The effect of the envelope design on the annual energy consumption of school buildings in Jordan

Hikmat H.Ali, Assosiate Proffecor

Department of Architecture
College of Architecture &Design
Jordan University of Science and Technology, Irbid-Jordan

Rifqa M. Hashlamoun ,lecturer
Department of Architecture and Interior Architecture
Al Yamama University , Al Riyadh - K.S.A

Building envelope design is considered to be an efficient energy - saving strategy . This research studies the effect of building envelope design on energy consumption in school buildings . For the sake of the research , two governmental school buildings with different envelope parameters are analyzed : a prototypical, and un-insulated school built before the educational reform in Jordan (Old Abu Alanda school) ;which represents around 2917 school prototypes , and thermally insulated site-specific school built after the educational reform (New Abu Alanda school). The study evaluates the thermal performance of the envelope in the old and new school buildings by comparing thermal conductivity values (U-values) for envelope parameters in both schools, and conducting thermal comfort assessment inside the old and new school classrooms using field monitoring and simulations . Furthermore, annual energy consumption for cooling and heating in both schools was computed using Design Builder simulation software. The results showed that in total, the newly built governmental school consumed 52% less energy than the old one. An analysis of the envelope effect on the resulted energy saving in the new school found that 66% of energy saving was due to the enhanced envelope parameters. In conclusion, by analyzing the effect of the relevant envelope parameters of the new school building on the energy saved for cooling and heating, it was found that Installing 12-cm louvers on the south elevation of the new school made the highest contribution to the energy saving for cooling, 9.1% ,while configuration of the wall and the addition of a 5-cm thermal polystyrene insulation in the new school had the highest impact on the energy saving for heating, 24.1%,whereas adding the shading on the north elevation produced smaller energy efficiency benefits in regards to cooling and negative benefits on the annual heating energy consumption .

Keywords—Energy Performance , Buildgns Envelope , School buildings , Jordan .

I. School Buildings in Jordan

More than 75% of existing governmental school buildings in Jordan built before the educational reform are not thermally insulated (MOE, 2014). Before 2003, all school buildings in Jordan were constructed to follow one of the standard designs prescribed by the MOE, according to which the layout of classrooms should be linear, and can be arranged around a double- or a single-loaded corridor in contact with the exterior of the building envelope. The envelope design and construction materials in the prototypical models were similar owing to limited financial resources as they did not contain any kind of thermal insulation (Ali Al-Arja & Awadallah, 2015). However, following the Vision Forum for the Future of Education in Jordan held in September 2002, the MOE released the Education Reform for the Knowledge Economy Program (ERfKE). The proposal set out in detail the government's intention for overall reform within an extensive and inclusive framework. A major component of this reform concerned with school buildings was an improvement in the physical learning environment (MOE, 2014). The MOE stopped the construction of prototypical school models and started building site-specific schools with upgraded architectural specifications. Since then, the number of governmental schools in Jordan has increased from 2719 in 2005 to more than 3864 in 2015 (MOE, 2015). According to the Department of Statistics, 40–70 new schools have been constructed annually from 2000 to 2012 (DOS, 2012). In light of the limited budget of the MOE, many non-government organizations (NGO) have offered initiatives supporting the construction of new schools (MOE, 2014).

With the construction of new site-specific insulated schools in Jordan, the cost of the construction of new schools has increased annually (MOE, 2014). However, no study has been conducted to compare the thermal efficiency of the envelope in old, prototypical school buildings built before 2003 with that of the new site-specific schools built after. Consequently, this research focuses on evaluating and comparing the thermal efficiency of the envelopes of old, un-insulated prototypical schools with new, thermally insulated site-specific schools in Jordan.

II. Theoretical Background

While this research focuses on a particular category of public buildings—schools—it is important to note that in general, the running cost of heating, cooling, and ventilation constitute the main cost in schools (Katafygiotou & Serghides, 2014). Furthermore, indoor air quality, energy efficiency, and thermal comfort are the three main aspects that directly influence the environment of school buildings and their occupants (Katafygiotou & Serghides, 2014). A study by (Santamouris et al., 2007) in Greece aimed to develop an energy rating system for school buildings using energy surveys for 320 schools, and found that a typical school building (50% of the stock) consumed 57 kW h/m² per year for heating and 20 kW h/m² per year for electricity and appliances, with total energy consumption of 72 kW h/m² per year. A recent study in Jordan aimed to set an energy use index (EUI) for typical governmental schools, found that the average electrical consumption for lighting and appliances in government school buildings ranged from 2 to 6 kWh/m²/year, whereas the average annual energy consumed for cooling and heating ranged from 44.33 to 49.56 kWh/m²/year, depending on the orientation of the school (Ali Al-Arja & Awadallah, 2015).

