Energy Demand Analysis for Building Envelope Optimization for Hot Climate:
A Case Study at An Najah National University

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ABSTRACT: The study aims to analyse the heating and cooling demand of the An Najah university campus, and to optimize the building envelope for two selected buildings, in order to achieve energy efficiency, and make use of solar energy. Building and urban simulation programs are used to evaluate the effects of applying different technologies and design strategies on the energy consumption. The university campus hosts 11 university buildings. The proposed methodology makes use of an urban energy modelling tool, called CitySim and building simulation tool called DesignBuilder based on EnergyPlus engine model to analyse the heating and cooling demand of the university campus and assess the solar potential of the site. The energy calculation considers the hourly heating and cooling demand per building, and for the whole campus. The solar irradiation received by the buildings envelope (walls and roofs) consider the impact of the urban environment, including the inter-reflections between buildings and albedo of the outdoor surfaces. The climatic data provided by Meteonorm. The geometrical information of the campus and selected buildings are retrieved by GIS while the physical characteristics of buildings are based on on-site previous studies. The results point to the potential for a significant decrease in energy consumption for cooling and heating.
Keywords: Building Envelope, solar energy, passive design features, hot climate, low energy consumption

INTRODUCTION

With the increasing population and living standards, the energy issue is becoming more and more important in today's world, because of a possible energy shortage. Because of the growing effect of global warming and the pending energy crises, the two disciplines have started striving for sustainability (Tester, 2005). Until recent years, energy efficiency has been a relatively low priority to building owners and investors in the Middle East. However, with the dramatic increase and awareness regarding energy use, energy efficiency is fast becoming part of real estate management, design, and operations strategy (Abdeen M. O, 2008.). In the Middle East, 40% of energy use is consumed in buildings, more than by industry or transport, and the absolute figure is rising fast, because of the recent construction boom. In hot climates, the energy consumption in building for cooling, and lighting is enormous due to problems of overheating and solar gain. These problems underline the need of a sustainable urban design to decrease the energy demand of buildings, and increase the use of renewable sources.

Palestine suffers from a shortage of natural resources, particularly energy and water, and imports almost 100% of its energy consumption needs from neighbouring countries (Abu-Hafeetha, 2009). More than 65% of this imported energy is consumed in buildings. In the year of 2005, the building sector in Palestine consumed more than 220ktoe, which represented 64% of national energy consumption and ranked first before the transportation and industrial sectors, as shown in (Fig. 1) (PCBS, 2005). Furthermore, it is important to clarify that most buildings are not equipped with heating and cooling systems. This leads to real health, environmental and safety problems as most people rely on dangerous heating sources. One of the major factors in the increased use of electric energy is the use of air conditioning units, which has recently become quite popular to attain thermal comfort during long hot summer and cold winter (Haj Hussein, 2012). Considering this reliance and the rapid urbanization and construction in the West Bank and Gaza Strip, there is an urgent need to not only address policies and guidelines, but also create and spread innovative sustainable construction technologies.

It is worth mentioning, that although the availability of solar energy in Palestine is high, its integration in the building design is very limited. Developing alternative energy efficient building envelope construction technologies and urban design strategies to make use of solar energy to achieve comfort in the Palestinian buildings becomes increasingly necessary. In response to the growing concerns about energy conservation in buildings and its implications for the environment, several evaluation indices on energy and thermal performance for building envelopes have to be carried out, which are able to ensure cost effective energy efficiency opportunities incorporated into new buildings. These indices should focus on U-value of roof, wall and window, thermal inertia of wall and roof, building's shape coefficient, window-to-wall area ratio, shading and coefficient of heat loss (Chow and Philip, 2000) (Yilmaz, 2007). In 2004, the ministry of local government has published their guidelines for energy efficient building design in Palestine (government, 2004) (ARIJ, 2003). Unfortunately, this guideline, which has not been applied to the design process of buildings, focused on the basic calculations for surfaces' U-values and calculation methods, etc. rather than modifying construction techniques or at least determining the best U-values and adequate passive strategies for each climatic zone. Moreover, a study of the regulations in the municipal building codes and energy efficient building code published in 2004 do not address the issues of energy efficiency in any building category. Owners, architects and even developers of buildings have not considered ways in which energy use can be reduced. Designs of buildings, in general, are not responsive to the requirements of Palestine's climate.

