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Urban Design Impact on Local Climate and its Consequences on Building Energy Demand in Morocco

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ABSTRACT

Urban design has a profound impact on the local climate, which can result in changes in temperature distribution and energy demand. The Urban Heat Island (UHI), a well-documented issue where cities typically experience higher temperatures than the cooler rural surroundings that envelop them, is closely tied to urban design and its geometrical features. This increase in temperature can lead to increased energy consumption, particularly for air conditioning, as populations strive to maintain thermal comfort. Within this framework, this paper seeks to advance our comprehension of the influence of urban design on the Urban Heat Island (UHI) effect and building energy requirements. It makes a valuable contribution to the expanding body of research in this field, offering insightful guidance on optimal urban design strategies tailored to diverse climate zones in Morocco. To achieve these goals, we explore multiple urban design scenarios incorporating variations in building heights, street aspect ratios, building layout configurations, and street orientations. We employ the Urban Weather Generator and EnergyPlus for our analysis, with the former enabling the generation of synthetic weather data that accounts for the UHI effect in urban contexts, and the latter facilitating building energy simulations. The simulation results reveal a wide-ranging hourly variation in Urban Heat Island (UHI) intensity, spanning from 11°C to -5°C across the cities under study. Among these cities, Ifrane, Marrakesh, and Fes exhibit the highest average annual UHI intensity. Incorporating UHI considerations into energy simulations has yielded notable outcomes. Low-rise buildings experience a reduction in total energy requirements, while mid-rise and high-rise buildings exhibit an increase. For instance, adopting an urban design scenario featuring 20-story buildings and a street aspect ratio of 0.33 led to a rise in total energy demands between 8% and 19%. Furthermore, the street aspect ratio (H/W) emerges as the primary driver of UHI, whereas street orientation and building layout exert the most substantial influence on building energy requirements. Inefficient building layouts result in a significant increase in building energy needs, ranging from 106% to 121%, while less energy-efficient street orientations lead to total energy needs escalating by 28% to 76%.

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1. Introduction

Urban design has a profound impact on the local climate, which can result in changes in temperature distribution and energy demand. The Urban Heat Island (UHI), a well-documented form of urban climate modification where cities encounter elevated temperatures in contrast to the cooler conditions found in the rural areas surrounding them. It is closely tied to buildings forms and streets arrangements, thermal properties of surface material and anthropogenic heat release (Arnfield, 1990; Lachir, 2022; Oke, 1981, 1982). The two later non-urban geometrical features are mostly linked to urban forms, since high density urban areas are often associated with more important modification of land surface thermal properties and heat release (Oke, 1988). (Salvati et al., 2017) demonstrated that urban form has the most significant impact, resulting in a relative increase of up to 120% in the average annual Urban Heat Island intensity within the Mediterranean region.

The UHI effect has been studied extensively in various cities worldwide, with a focus on understanding the factors that contribute to its magnitude. More recent Research emphasized the significant effect of urban heat island on thermal comfort and the building energy consumption. (Li et al., 2019), in a review of 24 case studies, reported that UHI in different urban contexts increased the cooling energy needs from 10% to 120% and decreased the heating energy needs from 3% to 45% . Yet, the urban context and its resulting UHI are often neglected in building energy simulations which leads to less accurate building energy estimation and unadapted energy efficient design options.

In Morocco, a North African nation with diverse climate and urban forms, energy-related issues are rising especially in the building sector, a crucial element within the energy system that is responsible for roughly one-third of total energy consumption. A new thermal regulation is introduced for new buildings and several studies are conducted on energy-efficient buildings (ADEREE, 2014). But in all cases, the urban context is often neglected and the climate data driving the Building Energy simulation are generally calculated from weather stations. These are generally located outside the cities and exclude the UHI effect that was shown to be intense in different Moroccan cities (Bahi et al. 2016; El Ghazouani et al. 2021; Fathi, Bounoua, et Messouli 2019). Lachir et al., (2016) conducted a temporal analysis of the monthly electrique energy consumption and corresponding mean air temperature in Marrakech and found that an increase of 1◦C causes a spike in energy needs of 4.4% at city level. This emphasizes the effect of rinsing urban temperatures on building energy consumption, particularly for air conditioning, as populations strive to maintain thermal comfort. However, our current knowledge of the urban heat island impacts on building energy consumption in morocco is very limited. Notable attempts to address this issue focused on investigating the effect of the streets aspect ratio on building energy consumption in a single climate zone and similar urban context (Jihad & Tahiri, 2016; M'Saouri El Bat et al., 2021).

To better understand the impact of urban design on the UHI effect and building energy demand in Morocco, this study simulates the urban microclimate induced by different urban forms and estimates its impact on the energy consumption of a typical residential building. It utilizes a modeling-based approach to forecast Urban Heat Island effects and energy requirements across various urban design scenarios. These are created by combining different values of the urban geometrical parameters. The results will provide valuable insights for urban planners and architects into the most effective urban design strategies for different climate zones in Morocco to reduce UHI effect and energy consumption. This paper makes a significant contribution to the expanding body of literature concerning this subject. Its findings are truly groundbreaking within the Moroccan context, as there have been limited studies addressing the impacts of Urban Heat Islands (UHI) on building energy to date.

2. Material and method

2.1. UHI and energy simulation tools

The urban heat island impact on building energy needs can be defined as the difference in the building energy needs simulated using two types of weather datasets. First, a meteorological dataset that accounts for the UHI effect. This is measured within the urban environment or simulated using urban climate models. Second, a meteorological dataset derived from the weather station at a rural location outside the city (UHI-free weather data). Lauzet et al., (2019) presented an overview of the different methods currently used to take into account the UHI in building energy simulations.

This study employs the Urban Weather Generator (UWG) (Bueno et al. 2013) to generate synthetic meteorological data for different urban settings and climates. This model use neighbourhood scale surface energy balance to transform a typical meteorological year weather files (TMY) into an urban weather file in the same format. The resulting weather file can be used for a more accurate energy simulation for buildings within the urban context (Kamal et al., 2021; Nakano et al., 2015). The model was evaluated against field measurements from different urban sites and showed high accuracy in urban temperature prediction (Salvati et al., 2016).

The UWG predict urban canopy air temperature and humidity as follows: 1) the observed meteorological variables of the weather station are transformed into meteorological conditions at a reference height above the weather station using models of land surface energy balance and heat diffusion. 2) The results are fed to the urban boundary layer model that estimates air temperatures beyond the urban canopy layer. 3) The conditions inside the urban canyon are calculated using the Town Energy Balance (TEB) (Masson, 2000). This model was improved to integrate a building energy model for a better estimation of the heat and mass transfer processes between buildings and the urban canyon.

The building energy simulations are performed using EnergyPlus (Crawley et al., 2001). It is a physics-based model that evaluates the thermal dynamics of buildings based on thermal transfer principles. The simulation software takes into account factors such as building orientation, shading context, envelope properties, HVAC systems, internal loads, usage schedule and meteorological data.