The building envelope may be defined as the totality of building elements made up of components that separate the indoor environment of the building from its outdoor environment (Oral, Yener, & Bayazit, 2004). It is originally designed in a way to ensure thermal comfort in buildings with minimum energy consumption. A study on envelope retrofit in office buildings in Turkey found that envelope optimization (wall insulation, replacement of glazing with low-e, and replacement of window frames) resulted in a 12.32% decrease in annual energy consumption for space heating and 19.42% in annual energy consumption for cooling to yield vital improvements in the indoor thermal environment.

Considering the effect of buildings envelope parameters (Walls , Roof , windows , shading elements ,..ect.) on annual energy consumption , and that In Jordan , no study has been conducted to compare the thermal efficiency of the envelopes in old, prototypical school buildings built before 2003 with that of the new site-specific schools built after. Consequently, this research focuses on evaluating and comparing the thermal efficiency of the envelopes of old, un-insulated prototypical schools with new, thermally insulated site-specific schools in Jordan. Also , it studies the effect of the enhanced envelope parameters in new school on the annual energy savings , as the results can be used later to consider retrofitting of existing schools envelope . Also the recommendations may be used when constructing new schools .

III. CASE DTUDIES

In order to establish the case-study experiment and reach the objectives of this research, two actual cases from typical public schools in Amman were chosen , Only classrooms would be addressed in this research, since they consume the largest part of energy in schools :

1. The Old Abu Alanda primary mixed school : is a two-story building built in 1992. The building was a typical Hai Nazal prototype model (Figure 1) , with a rectangular plan with perimeters of (53.5 m x 21.1 m).The school was oriented north –south with a 15º tilt toward the east .The external walls of the building were un-insulated, medium-weight concrete blocks with no insulation layer except a 5-cm air space. The roof of the building consisted of a reinforced concrete with no vapor or thermal insulation layer. There were 48 windows in the classroom zones, and all windows in the school were single glazed with aluminum frames and no thermal break strip. There were no shading devices on the windows except 20-cm projections. Table 1 summarizes the details of the envelope in the old Abu Alanda school. The area of the elements of the envelope was computed for the entire school building and the classroom zones separately for subsequent use in the analysis.

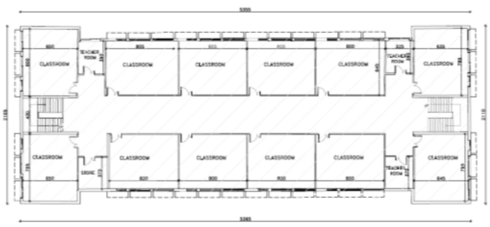


Figure 1: Old Abu Alanda school–first floor plan (Al Bitar, 2016).

Table 1: Old Abu Alanda school–envelope details (Researcher, 2017).

Element	Description	Details
External Walls	Total area: 1050 m² Classroom walls' area: 550 m²	20 mm solid concrete blocks + 50 mm air + 10 mm hollow concrete block + 15 mm cement plaster
	Wall thickness: 39 cm	
	Insulation: No thermal insulation	
	Description: Medium-weight concrete block wall.	
Roof	Total area: 1013 m²	200 mm reinforced concrete slab + 50 screed + 20 mm concrete tiles
	Roof thickness: 29 cm	
	Insulation: No thermal or vapor insulation	
	Description: Reinforced concrete slab	
Floor	Ground floor area: 1072.5 m²	Heavy concrete slab of 200 mm + mortar + 25 mm terrazzo tiles
	First floor area: 1072.5 m²	
	Classroom zone floor area: 800 m²	
	Description: Heavy concrete slab	
Windows	Total window area= 340 m²	Single-glazed 6 mm windows + aluminum frame (no air tightness).
	Classroom windows = 48 Classrooms window area = 180 m²	
	Description: Single-glazed windows	
	North WWR: 30%, East WWR: 30% South WWR: 30%, West WWR: 30%	
	Overhangs: Horizontal overhangs over the south and north windows, 20 cm projection.	

2. The New Abu Alanda Secondary Girls' School Abu Alanda secondary girls' school is a two-story building built in 2006 by the KFW donors . The building had three classroom wings projected from one linear mass (Figure 2) . The wings were directed north–south with a 15º tilt in the east. The external walls of the building consisted of medium-weight concrete blocks thermally insulated with a 5-cm polystyrene layer. The building had a reinforced concrete roof with a foam concrete thermal insulation layer and a vapor insulation layer covered with a fine aggregate finish. There were 54 windows in the classroom zones, and all were clear and double glazed with aluminum frames and a thermal break strip. As shading devices, there were louvers on both the north and south windows. Table 2 summarizes details of the external walls, roof, and floor in the new Abu Alanda School.

