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Retrofit Measures Evaluation Considering Thermal Comfort and Energy Efficiency in School Buildings Using Design of Experiments

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Abstract **Original Research Article**

An evaluation of retrofitting public school buildings for energy-efficiency without sacrificing thermal comfort was investigated using the design of experiments. A current school building was used as a case study for this research. Three building codes were applied to improve energy efficiency in school buildings in Jordan. These codes are the Jordan building code, The Pearl Rating System for Estidama ''Emirate of Abu Dhabi'' and Jordan Green Building Council booklet. By using the three codes, six-building construction cases were derived by changing the U- values to enhance the thermal insulation for buildings, such as changing the material used in external walls and roof or Window to Wall Ratio ''WWR''. A statistical factorial analysis was performed to understand the main effect of each variable on the heating and the cooling load and if there is any interaction between these variables. The seven parameters used in the statistical analysis were; U-roof (0.18-1.963 W/m^2. K), U-wall (0.24-0.682 W/m^2.K), U-glass (3.63-6.11 W/m^2.K), WWR for north, south, east and west (33.5%-50%). After keeping the U-wall constant (U_W= 0.682 W/m^2.K) based on the payback period results, a second statistical analysis was performed on other parameters such as external shading (no shade or 1.6m shade from building surface) and U-roof (0.18-1.963 W/m^2.K), U-glass(3.63-6.11 W/m^2.K), WWR for north, south, east and west (33.5%-50%). An optimization technique was finally utilized to summarize all the relations between variables and the cost of materials by using Lagrange multipliers; an equation was written and solved by EES software.

Keywords: Energy-efficient public buildings; building codes; Green Buildings; Retrofit measures.

1. INTRODUCTION

Buildings consume a large amount of energy all the time around the year, public building consume around 40% of the total energy consumption and in developing countries the percent increased around 60%-80%, M. W. Ahmad [1].

Energy efficient building design required the integration of many factors, such as orientation, shading devices, and well-building insulation, to limit energy consumption through a building. In addition, windows, glazed facades and openings have an important role in building energy consumption regarding heating, cooling or lighting. Highly glazed facades and large windows have been increasingly used in new buildings, allowing access to daylight, solar gain, and external view. Therefore, their impact on cooling, heating and lighting demand in buildings is significantly needed to be considered in building design. Proper shading design can contribute well to indoor illumination from daylight, improve thermal comfort, and control solar heat gains and view out. Sozer [2] carried out a study on three model buildings in Turkey: one included an original building with ASHRAE Standard 90.1without improvement in the exterior wall insulation and glazing system; the second was a proposed building with improved thermal wall insulation and glazing system over ASHRAE 90.1:2004. The third base case was a typical Izmir hotel with single glazing and without insulation in roof and walls with both electrical and gas energy savings in each one. The results showed that buildings erected in the 1990s in Turkey are energy efficient and show around 37% differences in heating and cooling loads between the original and those based on ASHRAE st.d 90.1; also, around 40% of differences in heating and cooling between the proposed and the original building. The conclusion that of all the above was as follows: "the proposed building will reduce 40% of the energy used in heating and cooling''. Kim [3] studied the relationship between the capital investment of energy-efficient design for houses and the most energy-saving one to help decision-makers to reach the most effective solution to save energy and money. Energy Consumption Measure (ECM) gave different results among four variables: wall, window, roof, and floor. The results showed that large saving occurs when the window thermal efficiency is improved, but the roof and floor are not an economic decision when the final decision depends on the available budget. Kim and Romero [4] investigated many parameters to reach the most efficient energy design in Spain. In the study, the building was facing fully south with 20% additional glazing in north and south façade, 35cm lintel in the window frame and 2 cm additional insulation to reduce about 13% of thermal energy consumption. Kapsalaki *et al*., [5] presented the tool of Net Zero Energy Building (NZEB) that can be used in any location in the world. This tool takes into account the climate and economic situation. The design variables included PV module, lighting, shading, glazing area, insulation in three locations, and the study focused on the Lowest Life Cycle Cost (LLCC) solution. The results showed that when LLCC increases the Initial Cost (IC) also increases, so the trend was to install smaller energy services (e.g. HVAC) and microgeneration equipment (PV) to save the initial cost. Similar research was conducted by Al-Araj and Awadallah [6] to find the most efficient design for schools and studied how to reduce the energy consumption in school buildings in Amman by using (design-builder software and thermal simulation software). The effect of the (orientation, windowpanes, shading effect, insulation, and building height) on energy consumption was also investigated. The results showed that the highest energy consumption was when the Window to Wall Ratio (WWR) was between 25% and 50%, and single Low-E glazing and a minimum U-value of 0.45 W/m^{2}K. All values were taken from the green building guide (GBG), and no shading was needed. On the other hand, when the building was oriented north south, the use of low WWR, double glazing and GBG U-value requirement of 0.45 W/m^2. K with adjustable shading would save more than 0.995JDs/m^2/year. For all orientation choices, high energy saving could be achieved when using low E- glazing compared to clear single glazing (18 JDs/m^2). However, when using low E-glazing the saving was estimated to be (25 JDs/m^2) compared with double-glazing (60JDs/m^2) and due to lower initial cost. Calcerano and Martinelli [7], studied optimization and simulation of the most suitable location of trees around the 2-floor building were carried out in Italy to reduce the energy consumption in the HVAC system. The study covered the period from 21st June to 22nd September. The results showed that the most effective location is when the building is south-oriented, to reduce the energy consumption in summer without any change in the solar gain in winter. Studying different building types, Liu and Kojima [8] evaluated the Energy consumption and Thermal Performance analysis (EETP) of 183 households taken in three cities during hot summers and cold winters for different characteristics building time. The results showed that the amount of energy consumption was different in the three types of houses: high-rise building had the best situation and the multistory building had the lowest energy consumption, but the multistory had the worse thermal performance in hot summer and cold winter zones. The high-rise building was the best and had the highest thermal performance.

