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Parametrically Optimizing Urban Street Form And Environmental Performance: The Case Of Izmir City

SARA KHELIL[1], IYNES LAOUNI[2], ALLA EDDINE KHELIL [3], DJIHED BERKOUK[4], TALLAL ABDEL KARIM BOUZIR[5]

[1,2,4] Department of Architecture, Faculty of Science and Technology, University of Biskra

[3]Department of Architecture and Industrial Design, University of Campania -Luigi Vanvitelli, via San Lorenzo Abazia di San Lorenzo ad Septimum - 81031 Aversa (CE)

[5] Institute of Architecture and Urban planning, University of Blida

Corresponding author: sara.khelil@univ-biskra.dz

Abstract

Through this research, authors hope to combine knowledge about parametric methodologies with the goal of designing improved urban environments. The city of Izmir, Turkey, was chosen as a representative of the urban and climatic challenges in this study. Ultimately, the purpose of this research is to reframe an urban design question (how urban street forms and configurations could improve the environmental quality and which is the most appropriate and optimal urban street form for Izmir city).

This study would look at whether parametric approaches may provide new solutions and design thinking methods in urban design. It demonstrates the potential of a new workflow based on parametric design to incorporate performative concerns into an urban design process via a flexible workflow to evaluate various environmental performance criteria. The used methodology might generate design concepts based on the designer's initial challenge. Furthermore, the design case opens up new avenues and perspectives for new challenges. The study's findings include recommendations and scenarios to consider while developing urban streets in Izmir to achieve the goal of ecological cities using parametric design principles.

Keywords: *ecological Street Scapes; environmental Performance; parametric design; urban design.*

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Introduction

Because the modern city expands without considering the climate / urban form relationship, today's urban reality faces serious problems, primarily due to unsuitable urban forms and configurations that do not respect the climatic conditions, which has altered the urban ecosystem and resulted in uncomfortable urban spaces (Itzhak, 2018).

Nowadays, there is a rising tendency toward adapting the built environment to climate features in order to minimize conflicts between climate and built environment and provide users with an appropriate urban environment (Amirtham 2015, Ruihan 2016). As a result, the conflicts between the design of urban areas and the requirements for weather, sun, and wind protection are reduced (Wei 2016). The bioclimatic quality of these places is a characteristic that can help to providing a comfortable living for city dwellers while also being tailored to user needs (Khelil and Cubukcu 2020).

The quality of urban streets is of great importance (Yubing 2020), and it is acknowledged that these spaces may serve to a high quality of life in an urban setting by creating pleasant and climatically appropriate urban surroundings. Many studies (experimental, empirical, and numerical) have been conducted to ensure appropriate comfort of urban streets, not only for city planning objectives, but also for environmental and climatic reasons. Various investigations have shown that streetscapes have an influence on the microclimate and outdoor thermal comfort in cities (XAVIER 1990, Maragogiannis 2011). A growing large number of studies used diverse analytical approaches to investigate the relationship between urban form and environmental performance (Jonathan 2019; Khelil and Cubukcu 2020). Certain criteria, such as orientation, geometry, surface covering, plant cover, sky view factor, and constructed area, are used to design the various street layouts.

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Many environmental factors influence street comfort, including sun radiation, infrared radiation, air temperature, humidity, and wind speed. In (Oke 1976), T.R Oke claimed that “urban streets and canyons can act as heat-retaining gorges by trapping long-wavelength radiation. These streets contribute to the increase of air temperature in cities." This theory, combined with the reality of urban street design in Turkey (Umut, 2021a), where planning regulations are vague, imprecise, and ambiguous in terms of clarifications regarding the impact of street geometry on environmental performance and issues (Umut 2021b, Khelil and Cubukcu, 2020), incited us to concentrate our research on urban street scapes.

Various issues and obstacles must be examined and resolved, and yet many scenarios must be tried and adjusted when it comes to urban street design. The usage of parametric design in this situation is highly suited for this context (Caetano 2019). This technique allows designers to quickly model various scenarios, visualizations, and quantification, and it provides adaptable solutions that may be re-computed based on stakeholder perspectives (Hernandez 2006, Holland 2012). The use of parametric design is common in architecture but uncommon in urban design and city planning.

The new roles of urban planners and designers, who are no longer simply creators of forms and spaces, but rather coordinators of organic and complex relationships of parameters that lead to optimal design solutions at an earlier stage of the design process, are called into question by parametric urban design (Nicolai 2018, Khelil and Cubukcu 2020).

We hope to reframe an urban design topic by doing this study: what is the appropriate urban street form and sectional geometry for producing ecological urban settings in Izmir, Turkey? We would solve a typical urban design challenge with implementations that centered on the parametric dependencies of spatial configurations,

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with the goal of improving the environmental performance of streetscapes through measurable street design aspects such as space between buildings, building heights, H/W ratios, and sky view factor.

In this regard, the goal of this research is to build a conceptual framework for the effects of street design on urban microclimate and to formulate recommendations for future street design and urban block planning using a parametric approach in order to achieve the goal of ecological cities. On the other hand, we want to see if parametric methodologies may help us find new ways to think about urban design in cities.