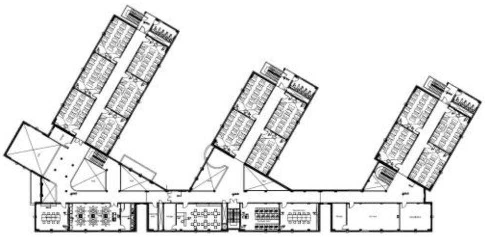
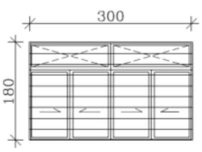


Figure 2: New Abu Alanda school–first floor plan (Al Bitar, 2007).

Table 2: Details of the walls, roof, and floors of the new Abu Alanda school (Researcher, 2017.

Element	Description	Details
External Walls	Total area: 2594 m^2	15 mm concrete cement blocks + 50 mm polystyrene layer + 10 mm hollow concrete block + 20 mm cement plaster
	Wall thickness: 40 cm	
	Insulation: Polystyrene layer (5 cm)	
	Description: Medium-weight concrete block wall with thermal insulation	
Roof	Total area: 2251 m^2	300 mm reinforced concrete slab + 50 mm foam concrete + 20 mm screed + 40 mm dpm with fine aggregate finish
	Roof thickness: 43 cm	
	Insulation: Foam concrete 5 cm	
	Description: Reinforced concrete slab	
Floor	Ground floor area: 2034.40 m^2	Heavy weight concrete slab 300 mm + 150 mm sand and mortar + 25 mm terrazzo tiles
	First floor area: 2251.87 m^2	
	Description: Heavy concrete slab .	
External windows **Internal windows**		Double-glazed windows, two leaves, sliding leaves, automatic self-closer Frame: Air-tight aluminum frame . Single-glazed windows with tilted leaves (6 mm) glass.

IV. Methodology

Data acquired from the previous section were used to develop base case models - actual case - for the selected schools. The base case is modeled with the relevant functional layout, orientation, ceiling heights, classrooms configurations, occupant density, envelope materials and specifications, and operation schedules. Base case modeling and simulation were carried using the dynamic thermal simulation tool Design Builder (DB) , in its forth version which is based on building performance simulation engine entitled energy-plus. The “base case” is thermally modeled in order to Evaluate annual cooling and heating energy consumption in both schools and thermal comfort , as there are no records for real energy draw. Electricity used for lighting and other appliances was exempted from this study. Only annual energy (in kWh/m^2) used for heating and cooling requirements was calculated to provide flexible results without depending on the type of fuel or cost. For base case modeling, the geometries of the selected school were constructed in DB based on as-built drawings and construction details provided by the Ministry of Education (MOE) and Al Bitar consultants’ office. Initially, three-dimensional (3D) DB models for the selected school were developed . For comparative purposes, only classroom zones were specified as active thermal zones (occupied area) in each schools. All zones except classrooms were specified as “unoccupied thermal zones;” hence, 16 classrooms in the old Abu Alanda school and 27 in the new school were selected for further analysis. The simulation was based on hourly weather data by taking into account solar gains through windows as well as heat conduction among the internal walls of classroom zones, once base case modeling was finished , data concerning the construction materials, envelope specifications, occupancy ratios, operation schedules, HVAC systems, and the rate of infiltration were assigned to the school models through the activity, construction, opening tabs in DB .

Table 3: Physical and operational characteristics used to develop base case models for old and new Abu Alanda school (Researcher, 2017).

Parameter	Old Abu Alanda school	New Abu Alanda school
Total area	2145 m^2	4299 m^2
Number of classrooms	16	27
Classroom area	50 m^2	48 m^2
Occupancy density	0.9` persons/m^2	0.75` persons/m^2
Classroom orientation	North/South 15º tilt	North/South, 15º tilt
Wall U-value (W/m^2-k)	1.38	0.46
Wall insulating material	Air	Polystyrene (5 cm)
Roof U-value (W/m^2-k)	1.10 (W/m^2-k)	0.44
Roof insulating material	None	Foam concrete
Window U-value (W/m^2-k)	5.77	2.66
Window SHGC	0.81	0.70
Overhang and louvers	20 cm projection above the windows and on sides of windows	7 Fixed external louvers on each window louver depth: 60 mm on north side 120 mm on south side
Ventilation system	Natural ventilation through windows, mechanical ventilation (ceiling fans)	Natural cross-ventilation (external and internal classroom windows), mechanical ventilation (wall-mounted fans)
Existing cooling system	None	None
Existing heating system	None	None
Heating set point ºC	18	18
Cooling set point ºC	24	24
Assumed infiltration	1 ach/h	0.5 ach/h

Initial assessment of Envelope Parameters

The initial assessment consisted of a comparison of the thermal characteristics of the parameters of the envelope in both schools. DB was used to obtain thermal conductivity (U-value) values for the elements of the envelopes of both schools. The following results were obtained:

- Walls and roof: The U-value of 1.38 W/m² K for the exterior walls in the old Abu Alanda School did not comply with the minimum standard of 0.57 W/m² K specified in the JEEBC (Jordan Energy Efficiency Building Code) , owing to the absence of thermal insulation. However, the thermal conductivity of 0. 46 W/m² K of the external walls in the new school was clearly within the acceptable range. For the roof, in the old school, the U-value of 1.10 W/m² K did not comply with the minimum standard of 0.55 W/m² K specified in the JEEBC. On the contrary, the new school had a U-value of 0.44 W/m² K, which is clearly within the acceptable range.
- Windows and frames: It was found that single-glazed windows in the old Abu Alanda School had much higher U-values (5.77 W/m² K) than double-glazed windows in the new school (2.66 W/m² K). Moreover, unlike window frames in the new school, the old school model had no thermal break strips.
- Existing shading systems: For external solar heat gain controls systems, 20-cm fixed horizontal projections surrounded windows of the old school on three sides; no louvers or shading devices were observed. In the new Abu Alanda School, external louvers with different depth were installed on the north and south elevations.

Indoor Thermal Environment Assessment of Selected Schools

In the second stage of assessment, thermal comfort data loggers (Q544949) , were used to monitor the indoor thermal environment of classrooms of the old and new schools. The classrooms were monitored in hourly basis from 9:am -1 :pm . Four classrooms were selected from each school based on occupancy ratio, orientation, and floor level; consequently two north and two south classrooms were selected . Indoor thermal environmental assessment was conducted in three stages: initial assessment of environmental parameters (Temperature and humidity) in the monitored classrooms, thermal comfort evaluation using the Adaptive Comfort Standard (ACS) model based on field measurements, and thermal comfort evaluation using Predictive Mean Vote (PMV)based on the results of DB simulations. The following was concluded:

In conclusion, the initial assessment of the parameters of temperature, humidity, and air movement in both schools indicated that the average indoor air temperature profiles in the old Abu Alanda School were higher than in the new one, considering that both had similar classroom orientations and the monitored classrooms had similar occupancy ratios. This indicates that the thermal resistance of the envelope of the old school was poorer than that of the new one.

Table 4: Average indoor air temperature, relative humidity, and air movement inside the monitored classrooms on October 13, 2016 (Researcher, 2017). Class A: Old Abu Alanda school–south classroom , Class B: Old Abu Alanda school–north classroom , Class C: New Abu Alanda school–south classroom , Class D: New Abu Alanda school–north classroom . Where X_i is the classroom on the ground floor and X is that on the first floor.

School	Class	Floor	Average indoor average temp. (C°)	Average relative humidity (%)	Air movement (m/s)
Old Abu Alanda	Class A_i	Ground	27.92	42.45	0.01
	Class A	First	28.24	40.78	0.01
	Class B_i	Ground	27.24	47.87	0.01
	Class B	First	27.42	44.12	0.02
New Abu Alanda	Class C_i	Ground	25.82	37.91	0.02
	Class C	First	26.22	37.67	0.03
	Class D_i	Ground	25.72	40.21	0.03
	Class D	First	25.88	38.81	0.05

- The highest average indoor air temperature (28.24ºC) was recorded in the old Abu Alanda school (south classroom/first floor), whereas the north classroom/ground floor in the new Abu Alanda school exhibited the lowest average indoor air temperature (25.72ºC).
- The average indoor air temperature in classrooms of the old Abu Alanda school during the monitored period was 27.6ºC, and was 25.9ºC in the four monitored classrooms in the new Abu Alanda school.

Considering that both schools had the same building and classroom orientations. This indicates that the envelope of the old Abu Alanda School had lower thermal resistance to outdoor temperature.

- **Thermal Comfort Assessment–(ACS) Model**

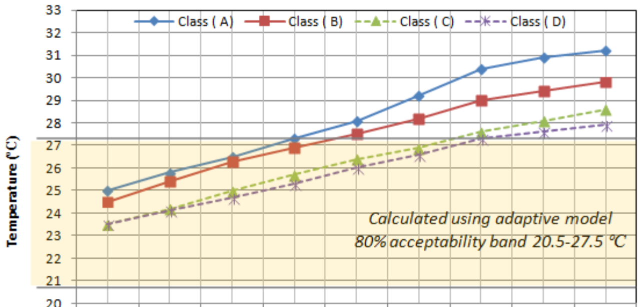
ACS model for naturally ventilated buildings employed by ASHRAE standard 55. was used In the ACS model, the mean monthly outdoor air temperature determines acceptable indoor air temperature. This relationship is expressed by the following formula:

$$Tcom = .31(Tout) + 17.8$$

$$80\% \text{ acceptability ranges} = T(com) \pm 3.5°C$$

Where T*com.* is the optimum indoor comfort temperature in Celsius in a selected month whereas T*out* is the mean monthly outdoor air temperature. From the above equation, it was found that based on the mean outdoor air temperature of 19.7ºC in Amman in October 2016 (Climate data organization, 2016), the indoor T*com* was 24ºC.