Belahya *et al*., [9] presented an example on the same topic in a dry land like ‘Algeria’ by using Design of Experiment (DOE). The study introduced the effect of the major critical parameters (13 parameters) in the building: (area of the building, factor shape, glass to wall ratio orientation …etc.). The results showed that the energy used in cooling is higher than that used in heating due to the hot climate. The transmission through the vertical wall will reduce energy consumption by 10KW/m2 year, but the effect of transmission on the ground is smaller in cooling and important in reducing heating load by eight KW/m^{2}year. On the other hand, the absorption factor of the solar radiation of the roof has the same effect in each cooling and heating cases. Alam and Islam [10], also investigated the most efficient window glazing and shading with overhang and side fines and their effect on solar energy transmitted to the indoor environment in a residential building in Bangladesh. The study used Energy Plus software to analyze three cases: a widow without overhang and side fins, window with overhang and without side fines, window with overhang and side fin. The results showed that the window with shading would be more efficient than that without shading for south facing. A single clear glazing window with side fines will be the most efficient for north facing. Windows using side fins and overhang are energy efficient in reducing both heating and cooling period, but using double Low-E clear (argon) glazing is more efficient.

Many studies investigated to reduce energy consumption in existing buildings; one of them by EL-Darwish and Gomaa [11], examined the relation between changing some features and some properties in the existing building under the name of “building retrofitting”. These properties include glazing, insulation, shading, and airtightness that show a reduction in energy consumption by about 33%. All the study results were collected in a new code for building Several advantages can be achieved from building retrofitting such as maintaining a new building code for each rejoin and decreasing the size of (HVAC) system unit Radwan *et al*., [12] which is the major benefit.

Building retrofitting can include one or more type of renewable energy utilization to reduce dependency on energy coming from fossil fuel. Ginidi *et al*., [13] introduced a solution for energy reduction in an office building by utilizing a photovoltaic cell system. Different types with the different structures were used, and then the project cost with the output capacity (KW) was calculated. AL-Saadi *et al*., [14] made a study for a 212 m^2 residential building in a hot climatic area in Oman. The parameters included in his study were the roof and wall insulation, lighting, and airtightness; using design-builder software, the reduction percentage achieved was around 42%. Edeisy and Cecere [15] studied the glazing retrofitting for building and concluded that changing to the recommended glazing type can reduce energy by around 16.5% by using the design-builder software. AL-Badry *et al*., [16] investigated building retrofitting by utilizing photovoltaic (PV) panels to achieve net-zero energy building and to reduce carbon emission as well. Liu *et al*., [17] take cost into account, i.e. the cost of energy efficiency retrofit of an existing building located in China, by using Energy Efficiency Retrofit (EER) program, through the availability of reroofing. A recent study by Salandin and Soler [18] took one factor or variable such as external wall alone and changed its layer and thicknesses using Integer Linear Programming (ILP). The external wall was chosen consists of six layers for more than 5.5 million combinations of selected material and different thicknesses.

In recent years, the energy cost has greatly increased due to limitations in fossil fuel resources and to instability in the cost of fuel due to many conflict issues in the region of the Middle East. The need to reduce energy consumption has risen and found other energy sources has become more important rather than at any time before.

Taking the annual energy consumption in Jordan, we find that the building sector has a higher value. Not only in Jordan but in the whole world, buildings consume a large part of the energy; as a result, finding a solution has become a necessity.

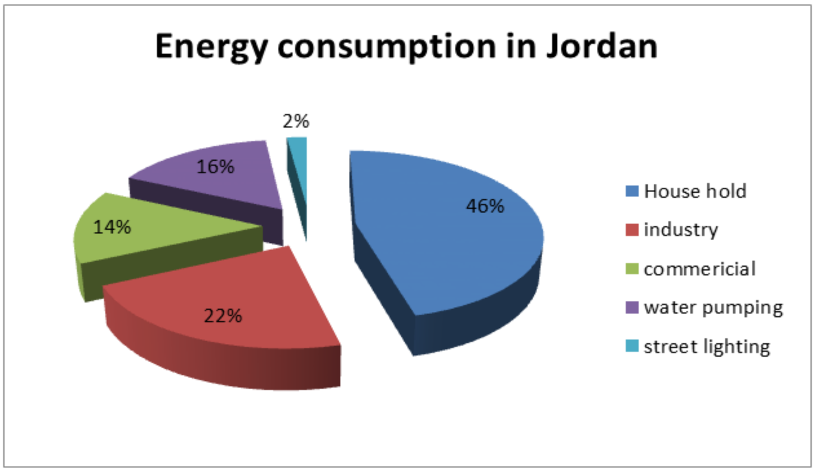

Figure 1: Annual energy consumption in Jordan, (MEMR, 2018)

Figure (1) shows the energy consumption in Jordan were the building sector (households) has a higher value followed by the industry sector, then the commercial sector; water pumping has the same energy usage as the commercial sector, followed finally by street lighting.

New building improvement called building retrofitting to achieve a new acceptable level for energy usage in order to find and build a new code for energy-efficient building.

2. METHODOLOGY

Many parameters affected on the energy consumption in public building such as infiltration, thermal mass of the building, orientation, shading devices and the thermal insulation of the building. In this study, the parameters are considered to improve school buildings' designs to become more efficient in energy consumption such as (thermal insulation (wall, roof and floor), glazing (single or double), window to wall ratio …etc.). To study all these complex parameters together, two soft wares, namely Hourly Analysis Program (HAP) and Mini Tab, were used to analyze the relationship between them and how they affect energy consumption in buildings.

Design of Experiment (DOE) will be used as an approach to analyze the complexity of these many variables; this would reduce the time and effort to calculate the cost of the new building design condition by changing all the previous parameters together.

In the current research, weather data, solar radiation in Jordan, Jordan code for buildings, and building data material used in (wall, floor, roof, layers of insulation if applied, glazing type) are required as an input to complete the analysis of this work. In order to achieve a high-performance envelope of the building, the DOE approach was implemented to decide the main parameters affected on the heating and cooling load of the building and omit the less significant ones. The focus of this study will be to determine the major parameters of building energy consumption, for example, U-Wall, U-Roof, U-Glass ...etc. and to propose an economical model with less heating and cooling load of the building, with the ultimate aim of developing a new building model for the school building.

In this study much-retrofitting, research was reviewed beginning with the definition of building-to-building procedures and materials, and finally the results.

The building retrofitting parameters were covered in many studies years ago, due to the need to reduce energy consumption and the limitation of fossil fuel resources. The most popular ones are window shading, glazing, window to wall area, thermal insulation and orientation, which help to reduce cooling, heating and lighting energy.

