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Green building outdoor thermal comfort in hot-desert climatic region

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Abstract: This paper studies the Egyptian building design strategies for different building envelope shapes based on the green building design using the DesignBuilder program by simulating the outdoor climate conditions depending on the Egyptian meteorological data. The simulated results are applied to Minia City as one of the hot-desert climate regions in Egypt. The research is performed on the hottest day in summer according to the analysis of climatic data overall months using the climate consultant tool. This research studies two main variables to characterize the quantitative relationships between the building form and the Natural Ventilation (NV) of thermal comfort to be achieved, which are mixed-mode maximum wind speed, and natural ventilation setpoint temperature. The research focuses on two output parameters, which are air velocity and pressure, relating to natural outdoor ventilation. The simulation findings revealed that the circle form offers the best case, which has a significant role in achieving thermal comfort that optimized the value between the two major parameters in building design, while the worst case is the U-shaped building based on the same two optimized values. Finally, the usage of natural ventilation, simultaneously with choosing the suitable building geometry, is principal for adapting the current outdoor air velocity and pressure, thus reducing the energy consumption of buildings.

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PUBLIC INTEREST STATEMENT

Outdoor areas suffer from a lack of attention to climatic design. In this study, the relationship between building form and natural ventilation has been investigated in one of the hot desert climatic regions (Minia City). The study assesses the wind speed and temperature parameters using the DesignBuilder tool as one of the most powerful and widely used software. The study is interested in studying outdoor thermal comfort and its effects on buildings. The paper suggests a combination between natural ventilation and choosing a suitable building form to adapt the air velocity and pressure to reduce the energy consumption of the buildings. The article follows up on the joint activities of the authors’ team in the design and evaluation field of building structures designed for climatically harsh outdoor conditions. The activity reflects the global challenges of global warming and CO\textsubscript{2} reduction in saving energy for heating and cooling.
**Practical application:** This paper studies the relationship between building form and natural ventilation to achieve outdoor thermal comfort and its effects on buildings. The study assesses the wind speed and temperature parameters using the DesignBuilder tool. The study suggests a combination between natural ventilation and choosing the suitable building form to adapt the air velocity and pressure to reduce the energy consumption of the buildings.

**Subjects:** Heating Ventilation & Air Conditioning; Civil, Environmental and Geotechnical Engineering; Design

**Keywords:** Climate conditions; outdoor air temperature; ventilation; natural conditions; geometry model; DesignBuilder

1. Introduction
Designer choices are crucial in the building’s potential success. Therefore, it is crucial to know the unique characteristics of the environments and microclimates around the building to keep the best choice through the design process. In hot-desert climate regions, it is important to follow passive strategies and designs that promote the adaptation of the occupants to local weather changes to gain thermal comfort in outdoor spaces.

Outdoor spaces are essential for sustainable communities, as they support multiple outdoor activities daily and contribute significantly to urban vitality and liveability. Encouraging the residents in outdoor spaces would help communities from various backgrounds, including physical, cultural, economic, and social factors of thermal comfort achievements (Chen & Ng, 2012).

Lately, interest in outdoor thermal comfort research has increased, particularly in tropical regions (Ahmed, 1996; Chun et al., 2004; Johansson, 2006; Johansson & Emmanauel, 2006; Salleh, 1994; Spagnolo & de Dear, 2003), where Egypt is located in the dry tropical region; This was not until the indoor thermal warmth principle was believed to be true to the outdoors. Moreover, it has been emphasized that the human thermoregulatory model (Zhao et al., 2020) is seen as insufficient in describing the requirements of thermal comfort in the outdoors owing to the complex outdoor climate. This study examines outdoor thermal comfort in the hot desert climate by examining factors affecting thermal comfort, including environmental parameters that influence the design’s microclimatic environment, such as temperature itself and the air motion.

The outdoor temperature greatly affects the indoor temperature, where the indoor-outdoor temperature relationship is nonlinear. However, there are four meteorological parameters – Temperature (T), Absolute Humidity (AH), Relative Humidity (RH), and Apparent Temperature (AT) determined the relationship between indoor and outdoor residential conditions. Outdoor temperature, indoor temperature, AT, and AH have been strongly associated, but RH is not (Lee et al., 2015).

