Energy demand and urban microclimate of old and new residential districts in a hot arid climate

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ABSTRACT: Different climates may need different design strategies for optimal thermal performance of buildings: the relationship between different texture of the cities (their form and morphology), the energy demand of buildings and the outdoor microclimate are essential parameters for a sustainable urban planning. Based on these assumptions, we propose an energy and microclimatic analysis of two districts of the city of Nablus (32°13' N, 35°16' E): the old town and a new residential area. The study investigates the design features of residential buildings, as well as their energy demand for heating and cooling. A list of bioclimatic strategies retrieved from the local vernacular architecture is provided (efficient use of materials, construction type and forms); based on the results, interventions for the new district are proposed and guidelines to improve the energy efficiency and the outdoor microclimate are provided for the city of Nablus. The results indicate the importance of taking microclimate strategies and building envelope technologies into account for energy efficiency and thermal comfort. The results can be adopted for further research to optimize the building envelope in hot and arid climates in order to mitigate buildings' energy demand and improve the outdoor and indoor thermal comfort.

Keywords: Energy simulations; outdoor human comfort; urban morphology; hot arid climate

INTRODUCTION

Different climates may need different design strategies for optimal thermal performance of buildings. Designing a building, that respond to the natural environment can provide a desired level of comfort in the prevailing environment (Baker, 1987). Unfortunately, in modern building, 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 relationship between the different texture of the cities (their form and morphology), the energy demand of buildings and the outdoor microclimate are essential parameters for a sustainable urban planning (Johansson, 2006) (Berkovic, Yezioro, & Bitan, 2012). Based on these assumptions, we propose an energy and microclimatic analysis of two districts of the city of Nablus: the old town and a new residential area. The city of Nablus (32°13' N, 35°16' E) is located in the northern part of the West Bank and according to Koeppen Climatic classification (Peel, Finlayson, & Mcmahon, 2007) presents a Csa climate (C: temperate; s: dry summer; a: hot summer), characterized by warm temperature, 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, between the Mount Ebal (940 meters) on the North, and Mount Gerizim (870 meters) on the South. The name of the city derives from the Latin name *Neapolis* that means new city, and was built by Vespasian, the Roman Emperor in 72 A.D. The old city is characterized by dense constructions and narrow streets; streets are hierarchically organized in three main groups according to their use: public (that cross the old city from East to West, and serve the central commercial area), semi-public (that relate the public streets with the valley) and private, also called *zeqaq*, which connect private houses. Characteristics of the site are the bridging houses, *qannater*, and the stone domed roofs. The traditional houses have an internal courtyard, which normally host a cistern, a fountain and some trees; the court is a semi outdoor environment, characterized by sheltered spaces. Several springs and wells are located in the city center, ensuring the water needed by inhabitants. The old town is divided into six districts: Al-Gharb, Al-Yasmeneh, Al- Qaryon, Al-Aqabeh, Al-Qaisaryyeh and Al-Habaleh (Yousof, 1995) .

The study proposed in this paper investigates the design features of residential buildings representative of middle-income households in one of the Palestinian climatic zones (3rd zone that represent the highest population intensity); it also analyses the present energy demand for heating and cooling for typical residential buildings as well as the possible energy savings by adopting certain energy efficient features of case studies.

A list of bioclimatic strategies retrieved from the local vernacular architecture is provided (efficient use of materials, construction type and forms); based on the results, interventions for the new district are proposed and guidelines to improve the energy efficiency and the outdoor microclimate are provided for the city of Nablus.

METHODOLOGY

The proposed methodology make use of an urban energy modelling, called CitySim (Robinson, 2011), to analyse the heating and cooling demand of the selected districts, showing the impact of the urban form (the traditional town versus the new district realized during the 20th century) on the energy demand of buildings and the outdoor microclimate. The energy demand of building includes the hourly heating and cooling demand per each building, as well as for the total district; the outdoor microclimate is quantified by the solar radiation received and stocked by the built environment, as well as the surface temperatures.
The climatic data are provided by the software Meteonorm (Bern, Remund, Müller, & Kunz, 2013) for a Typical Meteorological Year (TMY); the geometrical information of the district are retrieved by a GIS model. The physical characteristics of building, such as materials of the envelope and glazing ratio are based on onsite studies.