2.1 Factorial Design of Experiment Part

This research used the factorial design of an experiment to build a new model for school building construction; it included seven factors for each one, which means 128 runs to determine the significant and non-significant variables affecting heating and cooling loads in order to have a regression equation for both models.

The first case included a window to wall ratio for north, south, east, and west direction, U-value for roof and external wall, glazing(from single to double).

The second case: window to wall ratio for north, south, east, and west direction, U-value for the roof, glazing(from single to double), external shade on the south wall.

Simulation and Optimization

In this part, the design of experiment method will be used to define the simulation process for different chosen parameters. DOE method is a perfect solution to reduce the cost and the time required for any experiment with high accuracy. In this study, seven parameters are chosen to perform two factorial designs to study the effect of these parameters on the heating and cooling load and to investigate the main and multiple interactions between them.

These seven parameters are for the first case:
1. Overall heat transfer coefficient for the wall (U-wall)
2. Overall heat transfer coefficient for the roof (U-Roof).
3. Overall heat transfer coefficient for the window glass (U-Glass).
4. Window to wall ratio for the East wall (WWR-E).
5. Window to wall ratio for the West wall (WWR-W).
6. Window to wall ratio for the North wall (WWR-N).
7. Window to wall ratio for the South wall (WWR-S)

The second case factorial analysis has seven parameters:
1. External shading on the south direction.
2. Overall heat transfer coefficient for the roof (U-Roof).
3. Overall heat transfer coefficient for the window glass (U-Glass).
4. Window to wall ratio for the East wall (WWR-E).
5. Window to wall ratio for the West wall (WWR-W).
6. Window to wall ratio for the North wall (WWR-N).
7. Window to wall ratio for the South wall (WWR-S)

For each parameter, two levels will be studied: -1 for low level and +1 for the high level, where low level and high level present the original value for parameter without modification and the modified value for parameter after energy auditing.

Optimization is an approach to achieve the best design relative to a number of constraints associated with the problem. In this study, the optimum design for school building energy auditing will be based on the design of experiment results, plus working days for school during the year, which is mainly on cold days. This gave the heating load more importance in comparison with the cooling load.

The implementation of the action will have great results like:
1. Sustainable and passive design building and standards that have been developed in Jordan lately.
2. Energy efficiency building.
3. The potential for the future industry of devices like shading and thermal insulation procedure to reduce the energy losses due to thermal bridges.
4. Improve human performance and productivity that have a great impact on economic aspects.

2.2 Lagrange optimization method

If a function has a number of independent variables and a number of constraints, then Lagrange multipliers can be used, and the function continues and is differentiable.

The function needed to optimize U has $G_1$to G_m constraints; then, the model is represented as follows:

$U(x_1, x_2, x_3, \ldots, x_n)$ …….. Optimum

Constraints:

$G_1(x_1, x_2, x_3, \ldots, x_n) = 0$ ………………… (5-2a)

$G_2(x_1, x_2, x_3, \ldots, x_n) = 0$ …………………. (5-2b)

$G_m(x_1, x_2, x_3, \ldots, x_n) = 0$ ………………… (5-2n)

In Lagrange multiplier, minimum and maximum points for a solution of algebraic equation are found to determine the optimum (U). The objective function U(x) and the constraints G(x) are written in a new function Y(x) called Lagrange expression:

$$Y(x_1, x_2, \ldots, x_n) = U(x_1, x_2, \ldots, x_n) + \lambda_1 G_1(x_1, x_2, \ldots, x_n) + \lambda_2 G_2(x_1, x_2, \ldots, x_n) + \ldots\ldots + \lambda_m G_m(x_1, x_2, \ldots, x_n) \quad \text{……………..} \ (5\text{-}3)$$

λ: Lagrange multipliers.

3. Case study and building description

A real case study will be applied in a school located in a town near Irbid city with the aim to improve its building properties with the available cost to maintain an ideal school building design using the design of experiment (DOE).

Irbid city is located 70 Kms north of the Amman capital of Jordan in latitude 32.6^o and longitude 35.9^o. After Amman and Zarqa, Irbid has the third largest and is one with the highest population density in the Kingdom population with around 1,088,100 people. 85% of them are Jordanian and the rest are Syrians or Palestinians. It has an area of 30 square kms; 74.3% of the area is residential, 9.5% is service area, 7.7% unoccupied, 4.2% commercial, 3.3% industrial, and around 1.0% green area.

The current study applied in school buildings of two floors and with a total area of 1732.36 m^2. Schools are built with reinforced concrete and concrete blocks with large single glazed windows without shading devices. The schools use double-loaded corridors in the ground and first floors without windows to outside.

Table (1) shown weather in Irbid is hot in summer with warm nights and cold and rather wet in winter.

Table 1: Climate data for Irbid (Jordan Metrological Department)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average high (^{o}C)	13.4	14.3	17.7	22.8	27.2	30.0	31.5	31.8	30.1	26.7	20.7	15.5	23.5
Daily mean (^{o}C)	9.4	10.0	12.9	17.1	21.1	24.0	25.8	26.2	24.6	21.3	15.6	11.1	18.3
Average low (^{o}C)	5.3	5.7	8.0	11.3	14.9	17.9	20.1	20.5	19.0	15.8	10.5	6.7	13

3.1 Design variables

a- Pearl rating system for Estidama

This system creates sustainable building construction to balance the four-pearl: environment, economic, cultural and social. The type of building in pearl code includes an office building, retail (banks, post office, travel agencies), multi-residential: the pearl villa rating system, school: primary, secondary and colleges.

b- Green Building Council Case

In this case, the green building council was determined a specified value for each building component including roof, external walls, window glazing and the window to wall ratio for single glazing and double-glazing window. The R-value for each layer for the external wall and Table 2 & 3 shown the external wall layer roof layer properties.

c- Roof enhancement

This case included roof insulation according to Jordan building code; external wall, WWR and single glazing remain the same.