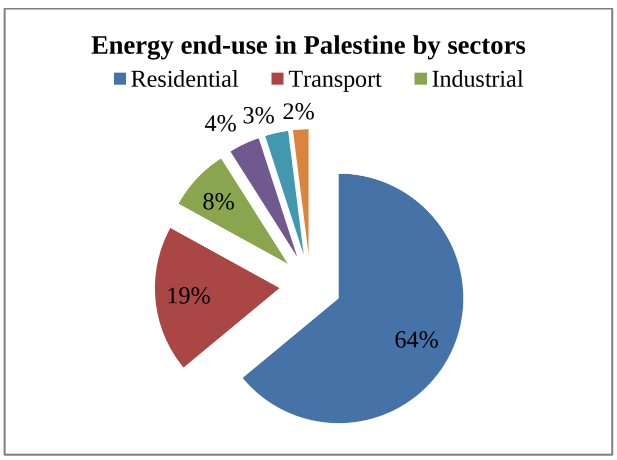

Figure 1: Energy end-use in Palestine by sectors for 2005 (PCBS, 2005).

Building envelope construction techniques has an important role in the approach for building energy efficiency. Building envelope, which by adaptive or responsive actions will make it possible to utilize more renewable energy for building purposes, as well as reducing the energy consumption for heating and cooling (Andresen, 2005,). Construction of buildings in Palestine depends on locally available materials such as natural building stone with distinct external envelope for traditional and contemporary buildings. The main difference between them is the smaller depth of external walls for contemporary buildings, which can be obtained by using new technologies. Building stone is one of the most preferred construction materials in Palestinian territories not only, because it is widely available in the local market but also due to its distinctive characteristics such as durability and hardness. These characteristics made this material a very expensive material compared to other materials such as plaster and fair face concrete.

There are many building envelope types of external walls used in Palestine; most of them use stone, concrete and hollow concrete block. According to a survey carried out by the ministry of local government, external wall types in buildings were:

1- Concrete external walls (20-25 cm thickness).
2- Hollow concrete block walls (10-20 cm thickness).
3- Stone walls, in which a layer of 7 cm thick stone is built, and then a new layer is casted (22-23 cm thickness of concrete or concrete and hollow concrete block) behind the stone layer.

The three types in some cases being thermally insulated by the following methods:

1- A layer of hollow concrete block added to the inner side of the wall.
2- A layer of hollow concrete block and a cavity added to the inner side of the wall.
3- A layer of hollow concrete block and a layer of isolation material used in the inner side of the wall.

To achieve energy efficient building and make use of renewable energy it worth mentioning that different climates may need different design strategies for optimum thermal performance of a building. Designing a building, that respond to the natural environment can provide a desire level of comfort in the prevailing environment (Baker, 1987). Unfortunately, in modern building technologies, the existing cities are redeveloped to form a series of glass; and concrete blocks of offices and houses, which commonly neglect the context of climate and culture.

The present study for An Najah university campus aims to analyse: site solar potential, effects of topography, heating and cooling demand, and building envelope optimization, in order to achieve thermal comfort, energy efficiency, and make use of renewable energy. The university campus hosts 11 buildings (1. Faculty of fine art building; 2. University theatre; 3. University library; 4. Faculty of pharmacy; 5. Faculty of medicine; 6. University scientific centres; 7. University mosque; 8. Faculty of engineering; 9. Faculty of science; 10 faculty of law; And 11. Child canter) (Fig. 2). Because of the growing of the students' population, the campus is growing and new buildings are planned to densify the area. The campus energy consumption is high, due to the lack of: thermal insulation; appropriate glazing type; effective shading and natural ventilation strategy. Building and urban simulation tools (CitySim and DesignBuilder based on EnergyPlus) are used to evaluate the effects of applying different technologies and design strategies on the comfort and energy consumption.