Methods and materials

In this study, a flexible parametric process is used, as evidenced by a typological evaluation of the link between different preset design factors and environmental performance. This project attempts to discover the suitable street pattern for Izmir city to generate ecological urban settings by an automated iterative investigation of the street form and its sectional geometry.

As a result, the authors employ a parametric assessment method (Khelil and Cubukcu, 2020), aiming to examine the correlation between density, design characteristics, and environmental performance. This study is based on an aggregated bottom-up approach based on performance predictions made using validated models.

This methodology has mainly two phases:

- The first phase concerns the evaluation of the selected dynamic urban parameters impact on the environmental metrics as presented in the proposed parametric workflow (Figure 1).

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- The second phase is about assessing the impact of the proposed scenarios of the combined dynamic parameters on the environmental performance.

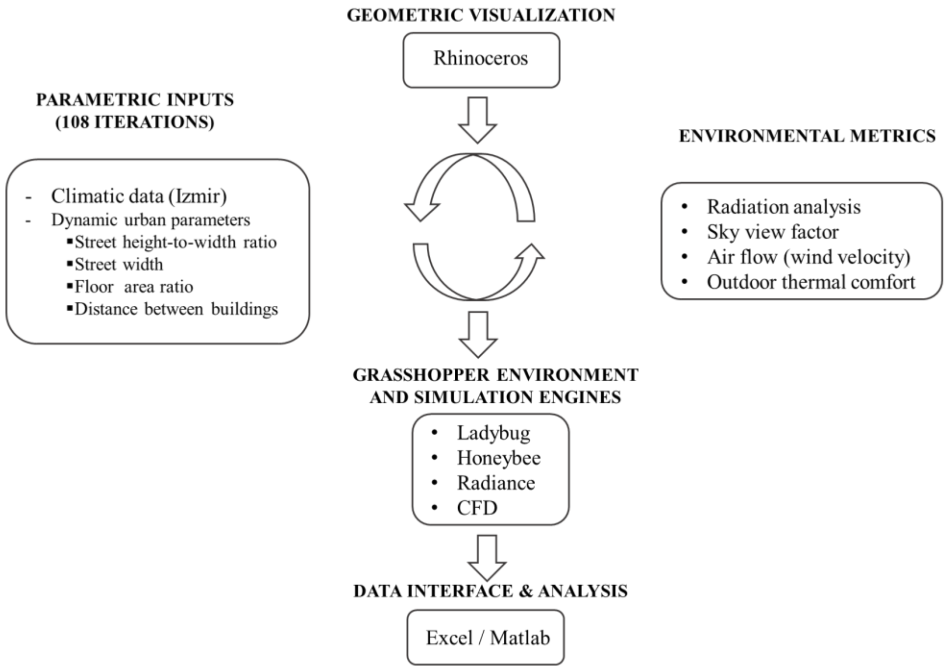

Figure 1: The proposed parametric workflow

Input parameters

To assess the environmental performance of various street typologies, fixed meteorological data and dynamic urban factors were integrated and combined.

(1) The selected dynamic urban parameters:

- Street height-to-width ratio (H/W): This is the ratio of total streetside building height divided by street width, and it defines the sectional proportion of the street canyon. A higher H/W value indicates a deeper street canyon, which influences the distribution and amount of reflection of radiation in the canyon. Furthermore, it has an impact on the canyon's wind circulation behavior. The authors choose four iterations based on (Kahraman and Cubukcu, 2017) (1, 1 / 1, 2/ 1, 6 / 3, 2).

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- Street width: This is the entire width of the street, including the width of two sides of the pedestrian walkway and the width of the complete car lane. This factor, in conjunction with the H/W factor, defines the sectional geometry of a street canyon. This factor has three iterations (7, 10, and 15).
- Building planting distance (D): This is the distance between buildings. This factor is available in three iterations (H/2, H, and 2H).
- The floor area ratio (FAR) was utilized to change the number of floors, with four iterations presented (2, 4, 8)

(2) For the static parameter, which is the meteorological input data, this study uses the design day selection technique to identify the most representative day of Izmir, in order to conduct a limited number of simulations while ensuring the ability to explore the impacts of various factors and variables.

In order to facilitate the parametric simulation, we have selected a design day from a typical year data for a decade (2012-2022) using “Meteonorm 7” software. It is chosen from among the 365 days in 2020, where its weather file contains detailed data on 24 hourly values of climatic criteria factors such as temperature, solar radiation, wind speed, and humidity. These meteorological conditions determine the ecological and environmental impact of the various designs. These factors, in addition to serving as control criteria in the selection of a design day, provide clues for interventions to reduce discomfort in occupied zones.

In this study, the 28th of July has been chosen as the design day. The hourly temperature, relative humidity, wind speed, and solar radiation data on that day are then utilized as meteorological starting input for the parametric simulation to produce microclimate conditions for the provided street canyons scenarios. The specialized Ladybug EPW input component in Grasshopper simply generates the data file.

Four environmental metrics were chosen as performance indicators to parametrically evaluate the environmental quality of the various scenarios: radiation, air flow, sky view factor, and temperature. Figure 2 shows the algorithmic configuration (parametric definition) for the analysis.