Table 2: External wall U- value

External wall case	U-value (W/m^2.K)
Green wall	0.457
Pearl case	0.237
Base case	0.682

Table 3: Roof U-value

Roof case	U-value (W/m^2.K)
Green case	0.306
Pearl case	0.181
Roof enhancement	0.848
Base case	1.963

The U-value for the glass type used in the building cases prototype are single and double glazing with U- value 6.11 (W/m^2.K) and 3.63(W/m^2.K).

3.2 Weather data

The weather data files included many variables and parameters:

- Taking weather data, location longitude, latitude and elevation into account during calculation.
- Calculating the overall heat transfer coefficient for wall, windows, roof, and door.
- Determining the cooling months and heating months throughout the year.

1. Cooling month: May, June, July and September.
2. Heating month: January, February, March, November and December.

- Defining a schedule for energy consumption, 8 hours system turned on from 7:00am to 2:00 pm, with occupancy time from 8:00 to 2:00pm.

4. RESULT AND DISCUSSION

4.1 Statistical Analysis

Design of Experiment (DOE): is a systematic procedure carried out under the controlled conditions to discover the unknown effect or to establish a hypothesis when conducting an experiment and we need to determine which factor or parameter is significant.

Factorial experiment: is one method of design of experiment deals with more than one factor and variable together, the study includes 7 variables, then the number of runs equal 2^k=2^7=128 run, each variable has two levels;

1. High level (the retrofitting case) and
2. Low level (the current case building)

This experimental design can tell the experimenter the main effect and to test if there is any interaction between the factors.

Table 4: Statistical analysis factors and their levels (Low level is the base case; high level is the retrofitting case)

First case analysis	Uw ($W/m^2.K$)	Ur ($W/m^2.K$)	Ug ($W/m^2.K$)	WWR(N) %	WWR(S) %	WWR(E) %	WWR(W) %
	High, 0.237 Low, 0.682	High, 0.18 Low, 1.963	High, 3.63 Low, 6.11	High, 33.5 Low, 50	High, 33.5 Low, 50	High, 33.5 Low, 50	High, 33.5 Low, 50

The first case analysis pearl system and negative case levels were chosen, but in the second analysis, the roof insulation was added to negative case roof construction and external shaded was added to the south window only with 1.6m long from the building surface. Figures 2 & 3 were below shown the normal plot, the interaction plot and the main effect plot for heating and cooling response.

The main significant variables affecting on the heating and cooling load are U-roof, U-wall, U-glass and WWR (North and South). The main effect plot shown the effect of retrofitted the U-roof, U- wall then U-glass and the WWR for north and south direction.

The interaction plot described the relation between interacted variables if the two lines red and blue are parallel then there is no significance. The regression equation for heating and cooling described the significance for each variable and its coefficient and sign described the normal plot relation if the variable on the right or left the normal distributed line.

Heating = 275.181 + 2.0531 wwn + 1.9203 wws - 0.0047 wwe + 0.3469 www - 23.4453 U-roof - 7.4813 U-wall - 5.6984 U-glass - 0.1891 wwn*wws - 0.0828 wwn*wwe - 0.1656 wwn*www+ 0.3609 wwn*U-roof + 0.0531 wwn*U-wall - 0.5328 wwn*U-glass - 0.5687 wws*wwe - 0.2828 wws*www - 0.1875 wws*U-roof + 0.7016 wws*U-wall - 0.8125 wws*U-glass + 0.0391 wwe*www - 0.0937 wwe*U-roof + 0.0016 wwe*U-wall - 0.3594 wwe*U-glass+ 0.2703 www*U-roof - 0.0187 www*U-wall + 0.0516 www*U-glass - 1.2359 U-roof*U-wall

Cooling = 420.502 + 3.425 wwn + 3.463 wws + 0.700 wwe + 0.459 www - 27.692 U-roof - 5.863 U-wall - 5.406 U-glass + 0.255 wwn*wws - 0.398 wwn*wwe - 0.095 wwn*www+ 0.247 wwn*U-roof - 0.017 wwn*U-wall - 0.648 wwn*U-glass - 0.142 wws*wwe+ 0.261 wws*www + 0.256 wws*U-roof + 0.192 wws*U-wall - 0.267 wws*U-glass- 0.005 wwe*www + 0.444 wwe*U-roof - 0.336 wwe*U-wall - 0.295 wwe*U-glass - 0.047 www*U-roof + 0.002 www*U-wall - 0.202 www*U-glass + 0.162 U-roof*U-wall+ 0.278 U-roof*U-glass + 0.073 U-wall*U-glass - 0.259 wwn*wws*wwe - 0.262 wwn*wws*www - 0.023 wwn*wws*U-roof + 0.381 wwn*wws*U-wall - 0.041 wwn*wws*U-glass + 0.106 wwn*wwe*www - 0.345 wwn*wwe*U-roof

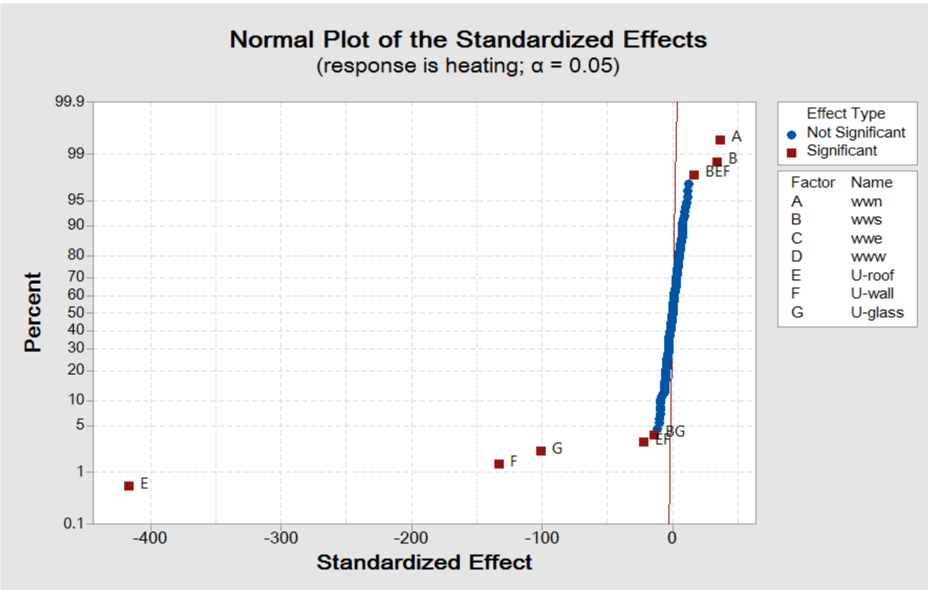

Figure 2: Normal plot for heating response

The normal plot for heating shown the most significant variable that affecting on the heating load arranged from the significant to the less significant variable: U- roof, U- wall, U- glass, WWR(N) and WWR(S), the points on the blue line represent the nonsignificant variables.