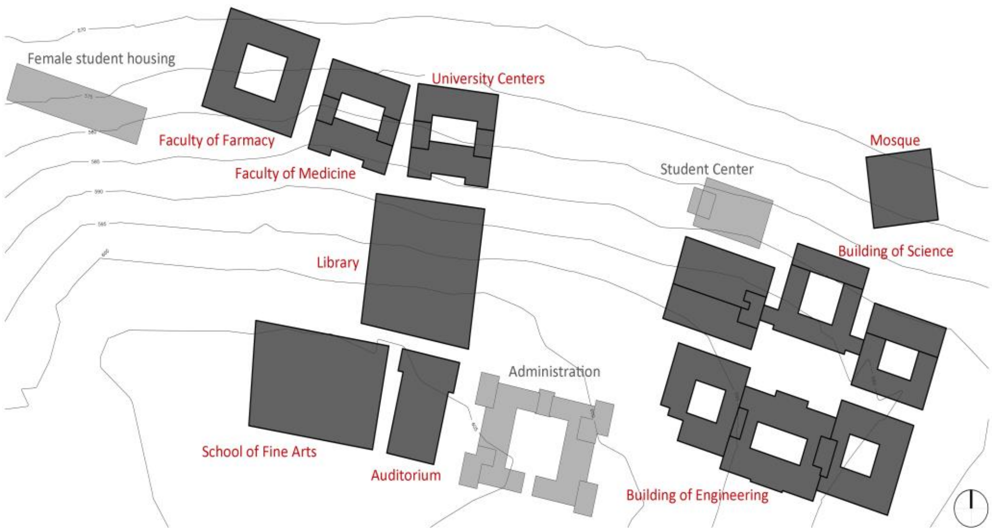

Figure 2: Map of the University; Existing building are coloured with dark grey, and the future buildings are coloured with clear Grey.

METHODOLOGY

In Palestine, there are six climatic zones. The city of Nablus (32°13' N, 35°16' E) is located in the Northern part of the West Bank in the mountains climatic zone and according to Koeppen Climatic classification presents a hot arid climate (Peel, 2007.), characterized by warm temperature, with low precipitations and high temperatures during the summer time. The city, located at 550 m above the sea level, presents a particular topography, because it is positioned in a narrow valley, oriented East-West. The university campus is located in the Western part of the city and hosts 11 university buildings, one per each faculty.

The proposed methodology makes use of an urban energy modelling, called CitySim (Robinson, 2009), to analyse the heating and cooling demand of the university campus and assess the solar potential of the site. The energy calculation considers the hourly heating and cooling demand per building, and for the whole campus. The solar irradiation received by the buildings envelope (walls and roofs) consider the impact of the urban environment, including the inter-reflections between buildings and albedo of the outdoor surfaces. The climatic data are provided by the software Meteonorm (Bern et al, 2013), and the geometrical information of the district are retrieved by GIS, the physical characteristics of buildings, such as the materials of the envelope and the glazing ratio are based on on-site previous studies. The glazing ratio is defined based on available drawings of facades of the buildings; the average ratio for all facades corresponds to 0.2. The envelope of the buildings has a central core made in concrete, and externally is covered by stones or plaster; the physical characteristics of the envelope are summarized in (Table 1). The infiltration rate in the buildings is assumed equals to 0.7 1/h, considering that the air insulation provided by the envelope is not performing. The temperature set point for heating and cooling is 21 and 26°C respectively. The ground covering is assumed to be made of concrete tiles, with an albedo equals to 0.25.

Based on the previous analysis, the output created by the software CitySim were used as input parameters for the simulations with DesignBuilder (a simulation program for checking building energy, carbon, lighting and comfort performance. Links with all major 3-D CAD software. Includes parametric analysis. It is relying on Energyplus calculation engine which is a whole building energy simulation program for modelling building heating, cooling, lighting, ventilating, and other energy flows) (Design Builder Software Ltd 2005-2016). This approach is used for two selected buildings (Faculty of fine art (1) and Faculty of engineering (8)) in order to optimize their energy performance. Using parametric study, we found the impact of different walls construction thermal insulation, glazing optimization, shading, and natural ventilation on energy consumption (Heating and cooling). Each predefined parameter has been systematically modified and evaluated to find the most effective one that minimized the most energy consumption, while maintaining the thermal comfort in the building unit. Crossed and comparative tests are realized to determine which compulsory indices have greatest impact on the yearly energy consumption. The simulation model was done using drawings for the existing buildings. The resulting DesignBuilder model contains over 40 different zones, different exterior wall types (existing and proposed), and different window types. Envelope physical properties were taken from previous onsite studies. HVAC system and activities were defined based on existing conditions. Internal gain, working hours, comfort conditions, and occupancy profile was provided based on (ASHRAE, 2010). The climatic data was also provided by the software Meteonorm