The next step involved defining the ranges of temperature around T*comf* corresponding to an 80% range of thermal acceptability in accordance with ISO 7730 (ISO Standard 7730, 2005). According to the ACS model, the acceptability value of 80% is defined by the mean comfort zone band of 7°C (De Dear & Brager, 2002); thus, In this study, the 80% band of acceptability was in 24.0 ± 3.5ºC.



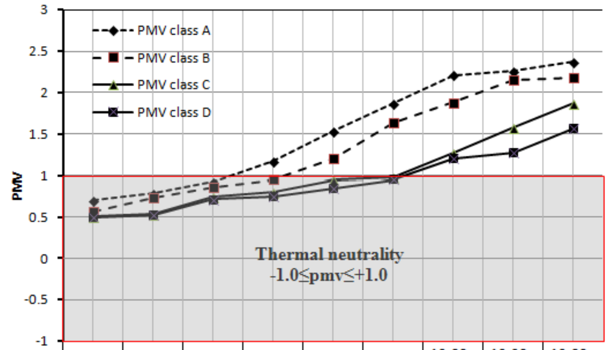
	9:AM	9:30AM	10:00AM	10:30AM	11:00AM	11:30AM	12:00PM	12:30PM	13:00PM
Class (A)	25	25.8	26.5	27.3	28.1	29.2	30.4	30.9	31.2
Class (B)	24.5	25.4	26.3	26.9	27.5	28.2	29	29.4	29.8
Class (C)	23.5	24.2	25	25.7	26.4	26.9	27.6	28.1	28.6
Class (D)	23.5	24.1	24.7	25.3	26	26.6	27.3	27.6	27.9

Figure 3: Indoor air temperature profiles inside old and new school classrooms with (ACS) comfort zone limit (24.0° ± 3.5ºC). Class A: Old Abu Alanda school–south classroom , Class B: Old Abu Alanda school–north classroom , Class C: New Abu Alanda school–south classroom , Class D: New Abu Alanda school–north classroom .

Based on the results (Figure 3) , students felt uncomfortable 56% of the time in classrooms of the old Abu Alanda School and 20% of the times in those of the new school.

- **Thermal Comfort Assessment–PMV Method**

According to specifications of ISO 7730 (ISO Standard 7730, 2005), the acceptable thermal environment for a PMV is between -1 and +1 and its PPD is below 20%. The DB software was used to estimate sub-hourly predicted mean vote values for the four classrooms mentioned in the previous section (Classes A, B, C, and D) .



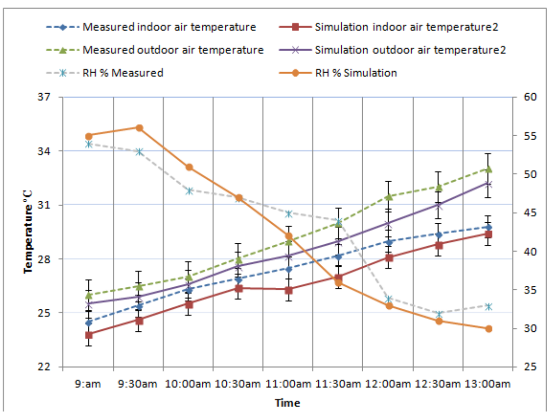
	9:am	9:30am	10:00am	10:30am	11:00am	11:30am	12:00pm	12:30pm	13:00pm
PMV class A	0.7	0.78	0.92	1.17	1.54	1.87	2.21	2.26	2.37
PMV class B	0.56	0.73	0.86	0.96	1.2	1.63	1.88	2.15	2.18
PMV class C	0.51	0.53	0.74	0.8	0.95	0.98	1.27	1.58	1.87
PMV class D	0.5	0.52	0.71	0.75	0.84	0.96	1.21	1.28	1.57

Figure 4 : PMV for the four classes (A, B, C, and D).

- The average PMV was 1.44 in the old Abu Alanda School and 0.85 in the new one. Consequently,
- the average PPD was 50% in classrooms of the old school and 19% in those of the new Abu Alanda School, which confirms the results of the previous section, where the old school had higher periods of discomfort than the new one.
- **Calibration Test–Base Case Validation**

For the validation of the base case models, a calibration test was conducted and indoor thermal measurements obtained from field monitoring were compared with the results of simulations. Furthermore, the outdoor air temperature readings obtained from the metrological department on the day of field monitoring were compared with the outdoor air temperature readings during the simulation in Design Builder. One classroom from each school was chosen for the calibration test: the north class in both the old (Class B) and the new Abu Alanda schools (Class D). Figures 5 shows a detailed comparison in terms of hourly indoor air temperature, relative humidity, and outdoor air temperature between the results of the simulation and field assessment on October 13, 2016.