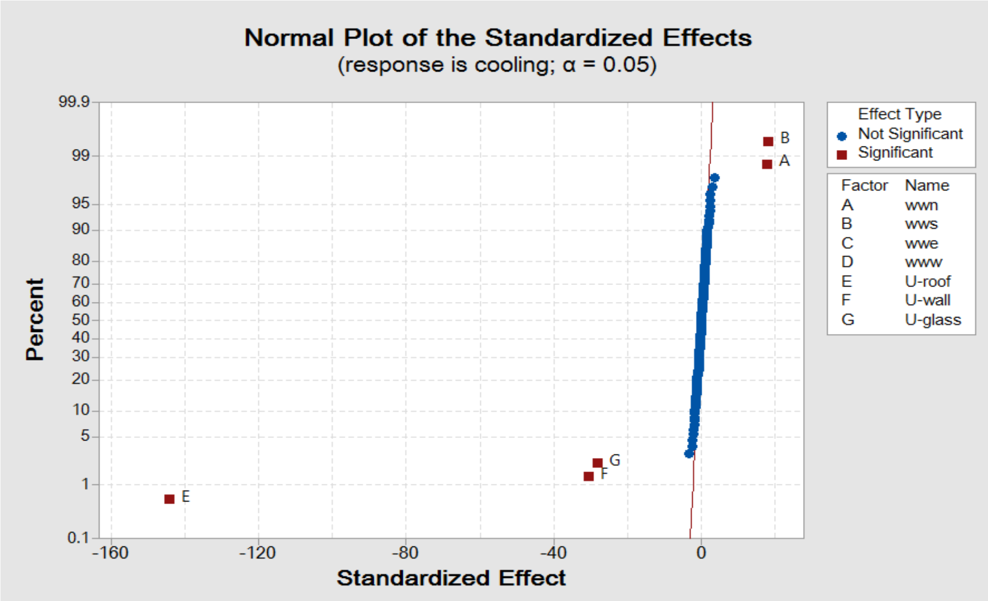

Figure 3: Normal plot for cooling response

The normal plot for cooling shown the most significant variable that affecting on the heating load arranged from the significant to the less significant variable: U- roof, U- wall, U- glass, WWR(N) and WWR(S), the points on the blue line represent the nonsignificant variables.

Table 5: Second statistical analysis model levels. (High level: roof thermal insulation, double glazing and south window external shading, low level: base case)

Variable	WWR(W) %	WWR(E) %	WWR(S) %	WWR(N) %	Ug ($W/m^2.K$)	Ur ($W/m^2.K$)	Shade (m)
Low level	Low:50	Low:50	Low:50	Low:50	Low:6.11	Low:1.963	Low:0
High level	High:33.5	High:33.5	High:33.5	High:33.5	High:3.63	High:0.848	High:1.6

For the second statistical analysis for the building envelop, the effect of shading included. The shade type used for the building envelop is overhang external shading with 1.6m from the building surface, revel depth=30cm, right and left extension=30.0cm, as shown in the figure (4) below.

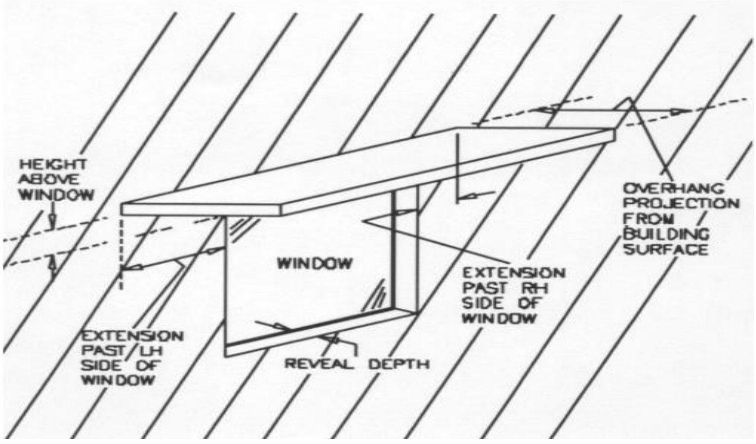

Figure 4: Overhang shading

4.3.1 Statistical analysis of the second prototype

Results are shown in the figures (5) (6) and (7).

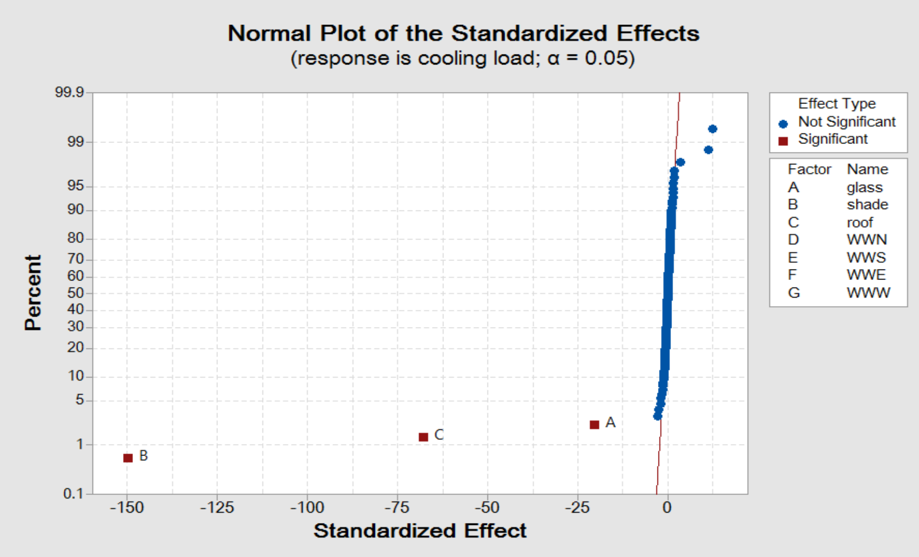

Figure 5: Normal plot for cooling regression equation with shading

The normal plot for cooling shown the most significant variable that affecting on the heating load arranged from the significant to the less significant variable: shade, U- roof and U- glass, the points on the blue line represent the nonsignificant variables.