2.2. The study region

The urban heat island and the building energy simulations are performed in different urban contexts to account for the diversity of the climate and the urban forms in Morocco. Figure 1 presents examples of typical urban fabrics in Morocco. The historical parts of cities have a compact urban fabric with low-rise houses and narrow streets while in the modern parts, we find a more open urban fabric with a variable range of building heights and street aspect ratios. Residential areas include detached low rise houses, compact low-rise economic houses and mid-rise buildings (with 6 floors in general). City centres usually have a mixed function and include mid-rise and high-rise buildings.

This study is performed for the six climate zones in Morocco. These are defined by the Moroccan thermal construction regulation according to climate data recorded across the country and the resulting energy needs to achieve thermal comfort in buildings (ADEREE, 2014). The zones from 1 to 6 are represented respectively by the cities of Agadir, Tangier, Fes, Ifrane, Marrakesh, and Errachidia. For each city, typical meteorological data derived from hourly weather data from 2007 to 2021 are used for the energy simulation purposes (ISO, 2005). The calculated daily composites of air temperature are shown in figure 2.

2.3. Urban design scenarios

The urban heat island simulations are performed for a simplified urban fabric of 100 residential buildings with 100m² footprint areas. The buildings have 40% glazing ratio and a well-insulated envelope. The construction of the building elements and their thermal characteristics are summarized in table 1. Air flows, internal loads and operation schedules are defined according to The EnergyPlus mid-rise apartment reference building. All the buildings are supposed to be air conditioned with heating and cooling temperature set points of 20 °C and 26 °C. All the HVAC waste heat is released in the urban canyons. The streets are supposed to be covered with asphalt with no vegetation and the traffic heat release is estimated according to the urban density. The urban morphology and its geometrical characteristics are the varying parameters of the simulations. These are as follows:

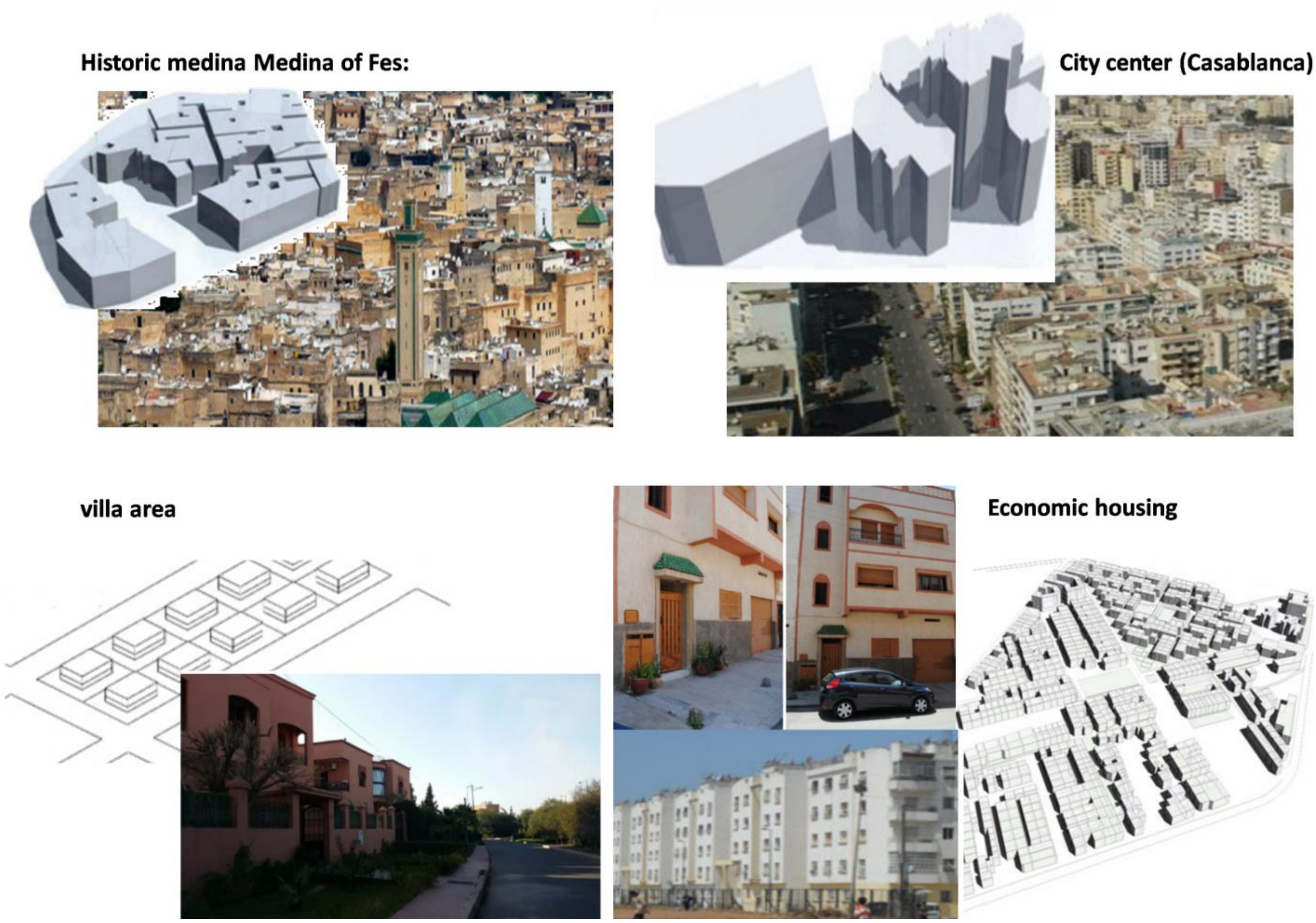

Figure 1. Examples of the urban fabrics in Morocco

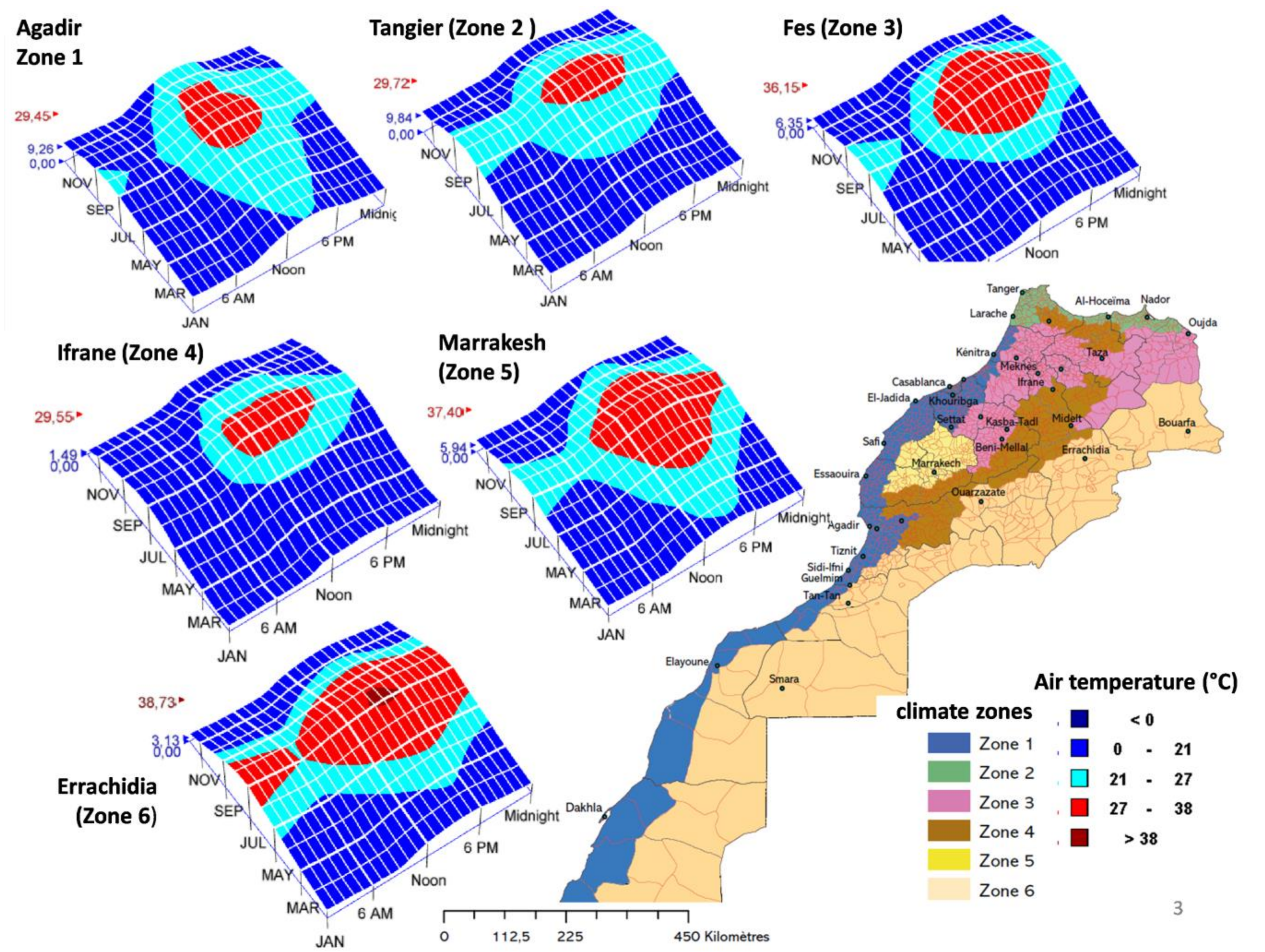

Figure 2. Daily composites of air temperature in the representative cities of Morocco climate zones

- Buildings height: this is indicated by the number of the buildings stories (3.2m height for each story). Considered building heights are between H=1 story and H=20 stories;
- Street aspect ratio (building height-to-street-width): four cases of H/W are considered; 1/3, 1/2, 1, 2 and 4;
- Building layout: four cases for buildings layout are considered. This will help evaluate different ranges of urban fabric compactness and façade areas. The cases are presented in figure 3;
- Street orientation: Four cases are considered: East-West (EW), Northeast-Southwest (NESW), North –South (NS), Northwest- Southeast (NWSE).

Table 1. The building envelope thermal characteristics

Envelope elements	Principal construction	Thermal characteristics
Exterior wall	Hollow concrete bricks of 20 cm with thermal Insulation	U=0.49 W/(m²°C) Albedo=0.5
Exposed roof	Concrete joist floor of 25 cm with thermal insulation	U=0.53 W/(m²°C) Albedo =0.5
Windows	Double Glazing (clear glass) 6 mm airspace	U=3.61 W/(m²°C) Solar heat gain g=0.7