Table 1: Stone cladding wall. Thermophysical parameters: Density, Specific Heat, Thermal Conductivity and Thickness.

Name	Density ρ (kg·m^{-3})	Specific Heat *c* (J·kg^{-1}·K^{-1})	Thermal Conductivity κ (W·m^{-1}·K^{-1})	Thickness (m)
Stone	2600	800	2.3	0.05
Mortar with steel grid	2200	1100	1.4	0.05
Reinforced concrete	2400	850	2.1	0.2
Hollow block	1200	1000	0.7	0.1
Plaster	900	1000	0.21	0.02

RESULTS

Campus energy demand analysis and solar potential

The heating and cooling demands for the whole campus buildings (1. Faculty of fine art building; 2. University theatre; 3. University library; 4. Faculty of pharmacy; 5. Faculty of medicine; 6. University scientific centres; 7. University mosque; 8. Faculty of engineering; 9. Faculty of science; 10 faculty of law; And 11. Child canter) are computed by the software CitySim, and summarized in (Fig. 3). The average annual heating demand of the campus corresponds to 58 kWh/m^2, and the average cooling demand corresponds to 46 kWh/m^2. The average cooling demand is lower than the heating demand due to the exposition of the campus as it is located on the Northern part of the valley.

Buildings 5 and 6, corresponding to the Faculty of Medicine and the University Centre respectively, have the highest heating demand (around 84 kWh/m^2: 44% higher than the average demand of the site). These buildings are positioned on the lowest part of the valley (height between 575 to 585 meters above the sea level), exposed to the North and consequently highly shadowed by the topography and the neighbouring buildings (Fig. 4). Additionally their geometry is subdivided into steps, increasing the external envelope exposed to the North.

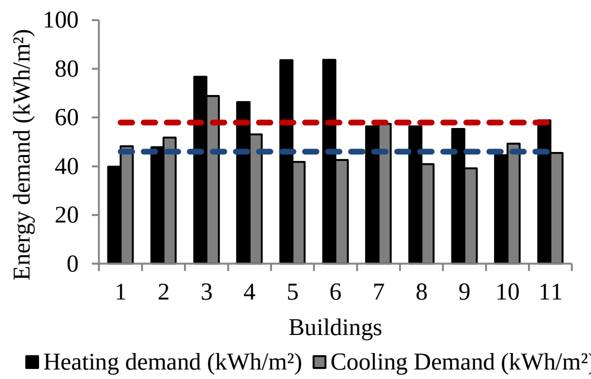

Figure 3: Energy demand per heating (Black columns) and cooling (Grey columns), expressed in kWh/m^2, as function of each building of the campus. The average cooling demand of the site (dotted blue line) and heating demand (dotted red line) are presented.

The highest cooling demand is observed in building 3, which hosts the library and has a low liveable area compared to the internal volume. The average energy demand of the site, defined as the sum of heating and cooling, corresponds to 104 kWh/m^2. These simulations considered the building without any occupants, artificial lighting and electrical devices.

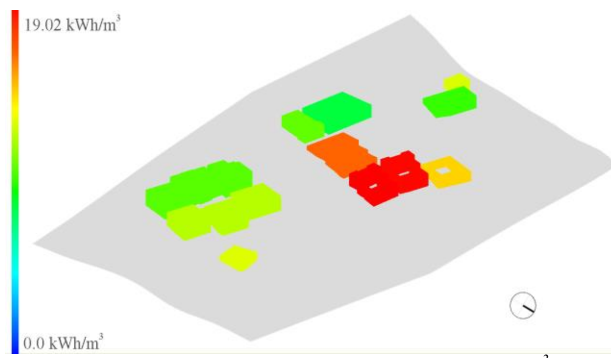

Figure 4: Heating demand of the campus (kWh/m^3). The highest demand is in buildings hosting the Faculty of Medicine and the University Centre (coloured in red).