Figure (6) summarized the energy consumption for the heating and cooling.

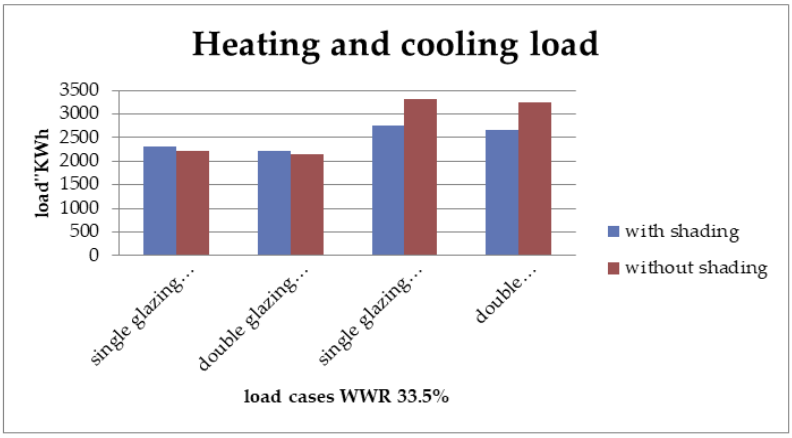

Figure 6: Heating, cooling load for shaded, and no shaded building

4.4.1 Simple Payback Period Summary

The simple payback period calculated for the six prototypes and the base case by calculating the material retrofitting cost and the annual bill energy consumption to find the lowest payback period.

Table 6: Payback period for the prototypes

Case	Material cost (JD)	Cooling cost (JD/year)	Heating cost (JD/ year)	Total year pill cost (JD)	Payback period Month, day
-1	80449.85	73023.49	17000	90023.49	-------
2	85709.44	67043.34	14500	18543.34	7 m, 13day
(+1)	124814.25	63520.77	13162	76682.77	3y,3m, 29 day
(+1) '(33.5%)	121905.39	61407.32	13187	74594.32	2y,8m, 8day
(+1)'' (50%) gypsum board	109120.25	63733.76	13540.8	77274.56	2y, 3m
(3)	139318.56	66437.12	13639	80076.12	5y,11m, 1 day
(3)' (33.5%)	135306.45	63799.30	14054	77853.3	4y,6m, 4day

4.4.2 Discount Payback Period.

The discount payback period includes the interest rate in calculation, the interest rate determined in Jordan by the central bank of Jordan annually, the calculated payback period below with interest rate i=5%, and the main equation used in the calculation are:

Table 7: The discount payback period

Case number	Capital investment	Cash flow (saving per year)	Payback period
(-1)	80449.85		
(2)	85709.44	71479.66	3moth,7day
(+1)	124814.25	13340.72	12year,11month,5day
(+1),33.5%WWR	121905.39	15429.17	10year, 3month, 22 day
(+1) 50%WWR, Gypsum board.	109120.25	12748	11year, 5month, 12day
(3)	139318.56	9947.37	19year, 11month,12day
(3), 33.55 WWR	135306.45	12170.19	16year, 7month, 20day
(2) Single glazing, 33.5% WWR, shading	89093.44	17853.81	5year, 10month, 18day
(2) double glazing, 33.5% WWR, shading	94430.74	20210.5	5year, 5month, 16day

The present study used Lagrange multipliers to find the minimum material cost in building and maximum energy saving used for space heating or cooling.

After regression analysis, the equation summarized the significant factors that were added to cost equation constraints to write the Lagrange equation for both heating and cooling loads as follows:

Optimized cooling equation:

$Y=(((1109120.25–80449.85)/(73023.49-(397.417-5.323*U_g-38.868*shade-17.59*U_r) *(8*20*3*0.256)))) + (\lambda_1*WWR*96.87) + (\lambda_2*WWR*87.44)$ ……. (5-5)

Optimized heating equation:

$Y = ((86996.85-80449.85)/((17000)-(275.181+2.053*WWR+1.92*WWR- 23.445*U_r – 7.481*U_w -5.698*U_g)*(8*20*796.25*5*3600/42000000))) +(\lambda_1*WWR*87.44) + (\lambda_2*WWR*96.87)$ ………….. (5-6)

Table 8: Optimization result for building in six prototypes

	Case	Shade (m^2)	Ug ($W/m^2.K$)	Ur ($W/m^2.k$)	U_w ($W/m^2.K$)	WWR (%)	Material cost (JD)	Annual bill (JD)	P.B.P (month)
1	Current case	0	6.11 DG	1.963	1.963	0.335	80449.85	90023.49	0
2	Jordan building code	1.6	3.63 SG	0.848	0.682	0.5	86996.85	81543.34	7m, 18 day
3	Pearl one roof material enhancement	1.6	3.63 SG	0.199	0.24	0.5	110407.3	77274.56	35m,17 day
4	Pearl 33.5%WWR	1.6	3.63 SG	0.18	0.24	0.335	123192.4	74594.32	50m,23 day
5	Pearl 50%WWR	1.6	3.63 SG	0.18	0.24	0.5	126101.3	76682.77	54m, 6 day
6	Green 33.5%	1.6	3.63 SG	0.306	0.46	0.335	136593.5	77853.3	66m,12 day
7	Green 50%	1.6	3.63 SG	0.306	0.46	0.5	140605.6	80076.12	71m, 4day

After the optimization procedure and calculation, the minimum payback period for the second prototype, which is the same for the base case with insulation material added for the roof structure and double-glazed window used. The longest payback period for the green building prototype with 50% WWR.