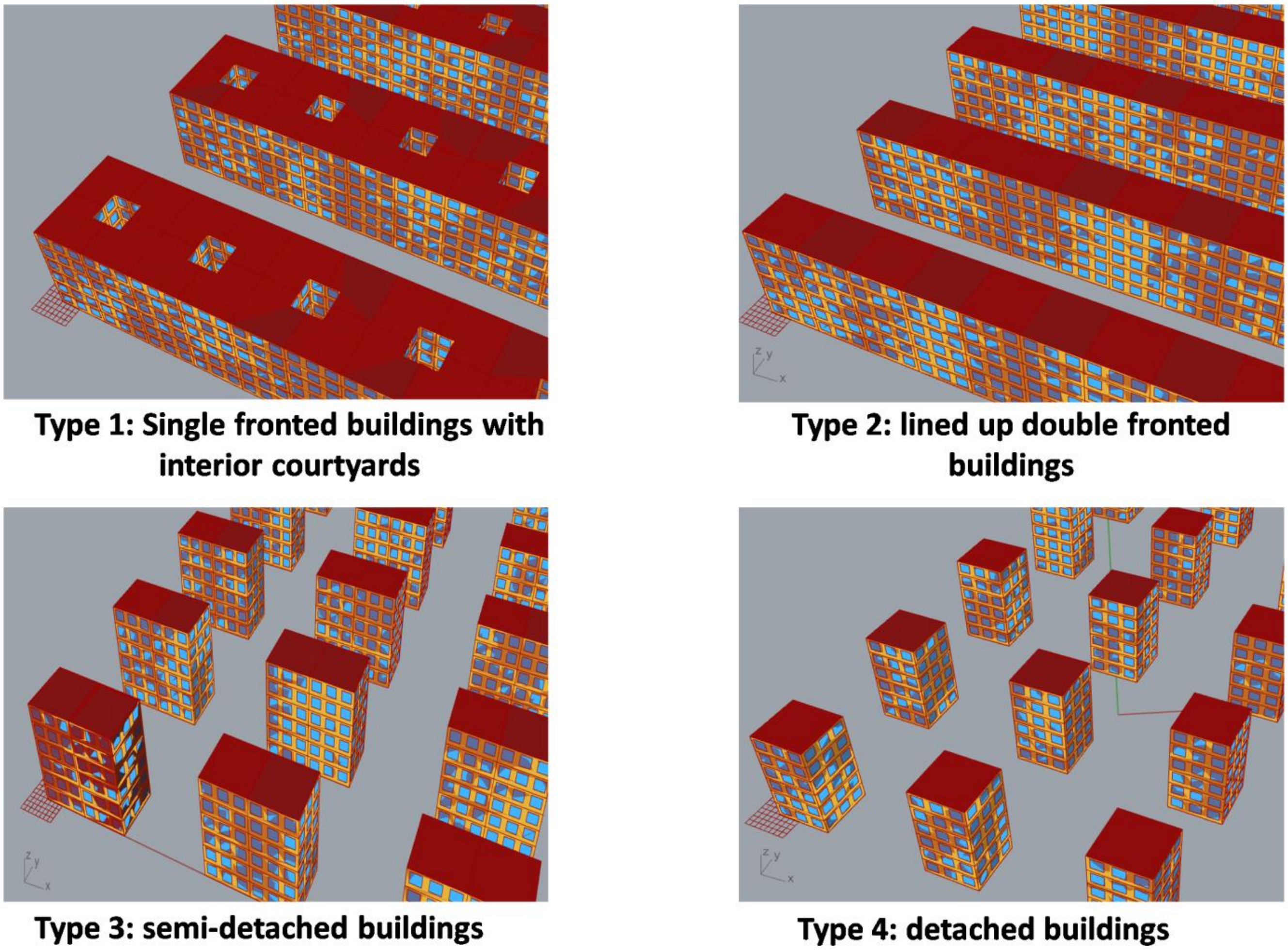

Figure 3. Buildings layout types

Multiple urban design scenarios are developed using the different values of the urban geometrical parameters (table 2). The urban 3D model for all scenarios are created and fed to the UWG and EnergyPlus using Ladybug components through the grasshopper plug-in tool for Rhinoceros (Ladybug Tools, L. L. C., 2021). This provides a parametric simulation module to automatically generate the urban 3D model, to extract the required inputs and to run the simulations.

Table 2. Urban design scenarios

Scenarios type (number of scenarios)	**Base Case: (1)**	**type1 (20)**	**type 2 (20)**	**Type 3 (4)**	**Type 4 (4)**
Buildings height (H) Indicated by stories	6	2, 6, 10, 20	From 1 to 20	6	6
Streets aspect ratio (H/W)	1	1/3, 1/2, 1, 2 and 4	1	1	1
Buildings layout	Type 2	Type 2	Type 2	Type 1, 2, 3 and 4	Type 2
Streets orientation	EW	EW	EW	EW	NS, NESW, EW and NWSE

3. Results

The base case urban design scenario represents the most common urban design options in Morocco. This scenario was first simulated in the UWG to compare the UHI effect in the different climate zones in Morocco. The UHI intensity is calculated as the difference in hourly temperature between the weather data generated by the UWG and that includes the UHI effect and the UHI free meteorological data measured at the rural weather station. The results for the 6 climate zones are presented in figure 4.These show that for all regions the maximum UHI intensity occurs during night time and a low negative UHI intensity occurs during midday. This presents an Urban Cool Island (UCI) and can be explained by the important heat storage capacity of buildings and the shadowing effects of surrounding buildings which reduce solar gains during the daytime (Yang et al., 2017). Meanwhile, the night-time UHI intensity is explained by the heat released by buildings and the decreased sky view factor and wind speed around buildings which limits the radiative and convective cooling of the urban area (Svensson, 2004).

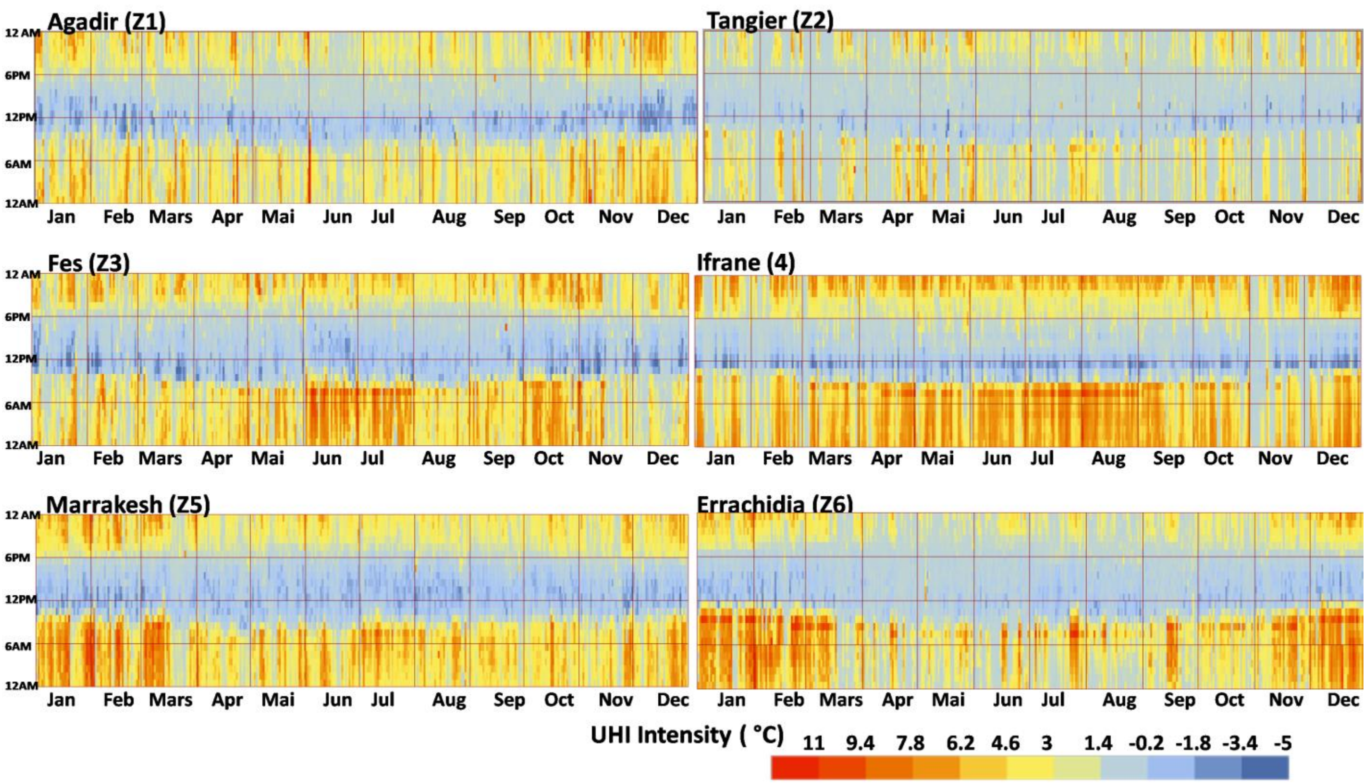

Figure 4. Hourly UHI intensity simulated for the base case urban design scenario in the cities representing the 6 climate zones in Morocco

Low values of UHI intensity are simulated in Agadir and Tangiers representing the first and second climate zones. These cities are located at the coast where sea breeze enhance wind speed and the transfer of cool air in the city. Highest values of UHI intensity are simulated in inland cities. Ifrane, a city with very cold winter and warm summer presented more important UHI intensity during warm months. While In Marrakesh and Errachidia, where the winter is relatively cold and the summer present very high air temperature that often exceed 40°C, simulated UHI intensity are more pronounced during the winter.

For a better understanding of UHI and how it is affected by urban geometry, further analysis of the simulations outputs are performed. For each simulation, the AverageUHI is calculated considering only positive values of hourly UHI intensity. This evaluates the Night-time UHI. The negative values of hourly UHI intensity are averaged to get the AverageUCI that assesses the daytime urban cool island. The simulations of urban design scenarios type 1 allows to assess the impact of different building heights and street aspect ratios on UHI effect. The results are reported in figure 5 and show a large variation of AverageUHI between 1.9°C and 3.8°C over the 6 climate zones against a less important variation of AverageUCI between -1.3°C and -0.7°C.