The old town

The old town of Nablus is composed by six districts hosting residential and commercial functions; between them the residential Al-Habaleh district (also called Haret El-Hablleh) was selected as case study (Fig. 1).

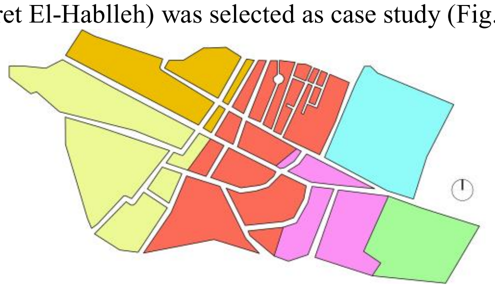

Figure 1: Old town of Nablus, with the six districts: Al-Gharb (Orange), Al-Yasmeneh (Yellow), Al- Qaryon (Red), Al Aqabeh (Pink), Al-Qaisaryyeh (Green) and Al-Habaleh (Ciano).

The buildings of the old town are built with local limestone (Yousof, 1989) with typical white, yellowish and greyish colours; the thickness of the envelope in traditional houses varies between 80-120 centimetres: the thickness is related to static reasons - supporting the weight of the roof and the thrust of vaults- and thermic reasons, ensuring the thermal inertia (Hadid, 2002).The walls are composed of three layers: two external layer of stone and an internal layer filled with mortar and stone rubble (Table 1); the glazing ratio is retrieved by the plans of a courtyard house in the old town (Al-Amad, 1998) and is assumed equal to 0.1, considering the average between the walls facing the street (with a low glazing ratio) and walls facing the internal courtyard, with a superior glazing ratio. Flat roof are traditionally composed of one layer of stone tiles, covered by mud earth, and supported by a wooden structure (Salameh, n.d.).

Table 1: Traditional walls. Thermophysical parameters: Density, Specific Heat, Thermal Conductivity and Thickness.

Name	Density ρ (kg/m^3)	Specific Heat *c* (J/kg·K)	Thermal Conductivity κ (W/m·K)	Thickness (m)
Limestone	2000	1000	1.4	0.35
Mortar and stone rubble	2000	1050	2.0	0.15
Limestone	2000	1000	1.4	0.30

The old town was originally designed for pedestrian, but during the 20th century, to guarantee the access of car in the historical centre, streets were widened and the stone covering of the ground were replaced by asphalt, changing the morphology of the old town. Based on these data, the ground covering is in asphalt in the street (albedo equals to 0.1) and stone in the courtyard (albedo equals to 0.58); in the district nine green areas are present (Figure 2) and the height of building ranges between three to twelve meters (Shakhsher, 2010).

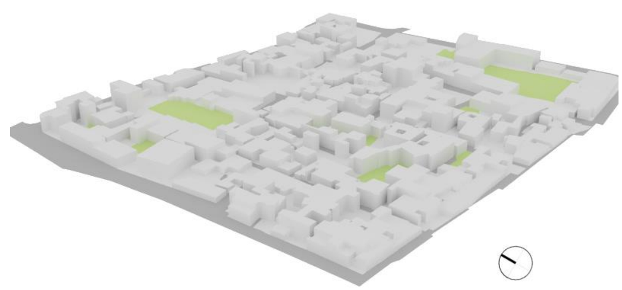

Figure 2: 3D view of the Al Habaleh district; the Gardens (Green) and the main streets (Grey) are defined.

The new residential area

The new residential area is located on the North-western area of Nablus city (Figure 3); the selected area is composed of 44 buildings, nine between them belongs to An-Najah National University whereby a group of employees of the university established a cooperative housing society. In the nine buildings the internal distribution varies between one to two apartments each floors; the total number of apartments corresponds to 115. The physical characteristics of walls are defined in Table 2 (U-value=1.9 W m^{-2}·K^{-1}); the U-value of roof and ground floor correspond to 1.1 and 2.7 W m^{-2}·K^{-1} respectively; the glazing U-value corresponds to 2.7 W·m^{-2}K^{-1} (average between the glazing and the frame) and the g-value to 0.7.