Outdoor thermal conditions are related to several health effects as indicated by many studies (White-Newsome et al., 2012), they used the outdoor data as indicators for the personal health outcomes. However, indoor temperature and RH were used to calculate AT and AH. AT incorporates the mean temperature and the temperature at the dew point. However, the daily temperature for outdoor spaces, dew-point temperature, and RH can be obtained from the city of case study Meteorological Administration. Then, we can calculate the outdoor AT in the same way as the indoor AT.
The indoor and outdoor AT and AH have important impacts on both enhancing comfort and reducing energy consumption (Brager & Dear, 1998; Elshafei, 2021). It is agreed that variables that affect thermal comfort can be clustered into two groups: environmental factors and human factors. The environmental factors include air temperature, mean radiant temperature, air velocity, and relative humidity (Ghada et al., 2021; Sedki, 2013), where the air temperature factor is the most frequently utilized parameter of thermal comfort (Yang et al., 2016). The relative humidity is also another significant factor influencing thermal comfort, where high humidity rates within buildings inhibit skin sweat evaporation (Elson & Eckels, 2015). So, to reduce the humidity levels two ways have a significant effect on thermal comfort, especially in hot-desert climates which are dehumidifiers and natural ventilation (Arslanoglu & Yigit, 2016; Elshafei et al., 2017).

Natural ventilation is one of the main passive techniques for areas with a hot and humid atmosphere where ventilation is inaccessible. Ventilation is significant for humidity control and the user’s health, which occurs due to varying pressure or temperature. The important factors that affect the ventilation strategy performance can be summarized as the location of the building, its geometry, ventilation area, and airspeed, the position of the windows, and the angle of wind incidence (where the positive pressure incident, which occurs on the building face is considered (windward), and the negative pressure is on the leeward face). Also, other passive techniques can be used to achieve thermal comfort such as stack effect ventilation, cross-ventilation, ventilation through in-between spaces, ventilation through the roof, and ventilation under the building (Enteria et al., 2020; Ghiaus & Roulet, 2012; Martins & da Graça, 2016). Moreover, and regularly inside regions, for example, a hot environment district as Egypt, the analysts’ current pass of the new methods that would demonstrate helpful in illuminating plan and decision-making inside the public domain; in these areas, such gaps of knowledge are especially obvious inside city masterplans, as exemplified by cases like numerous African areas.

This study uses NV to present the observed and estimated relationship between four different building configurations in Minia City as a case study and its microclimate. The study aims to extract the most effective building configuration that can enhance the thermal comfort performance of outdoor spaces during the hottest days in the summer. The novelty of this research reflects the role of planning procedures that can be applied to improve outdoor thermal comfort and control the climatic consequences of planning at an early stage to achieve one of the concepts of green building.

2. Literature review

Owing to climate change and rising heat stress in cities, interest in thermal comfort evaluation has grown over the last decade. Yet the number of research on thermal comfort for outdoor conditions has been relatively small. On the other hand, numerous studies in indoor thermal comfort have been performed (Spagnolo & de Dear, 2003; Swaid et al., 1993).

Baruch et al. (2004) conducted experimental research in the commercial plazas in Japan. The objective of their study was the evaluation of the effects of various design parameters on thermal comfort according to the seasonal changes in the climate. A comprehensive questionnaire was administered to the study. Where the environmental variables were the surface temperature, the ambient air temperature, humidity, and exposure to the sun below different wind speeds. Data analysis allowed the development of a formula predicting the thermal sensation of an outdoor stay subject as a function of air temperature, wind speed, and solar radiation. The formula also covers the impact of acclimatization on natural temperature variations. However, humidity and surface temperature of the local areas were observed to have a marginal effect, where the impact of exposure to the sun with the unblocked wind was equal to an increase in air temperature of 7.5°C, and the result of lowering wind speed by around 50% under sun exposure by blocking the heat.
Fanger (1970) presented the noticed and estimated relationship between the building configuration in New Aswan and the changes in microclimate. The research sought to find the most efficient design of buildings that could enhance the thermal efficiency of urban open spaces throughout the summer by studying the most effective parameters, which affect thermal comfort in the outdoors. The results in the analysis were implemented based on on-site observations and microclimate simulations utilizing ENVImet tool, which was performed on normal climate conditions during October for 24 hours. The results indicated that the key parameters influencing the outdoor thermal activity are the patterns of solar radiation and shading, so the urban-type that gives more shade to its spaces gives more thermal comfort, and that is also ensured by Fanfare (Prajongsan & Sharples, 2012). Where the findings revealed quantitatively that, owing to the Sky View Factor (SVF) and direction of the building, there was a broad variety of Physiological Equivalent Temperature (PET) values (20°C) at noon. These variances resulted in relatively comforting spaces.