Results indicate that street aspect ratios (H/W) have a larger impact on UHI compared to building heights. It is shown that AverageUHI increases with higher values of street aspect ratio. This because the wide and more open urban canyon presents a high sky view factor and allows a rapid radiative cooling during night time. While in deep canyons, the heat is trapped in the urban canopy and also convective cooling is less efficient because of the reduced wind speed in the more compact area. These patterns are more pronounced when building height increases. For a high-rise building of 20 stories, a change in H/W from 1/3 to 4 induced an increase in AvrageUHI of 0.74°C in Marrakesh, 0.55°C in Ifrane and Fes, 0.48 in Agadir and 0.26°C in Tangier and Errachidia.

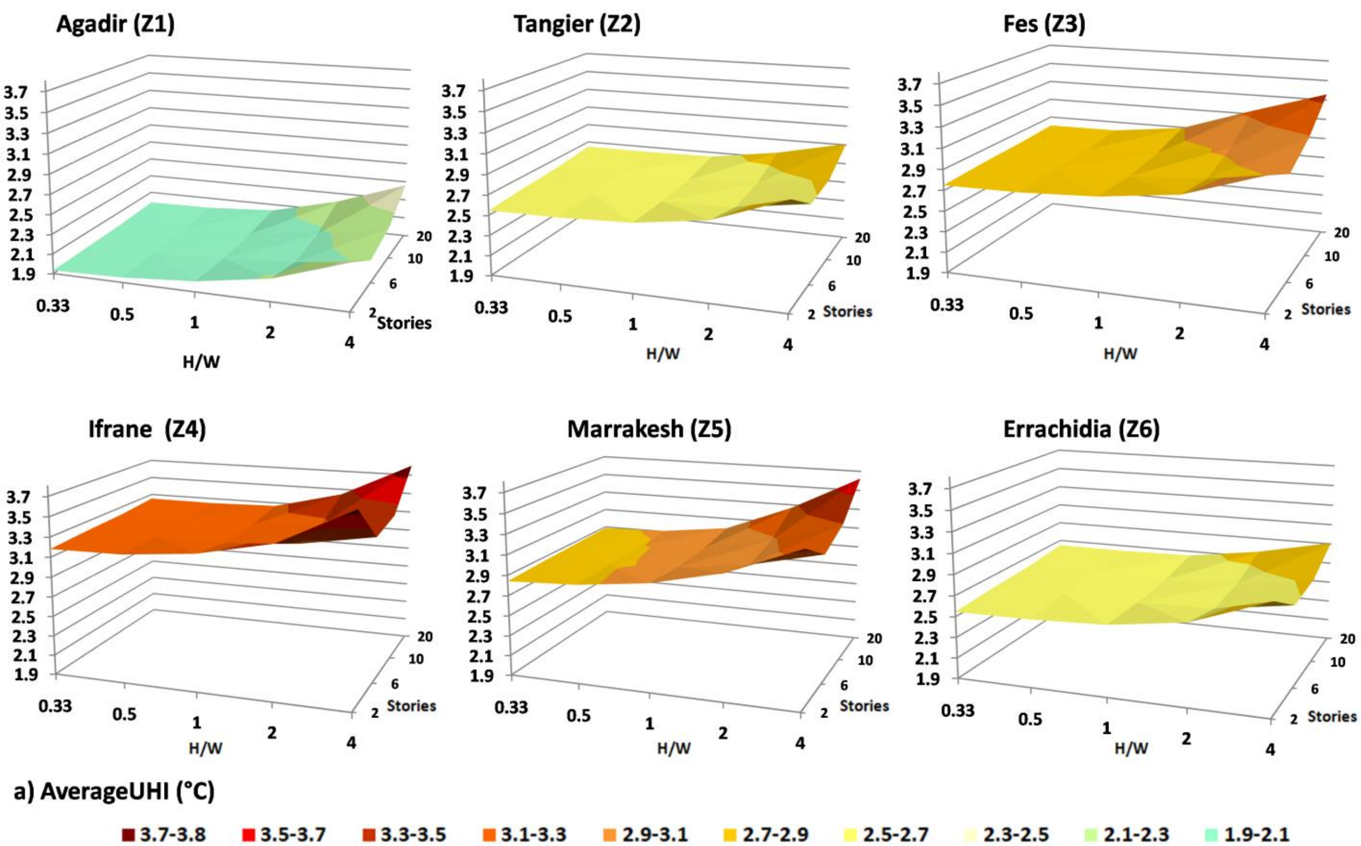

Figure 5.a. Variation of average UHI with buildings height and street aspect ratios for the 6 climate zones in Morocco