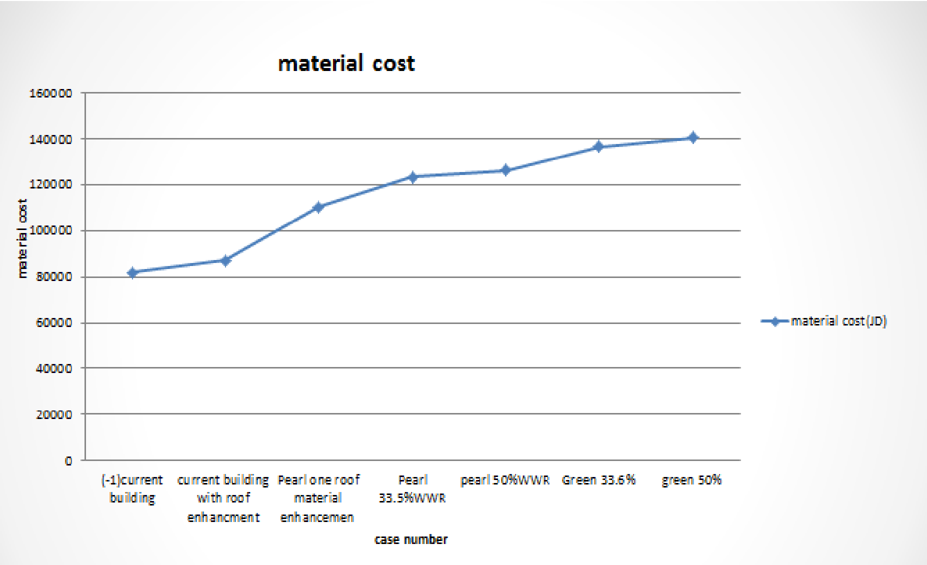

Figure 7: Material cost in six building prototypes

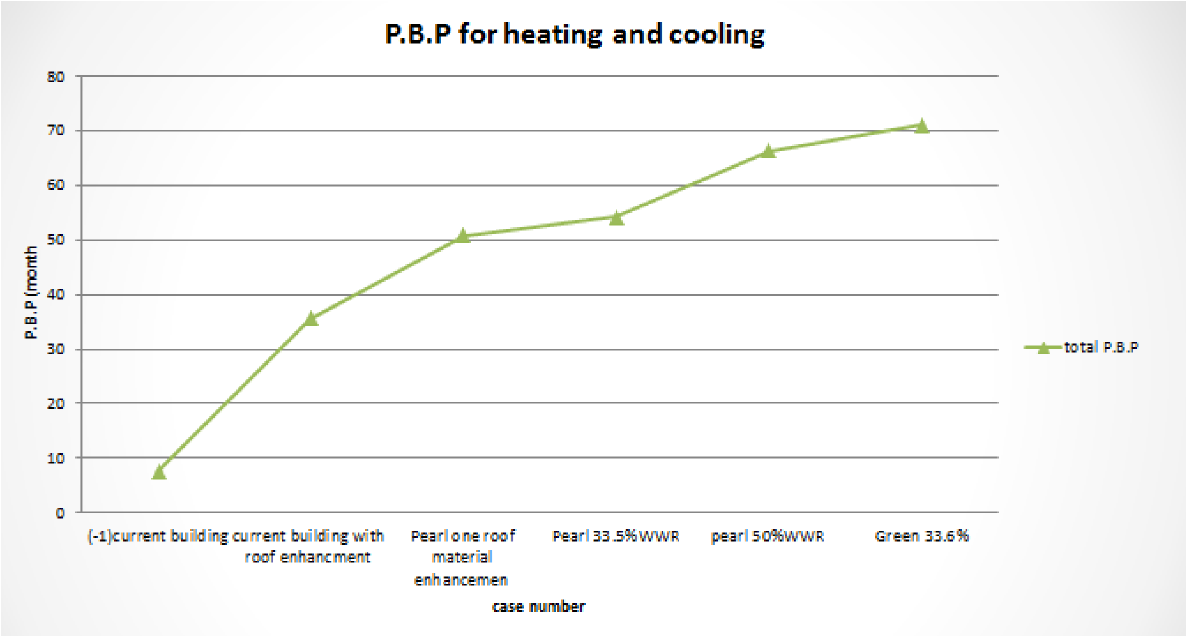

Figure 8: P.B.P for heating and cooling.

In figure (7) the material cost increased from the first prototype, which has the minimum cost, to the sixth prototype, which has the maximum material cost. Figure (8) shown the payback period increased with the material cost increased from the lowest P.B.P from the first prototype to the six prototypes.

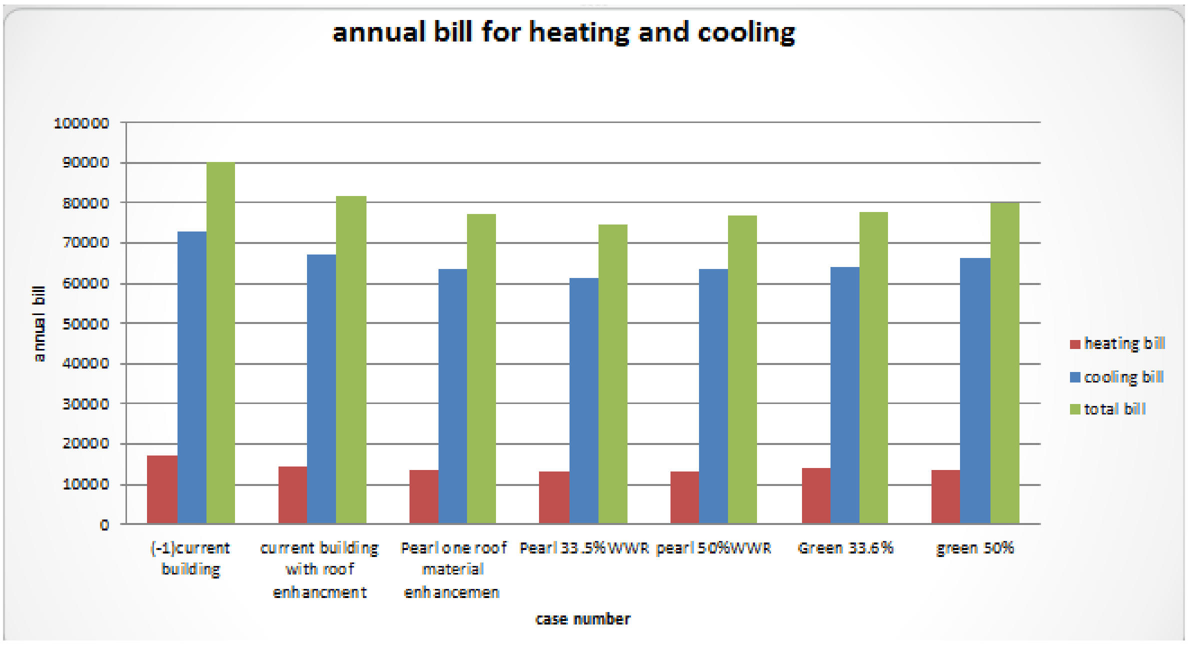

Figure 9: Annual bill for heating and cooling

The annual energy bill summarized in Figure (9) for the cooling, hearing and the total annual energy bill, the lowest energy bill for the Pearl prototype with WWR 33.5% and the maximum energy bill for the base case building structure.