Nguyen et al. (2014) examined the effect of outdoor weather observations and the indoor conditions in Boston, USA. The study focused on four weather measured parameters, which are temperature, apparent temperature, absolute humidity, and relative humidity. The results showed that the ambient temperature is not a sensitive predictor of indoor temperature sensitivity during colder months. Their study ensured that the human health outdoor environment has a great effect on the indoor environment. Applying bioclimatic approaches to projects situated in hot-humid environmental regions will result in substantial benefits associated with energy conservation and consumer satisfaction.

Triana et al. (2018) demonstrated the effectiveness of the energy conservation that was introduced to a traditional hot housing project in Salvador, Brazil, in a hot–humid climate. They studied the environmental situation for two environment change scenarios 2020 and 2050 as indicated in the 3rd Intergovernmental Panel on Climate Change (IPCC) report (UNEP, WMO, IPCC, 2000). Their assessment was applied to the residential activity and hours of discomfort by using the CCWorldWeatherGen Tool (which converts current weather files to future weather files for use in the thermal and energy simulations). The results showed that due to heat, there is a tendency to increase the hours of discomfort by 56% in future scenarios compared with the current one. However, the adaptation steps that have been proposed in their study will get the best results by considering the natural ventilation.

Nikolopoulou et al. (2001) investigated the thermal comfort condition of resting areas as an urban open space in Cambridge. Their study focused on behavioral factors and the need for forecasting resources in the design and preparation of thermal outdoor comfort. They conducted thermal sensation evaluations given on a 5-point scale ranging from cold to hot. The most significant discovery of their study was the broad difference between the interviewees’ real thermal comfort sensation as defined in the Actual Sensation Vote (ASV) and the state of theoretically Predicted Mean Vote comfort (PMV) assessment.

Zacharias et al. (2001) studied the outdoor environment in public squares in seven corporate plazas in the downtown region of Montreal. They used the test ANOVA through multiple regression analyses. The authors found that microclimatic factors such as (temperature and light) account for approximately 12% of the present variation in the open spaces, while the location and period of the public square of the day reflect 38% and 7%, respectively.

Shabbir Ahmed (2003) presented outdoor comfort based on field investigations carried out in Dhaka, a town in the Wet-Tropics area. The findings provided by the study were carried out randomly in many chosen urban environments. The findings include factors affecting outdoor
comfort as an ambient temperature that contributes to the comfortable indoor environment. Thus, comfort outdoors in the Humid Tropics is an achievable goal for urban designers, consequentially comfortable outdoors reduces the energy consumption to create comfortable indoors.

Shooshtarian et al. (2020) presented a review in an urban context to evaluate the outdoor thermal comfort in Australia. Various suggestions are proposed in their analysis. Firstly, a local standard for determining thermal comfort needs to be established. Having such a local standard could give higher levels of confidence in assessing thermal comfort conditions, at least for different climatic zones. Secondly, it is also proposed that qualitative analyses can be incorporated in future research, where the relationship between perceived environmental efficiency and thermal outdoor comfort may be further explored. Finally, knowing the principal basics of comfort and the behavior of the citizens at these locations is essential to understand well the bioclimatic strategies, where the durable and pleasant structures for buildings are more effective in areas with a hot-humid atmosphere.

Zhang et al. (2020) investigated the correlation between air temperature and urban morphology parameters in a cold-climate city in Harbin, China. They studied the urban morphology parameters that affected the outdoor air temperature by conducting a field measurement using the multi-linear regression models. The results indicated the number of building floors had a significant effect on the daily average temperature; However, when the building had more than 20 stories, the temperature did not vary much with the building height. The degree of effect of urban shape on temperature was time, and space where the highest influence of temperature was found within a hundred-meter radius of the location of interest. In the summer, however, a 0.5 increase in the green plot ratio reduced (raised) the daytime average temperature by 0.8°C (1.3°C) (winter).

Ibrahim et al. (2021) investigated the morphological changing characteristics of three-block typologies (scattered, linear, and courtyard) and their associated parameters on environmental conditions, outdoor thermal comfort, and energy use intensity in Cairo city, Egypt, using the Ladybug tools simulation plugins. They considered some design parameters and indicators. The results indicated a substantial link between design factors and combined thermal comfort and energy consumption with urban density. The design characteristics had a consistent influence on the distinct typologies. Across all typologies, compact and medium-density urban forms are found to elicit the highest overall performance, particularly for ordinal orientations (e.g., 45°). When it concerns thermal comfort, compact high-density dispersed forms are preferred, whereas court-yards surpass other typologies in terms of energy efficiency and overall performance.