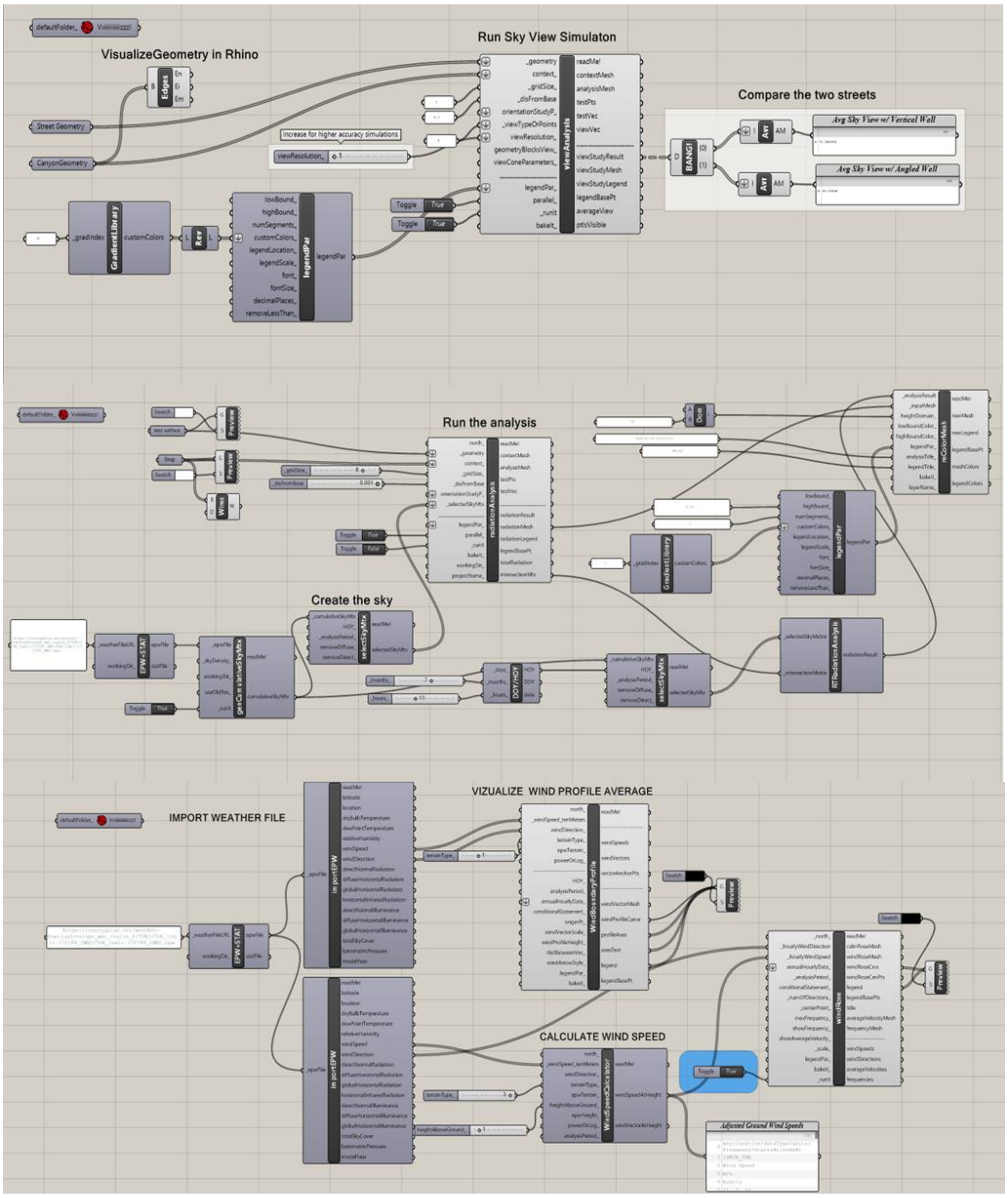

Figure 2: The developed algorithmic setting (parametric definition) for the analysis.

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Results and discussion

Phase1:

Tables 1, 2, 3, 4 present the evaluation results of the impact of the selected dynamic urban parameters on the environmental metrics. From the simulation results, we distinguish that the difference in air temperature between the different various profiles are small in the early morning until 6h and in the evening from 20h especially for the deepest and confined streets (H/W = 3,2; W=7; D= H/2, H; FAR= 8) . The variances start at 14h and are maximal in the afternoon hours. The air temperature between 24h00 and 06h00 has always known a decisive rise going up to 6 to 8 ° C.

The air temperature at the deepest street is generally lower than that of the widest street. The difference reaches a maximum of 5 ° C during the day and it essentially results from the difference in geometry and configuration especially the H / W ratio. The highest temperature value 42°C occurs at 14h, for the street having a H/W ratio of 1/6, it is considered as the warmest one due to the long exposure to solar radiation from 6h30 to 20h.

The maximum Temperature values are reached at different times of the day, namely around: 14h for the case of the street having H/W ratio of 1/6, 16h for the case of FAR=2 and for building planting distance 2H. The warming up of the streets follows the solar exposure. On average, the streets having an H/W ratio of 3/2, FAR=8, and a building distance of H/2 and the minimum street width, are the coldest one. The temperature decreases with the increase of H/W ratio and FAR. This is explained by the fact that the shading effect caused by the importance of the height of the street greatly contributes to reducing the air temperature and the duration of sunshine.