Table 2: Stone wall. Thermophysical parameters: Density, Specific Heat, Thermal Conductivity and Thickness.

Name	Density ρ (kg/m³)	Specific Heat *c* (J/kg·K)	Thermal Conductivity κ (W/m·K)	Thickness (m)
Stone	2600	800	2.3	0.05
Reinforced concrete	2400	1100	1.8	0.13
Hollow block	1200	1000	0.7	0.1
Plaster	900	1000	0.21	0.02

The ground covering is made of asphalt in the street (albedo equals to 0.1) and natural soil in other spaces (albedo equals to 0.3), as shown in Figure 3.

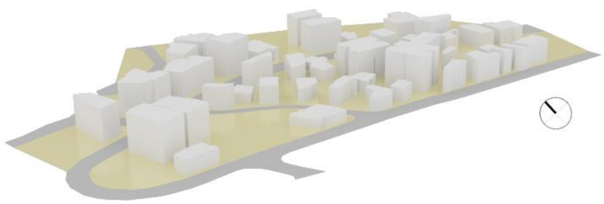

Figure 3: 3D view of the new residential district; the main streets (Grey) and the sandy soil (Yellow) are defined.

The old town and the new residential area

Three parameters to describe the urban density and the buildings form are defined, the Floor Area Ratio (FRA), defined as ratio of the gross floor area to the site area, the Site Coverage (SC), defined as the ratio of buildings footprint to the site area (Ng, 2010) and the Form Factor.

Table 3 summarizes the characteristics of the built environment (site area, total floor area and total gross area) as well as the density of the site (Floor Area Ratio and Site Coverage) and the compactness of buildings (Form Factor). The Form Factor is defined as following:

$$FF = \frac{(W + R + 0.5G)}{A}$$

where W is the wall area, R is the roof area, G is the ground area and A is the gross area of the building. All values are expressed in m².

The site areas are similar (1'260 m² of difference) as well as the total gross area (309 m² of difference), that corresponds to an equivalent occupation of the soil (FAR= 1.29 and 1.27) but a large difference exists in site coverage: the footprint of buildings corresponds to the 60% of the site in the old district and just the 25% in the new residential area.

Table 3: Site Area (m²), Total Footprint Area (m²), Total Gross Area (m²), Floor area Ratio (-), Site Coverage (%) and Form Factor (-) for the selected districts.

Site	Old Town	New Residential Area
Site Area (m²)	49'418	50'678
Total Footprint Area (m²)	29'700	12'422
Total Gross Area (m²)	63'825	64'135
Floor Area Ratio (-)	1.29	1.27
Site Coverage (%)	60	25
Form Factor (-)	1.86	0.84

Improvement of the energy demand of buildings in the new residential area: sensitivity analysis

The energy demand of the new residential area is improved, by applying the following two strategies:

- External envelope: improvement of the thermal insulation of buildings, by adding external insulation layers (35 cm of EPS) on walls and roofs, and by replacing the actual windows with energy performant windows (U-value = 1.1 W m^{-2}·K^{-1}).
- Automatic shadowing: shading devices are automatically activated within CitySim if the solar irradiance impinging the facades is higher than 150 W m^{-2}.

The natural ventilation of buildings is activated in CitySim: during the warm seasons, windows are automatically open if the outdoor air temperature is 1°C lower than the internal one. The objective of these simulations is to understand what is the impact of the proposed strategies in the heating and cooling demand of the site.

RESULTS

The old town

The heating and cooling demand is calculated by the software CitySim, considering the energy required to maintain an internal temperature between 20 to 26°C; the average heating and cooling demand of the site correspond to 88 kWh·m^{-2} and 12 kWh·m^{-2}, respectively. Based on the results, there is a strong relationship between the energy demand of buildings (sum of heating and cooling) and the Form Factor, as shown in Figure 4. The correlation between the total energy demand, expressed in kWh·m^{-2}, and Form Factor is high (R^2 equals to 0.9624), as well as considering the correlation between FF and the heating demand (R^2 equals to 0.9426), that means that doubling the Form Factor from 1 to 2, the heating demand doubles. On the contrary, the correlation between cooling demand and FF is lower (R^2 equals to 0.6149).