Figure 5 shows the yearly solar irradiation on the site (max value equals to 2,068 kWh/m²): the campus is exposed to the North, and the annual solar irradiation is drastically reduced because of the orientation, passing from 1,154 kWh/m^2 for a vertical facade exposed to the South (School of Fine Arts) to 514 kWh/m^2 for a vertical facade exposed to the North (University Centre) showing a reduction of the 44%; this difference is higher during the winter time, as an example the daily solar irradiation during the 21st of December on a Southern exposed facade corresponds to 5 kWh/m^2, and 0.4 kWh/m^2 on a Northern exposed façade. On the contrary, during the summer time the difference is lower, because the solar irradiation is higher on the East and West orientation, than in the South.

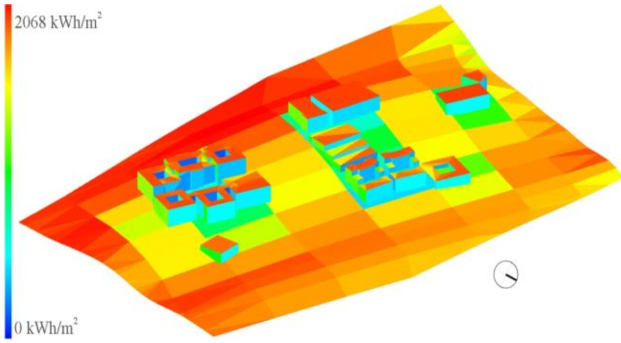

Figure 5: Yearly short wave irradiation on the campus, the maximal value corresponds to 2'068 kWh/m²

The solar potential of the site is defined (Fig. 6): the maximal solar irradiation is received by the Building of Science, and it corresponds to 1,358.45 kWh/m2 (average per all building's facades and roofs): the lower solar irradiation is received by the university center, and corresponds to 993.76 kWh/m2 (average per all building's facades and roofs), the low radiation is explained by the large exposition to the North, and by the shadowing on the South. Naturally, considering the potential in kWh not averaged for the surface, the highest potential will be in buildings 8 and 9, hosting the Building of Science and the Building of Engineering.

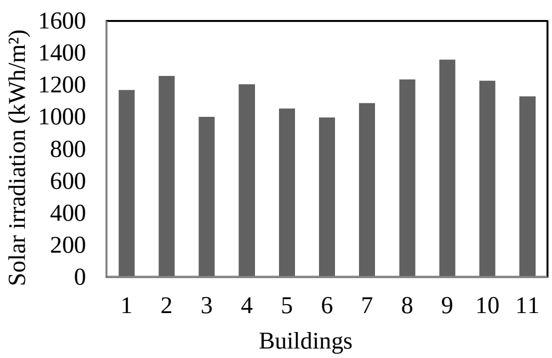

Figure 6: Cumulative annual solar irradiation (kWh/m²) impinging on each building of the campus.

Building envelope optimization for selected buildings

Based on the previous analysis, created by the software CitySim to evaluate the energy demands and site solar potentials, two buildings were selected and the optimization parameters were developed. The optimization of the building envelope was done for more adaptation to the climate context using DesignBuilder software version 4, which is based on Energy Plus thermal analysis tool for two buildings at the campus (faculty of fine art and faculty of engineering). The optimization was done to reduce the energy demand of buildings, by adding thermal insulation, replacing the existing glazing, using shading and improving the natural ventilation, as shown in (Table 2).

Table 2: Optimization parameters: buildings envelope.

Parameter	Existing envelope	Optimized envelope
Insulation U-value	2.8 W/m².K	0.75 W/m².K
Glazing U value	5.3 W/m².K	1.8 W/m².K
Shading	N/A	60 cm overhang on South windows
Natural ventilation	N/A	April, May, October and November

1. Faculty of Engineering

Faculty of engineering which hosts the largest number of students at the new campus has 4 floors and 2 basements with a total floor area of 12400 m². It has 3 open courtyards and the long façade is oriented south north. The average annual energy consumption for heating and cooling for all working days of the year decreased by improving the building envelope (using thermal insulation, glazing optimization, shading, and natural ventilation) compared with the existing condition, as shown in (Fig. 7).