Maximum solar radiation amounts are recorded in the case of FAR=2 between 12h to 14h, they do not exceed 10 Kw/h in all the cases for the widest geometry. The

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Streets having a width of 10, 15 and H/W ratio of 1/6, 1/1 , building planting distance (D) of 2H and a small FAR are highly exposed to sun from 10h To 18h, with a value around 8 Kw/h, which is due to the opened geometry and configuration that allow the sun's rays reach the streets space.

Wind is one of the factors that determines whether a street or public space succeeds or fails. It has a significant impact on thermal comfort since it is a very detectable component of the urban microclimate. It can provide ventilation in the summer and be a nuisance in the winter.

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Table 1: impact of the street height-to-width ratio (H/W) on the environmental performance

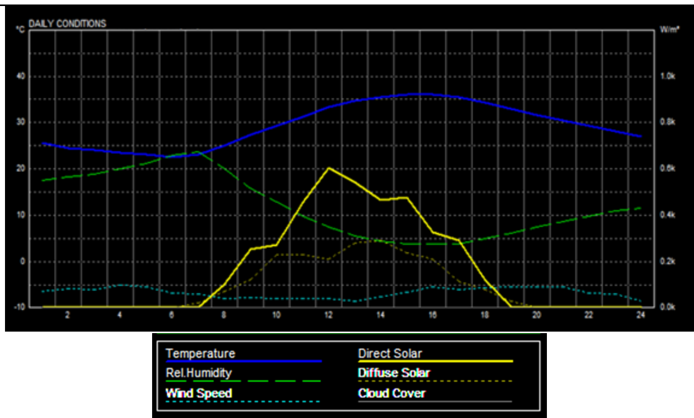
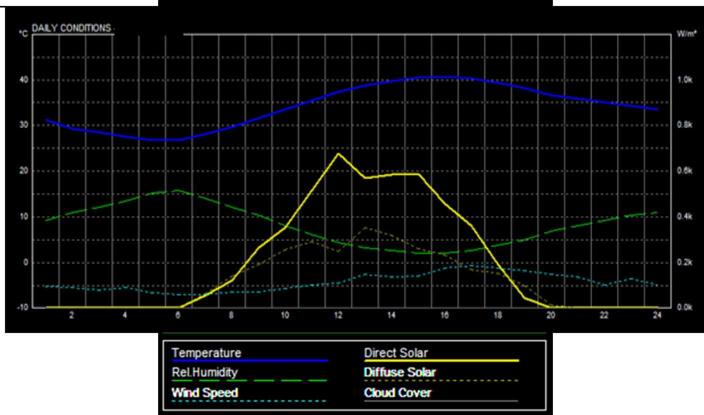
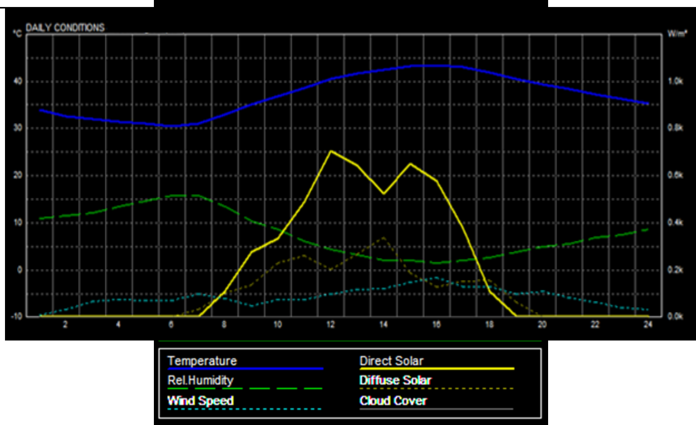
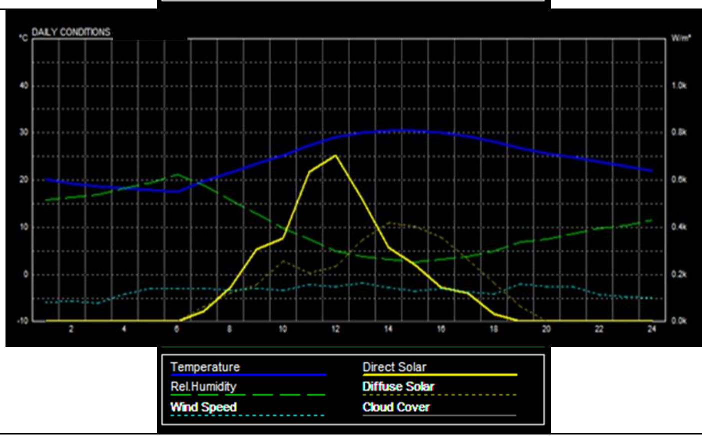
H/W	Environmental metrics
1/1	
1/2	
1/6	
3/2	

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Table 2: impact of the street width (W) on the environmental performance