Saud et al. (2021) presented seven thermal comfort indices for measuring outdoor thermal comfort. The indices include predicted mean vote, discomfort index, cooling power index, humidex, wet bulb globe temperature, standard effective temperature, and universal temperature climatic index. The thermal comfort indices were compared to the thermal sensation vote, derived from a thermal comfort questionnaire completed by fans situated in six distinct zones in a semi-open air-conditioned stadium. As a result, the values of the seven thermal comfort indices were predicted using CFD simulations. With average variances of 14% and 15%, the WBGT index was rated the best acceptable to measure outdoor thermal comfort for hot and dry locations, followed by the UTCI and the SET indices. In comparison to other indexes, the CPI index was regarded as unsuitable for hot and dry environments.

Mahmoud et al. (2021) planned a new campus at Aswan University, New Aswan city, to investigate thermal improvements in a hot desert environment based on environmental concerns of the surrounding climatic circumstances. This study uses ENVI-met software to offer analytical and empirical data, highlighting the potential for their adoption in outdoor environments. They used coupled scales to develop effective thermal adaptation guidelines, which include geometrical
details and urban form planning, by analyzing five urban forms and 18 urban geometry scenarios and quantifying their thermal impacts on outdoor spaces using on-site measurements and micro-climate simulations. The outcomes are rated based on their impact on pedestrian thermal comfort. The proposed technique might lower the average physiological equivalent temperature by 6.8°C in the N-S canyons and 4.2°C in the E-W canyons during peak time. Also, they introduced design guidance for planners and decision-makers.

Bandurski et al. (2020) proposed a green construction idea on designed buildings that are still being developed, in which cooling efficiency is based on the synergy of shadow and evapotranspiration. The green structure, which might be utilized as street furniture, protects people and items from the negative impacts of the urban environment while also providing a pleasant and healthy microclimate within. The findings of short-term temperature and humidity measurements are examined. In addition, they carried out a dynamic simulation of the performance of green structures in courtyards. The results revealed a reduction in the perceived temperature within this structure. In a courtyard case study, the average potential decrease in the Universal Thermal Comfort Index and the mean radiant temperature produced by the green construction is 5–8°C and 17–29°C, respectively, depending on climate type. TRNSYS software is also an excellent tool for simple outdoor microclimate study, according to simulation results.

Many reviews examined the growing recognition of microclimatic factors in design, revealing the principles, guidelines, strategies, mapping, evaluation, and the benefits and drawbacks. However, some studies identified ways that landscape architecture researchers have used to enhance the outdoor thermal comfort environments. The microclimatic design can improve the public’s health and well-being by creating thermally suitable outdoor settings that achieve the quality of human existence in metropolitan areas. Subjective surveys and objective measures were used in these review studies. Researchers investigated several factors that influence outdoor thermal comfort, green spaces, and heat mitigation measures. They concluded that increased vegetation, suitable design, and heat reduction methods have an observed change that can enhance OTC conditions. The studies showed that the findings help designers through urban planning principles, and also, they assisted researchers in choosing the best numerical simulation tool for their needs (Jiawei & Brown, 2021; Kumar & Sharma, 2020; Lam et al., 2021).

3. Methodology
The discussion of this research reflects the importance of guidelines for the planning that can be applied to help improve outdoor thermal comfort. This study presents the observed and estimated relationship in the case study between the used building configurations and a selected hot-desert microclimate case (Minia City). The study aims to extract the most effective configuration of the building that can improve the thermal performance of urban outdoor spaces during the summer, thus affecting the thermal comfort of the indoor also.

Thus, a simulation of thermal performance analysis for natural ventilation is essential to predict the thermal comfort inside and outside the building for reaching better thermal environments. An examination and prediction of thermal comfort using DesignBuilder, based on the state-of-the-art EnergyPlus building efficiency simulation software, is conducted for one of the Egyptian hot-desert climates Minia City, which is located in a hot desert region; therefore, this study examines the actual thermal conditions based on the two major parameters air velocity and air pressure for different configurations.
Figure 1 shows the suggested practical methodology, which will act as a guide for the other similar hot-desert climatic conditions, through framing user guide for the first steps of planning, to achieve that practical methodology the following steps are followed:

- A theoretical analysis is conducted for a set of researches based on climate measurements and simulations to rank the climatic factors that affect indoor and outdoor thermal performance. Like analysis will help to reach the suitable mitigation strategies, which can be followed in hot-desert areas to enhance outdoor spaces' thermal comfort.

• A comprehensive review is studied to evaluate the role of increasing geometric variables in regulating the thermal behavior of urban spaces in a specific climatic area.