Figure 5: Measured vs. simulated internal indoor air temperature, relative humidity, and average hourly outdoor air temperature–old school model/north classroom (Researcher, 2017).



The discrepancies between the measured and predicted results in both classrooms might have obtained because there were numerous paths for the infiltration of airflows in the buildings that allowed indoor heat to dissipate. However, in the DB model, the infiltration rate was fixed at values lower than those for the real buildings. Moreover, the simulated outdoor temperature was lower than that obtained from the metrological station. However, in both schools, the indoor temperature readings were in agreement with the simulation results.

Results and discussions

The following paragraphs address results and analysis for generated models, stating the annual energy demand for cooling and heating only. for energy use comparison, annual energy consumption for cooling and heating in classrooms of both schools were normalized per meter square in KWh/m²/year. The annual energy use generated in this research was validated based on the study by (Ali Al-Arja & Awadallah, 2015) . that had established an Energy Use Index(EUI) for government schools in Jordan. Figure 6 shows the annual energy consumption for cooling and heating, and the total energy consumption in kWh/m² for both schools in their original orientation (N–S/15º tilt).

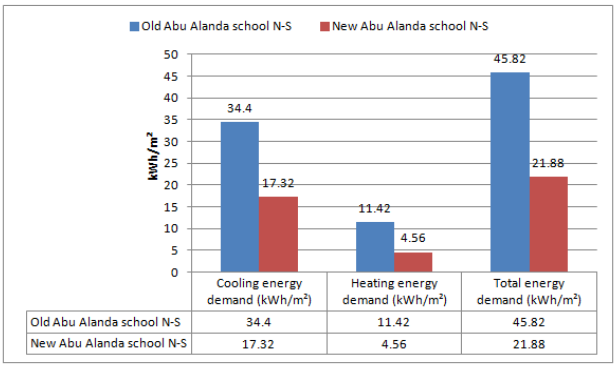


Figure 6: Annual cooling, heating, and total energy consumption for both schools in the original orientation (N–S/15º tilt).

From the above simulation results, by comparing annual energy consumption for cooling and heating in both schools, it was found that:

- Annual energy consumption for cooling in the new Abu Alanda School was 50% less than that in the old school.
- Annual heating energy consumption in the new school was 60% less than that in the old school.

In total, the new Abu Alanda School consumed 52% less energy for cooling and heating than the old one.

Effect of Schools' Orientation on Annual Energy Consumption for Cooling and Heating

To investigate the effects of orientation on annual energy consumption for cooling and heating in the two schools, base case models of both were simulated by assuming two orientations:

- Actual orientation (N–S/15 º tilt)
- Assumed orientation (E–W).

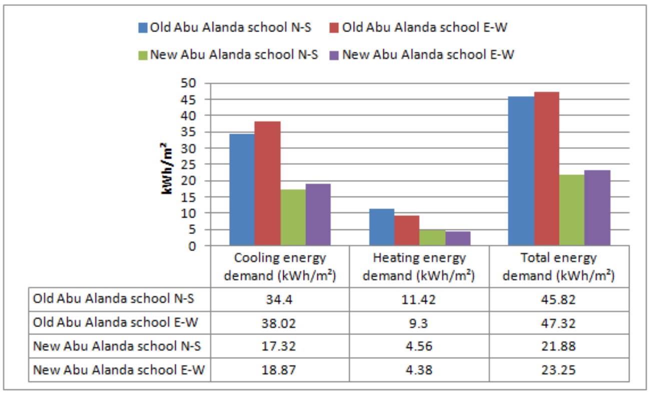


Figure 7: Annual cooling, heating and total energy demands in two schools for (E–W) and (N–S/15º tilt) orientations.

Based on the above analyses, it was found that regardless of the orientation of the schools, annual energy consumption for cooling in both the old and new Abu Alanda schools was much higher than that for heating. Moreover, in both schools, the E–W orientation consumed more energy for cooling and less for heating than the N–S orientation. Figure 7 shows that orientation did not have a major impact on energy consumption for heating and cooling. However, in both schools the E–W-oriented buildings consumed more energy for cooling than those oriented in the N–S direction.

Effect of Schools' Envelope on Annual Energy Consumption for Cooling and Heating

The above results show that the new Abu Alanda School consumed 50% less energy for cooling and 60% less for heating than the old one. This was because of the sum of the relevant parameters, including the design layout, model massing, envelope details, infiltration, and occupancy density.

To assess the effect of the envelope only on the resultant energy saving for cooling and heating in the new school compared with the old one, the parameters of the base case model of the old school (Table 5) were assigned to those of the new one. Applying the experimental design approach and changing one parameter at a time, it was possible to estimate the impact of changing each parameter (to match the original base case model) on energy saving for cooling and heating.