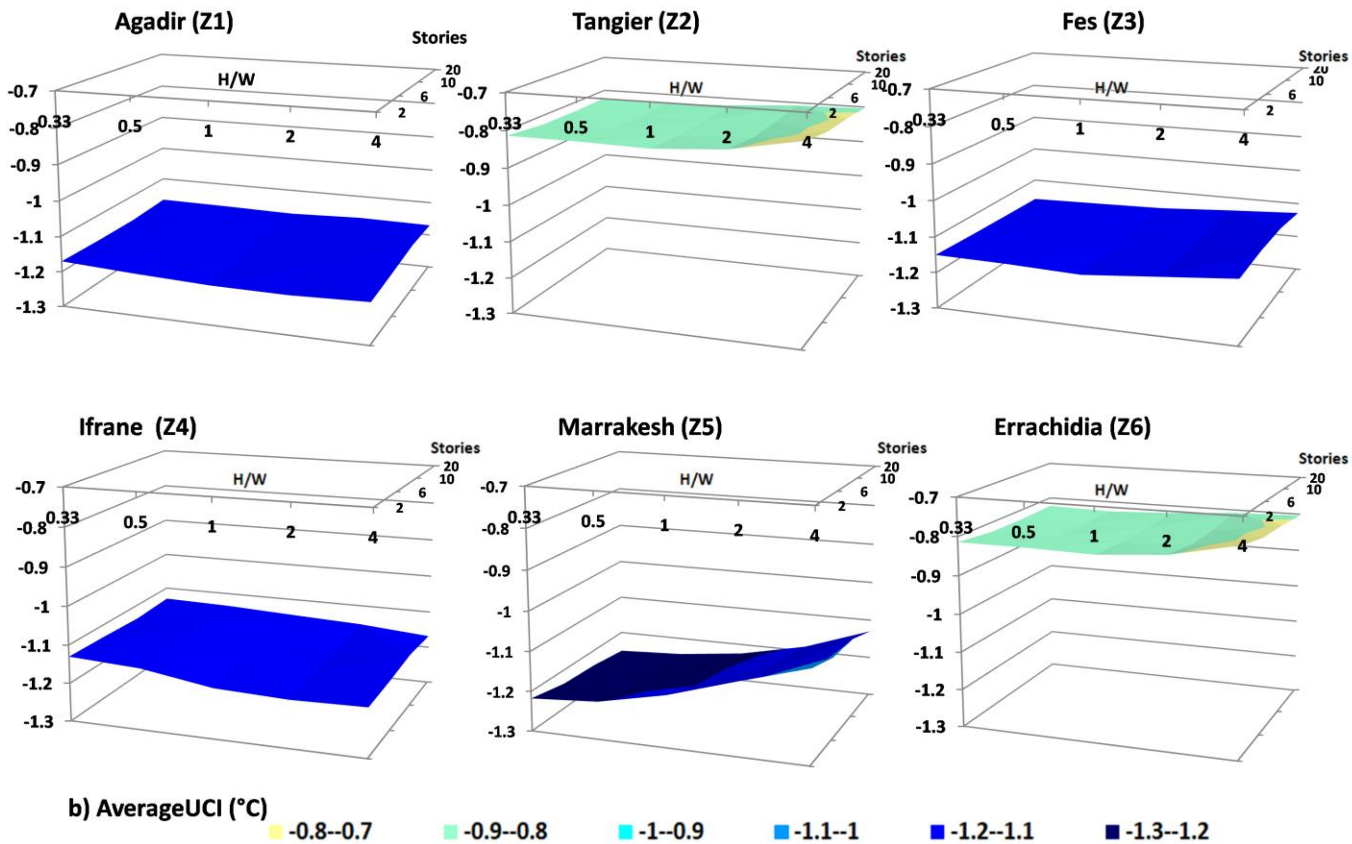

Figure 5.b. Variation of average UCI with buildings height and street aspect ratios for the 6 climate zones in Morocco

The analysis of building energy consumption is more relevant to understand the effect of urban forms on UHI consequences and the thermal behaviour of buildings. This accounts for the cumulative effect of hourly UHI Intensity. In addition, both the negative and the positive effects of UHI are considered. For this, EnergyPuls is employed to simulate the total annual heating and cooling needs for a specific building in the middle of the studied area. The simulations are performed in the 6 climate zones for all the urban design scenarios using 2 different weather data. First, the UHI free meteorological data measured at the weather station is used to calculate the UHI free cooling and heating needs then the weather data generated by the UWG is used to calculate the cooling and heating needs that account for the UHI effect. The analysis focuses on the effect of urban design options on both building energy efficiency and the changes in building energy estimation when UHI effect is included in the weather data.

The energy results for the urban design scenarios Type 2 are given in figure 6. These shows the variation of energy needs in the 6 climate zones when varying building heights from 1 to 20 stories with H/W=1. As expected the consideration of UHI in building energy estimation decreases the heating needs and increases the cooling needs. In all climate zones, the cooling loads of low-rise buildings are generally less important than the heating load because of the low solar access. This trend quickly reverses when the story number is higher than 2, except in Ifrane, the coldest climate zone, where the cooling load prevails for low-rise and mid-rise buildings. The UHI effect on cooling need increases with building heights while the effect on heating needs decreases.

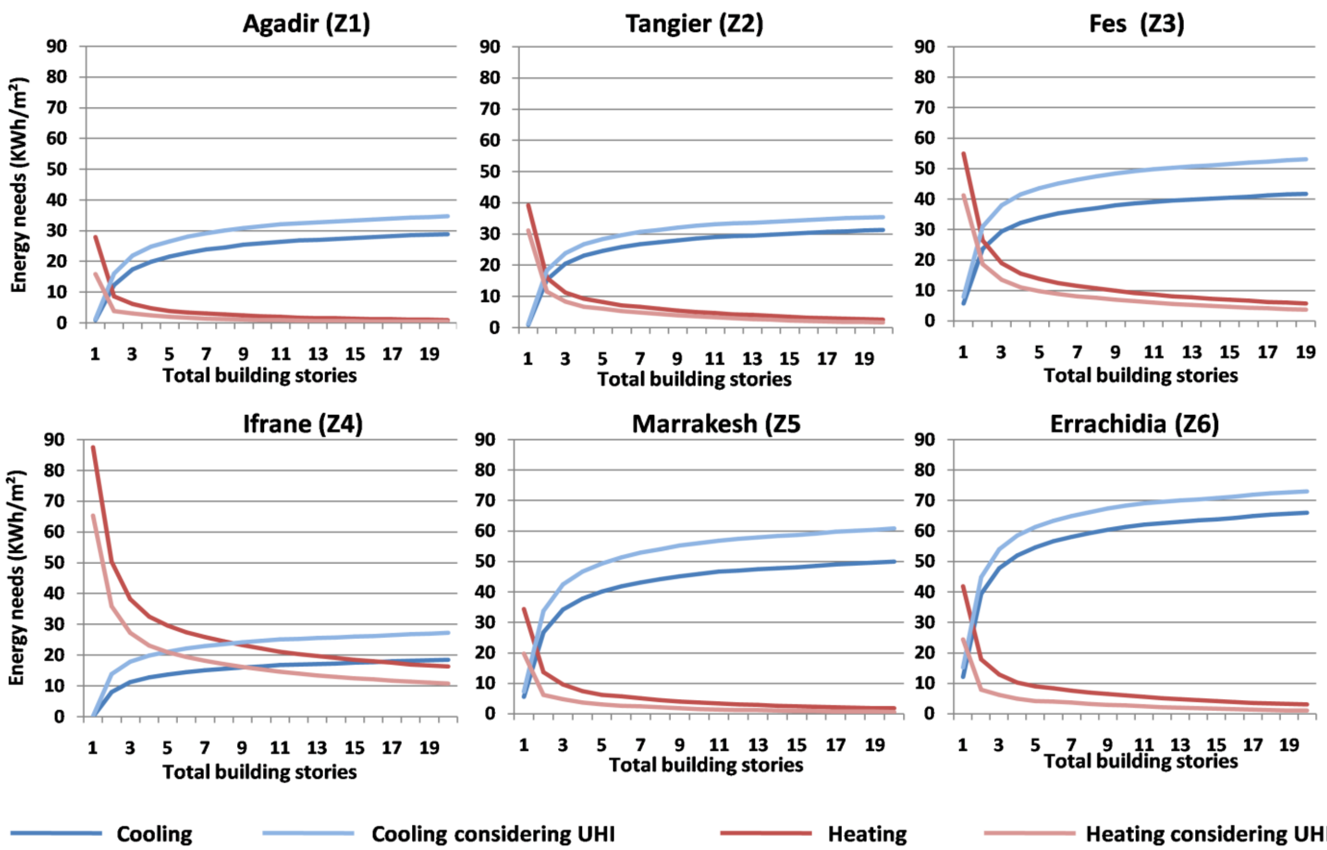

Figure 6. Impact of building heights and UHI on building energy needs for the urban design scenarios type 2 in the 6 climate zones

Figure 7 provides more insight on the effect of building heights and H/W variation on building energy needs. It summarizes the energy results of urban design scenarios type 1. It shows for all cities except Ifrane that low-rise buildings can be more energy efficient with adequate values of H/W. high values of H/W increase the energy needs for a low-rise building as the heating needs increase. H/W=1 is found to be the best design option in Agadir, Marrakech and Errachidia. While H/W=0.5 showed a slightly better energy efficiency in Tangier and Fes. In terms of UHI effect, it is found for low-rise buildings with different H/W values that the consideration of UHI reduced the building energy needs. This reduction is maximal for high H/W and is up to 12.3% in Agadir, 6% in Tangier, 3.8% in Fes, 17% in Ifrane, 4.6% in Marrakech, and 12.5% in Errachidia.