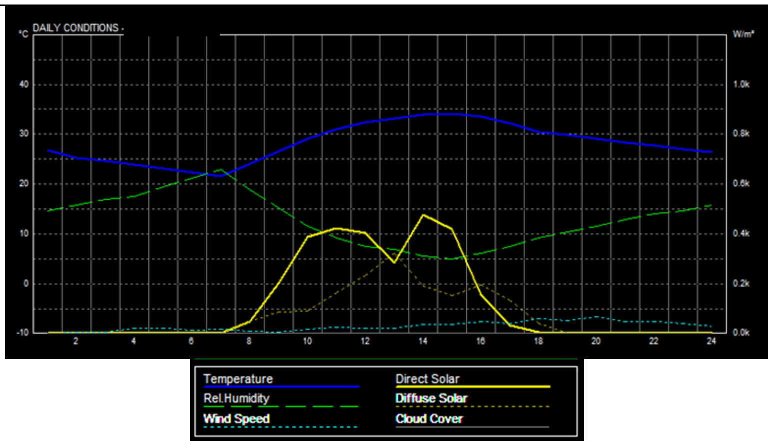
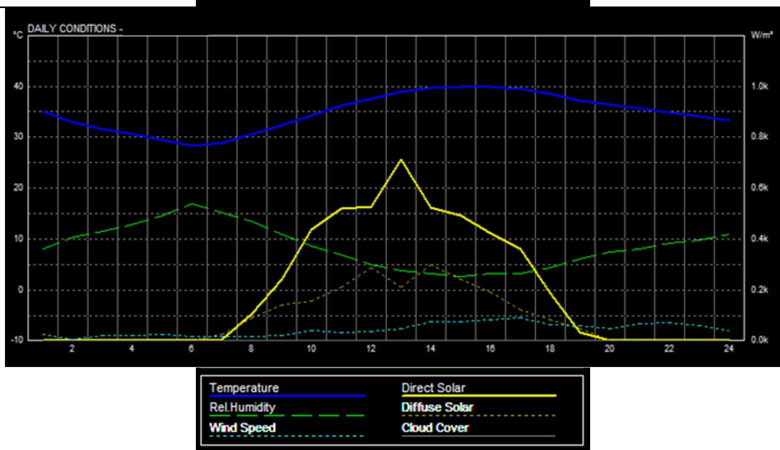
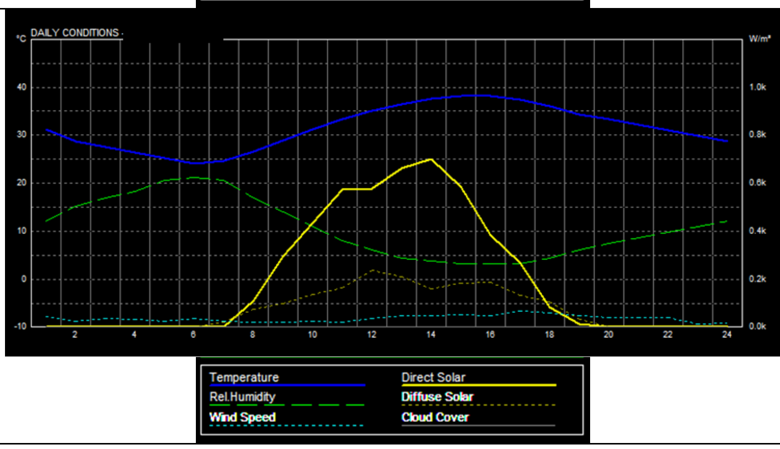
W	Environmental metrics
7	
10	
15	

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Table 3: impact of the building planting distance (D) on the environmental performance

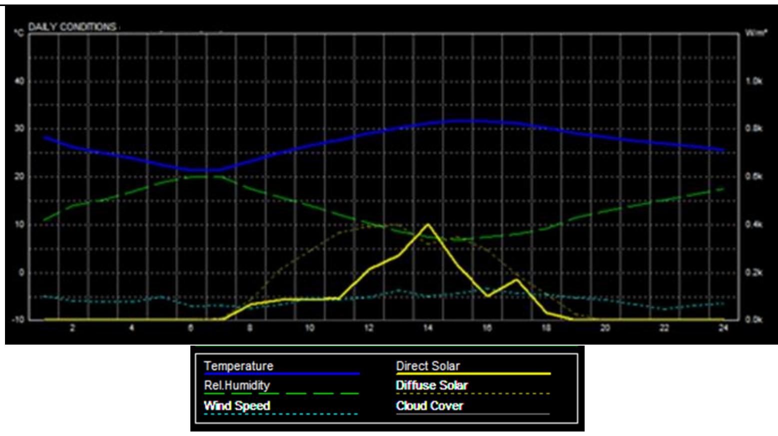
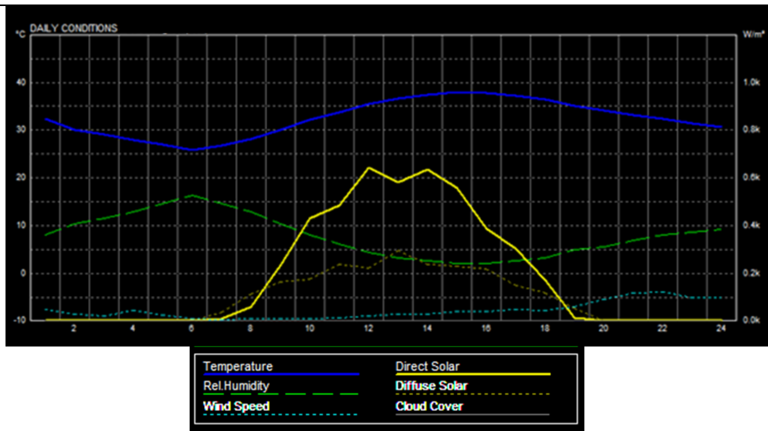
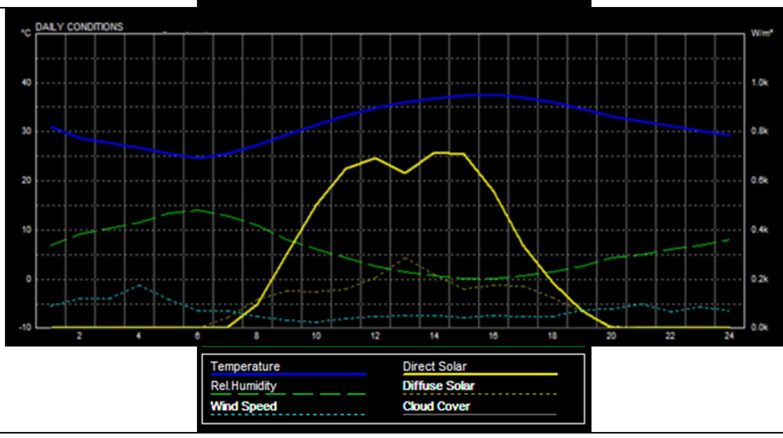
D	Environmental metrics
H/2	
H	
2H	