5. CONCLUSIONS

A new prototype for energy-efficient public buildings was investigated using design of experiments. Three building codes were studied and improved to find a new prototype for school buildings in Jordan; the main codes are Jordan building code, The Pearl Rating System for Estidama ''Emirate of Abu Dhabi'' and Jordan Green Building Council booklet. For the three codes, six-building construction cases were studied, by changing the material for external walls and roof or Window to Wall Ratio ''WWR''. The energy bill for the entire year was found to calculate the payback period. The study also included a statistical analysis applied for seven parameters to find the significant factors in energy consumption. The seven parameters are U-roof (0.18-1.963 W/m^2.K), U-wall (0.24-0.682 W/m^2.K), U-glass (3.63-6.11 W/m^2.K), WWR for north, south, east and west (33.5%-50%) and external shading (no shade or 1.6m from building surface) after keeping the U-wall constant (U_W= 0.682 W/m^2.K) depending on the payback period results. An optimization technique was finally used to summarize all the results by using Lagrange multipliers. It was found that the main significant factors affecting the heating and cooling load of the building were U_r, U_w and Ug, then WWR (North and South). The external shading devices recommended to reduce the cooling load by 18% for double glazing 33.5%WWR, whereas the heating load was increased by 3.5% for double-glazing with 33.5% WWR for both cases due to the increased in the lighting energy used to overcome the natural lighting. Based on the research findings and results, the followings are advised:

1. For public buildings such as school buildings, the semester can be shifted to August, September and October to enhance the cooling system efficiency if an external shading device is used; thus, the first semester" winter season'' can be shortened to reduce the energy used in heating.
2. The use of double-glazed window increases the payback period with no significant reduction in the cooling load when external shading is used.
3. Investigating a movable fin built in the external shading device itself can increase the efficiency of shading in winter by heating the air inside the room, and thereby reducing the need for electrical light.

REFERENCES

1. Ahmad, M. W., Mourshed, M., Mundow, D., Sisinni, M., & Rezgui, Y. (2016). Building energy metering and environmental monitoring–A state-of-the-art review and directions for future research. *Energy and Buildings*, *120*, 85-102.
2. Sozer, H. (2010). Improving energy efficiency through the design of the building envelope. *Building and environment*, *45*(12), 2581-2593.
3. Kim, D. (2010). Optimizing cost effective energy conservation measures for building envelope. *Energy Engineering*, *107*(3), 70-80.
4. Ruiz, M. C., & Romero, E. (2011). Energy saving in the conventional design of a Spanish house using thermal simulation. *Energy and buildings*, *43*(11), 3226-3235.
5. Kapsalaki, M., Leal, V., & Santamouris, M. (2012). A methodology for economic efficient design of Net Zero Energy Buildings. *Energy and Buildings*, *55*, 765-778.
6. Ali Al-Arja, O., & Awadallah, T. S. (2016). Energy consumption optimization in schools sector in Jordan. *Architectural Science Review*, *59*(5), 400-412.
7. Calcerano, F., & Martinelli, L. (2016). Numerical optimisation through dynamic simulation of the position of trees around a stand-alone building to reduce cooling energy consumption. *Energy and Buildings*, *112*, 234-243.
8. Liu, H., & Kojima, S. (2017). Evaluation on the energy consumption and thermal performance in different residential building types during mid-season in hot-summer and cold-winter zone in China. *Procedia Engineering*, *180*, 282-291.
9. Wang, C. (2017). A Fast Evaluation Method for Energy Building Consumption Based on the Design of Experiments.
10. Alam, M. J., & Islam, M. A. (2017). Effect of external shading and window glazing on energy consumption of buildings in Bangladesh. *Advances in Building Energy Research*, *11*(2), 180-192.
11. El-Darwish, I., & Gomaa, M. (2017). Retrofitting strategy for building envelopes to achieve energy efficiency. *Alexandria Engineering Journal*, *56*(4), 579-589.
12. Radwan, A. F., Hanafy, A. A., Elhelw, M., & El-Sayed, A. E. H. A. (2016). Retrofitting of existing buildings to achieve better energy-efficiency in commercial building case study: Hospital in Egypt. *Alexandria engineering journal*, *55*(4), 3061-3071.
13. El Gindi, S., Abdin, A. R., & Hassan, A. (2017). Building integrated Photovoltaic Retrofitting in office buildings. *Energy Procedia*, *115*, 239-252.
14. Al-Saadi, S. N., Al-Hajri, J., & Sayari, M. A. (2017). Energy-efficient retrofitting strategies for residential buildings in hot climate of Oman. *Energy Procedia*, *142*, 2009-2014.
15. Edeisy, M., & Cecere, C. (2017). Envelope retrofit in hot arid climates. *Procedia environmental sciences*, *38*, 264-273.
16. Albadry, S., Tarabieh, K., & Sewilam, H. (2017). Achieving net zero-energy buildings through retrofitting existing residential buildings using PV panels. *Energy Procedia*, *115*, 195-204.
17. Liu, Y., Liu, T., Ye, S., & Liu, Y. (2018). Cost-benefit analysis for Energy Efficiency Retrofit of existing buildings: A case study in China. *Journal of cleaner production*, *177*, 493-506.
18. Salandin, A., & Soler, D. (2018). Computing the minimum construction cost of a building's external wall taking into account its energy efficiency. *Journal of Computational and Applied Mathematics*, *338*, 199-211.