In Ifrane, High-rise buildings with a low aspect ratio are the best design options in therm of energy efficiency. A 20-story building with H/W=1/2 reduced the energy needs by 40% compared to the case of a 2-story building with H/W=4. Meanwhile, in other cities high-rise buildings with a low aspect ratio increase solar exposition and buildings overheat. This adds to the UHI effect that increases the prevailing cooling energy needs and leads to higher energy needs compared to low-rise buildings. The results show that urban design scenario with 20-story buildings and street aspect ratio of 0.33 increases the energy needs compared to the case of a 2-story buildings with street aspect ratio of 1 by: 90% in Agadir, 30% in Tangier, 18% in Fes, 61% in Marrakech and 48% in Errachidia. However, in Agadir, high H/W can enhance significantly the energy efficiency of mid-rise and high-rise buildings.

The negative impact of UHI on total energy need is more important in the case of high-rise buildings. The consideration of UHI in the energy simulations for the urban design scenario with 20-story buildings and street aspect ratio of 0.33 increased the total energy needs by: 13% in Agadir, 8% in Tangier, 19% in Fes, 14% in Ifrane, 16% in Marrakech and 7% in Errachidia.

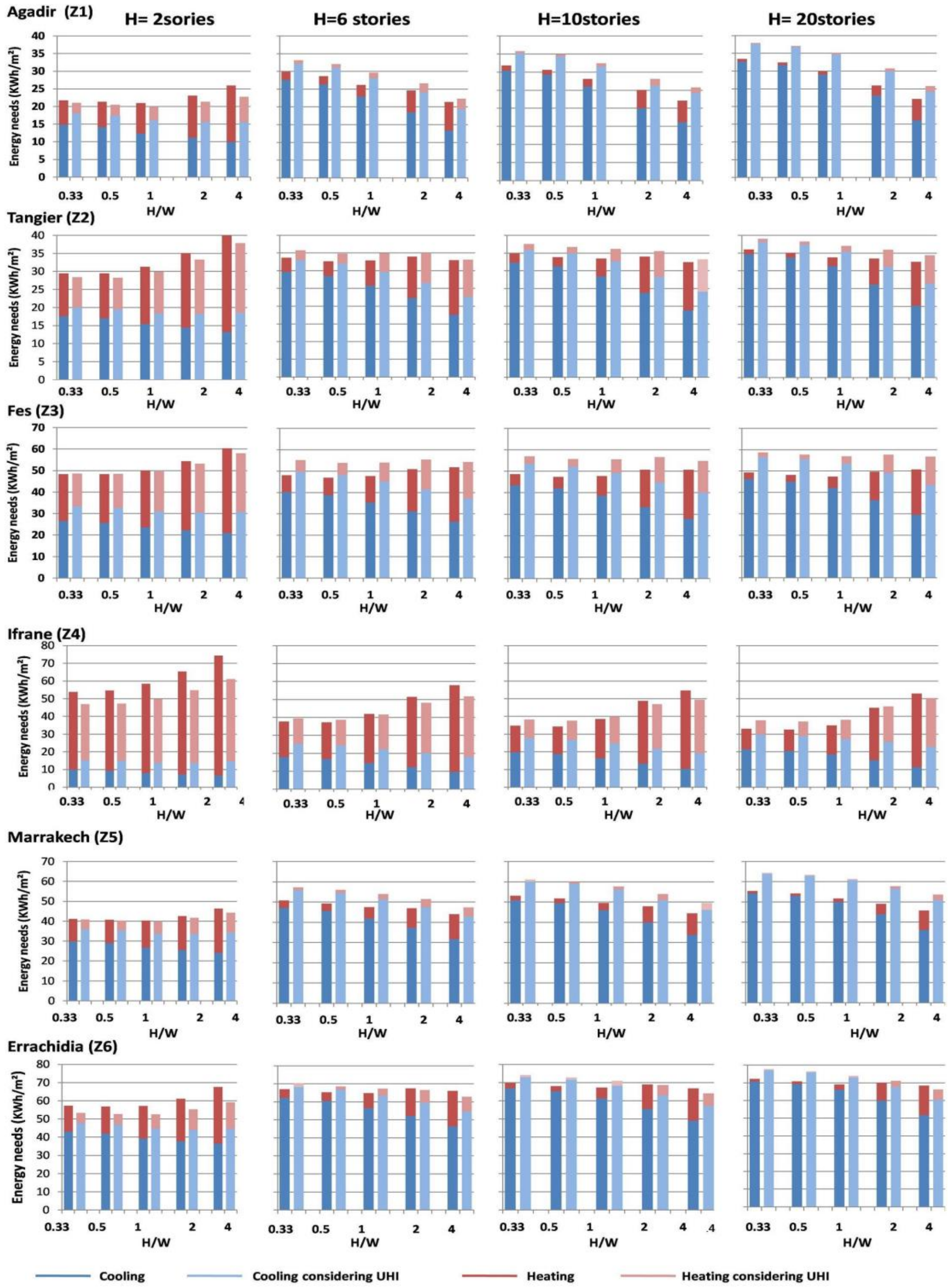

Figure 7. Impact of building heights and street aspect ratios on building energy needs

The variation of street orientation and building layout produced a small change in UHI intensity ranging between 0.1°C and 0.2°C. However the impact on building energy needs is more significant. Table 4 shows the energy simulations results under urban design scenarios type 3. In these scenarios we consider a constant building height of 6 stories and H/V =1 and we change the building layout as explained in figure 2. The results show that the layout type 1 and type 2, representing the single-fronted buildings with interior courtyards and lined up double-fronted buildings are the most energy efficient with a slight difference. The first been the best in all climate zones when the UHI effect is included in the energy simulation. The less energy efficient option is layout type 4 representing the detached buildings. This increased very significantly the cooling energy needs and slightly the heating energy needs and the UHI impact. It results in an increase in total energy needs including the UHI effects of 121% in Agadir, 108% in Tanger, Fes and Ifrane, 106% in Marrakech and 111% in Errachidia.