• Evaluate the outdoor thermal conditions based on Adaptive Standard Comfort (ASC) models (ASHRAE STANDARDS, STRATEGIC PLAN, 2014) during the hottest climate condition day after analysis of the climatic features for the case study using climate consultant software.

• Examine the outdoor comfort conditions as well as natural ventilation for different buildings in one of the hot-desert climatic regions in Egypt using DesignBuilder/Energy Plus software.

• Then, select the best appropriate configuration that mitigates the enhancing of the outdoor thermal comfort around the building.
4. Case study analysis
There is evidence of the need for buildings to adapt to their climates that grants the designers the ability to impact the creation of sustainable cities, through the incorporation of architectural requirements that are adapted for climate constraints. For that aim, the local environment analysis is considered as one of the most important starting points.

4.1. Climatic classification
According to the Köppen–Geiger classification (Peel et al., 2007) the average air temperatures of the equatorial environments are ranged between 24°C and 27°C, while the daily levels of relative humidity are moderate, see Figure 2. The predominantly hot and desert condition is characterized throughout the year based on similar solar radiation, which affects all of the building's orientations, particularly buildings in the east and west directions. From the building architecture optimization, the elevated air temperature, and relative humidity levels that apply to the building should be studied to be in the acceptable bioclimatic parameters, such as openings, walls, shadings, and cross-ventilation (Enteria et al., 2020). On the other hand, the building that is subjected to the hot desert climatic characteristic must not only find solutions for the hot and humid phases but also adapt to winter and moderate circumstances.

In the specific case of the predominance of hot, humid, and desert, the small variation of air temperature and humidity throughout the year leads local people to feel comfortable adapting to and living with these conditions. Thus, designers must search adequately for limitations of human thermal comfort; otherwise, they may face an overdependence on conventional air-conditioning systems. In other words, enriching thermal environments along with reducing the usage of energy in buildings is an ideal circumstance that designers must promote.

Egypt has a variety of climate zones varying from very hot to cold (Mahmoud, 2011), with a high level of solar radiation (S.R.D.- SODA. 2013, GMS company 2013). The Egyptian Residential Energy
Code (EREC) divided Egypt into eight separate climatic zones (2005), Figure 3 shows the classification of the climatic zones in Egypt and the location of Minia city (the chosen case study). According to the theory of Adaptive Comfort, and as Givoni (1998) has stated, the person who lives in hot environments would acclimatize with the higher temperature (Givoni, 1998; Humphreys, 1996; Humphreys et al., 2013). The EREC (2005) updated the version of the thermal comfort zone (22.2°C–25.6°C) to (20°C–29°C), where the slightly hot zone average values (25.6°C–34.5°C) and the slightly cool region (22.2°C–17.5°C).

4.2. Case study overview
The case study selected is Minia City, which is the capital of the Minia Governorate in Upper Egypt. It is located on the west side of the Nile River at about 245 km south of Cairo. Minia is known to be one of the climatic areas of North Upper Egypt, situated between the Longitudes 30°45’1.08” E and the Latitudes 28°6’35.57” N and was deemed as a desert area, as shown in Figure 3 (http://solargis.info 2013).
The goal for designers to achieve comfort should be started by applying passive strategies in design to decrease the need for air-conditioning that increases energy consumption. Therefore, requirements for passive building architecture techniques should be adapted with the orientation of buildings; shape, and dimensions of exterior and interior spaces, to achieve thermal comfort.

To study the relationship between the bioclimate and the proper shape that enhances the thermal comfort, the study proposed the primary data (as input data for DesignBuilder software) for the buildings as a residential building. The simulation was then carried out based on “real” hourly weather data implemented for the chosen various building geometries on a region of approximately 200 m² (rectangle with dimensions 20 m×10 m, square form with side length 15 m and has an internal square with a side length of 5 m as a court, U-shaped building with outside measurements 25 m×10 m and inside measurements 10 m×5 m, triangle with radius 8 m), as shown in Figure 4, where the different chosen shapes and their dimensions are listed.

4.3. Analysis of climatic parameters
The local climate statistics should be studied, taking into account the annual characteristics of the temperature, solar radiation, relative humidity, natural ventilation, precipitation, and cloud cover, also considering the microclimatic conditions (Kumar et al., 2018; Maciel et al., 2007). Therefore, areas in a hot-desert, humid environment have general characteristics, but also have their unique features, which suggest the probability and degree of efficiency of passive approaches in the chosen projects.