The effect of adding thermal insulation is the most effective, which results in reducing the heating demand from 56.2 kWh/m² per year to 30.6 kWh/m² (a reduction of 45%). The second effective parameter is the use of Natural ventilation for the months of April, May, October and November, which reduced the energy for cooling from 54.1 kWh/m² per year to 34.5 kWh/m² (a reduction of 36%). Changing the glazing type from existing single glazing to a double-glazing reduced the energy for heating from 56.2 kWh/m² per year to 42.5 kWh/m² (a reduction of 24.5%) but increased the energy for cooling by 4.8%. The use of horizontal shading on the South facade reduces the energy for cooling from 54.1 kWh/m² per year to 42.9 (a reduction of 20.7%), but increases the energy for heating by only 5%.

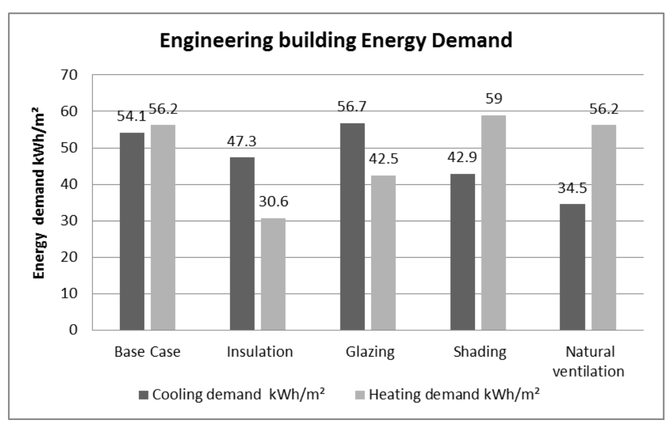

Figure 7: Engineering building: energy consumption before and after the optimization.

2. Faculty of fine art

Faculty of fine art building has a square shape and it has a closed courtyard in the middle. It has 2 floors and 2 basements with a total floor area of 7840 m². The average annual energy consumption for heating and cooling for all working days of the year decreased by improving the building envelope (using thermal insulation, glazing optimization, shading, and natural ventilation) compared with the existing condition for the faculty of fine art building, as shown in (Fig. 8).

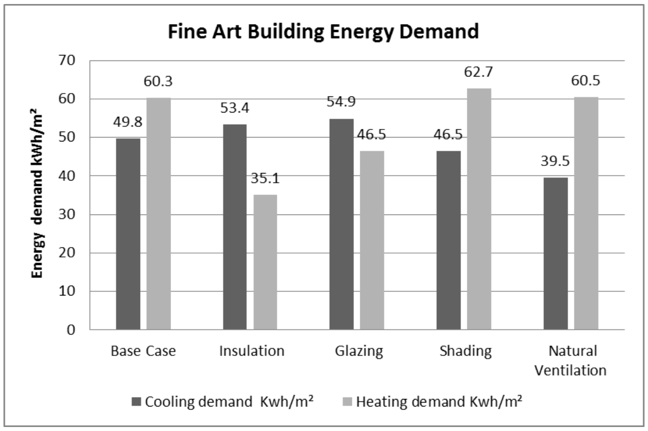

Figure 8: Fine art building: energy consumption before and after the optimization.

The energy consumption reduction was less than the Faculty of engineering because this building is oriented to the North and has less opening on the South. The effect of adding insulation is the most effective, which results in reducing the heating demand from 60.3 kWh/m² per year to 35.1 kWh/m² (a reduction of 41.8%) but increased the energy for cooling by 7.2%, which is due to the internal gain and the thermal mass - in the case of insulation we reduce the effect of thermal mass- from absorbing the internal gain. The second effective parameter is changing the glazing type from existing single glazing to a double-glazing reduced the energy for heating from 60.3 kWh/m² per year to 46.5 kWh/m² (a reduction of 22.9%) but increased the energy for cooling by 10.2%. The use of Natural ventilation for the months of April, May, October and November, which reduced the energy for cooling from 49.8 kWh/m² per year to 39.5 kWh/m² (a reduction of 20.7%). The use of horizontal shading on the South facade reduced the energy for cooling from 49.8 kWh/m² per year to 46.5 (only a reduction of 6.6%) but increased the energy for heating by 4%. This is due to the fact that there is less opening on the south elevation.

