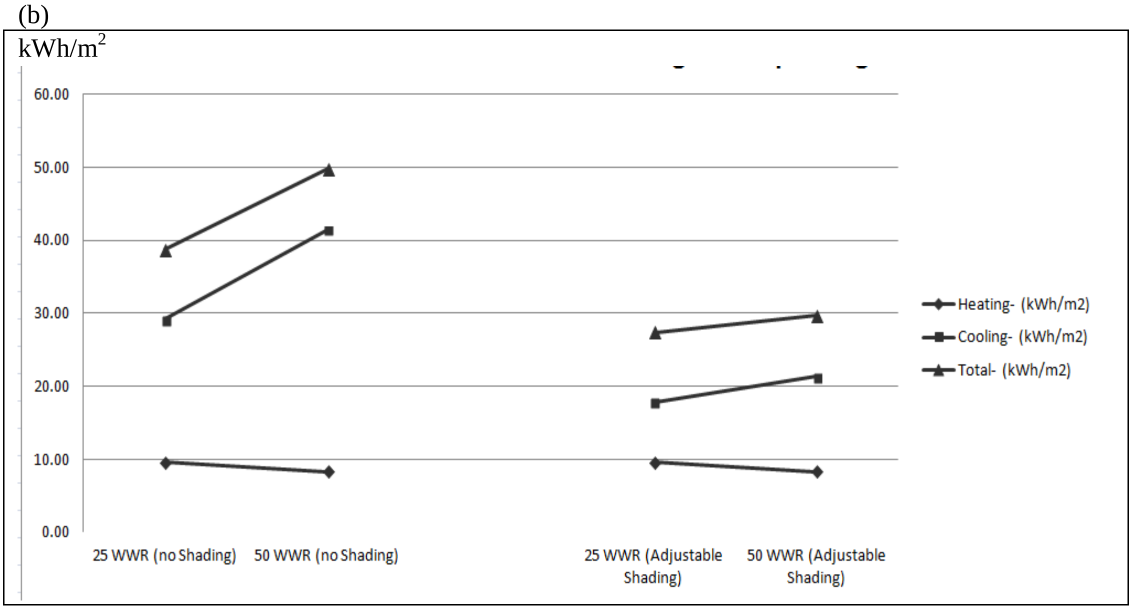


Figure 6: Heating, cooling and total energy consumption when using adjustable shading devices on (a) the SW, (b) the SE façade with single Low-E glazing.*

*Note: **

25 WWR (no Shading)=	*0.25 WWR windows with no shading*
25 WWR (Adjustable Shading)=	*0.25 WWR windows with adjustable shading*
50 WWR (no Shading)=	*0.5 WWR windows with no shading*
50 WWR (Adjustable Shading)=	*0.5 WWR windows with adjustable shading*

The energy needed for space heating was adjusted to be the same for the both NE-SW and NW-SE orientations, indicating the use of un-shaded façade in winter. Moreover, **adding adjustable shading** in summer decreases energy demand (when compared to un-shaded cases) by:

- **12%** lower cooling demand for **high** WWR in NE-SW cases.
- **10%** lower total energy demand for **high** WWR in NE-SW cases.
- **39%** lower cooling demand for *low* WWR in NE-SW cases.
- **30%** lower total energy demand for *low* WWR in NE-SW cases.
- **48%** lower cooling demand for **high** WWR in NW-SE cases.
- **40%** lower total energy demand for **high** WWR in NW-SE cases.
- **39%** lower cooling demand for *low* WWR in NW-SE cases.
- **29%** lower total energy demand for *low* WWR in NW-SE cases.

This concludes that adjustable shading is highly recommended to be used for NW-SE oriented cases with high and low WWR facades, and recommended for NE-SW oriented cases with low WWR not high WWR.

Moreover, it was noticed that the amount of energy consumption needed for heating for both the NE-SW and NW-SE cases is very low, less than 10 kWh/m^2. This is due to the high internal loads created by the greatly dense occupation of classrooms in Jordan, and allowing solar radiation transmittance in winter.

4. Comparison of results with other orientations:

In this section, an overall comparison will be done for all 8 orientation assumptions, 4 of them were studied in a previous research (*Al-Arja O., Awadalla T., 2015*) for the N-S and E-W orientated school façades and the other 4 orientations, NE-SW and NW-SE were studied in this research.

4.1 Effect of Shading with Window to Wall Ratio (WWR):

From tables 9,10 and 11, it is shown that the **E-W orientation** has the most negative impact for energy consumption, where in the **N-S orientation** when adding proper shading devices maximises energy savings when compared to other orientations, given the lowest negative impact on heating and the highest positive impact on cooling. However, for the total energy consumption savings, the **NW-SE case** has the highest value. In addition, the impact of energy savings that shading has on high WWR is higher than on low WWR, where savings are increased from (5 to 10) % for all orientations, excluding the E-W orientation where the impact is the same for both WWR values.