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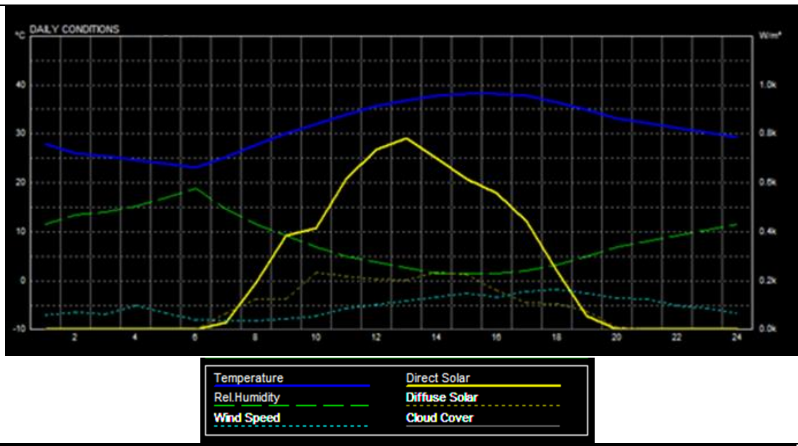
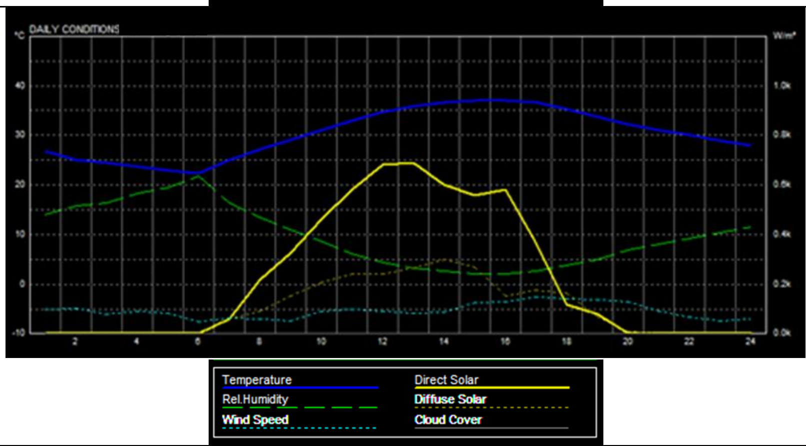
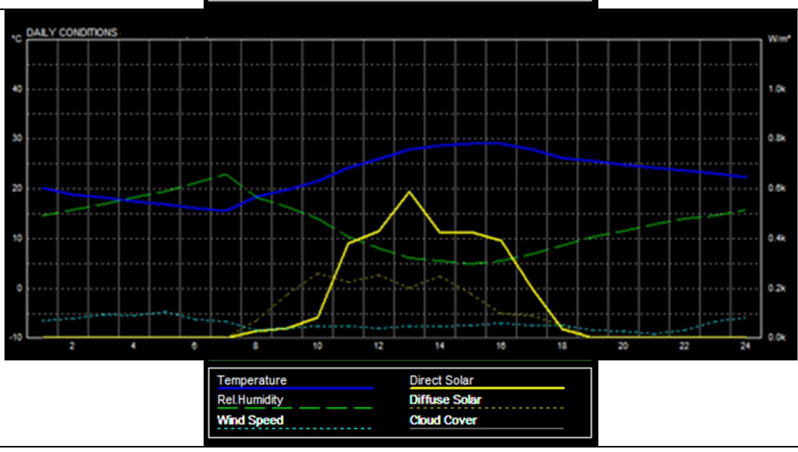
Table 4: impact of the Floor area ratio (FAR) on the environmental performance

FAR	Environmental metrics
2	
4	
8	

The study findings demonstrated that the confined configuration and semi-opened geometry are the most efficient (H/W= 3,2; W= H/2, H; FAR= 8, 4). They are protected, well-ventilated, cool, and comfortable. In the face of Izmir's wind regime, their spatial structure is the most appropriate form. It increases outdoor ventilation in

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the summer by eliminating excess humidity, overheating, and pollution and consequently induces better ventilation inside.