The building envelope optimization reduced the energy consumption for the two selected buildings. The energy consumption can be reduced by more than 50% by adapting the building envelope optimization as described in (Table 3).

Table 3: Summary for building envelope optimization effects on the two selected building energy consumption for heating and cooling.

Building	Engineering		Fine art	
Parameters for the optimization	Variation in cooling demand (%)	Variation in heating demand (%)	Variation in cooling demand (%)	Variation in heating demand (%)
Insulation	-12.6	-45.5	+7.2	-41.8
Glazing	+4.8	-24.4	+10.2	-22.9
Shading	-20.7	+5	-6.6	+4
Natural Ventilation	-36	0	-20.7	0

DISCUSSION AND CONCLUSION

The study analyses the heating and cooling demand of the An Najah university new campus, to assess the site solar potential, buildings energy demands, orientation and topography effects, and to optimize the building envelope for two selected buildings (Faculty of fine art (1) and Faculty of engineering (8)), in order to achieve energy efficiency, and make use of renewable solar energy.

The first approach analysis, (Campus energy demand analysis and solar potential) realized with the software CitySim, shows the impact of the topography as well as the build environment on the energy demand of the campus and the solar potential. The total energy demand of campus corresponds to 104 kWh/m^2: the average heating demand corresponds to 58 kWh/m^2 and the average cooling demand corresponds to 46 kWh/m^2. Solar irradiation of the site is very much affected by the location on the northern mountain, the topography and the orientation. The maximum value for the solar irradiation on the site is 2'068 kWh/m² and the maximum solar irradiation is received by the science building that equal to 1,358.45 kWh/m². The solar potential of the site is limited due to the site topography and building orientation, however the buildings of science and engineering have the highest solar potential.

In the second approach; the building envelope was optimized to reduce the energy consumption for the two selected buildings (faculties of engineering and fine art). The energy consumption can be reduced by more than 50% by adapting the building envelope optimization (using thermal insulation, glazing optimization, shading, and natural ventilation). Adding thermal insulation can reduce the heating and cooling demand for more than 40% and 10% respectively, it worth mentioning that thermal insulation should be carried out with attention as it adds to the building thermal mass as in the faculty of fine art, and hence the thermal insulation could have negative effect on cooling load. Replacing the existing glazing with optimized double glazing can reduce the energy for heating by more than 20% but attention should be taken into consideration regarding the cooling load which can be increased by more than 5% if tinted glazing and natural ventilation not used. Adding shading devices only on the south elevation –as an example- can reduce the energy for cooling by more than 20% if you have exposed windows to the south and only 6% if not, attention should be taken about winter as non-calculated shading could have negative effects on heating load. And finally the use of natural ventilation for the months of April, May, October and November can reduce the energy for cooling by more than 20%. Natural ventilation in summer (June, July, August and September) can be used when the outdoor temperature allow –control needed- to optimize the performance.

As a recommendation, each building needs different approach depending on the orientation, building shape, windows size and many other factors. In this study the selected building envelope optimization can be done through:

1. Adding thermal insulation, further study needed to determine the appropriate U value and external wall construction
2. Replacing the existing glazing with optimized double glazing.
3. Adding shading to the South façade, further study needed to determine the effects on different climate zones.
4. Use the natural ventilation during the months of April, May, October and November and a night time ventilation for the months of June, July, August and September, further study needed to determine the effects on different climate zones.

Finally, further detailed analysis of the campus, by the use of EnergyPlus is on-going, to optimize building envelope for hot climate and for different types of buildings. The future work will address the potential of integrating renewable energy –especially solar energy- in building envelope optimization for selected climatic zones.

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