One of the software that helps in evaluating the unique features for the case study chosen is the Climate Consultant 6.0 tool. It is a “simple, easy-to-use, interactive programming that shows climate details in hundreds of building shapes that are useful to architects, contractors, engineers,
and homeowners”. This program includes temperatures, wind speed, humidity, solar radiation, and sky cover 2-D and 3-D graphics together in any unit Metric or Imperial for any hour of the year.

Also, it plots sun shading and sundials charts with the hours in case solar heating or shading is required. The climate consultant tool provides the psychrometric chart analysis, which shows the most proper passive design strategies. While the wind wheel provided in the software integrates wind direction and velocity with simultaneous temperature and humidity, which can be presented hourly, daily, or monthly. While energy codes (H.a.B.N.R.C. (HBRC) & Edeisy, et al. 2018) present specific styles of buildings in each climate zone, architecture people must install or manage these buildings, to recognize the particular characteristics of their environment, and how it influences the energy consumption of their buildings. The data reads in the Climate Consultant software is in the EnergyPlus Weather File (EPW) format, which the Department of Energy offers it with no cost “(There are more than 1300 stations licensed in this style from around the world)” (Kumar et al., 2018). Climate Consultant Software investigated several parameters, which affect climate change. These parameters are discussed below.

4.3.1. Temperature analysis
From Figure 5, the temperature range of Minia City is analyzed along the year, which indicates that the temperature in Minia has a desert climate, with a very hot summer and relatively cool winter. Also, there is an extreme temperature, aridity, and light rainfall. Where the average temperatures are ranging between maximum and minimum in July 36.6°C and in January 19.4°C, where the humidity ranges between 52% in January and 25% in May, also, the air velocity ranges between 4.2 in August and 3.4 in January. From the previous analysis for the several climatic parameters along the year, the study concluded that August and July are considered the critical months that needed to be studied to achieve thermal comfort.

The hourly average temperature is shown in Figure 6, where the monthly variation is indicated at the abscissa and the ordinate side temperature. The position, longitude/latitude, elevation for Minia City is seen in the top-right corner of the Map. From this figure, we noticed that August month is a significant month to review because it has the largest diffuse (spread of temperature over a wide area or between a large number of people).
Figure 7 displays the temperature variation where the adaptive comfort is shown as a grey part among the bar chart that indicates the maximum temperature above and below the mean value, the yellow section indicates the annual normal high and low values at 23–30°C and 22–15°C, respectively. Annual high-temperature design and low-temperature design lie within the range of 29–39°C and 15–1°C, respectively.

4.3.2. Sky cover analysis

Sky Cover refers to the percentage of the sky covered by clouds as seen from a specific location. However, clouds occupy an average of 10% of the atmosphere. The Sky Cover bar is seen in Figure 8. It influences the thermal efficiency of a building during the cycle of transferring resources, such as reflected radiation, short-wave radiation, long-wave radiation, and evaporative...
exchanges, which ultimately influence people’s thermal comfort (Abu Bakar et al., 2016; Muhaisen, 2005). Finally, from the figure, it appears that August month has the lower range of sky cover about only 4%, which means the higher exposure to the sun.

4.3.3. Wind speed analysis
Wind velocity variation is induced by air moving from high to low altitude, typically due to temperature differences.

Wind direction is described as the number of degrees calculated in the clockwise direction from the north; for smooth winds, wind direction is equal to zero. The weather data summary shows the monthly mode in which the wind direction most commonly occurs. They are measured in increments of 10 degrees.
The estimated wind velocity is on average 1–5 mph, where the strongest velocity is 12 mph strong, as can be shown in Figure 9. The wind rose, which describes the region's predominant frequency and direction and velocity of the wind, where the wind rose plotted from January to December. The red shade displays temperature variation from 24°C to 38°C and the dark red shade indicates a temperature over 38°C. Medium green shade displays 30–70% relative humidity. The triangles in the light orange shade of pencil nib represent low wind speed when the high speed is depicted in the dark orange line.

4.3.4. Psychrometric chart analysis

Psychrometric Chart for Minia City, shown in Figure 10, is an important design tool in the Climate Consultant.

The diagram shows a dry bulb temperature around the bottom and air humidity content up the side. The vertical axis can be defined as the humidity ratio of pounds of water per pound of dry air (or grams of water per kilogram of dry air) or as the vapor density. The curved row on the extreme left is the saturation axis (100% Relative Humidity line), which reflects the fact that air will hold low humidity at lesser temperatures than at higher temperatures. Each hour on this map is seen as a dot in the EPW file for climate data. Any dots can reflect over an hour, for example, when a specified temperature and humidity happen more than once in a month, the value of a given hour may follow the requirements for more than one strategy region. The psychrometric map above displays the design strategies (January–December) development techniques. This indicates that in that specific region, 7.1% cooling and 14.8% of heating are needed.