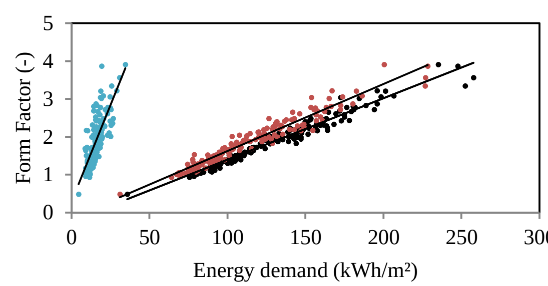

Figure 4: Linear Correlation between the Form Factor of buildings and their energy demand: total energy demand as sum of heating and cooling (Black), energy demand for heating (Red) and for cooling (Blue).

This behaviour is explained by analysing two buildings (so called Building 10 and 23) oriented North- South with a similar FF and heating demand (difference of 14%), but a different cooling demand (difference 46%), as shown in Table 4: both buildings have one floor, and they are unobstructed on the South side, but building 23 is shadowed by neighbouring buildings on the East and West side, and building 10 has no shadowing protections in the previous orientations. The average solar irradiation received by building 10 during the summer time corresponds to 244 kWh·m^{-2} on the facades, and 566 kWh·m^{-2} on the roof; in building 23 the average solar irradiation is 147 kWh·m^{-2} on the facades, and 542 kWh·m^{-2} on the roof. By comparing the results, the solar irradiation on the facades is drastically reduced in building 23: knowing that at this latitude the sun rays are higher on the East and West side during the summer time, and on the South during the winter time, the corresponding cooling demands can be understood.

Table 4: Analysis of the Buildings 10 and 23: Cooling Demand (kWh·m^{-2}), Heating Demand (kWh·m^{-2}) and Form Factor (-).

Building	Cooling demand (kWh·m^{-2})	Heating Demand (kWh·m^{-2})	Form Factor (-)
10	33.6	200.5	3.9
23	17.8	228.3	3.8

Figures 5 shows the yearly solar irradiation on the site, with a maximal value on the roof top that corresponds to 1’982 kWh·m^{-2}; in the courtyard the solar irradiation is drastically reduced, with an average value that corresponds to 639 kWh·m^{-2}.

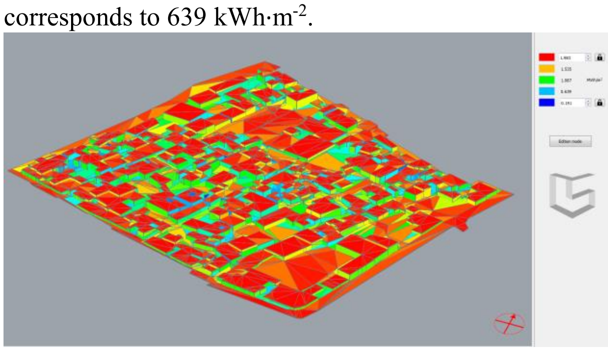

Figure 5: Yearly solar irradiation on the Alhabaleh district (max value equal to 1’982 kWh·m-2).

The new residential area

The average heating and cooling demand of the site correspond to 71 kWh·m^{-2} and 20 kWh·m^{-2} respectively; showing an increase of the average cooling demand by 40%, and a decrease in heating demand by 20% compared to the old town.

The correlation (Figure 6) between the total energy demand, expressed in kWh·m^{-2}, and Form Factor is high (R^2 equals to 0.9612), as well as considering the correlation between FF and the heating demand (R^2 equals to 0.9252); as in the previous case study, the correlation between cooling demand and FF is lower (R^2 equals to 0.5464).

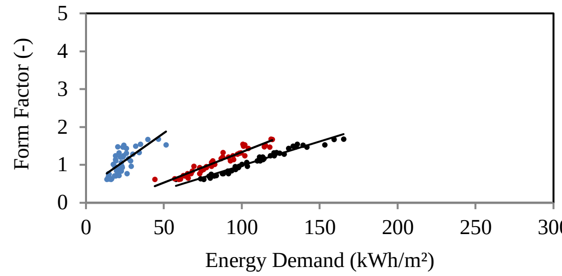

Figure 6: Linear Correlation between the Form Factor of buildings and their energy demand: total energy demand as sum of heating and cooling (Black), energy demand for heating (Red) and for cooling (Blue).