Table 4. Total building energy needs for urban design scenarios type 3 in the 6 climate Zones

Building layout	Type 1		Type 2		Type 3		Type 4	
Agadir (Z1)	24*	(+1.4)**	26.2	(+3.5)	50.3	(+3.6)	53.1	(+3.1)
Tangier (Z2)	32.5	(-1.1)	33.0	(+2.0)	58.2	(+2.2)	63.3	(+2.0)
Fes (Z3)	47.9	(+1.5)	47.7	(+6.3)	88.4	(+8.1)	94.3	(+8.5)
Ifrane (Z4)	44.7	(-5.8)	41.9	(-0.4)	78.5	(-1.0)	80.9	(+0.0)
Marrakech (Z5)	46.2	(+2.4)	47.5	(+6.5)	88.2	(+8.5)	93.0	(+7.6)
Errachidia (Z6)	64.4	(-3.2)	65.0	(+2.4)	119.7	(+2.6)	127.6	(+1.9)

***Building energy needs in KWh/m² estimated without considering the UHI effect**
****The impact of UHI consideration on energy needs in KWh/m²**

The UHI and energy simulation of urban design scenarios type 4 help to evaluate the impacts of street orientation. The energy simulation results are summarized in table 5 and show that the north-south orientation leads to the best building energy efficiency for all cities except or Ifrane were the street orientation East-West is more efficient for the city cold climate. The North-South oriented streets provide enough shadow, cooler surfaces and less energy demand for cooling. The east-west orientation allows a maximum solar gain through the south façade that is difficult to keep in shade. This is helpful in the case of cold climate cities. Otherwise, the energy needs increases. Also the UHI effect and its impact on the energy need is more important. The most unfavorable street orientation is the northwest-southeast for Ifrane and northeast-southwest for the other cities. Compared to the best options, these orientations increase the total energy needs by 76% in Agadir, 41% in Tangier, 28% in Fes, 29% in Ifrane, 47% in Marrakech and 38% in Errachidia.

Table 5. Total building energy needs for urban design scenarios type 4 in the 6 climate Zones

Streets orientation	East West		Northeast Southwest		North south		Northwest southeast	
Agadir (Z1)	26.2*	(+3.5)**	34.0	(+2.4)	19.8	(+0.8)	24.2	(+0.1)
Tangier (Z2)	33.0	(+2.0)	41.3	(+1.4)	30.5	(-0.3)	34.7	(-0.6)
Fes (Z3)	47.7	(+6.3)	59.2	(+5.6)	48.3	(+2.2)	54.0	(+2.0)
Ifrane (Z4)	41.9	(-0.4)	51.9	(+0.7)	54.0	(-5.4)	57.9	(-4.2)
Marrakech (Z5)	47.5	(+6.5)	59.5	(+5.7)	41.6	(+2.6)	47.6	(+1.9)
Errachidia (Z6)	65.0	(+2.4)	80.9	(+0.5)	61.8	(-2.9)	69.8	(-3.9)

***Building energy needs in KWh/m² estimated without considering the UHI effect**
****The impact of UHI consideration on energy needs in KWh/m²**

4. Discussion

The results of the study showed that urban design exerts a substantial influence on the UHI effect and building energy needs in Morocco. In all climate zones, the results indicated that urban forms has a significant impact on the magnitude of the UHI effect. A first comparison of the UHI effect in the different climate zones in Morocco showed that the UHI is particularly altered by local climates. Its intensity decreases significantly under the convective cooling effect of strong cold wind. For a common urban design scenario, hourly UHI intensity varied between 11°C and -5°C in the studied cities. The highest average annual UHI intensity is simulated in Ifrane, Marrakesh and Fes.

The simulation results showed that the street aspect ratios H/W has the most important influence on UHI intensity compared to the other studied geometrical parameters of the urban design. The compact urban area with tall buildings and narrow streets present more intense UHI during nighttime. However, during the daytime this urban design option might be more advantageous. Although a significant correlation between H/V and the temperature decrease in urban canyons during the daytime was not identified, the important shading in deep urban canyons decreases the mean radiant temperature. This might enhance the thermal comfort during the daytime as suggested by (Ali-Toudert & Mayer, 2006; Mahgoub, 2013).

In terms of building energy needs, it was observed that the consideration of UHI in energy simulation resulted in a decrease in energy needs estimation for low-rise buildings and an increase for mid-rise and high-rise buildings in all cities, except in Ifrane where they consistently decreased. When urban context and its resulting UHI effect were taken into account, it was determined that in cold climates, urban design featuring tall buildings with low street aspect ratios is more energy efficient. Conversely, in hot climates, low-rise buildings with H/W=1 were found to be more adapted.

Streets orientation and building layout have a small impact on UHI intensity but a very significant effect on building energy needs. The building layout is the most important parameter. The results show that detached buildings are the worst option that can increase the energy needs of more than 100% compared to single-fronted buildings with interior courtyards in all climate zones.

Overall, the results of the study provide valuable insights into the most effective urban design strategies for reducing the UHI effect and building energy demand in different climate zones in Morocco. However, a further development of this study is still needed for a more comprehensive understanding of the best design options. This should add other performance criteria such as the thermal comfort and include more urban design scenarios to test the impact of different construction materials, urban land use and more importantly the integration of vegetation within the urban fabric. This is shown to be a very effective solution for UHI mitigation (Gunawardena et al., 2017; Lachir et al., 2016). The biophysical processes of vegetation within the urban canyon are not fully detailed in the UWG. Combining the UWG with a comprehensive land surface biophysical model can enhance our understanding of how integrating green spaces and green roofs into urban design impacts the Urban Heat Island (UHI) effect and building energy demand.

5. Conclusion

The study's results add to the expanding corpus of literature. On the relationship between urban design and the local climate, and its consequences on building energy demand. The results indicate that urban design has an important impact on the UHI effect and building energy needs in Morocco and recommend always including the urban context and its consequent UHI effect in building energy simulation for a more accurate estimation of buildings' energy needs.

The study examined the impact of various factors, including building heights, street aspect ratios, building layout, and street orientation on Urban Heat Island (UHI) intensity. It revealed that the height-to-width ratio (H/W) has the most significant influence on UHI intensity and that an optimal combination of H/W and building height can enhance building energy efficiency. The study suggests that, in Agadir, Marrakech, and Errachidia, low-rise buildings with an H/W ratio of 1 are preferable, while in Tangier and Fes, an H/W ratio of 0.5 is recommended. However, in cold climates such as Ifrane, high-rise buildings with a low aspect ratio are found to be more energy-efficient.

Regarding building layout and street orientation, these factors were found to have a minor impact on UHI but a notable effect on building energy requirements. Therefore, the study recommends the adoption of single-fronted buildings with interior courtyards and favours an East-West street orientation in Ifrane, while in other cities, a north-south orientation is preferred.

As a final point, the findings of this study shed light on the crucial factors influencing Urban Heat Island (UHI) intensity and building energy efficiency in various climate zones of Morocco. This provides valuable information for urban planners and architects in Morocco to develop more sustainable and energy-efficient urban design strategies in different climate zones.

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Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

Ethics statements

Studies involving animal subjects: No animal studies are presented in this manuscript.
Studies involving human subjects: No human studies are presented in this manuscript.
Inclusion of identifiable human data: No potentially identifiable human images or data is presented in this study.

Conflict of Interests

The author declares no conflict of interest.

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