Also, included in the Psychrometric Chart is the table of Effective Design Strategies, which is presented in the upper left of Figure 10, that shows the percentage of time for the number of hours that falls within each strategy series, while changing any parameter of the building design or any of the default criteria will change these numbers. In our case study for Minia City, it shows that 23.3% of the hours a year are within the range of comfort. The best overall cooling system technique is Natural Ventilation, which accounts for 21.9% of the hours and can be paired with all the other cooling techniques. The second most successful method for ventilation is Sun

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Figure 10. Psychrometric chart adaptive comfort for Minia city.
Figure 11. The outdoor simulation grids for the four selected shapes (Rectangle, Hollow-square, U-shaped, Circle).

Shading, which constitutes 7.1% of the hours. One particular approach is the high thermal mass, which covers 15.2% of the hours, but that means a very different building type of construction.

The psychrometric chart has lots of other options that can be changed from the panel on the left. For example, you can choose direct solar radiation, wind speed, or sky cover, instead of using colors to reflect dry bulb temperature. You can also select individual months or de-select them. Only the daily high and low hours can be displayed with a colored line drawn between each rather than showing each hour as a dot on the chart that represents the daytime temperature differences, which help to resolve questions as to whether high mass construction design strategies are appropriate for this climate (Milne et al., 2007).

5. DB simulated model
The previous analysis for the annual weather data on climate consultant software allows getting the overall climate analysis for the case study Minia City that helps to get a suitable month that needs achieving thermal comfort and then understanding the appropriate design strategies. After the climate analysis that provides data for the case study development, the study uses another software that depends on Building Information Modelling (BIM) technology, such as DesignBuilder (DB) software. The DB is used as a Simulation modeling tool to enhance outdoor thermal comfort using natural ventilation. However, the Weather Data File
used in the simulation step was the EPW file (Minia, 2020) (http://apps1.eere.energy.gov 2012).

Simulation using DB software was conducted to get the values of outdoor air velocity and outdoor pressure within hot-desert climate zone for Minia City during the middle of the hottest month 14th (August). Consequently, specify comfort conditions. The first step regarding simulation is the simulation grids built by DB itself, as shown in Figure 11 that shows the outdoor simulation grids for the four selected shapes (Rectangle, Hollow-square, U-shaped, Circle). According to the actual temperature, our study aims to evaluate the performance of thermal comfort in outdoor spaces for residential buildings, in Minia City as a case study. The evaluation was directed by measuring the impact of the chosen urban forms (building blocks) on the outdoor spaces’ thermal comfort. The results will help define the appropriate model for urban architecture concerning the environmental vision.

6. Results
The numerical method of DesignBuilder includes re-throwing the differential conditions into units that are described as a limited volume grid. Then, the condition series will be interpreted as an arrangement of straight arithmetic conditions for each cell within a matrix and the general conditions will be discussed using an iterative method found in all associated programming; finally, the buildings will be analyzed. When a CFD calculation is launched, a grid is
automatically created for the chosen model domain by recognizing all the vertices included in the model entity, then creating the primary coordinates along these vertices for the main grid axes.

For all the buildings, a uniform grid system with 139,392 cells was applied, incorporating 66 cells \times 66 cells \times 32 cells with a maximum aspect ratio of 12,287, which is a deserving proportion for model testing. The simulation for the selected cases is conducted for the day 14th August as a critical month for thermal comfort. Figure 12 shows the visualization and sun path for the different shapes of the buildings in Minia City; Also, Figures 13–16 show the CFD slices results (air velocity, and pressure) for the same day of the different four chosen shapes in Minia City, as an example. As it is shown in the figures, we took a slice at every elevation configured in each shape.

The slices illustrate the air velocity and air pressure distributions along the elevations, which are represented as colored values and contours. The slices revealed the values using colors as low or high; however, with each graph, each color is linked to a value in the attached bottom key in each figure. Results from the simulation were used as input data for the CFD study. These measurements are characterized to get thermal comfort more accurate.

The findings revealed quantitatively increases in variability in external air velocity and decrease in outdoor temperature pressure concerning the comfort level using the adaptive

Figure 13. The rectangle shape simulation slices.
method utilized for the ASHRAE standard (ASHRAE STANDARDS, STRATEGIC PLAN, 2014). Sustainable design can be said to improve the thermal comfort of outdoor residential spaces, where the efficiency of thermal comfort is a trade-off between different design factors to achieve a target level of comfort, which varies depending on the climate design of outdoor spaces.