Table 9: Percentage of Energy Consumption for all School façade Orientations

	N-S	**E-W**	**NE-SW**	**NW-SE**
Cooling	70	78	70	65
Heating	30	22	30	35

Table 10: Percentage of Energy Consumption when adding fixed external shading devices for all School façade Orientations

	N-S	**E-W**	**NE-SW**	**NW-SE**
Heating increased by shading	5	19	12	10
Cooling decreased by shading	30	15	27	30

Table 11: Percentage of total Energy decrease when adding shading devices for all School façade Orientations, according to WWR.

	N-S	**E-W**	**NE-SW**	**NW-SE**
Total energy consumption decrease- Low WWR	5	9	17	25
Total energy consumption decrease- High WWR	15	9	25	30

4.2 Effect of U-Value with Window to Wall Ratio (WWR):

From Table 12, it is shown that the impact of insulation in the building envelope verses no-insulation, is almost the same for all orientations, where it has (**40 to 59)%** positive impact on heating consumption. The highest savings occurred in the E-W orientation, where the lowest savings were achieved in the N-S orientation.

Table 12: Percentage of heating energy saving when achieving the EEB Code minimum requirement of U-value 0.57 W/m^2.K compared to un-insulated cases for all School façade Orientations

	N-S	**E-W**	**NE-SW**	**NW-SE**
Heating Demand- Low WWR	50	59	55	50
Heating Demand- High WWR	40	59	48	50

In addition, table 13 shows that when comparing GBG U-value requirements with the EEB U-value requirements, savings don't exceed 14% of energy consumption use for heating, which is almost the same for all orientations.

However, table 14 shows that when adding 50cm deep horizontal/ vertical shading device on all orientations, the highest heating energy increase is noticed in the E-W case, where the N-S orientation has the lowest heating demand potential. This concludes that it is not recommended to shade the East and West facades with fixed 50cm deep vertical shading device; adjustable shading devices should be used instead.

Table 13: Percentage of heating energy saving when achieving the GBG U-value requirement of 0.45 $W/m^2.K$ compared to the cases with EEB Code minimum requirement of U-value 0.57 $W/m^2.K$ for all School façade Orientations

	N-S	E-W	NE-SW	NW-SE
Heating Demand	10	14	13	11

Table 14: Percentage of heating energy increase when adding 50cm Deep Horizontal/Vertical shading for all School façade Orientations

	N-S	E-W	NE-SW	NW-SE
Un-Insulated- Heating Demand- Low WWR	13	20	13	10
Un-Insulated- Heating Demand- High WWR	15	27	16	15
EEB- Heating Demand- Low WWR	13	30	15	16
EEB-Insulated- Heating Demand- High WWR	15	43	18	22

4.3 Effect of U-Value with Shading AND Window to Wall Ratio (WWR):

Table 15 shows how cooling energy demand increases when complying with the EEB code requirements for all orientations, where the N-S facade has the highest potential increase and the NE-SW orientation has the lowest increase in cooling demand. This indication does NOT eliminate the importance of complying with minimum U-value required by the EEB code for all orientations.

On the other hand, table 16 shows that when replacing high WWR with low WWR cooling demand savings are higher, for all un-shaded orientations. The highest difference in performance between low and high WWR is achieved in the NW-SE orientation, where the NE-SW orientation has the lowest difference in performance. This should be taken into consideration without compromising the quality of daylight penetration in classrooms.

Table 15: Percentage of cooling energy increase when achieving the EEB Code minimum requirement of U-value 0.57 $W/m^2.K$ compared to un-insulated cases for all School façade Orientations

	N-S	E-W	NE-SW	NW-SE
Cooling Demand- Low WWR	14	10	6	10
Cooling Demand- High WWR	14	13	9	13

Table 16: Percentage of cooling energy savings when using un-shaded Low WWR instead of un-shaded High WWR for all School façade Orientations

	N-S	E-W	NE-SW	NW-SE
Cooling Demand	30	32	25	33

4.4 Effect of Window Glazing with Shading AND Window to Wall Ratio (WWR), on Heating Demands:

Table 17 shows the impact of 3 glazing types usage in comparison with each other, for both low and high WWR. It is found that single Low–E glazing has the most positive impact when compared with single glazing, in addition to its feasibility regarding cost and market availability, for all orientations.