The sky opening or visibility factor, often known as the sky factor, is the part of the sky visible from a certain place (Marie, 2004). This factor is critical in the warming of air and surfaces. The SVF was computed at the level of the various street layouts (Table 5).

After analyzing the changes in air temperatures, solar radiation, and wind speed in various setups based on different SVF values, it was discovered that the SVF has a significant impact on temperature variation and outdoor thermal comfort. When the SVF increases, the outdoor thermal comfort decreases.

Table 5: impact of the Floor area ratio (FAR) on the environmental performance

	H/W ratio				Street Width (W)			Building distance (D)			FAR		
	1,1	1,2	1,6	3,2	7	10	15	H/2	H	2H	2	4	8
SVF	0.32	0.48	0.58	0.34	0.38	0.46	0.50	0.35	0.37	0.42	0.48	0.46	0.39

Phase2:

By changing and combining the input parameters (H/W ratio, FAR, width, distance between the buildings), a set of 108 scenarios (4x3x3x3) cover all possible combinations of the previous parameters they are produced via Grasshopper, where each alternative scenario is evaluated. We have assessed the impact of the proposed scenarios on the environmental performance based on the environmental metrics (Solar Radiation, Temperature, wind speed and Sky View Factor).

Figure 3 presents the results of the second phase, after combining the different dynamic parameters. The obtained simulation results are translated into scales in order to facilitate the comparison of the results, where each line presents an iteration scenario and its impact on the environmental metrics.

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In the research (Eskin, 2008; Inanici, 2000) the authors have determined a comfort range of the different environmental metrics for Izmir city. The metrics values must be comprised in the range: for the temperature, the range is between 25° - 35°, however the Wind speed is from 2 m/s to 6 m/s; for the solar radiation the range is between 0.4 Kw/h – 0.65 Kw/h; and for the sky view factor the range is from 0.34 to 0.45.

Based on these climatic metrics data, we have superposed the different comfort ranges on the scales of the iterations scenarios as presented in the Figure 3. After combining the obtained results and the comfort ranges of Izmir city, we concluded that the most optimized geometries and configurations to ensure the outdoor thermal comfort in the city of Izmir are the scenarios who guarantee that their environmental performance is included in the comfort range:

- H/W= 3/2, W= 7, D= H/2, FAR= 8
- H/W= 3/2, W= 7, D= H, FAR= 8
- H/W= 3/2, W= 10, D= H, FAR= 8
- H/W= 3/2, W= 10, D= H/2, FAR= 8
- H/W= 3/2, W= 7, D= H/2, FAR= 4
- H/W= 3/2, W= 7, D= H, FAR= 4
- H/W= 3/2, W= 10, D= H, FAR= 4
- H/W= 3/2, W= 10, D= H/2, FAR= 4
- H/W= 1/1, W= 7, D= H/2, FAR= 8
- H/W= 1/1, W= 7, D= H, FAR= 8
- H/W= 1/1, W= 10, D= H, FAR= 8
- H/W= 1/1, W= 10, D= H/2, FAR= 8
- H/W= 1/1, W= 7, D= H/2, FAR= 4

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- H/W= 1/1, W= 7, D= H, FAR= 4
- H/W= 1/1, W= 10, D= H, FAR= 4
- H/W= 1/1, W= 10, D= H/2, FAR= 4