The simulation results are obtained in summer (hottest time) under the climatic conditions of the case study climatic condition, as discussed in detail in section 4.3. Simulations were performed using the steady-state condition option in the DB tool, resulting in the exportation of the environmental zone wind and hourly pressure data.

The results at each building elevations 1,2,3,4 in case of each shape (rectangle, hollow square, U-shaped, circle) are as follows: the air velocity and air pressure for the four elevations of the rectangle shape are (4.95, 1.35, 1.35, 0.9) m/s, and (9.08, −2.37, −2.37, −3.8) Pa, respectively. While (4.85, 1.83, 1.83, 1.37) m/s, and (8.55, 0.97, 0.97, 2.55) Pa for the hollow square. Then, for the U-shaped building (4.4, 1.32, 1.32, 0.88) m/s, and (3.84, −1.57, −1.57, −2.83) Pa. Finally, for circle shape (4.62, 1.39, 1.39, 0.92) m/s, and (8.3, −3.39, −3.39, −5.07) Pa.

7. Discussion
From the above results, it is clear that the two values are the same for each elevation because they represent the two sides for each shape have the same properties. So, according to these results,
we can interpret the best case that achieves the highest air velocity and lower pressure that achieve the thermal comfort is the circle shape. Figure 17 shows the analysis for the chosen forms in our case study.

Also, it seems from these results that the worst case was the U-shaped building, where the two shapes rectangle and hollow square are in between the best and worst case. Also, we can inform you that the results can change accordingly to change the building orientation. To get deeper into these findings, Figure 18 shows the benchmarks based on the two major parameters: the air velocity and air pressure for all four shapes. Finally, based on the output results, the researchers must take in their minds that each climate zone has its study and strategy. Moreover, the effects of variations in each factor are examined. Finding the most appropriate building design strategy can thus help engineers pay more attention to the building design features before implementing their designs.

Outdoor spaces are important in supporting the quality of life in communities, and outdoor thermal comfort, however, is a complex issue within an urban environment. In this article, the coupling of building configurations and natural ventilation was studied for the four suggested forms (Rectangle, Hollow square, U-shaped, Circle) of buildings in summer hot-desert areas. The shapes are compared
Figure 16. The circle shape simulation slices.

Figure 17. The analysis for air velocity and pressure in Minia city for the chosen shapes.

(a) Rectangle shape.
(b) Hollow Square
(c) U-Shape shape.
(d) Circle shape.
against the influence of temperature, pressure, and air velocity to identify the suitable model for urban geometry in a residential building concerning the environmental vision.

8. Conclusion and future work

Quantitatively, the findings showed a relationship between the geometrical form and the achievement of outdoor thermal comfort. The efficiency of thermal comfort is a trade-off between different design factors to achieve a target level of comfort, which varies according to the outdoor shapes’ climate design.

Accordingly, the circle shape is considered the best shape, where it has a significant role in achieving thermal comfort that fulfills the optimized value between the two major parameters: the air velocity and air pressure in the building design. The worst case is the U-shaped building design based on the similarity of the two optimized values. To sum up, these results are a good indicator of which outcomes from the integration for the bioclimatic techniques and the main utilized parameters into the architecture design. We can predict that the relationship between climatic change and building geometry can help researchers and designers assess natural outdoor ventilation. In future work, we will apply the new AI techniques as Machine Learnings algorithms that can build new models to investigate the relationship among multiparameter of the climate change and the green architecture design to achieve the main outputs as NV and Thermal comfort.

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| ASV       | Actual Sensation Vote | NV     | Natural Ventilation |
|-----------|-----------------------|--------|---------------------|
| ASC       | Adaptive Standard Comfort | N-S | North-South |
| AH        | Absolute Humidity | OTC | outdoor thermal comfort |
| AT        | Apparent Temperature | PET | Predicted Mean Vote comfort |
| BIM       | Building Information Modelling | MV | Physiological Equivalent Temperature |
| CFD       | Computational fluid dynamics | RH | Relative Humidity |
| CPI       | cooling power index | SVF | Sky View Factor |
| DB        | DesignBuilder | SET | Standard effective temperature |
| EREC      | Egyptian Residential Energy Code | T | Temperature |
| EPW       | EnergyPlus Weather File | UTCI | Universal temperature climatic index |
| E-W       | East-West | WBGT | Wet bulb globe temperature |
| IPCC      | Intergovernmental Panel on Climate Change | |

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