Figures 7 shows the yearly solar irradiation on the site, with a maximal value on building’s roof top that corresponds also to 1’982 kWh·m^{-2}.

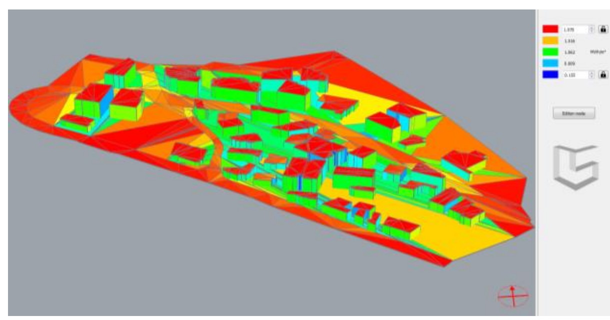

Figure 7: Yearly solar irradiation on the new residential are (max value equal to 1’982 kWh·m^{-2}).

The old town and the new residential area

As previously analysed, the average cooling demand of building in the old district is 40% lower compared to the new residential area (12 kWh·m^{-2} and 20 kWh·m^{-2} respectively). Additionally, the average Form Factor of the old town is higher compared to the new residential area (1.86 and 0.84 respectively), so if the cooling demand of building is analysed just for buildings with the same FF, the difference between the two selected area increases: the average cooling demand of buildings with a FF comprised between 1 and 2 corresponds to 27.0 kWh·m^{-2} in the new area, and 15.0 kWh·m^{-2} in the old town. This fact underlines the impact of the urban shadowing effect in the energy demand of buildings.

By analysing the microclimate, an important element that differentiates both areas is the surface temperature; in this case study the ground surface temperature is analysed: Figure 8 summarizes the average, maximal and minimal surface temperature in both locations; the average annual temperature is 5°C higher in the new district compared to the old town, with a peak during the month of July, when the difference reaches 7°C. On the contrary, the difference during the winter time is lower, with a difference of 3°C; the minimal temperatures during the year are similar, but the maximal are in average 19°C higher.

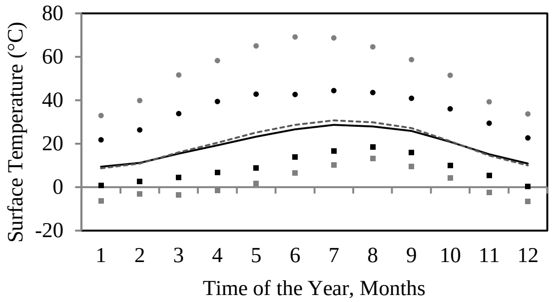

Figure 8: Average monthly surface temperature in the old Al-Habaleh district (Black continuous line) and in the new residential area (Grey dotted line). Maximal (circle) and minimal temperature (square) per each month.

The cumulative radiation on the built environment (as sum of buildings and ground) corresponds to 1'240 MWh in the new residential area, and 1'183 MWh in the old town; a difference that is not significant. However, it is interesting to quantify the average solar irradiance on the ground in both locations: Figure 9 shows the average solar irradiance (W·m^{-2}) received by the ground in three summer days (21st to 23rd July) of a Typical Meteorological Year for the city of Nablus, when the nebulosity of the site is comprise between 0 to 4 octas. The solar irradiance on the ground of the new district at midday corresponds to 840 W·m^{-2}, 22% more than in the old district of Al-Habaleh (650 W·m^{-2}); furthermore the value is higher during all daytime, showing the positive impact of the built environment in the mitigation of the urban climate through shadowing.