The impact of seven factors including envelope elements on the energy consumed for cooling and heating was studied: envelope parameters, mass and configuration, occupancy, internal windows, floors and partitions, and infiltration.

Table 5: Effects of parameters of the new Abu Alanda school base case model on cooling and heating energy saving (compared with the old Abu Alanda school) - (Researcher, 2017) .

Base case parameter	Old Abu Alanda school	New Abu Alanda school	Cooling energy saving (%)	Heating energy saving (%)
Walls	Concrete solid blocks (no insulation; U-value, 1.38 (W/m² k)	Concrete blocks, 5 cm polystyrene insulation; U-value, 0.46 (W/m² k)	4.19	25.12
Roof	Reinforced concrete, screed, and tiles (no insulation; U-value, 1.1 (W/m² k)	Reinforced concrete, foam concrete screed, and DPM; U-value, 0.44 (W/m² k)	7.12	19.68
Glass	Single-glazed windows; U-value, 5.77 (W/m² k); SHGC, 0.81	Double glazed windows; U-value, 2.66 (W/m² k); SHGC, 0.70	4.13	14.09
Frames	Aluminum frames	Aluminum frame, thermal break	1.2	1.9
WWR	30%	25%	2.33	-1.99
Louvers on south	No louvers on south side	120 mm louvers on south side	1.03	-0.76
Louvers on north	No louvers on north side	60 mm louvers on north side	9.13	-7.16
Internal windows	No internal windows	Single-glazed internal windows	7.23	-2.28
Floors	Heavy concrete slab 20 cm	Heavy concrete slab 30 cm	0.23	8.45
Partitions	10 cm brick	15 cm brick	0.34	1.7
Infiltration	1 ach/h	0.5 ach/h	5.04	6.34
Layout	Simple rectangular building	Three masses projecting from horizontal mass	3.15	-1.21
Occupancy	0.90	0.75	5.13	-3.8
Total energy saving (%)			50%	60%

- **Installing 12-cm louvers** on the south elevation of the new Abu Alanda School made the highest contribution to energy saving for cooling, 9.1%. This is owing to the shading effect in the blocking of direct sunrays in the afternoon hours. However, installing shading louvers in the new school increased annual consumption for heating by 7.1%, which indicates that using rotating shading devices is more feasible in hot and arid climates. However, considering the low budget allocated to government schools, a lack of maintenance, and low heating energy costs in Jordan, the increase in demand for heating can be compromised by saving on energy consumed for cooling.

- **The internal windows** in the new Abu Alanda School had the second-highest impact on energy saving for cooling, 7.2%, with a slight increase in demand for heating, 2.2%. However, internal windows promoted cross-ventilation in the summer and contributed slightly to a rise in demand for heating during the winter.

- **The configuration of the wall** and the addition of a 5-cm thermal polystyrene insulation in the new Abu Alanda School had the highest impact on energy saving for heating, 24.1%. Moreover, it contributed 4.1% to the resulting energy consumed for cooling, which indicates the importance of exterior wall insulation for energy saving on heating during the summer months in Amman.
- **Roof insulation** in the new school had the second-highest impact on energy saving for cooling and heating—7.1% and 18.6%, respectively. This agreed with the study by (Shariah et al., 1997) that had investigated the effects of roof insulation on annual energy consumption for cooling and heating in residential buildings in Jordan. This study found that insulating the roof with a 5-cm insulation reduced annual energy loads for cooling and heating by approximately 29% in Amman and 24% in Aqaba. Consequently, roof insulation is recommended to save energy used for heating in hot and arid climates.

- **The use of double-glazed window** panes in the new Abu Alanda School (U-value, 2.66 W/m² k; SHGC, 0.7) instead of single-glazed window panes in the old school (U-value, 5.77 W/m² k; SHGC, 0.81) resulted in energy saving for cooling and heating by 4% and 13%, respectively. This indicates that lowering the U-value has a significant impact on energy saving for heating. However a reduction in the energy used for cooling depends mainly on the SHGC.

- **The 25% WWR** in the new Abu Alanda School instead of 30% in the old one contributed slightly to saving energy consumed for cooling and heating—2.33% and 2%, respectively.
- **Adding a 6-cm shading to the new Abu Alanda School on the north elevation** had a minor impact on energy saving for cooling, 1%. Moreover, it slightly increased heating energy demand. Thus, it is not feasible to install shading devices on the north elevation in schools in Amman.

Considering the walls, roof, WWR, window glass and frame, and shading devices as components of the envelope , Figure 8 shows their effect on total energy saving in the new Abu Alanda School (considered as energy saving on cooling + heating) compared with the effects of other parameters (infiltration, internal windows, occupancy, floor, layout, and partitions) on total energy saved.
In conclusion, by analyzing the effect of the relevant parameters of the new school building on energy saved for cooling and heating, it was found that enhanced envelope parameters made the highest contribution to this in the new Abu Alanda School (66%), followed by the reduction in infiltration in the new school (10%). The layout of the school building and its configuration had only a 4% effect on total energy saving. Consequently, envelope retrofitting in school

buildings in Jordan can have a vital impact on energy saving for cooling and heating. Furthermore, the internal windows had a 9% effect on total energy saving. Thus, enhancing cross-ventilation through internal windows can also contribute to total energy saving.