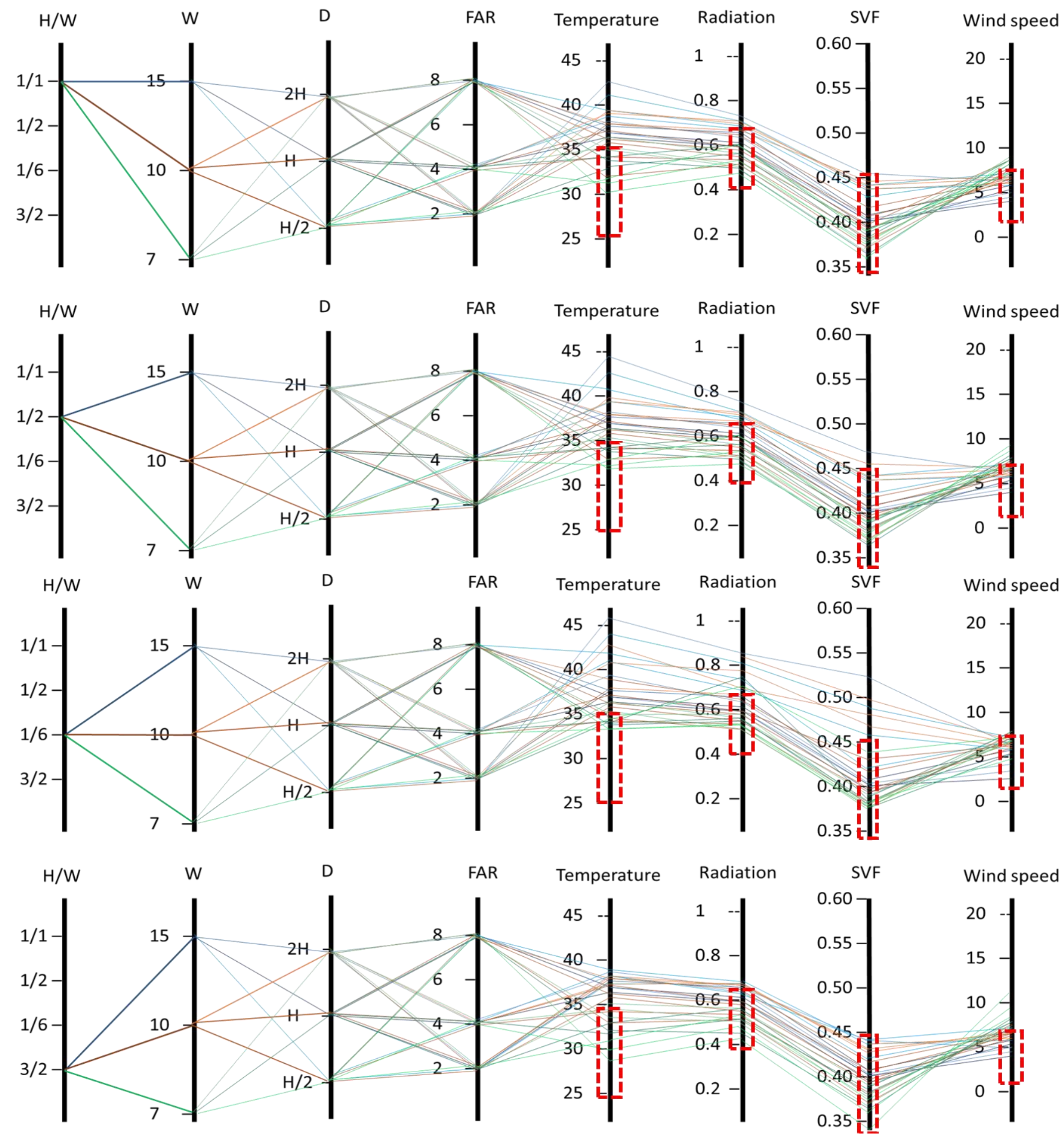

Figure 3: impact of the different proposed scenarios on the environmental performance

Conclusion

The purpose of this pilot study is to provide recommendations and guidelines for future street design and urban block planning in the city of Izmir, Turkey, in order to achieve the goal of ecological cities using parametric design principles. The authors created an

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experimental methodology based on quantitative and comparative analysis utilizing parametric models and simulations to characterize this influence. The first step of this study involved assessing the influence of the specified dynamic urban factors on environmental indicators. The second phase is concerned with the influence of various dynamic input parameter combinations on environmental performance.

Authors were able to classify the reasons of air warming in Izmir based on the results and by comparing geometrically various places (open and restricted) as follows:

- The SVF is a critical parameter that contributes to urban air warming (In terms of the geometry of the streets, the width of these can dictate the importance of the SVF).
- As the height-to-width ratio (H/W) of the street increases, so does the temperature.
- When considering the impacts of solar radiation, the shade of outdoor spaces is quite beneficial since it substantially adds to the decrease of radiant heat gains, which directly influences the air temperature.
- This shadow effect is created by the design of an urban roadway and lessens the surface and air temperatures.
- In the face of Izmir's wind regime, the spatial organization of the restricted configuration and semi-opened geometry is the most appropriate shape. They are safe, well-ventilated, cool, and comfy.
- The temperature fluctuation and outdoor thermal comfort are influenced by the Sky View Factor. When this component rises, outdoor thermal comfort falls.
- The most optimized urban street configurations to ensure the outdoor thermal comfort in the city of Izmir are the scenarios who guarantee that their environmental performance is included in the comfort range:

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- H/W= 3/2, W= 7, D= H/2, FAR= 8
- H/W= 3/2, W= 7, D= H, FAR= 8
- H/W= 3/2, W= 10, D= H, FAR= 8
- H/W= 3/2, W= 10, D= H/2, FAR= 8
- H/W= 3/2, W= 7, D= H/2, FAR= 4
- H/W= 3/2, W= 7, D= H, FAR= 4
- H/W= 3/2, W= 10, D= H, FAR= 4
- H/W= 3/2, W= 10, D= H/2, FAR= 4
- H/W= 1/1, W= 7, D= H/2, FAR= 8
- H/W= 1/1, W= 7, D= H, FAR= 8
- H/W= 1/1, W= 10, D= H, FAR= 8
- H/W= 1/1, W= 10, D= H/2, FAR= 8
- H/W= 1/1, W= 7, D= H/2, FAR= 4
- H/W= 1/1, W= 7, D= H, FAR= 4
- H/W= 1/1, W= 10, D= H, FAR= 4
- H/W= 1/1, W= 10, D= H/2, FAR= 4

The parametric tools were quite helpful in determining the best combination of the various design parameters to achieve a balance of the performance criteria. The findings also aided in comprehending the combined influence of the design variables on performance.

Data Availability Statement

The authors declare that: all data, models, and code generated or used during the study appear in the submitted article.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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