Table 17: Percentage of savings in heating demand achieved from each glazing type compared to each other for different WWRs, for all School façade Orientations

	N-S	E-W	NE-SW	NW-SE
Saving on Heating- Low WWR-single Clear compared to Single Low E	9.1	8.6	8.2	8.8
Saving on Heating- Low WWR-single Low-E compared to Double Clear	3.2	3.0	3.5	3.5
Saving on Heating- high WWR-single Clear compared to Single Low E	14.7	14.7	12.7	14.9
Saving on Heating- high WWR-single Low-E compared to Double Clear	4.8	5.0	6.4	5.4

4.5 Effect of Window Glazing with Shading AND Window to Wall Ratio (WWR), on Cooling Demands:

In table 18, it is found that when using high WWR instead of low WWR, cooling is increased for all orientations, where the increase is the highest in the E-W orientation, and the lowest in the N-S orientation, regardless of shading device availability.

Table 18: Percentage of cooling energy increase when using High WWR instead of Low WWR for all School façade Orientations

	N-S	**E-W**	**NE-SW**	**NW-SE**
No Shading Device	25	30	26	28
With 50cm Deep Horizontal/ Vertical Shading Device	15	24	19	20

4.6 Effect of adding Adjustable shading (the Optimum Case)

Table 19 shows the percentage of energy saving when using adjustable shading devices, where they are on in summer, and off in winter. The table shows that the higher the WWR the higher the saving in cooling and total energy consumption. The highest savings are achieved in the NW-SE orientation, and the lowest impact is in the E-W orientation.

Table 19: Percentage of energy saving when adding adjustable shading in summer for all School façade Orientations

	N-S	**E-W**	**NE-SW**	**NW-SE**
Cooling Demand- High WWR	35	20	12	48
Cooling Demand- Low WWR	27	12	39	39
Total Consumption- High WWR	27	17	10	40
Total Consumption- Low WWR	19	10	30	29

Conclusions and Recommendations:

Based on the analysis and findings of the research, the following conclusions and recommendations can be drawn:

- For schools sector in hot arid climate generally, and in Jordan specifically, the Energy Use Index (EUI) is concluded from the research, and refers to energy consumption/ meter square of area/ year for both heating and cooling demand. The following table shows the EUI values:

Facades Orientation	**Lowest (Best case scenario) kWh/m^2/year**				**Highest (Worst case scenario) kWh/m^2/year**				**Average kWh/m^2/year**
	Low WWR	Double glazing	GBG U-value	adjustable Shading	High WWR	Single Low-E	GBG U-value	No Shading	
N-S	24.36				40.36				32.0
E-W	31.05				53.5				42.0
NE-SW	23.42				48.94				36.0
NW-SE	23.77				52.08				38.0

The average consumption value could be used as an Energy Use Index for future studies on energy consumption in School`s buildings in Jordan.

- Based on energy costs in Jordan for 2015, the following values show savings for optimum case scenarios of all orientations if compared with the average energy consumption value, and increase in energy consumption cost when compared with the worst case scenarios. The values are represented in JDs/m^2/year, and as total cost increase or decrease for the school studied in this research with the area of 1224 m^2.

Facades Orientation	**Worst compared to average (additional consumption)**		**Optimum compared to average (Saving in energy consumption)**	
	JDs/m^2/year	**Total for School JDs/year**	**JDs/m^2/year**	**Total for School JDs/year**
N-S	1.254	1534.9	1.146	1402.7
E-W	1.725	2111.4	1.643	2011.0
NE-SW	1.941	2375.9	1.887	2309.7
NW-SE	2.112	2585.1	2.135	2613.2

- Use efficient glazing materials whenever the WWR is higher, for all orientations of school buildings in Amman - hot arid climate zones.
- Always provide shading for high WWR in all facade orientations of school building in Amman, and hot arid climate zones.
- For economic feasibility, use single Low-E glazing (30 JDs/m^2) instead of double glazing (70 JDs/m^2) for all orientations (skewed and basic) of schools in Amman, and hot arid climate zones. This is due to the relatively high energy savings achieved when using single low-e glazing compared to clear single glazing (20 JDs/m^2), and the relatively lower initial costs compared to double glazing.
- It is recommended that both heating and cooling savings issue should be addressed equally in School`s building design in Amman, and hot arid climate zones, regardless of orientation, because of the relatively high energy prices (0.145 JD/kWh in 2015), *(Jordan Electric Power Company, 2015)*
- As recommended in the previous research, the minimum U-value requirements of the Energy Efficient Building (EEB) Code of Jordan should be complied, not the Green Building Guideline (GBG) requirements, for all basic orientations of School`s buildings in Jordan, due to its feasibility when comparing initial costs with predicted savings.
- As recommended in the previous research, incentive schemes should be developed for the use of automatically adjustable shading devices on the main facades of School`s buildings, in order to offset the high cost of adjustable shading devices (which ranges from 15 to 30 JDs/m^2)), and to encourage the proper usage of these shading devices.

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