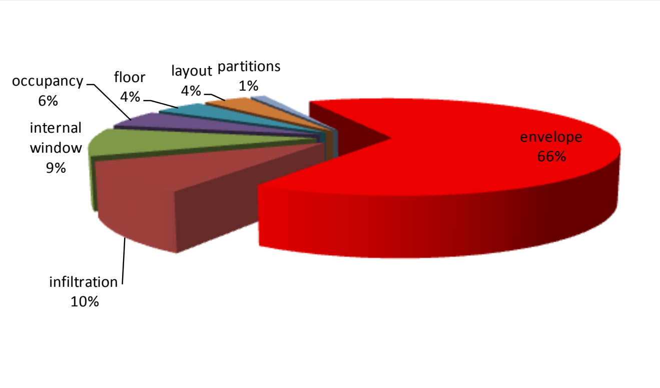


Figure 8: Envelope impact on total energy saving in new school compared with the impact of other parameters (Researcher, 2017).

Recommendations

1. envelope retrofitting in school buildings in Jordan can have a vital impact on energy saving for cooling and heating.
2. Use low U-value insulation in the external walls and roofs of the building. Thermal conductivity has a significant impact on heating energy consumption in Amman.
3. Although applying fixed solar heat gain control system on the south elevation results in some increase in annual heating energy consumption, this is balanced by the resultant energy saving for cooling. Furthermore, energy prices for cooling in Jordan are much higher than those for heating. Consequently, fixed solar heat gain control systems are recommended to retrofit government schools in Jordan.
4. lowering the U-value of the glass has a significant impact on energy saving for heating. However a reduction in the energy used for cooling depends mainly on the SHGC.

References

[1] MOE. (2014). Education Reform for Knowledge Economy second phase (ERfKE II)- Annual Narrative Report, Development Coordenation Unit .Jordan .

[2] Ali Al-Arja, O. & Awadallah, T. S. (2015). Energy consumption optimization in schools sector in Jordan. Architectural Science Review, 59(5), 400-412.

[3] MOE. (2014). Education Reform for Knowledge Economy second phase (ERfKE II)- Annual Narrative Report, Development Coordenation Unit .Jordan .

[4] MOE. 2015. The Annual statics report for 2014/2014 school year. Jordan.

[5] DOS. 2012. Annual Statistics Report, Jordan.

[6] MOE. (2014). Education Reform for Knowledge Economy second phase (ERfKE II)- Annual Narrative Report, Development Coordenation Unit .Jordan .

[7] MOE. (2014). Education Reform for Knowledge Economy second phase (ERfKE II)- Annual Narrative Report, Development Coordenation Unit .Jordan .

[8] Katafygiotou, M. C. & Serghides, D. K. (2014). Analysis of structural elements and energy consumption of school building stock in Cyprus: Energy simulations and upgrade scenarios of a typical school. Energy and Buildings, 72, 8-16.

[9] Katafygiotou, M. C. & Serghides, D. K. (2014). Analysis of structural elements and energy consumption of school building stock in Cyprus: Energy simulations and upgrade scenarios of a typical school. Energy and Buildings, 72, 8-16.

[10] Santamouris, M., Mihalakakou, G., Patargias, P., Gaitani, N., Sfakianaki, K., Papaglastra, M. & Geros, V. (2007). Using intelligent clustering techniques to classify the energy performance of school buildings. Energy and Buildings, 39(1), 45-51.

[11] Ali Al-Arja, O. & Awadallah, T. S. (2015). Energy consumption optimization in schools sector in Jordan. Architectural Science Review, 59(5), 400-412.

[12] Oral, G. K., Yener, A. K. & Bayazit, N. T. (2004). Building envelope design with the objective to ensure thermal, visual and acoustic comfort conditions. Building and Environment, 39(3), 281-287.

[13] ISO Standard 7730, 2005. Ergonomics of the thermal environment — Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria, Third edit. ed.

[14] De Dear, R. J. & Brager, G. S. (2002). Thermal comfort in naturally ventilated buildings: revisions to ASHRAE Standard 55. Energy and Buildings, 34(6), 549-561.

[15] Ali Al-Arja, O. & Awadallah, T. S. (2015). Energy consumption optimization in schools sector in Jordan. Architectural Science Review, 59(5), 400-412.

[16] Shariah, A., Tashtoush, B. & Rousan, A. (1997). Cooling and heating loads in residential buildings in Jordan. Energy and Buildings, 26(2), 137-143.