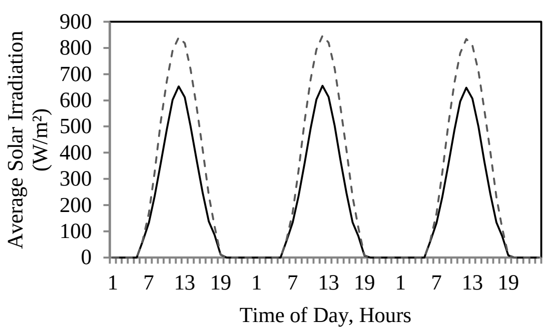

Figure 9: Average solar irradiation (W·m^{-2}) received by the ground in the old Al-Habaleh district (Black continuous line) and in the new residential area (Grey dotted line) for three summer days, 21st to 23rd July.

The same behaviour exists during the winter time: the solar irradiation on the ground is lower in the old town compared to the new residential area.

Based on the previous analysis, the urban microclimate is more comfortable in the old town, compared to the new residential area. This is related to the density of the site (site coverage) and the ground covering (gardens and local stone, versus asphalt and clay soil): the shadowing protections created by the density of the built environment reduce the solar radiation impinging on pedestrians and buildings. Additionally, the thermal inertia of buildings is higher, and consequently the built environment stores the heat during the daytime, and releases it during the night time, reducing the environmental temperature.

Improvement of the energy demand of buildings in the new residential area: sensitivity analysis

Table 5 summarizes the obtained results, based on the improvement of the energy demand of buildings compared with the real case study. By improving the insulation of the envelope, the heating demand could be reduced by 50% and the cooling by 17%; on the contrary by adding the shadowing strategy the heating demand would increase by 13% (as the positive impact of solar gains is reduced during the winter time) and the cooling demand is reduced only by 47%. By improving the natural ventilation, the heating demand is constant and the cooling demand is reduced by 9%. Based on the obtained results, the insulation of buildings has the highest impact in their energy demand, followed by the U-value of windows and the shadowing strategies.

Finally, a complete refurbishment of buildings is proposed, by adding all the proposed strategies: the final energy demand would be decreased by 60%, passing from 91 kWh·m^{-2} to 54 kWh·m^{-2}.

Table 5: Summary of the impact of the proposed improvements in the heating and cooling demand of the new residential district.

Proposed improvement	Variation Heating Demand (%)	Variation Cooling Demand (%)	Total energy demand for Heating and Cooling (%)
U-value envelope	-50	-17	-41
U-value windows	-21	-5	-17
Shadowing	+13	-47	-2
Ventilation	0	-9	-2

CONCLUSION

The old town of Nablus is an important example of bioclimatic architecture, and some guidelines can be expressed according to the morphology of the old town:

- The high density of the build environment (Floor Area Ratio corresponding to 1.29, and a site coverage of 60%) reduces the solar radiation received by the built environment, decreasing the surface temperature of the district and consequently improving the liveability in the outdoor environment.

- The thermal inertia of the walls, composed of 80 to 120 cm of stone, improves the diurnal storage of heat that is then dissipated during the night time.
- The courtyard form of houses recreates a semi outdoor environment, naturally shadowed and refreshed by evapotranspiration, thanks to fountains and trees.
- The bridge houses are vernacular shadowing strategies, able to improve the liveability of streets.

The following guidelines are proposed to reduce the energy demand of building and improve the urban microclimate:

- Increase the shadowing devices to improve the outdoor human comfort; it reduces the ground surface temperature and selectively protect the building from the sun rays.
- Improve the thermal insulation of buildings, by adding external insulation layers and replacing the existing windows with energy performant ones.
- Increase the reflectivity of roofs, reducing the heat stocked in the buildings.
- Design the outdoor environment, by increasing permeable surfaces and planting native trees.
- Increase the vertical density of the built environment in the old town, and horizontally in the new residential area.

The results indicate the importance of taking microclimate strategies and building envelope technologies into account for energy efficiency and thermal comfort. The results can be adopted for further research to optimize the building envelope in hot and arid climates in order to mitigate buildings energy demand and improve the outdoor and indoor thermal comfort.

Future development of this case study will be:

- Analysis of the outdoor human comfort in the selected areas, showing the impact of the urban form on the pedestrians' thermal sensation.
- Analysis of the solar potential of both districts, by applying phovoltaics and solar thermal panels on the rooftop of the buildings.

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