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Field study on determining the impact of design decisions on energy efficiency at settlement scale

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Abstract

Urban settlement patterns are a major factor affecting regional energy consumption and are also one of the causes of energy consumption from buildings on a global scale. For this reason, it is an important and necessary approach to ensure energy efficiency in settlement and structural scales, especially in large-scale projects designed in dense urban fabric, considering the various effects they will cause. Within the scope of this study, the effects of buildings on their surroundings at the settlement and structural scales are analyzed through a group of buildings that contain many functions within the urban fabric and spread over a large area. It is planned to determine the effects of the buildings within the scope of a multi-unit project consisting of a total of 10 blocks in Sakarya Serdivan and opened in 2021, which is clearly separated from the surrounding settlement, on the dense residential, commercial and educational units around them, considering environmental factors in the context of energy efficiency. With this study, it is aimed to reveal the importance of the decisions taken at the design stages for sustainable settlement planning within the urban texture. For this purpose, firstly, a literature review was conducted on the contribution of decisions taken at the settlement and structural form scales in preventing/reducing energy consumption and energy efficient design criteria for the geographical location of the building group under consideration. In this direction, it is aimed to determine the compliance of the buildings in the existing design with these criteria and the effects of the buildings on the built environment at close scale and on the built environment with Autodesk Forma software, which can perform solar analysis, microclimate and comfort analysis with artificial intelligence support by enabling environmental analysis at these scales. Thus, the environmental impacts caused by the building group within itself and within the urban fabric and their relations with settlement geometries such as building layout types, building orientation and forms of buildings were evaluated.

Keywords: artificial intelligence, autodesk forma, energy efficiency, settlement scale

1. Introduction

Today, a large part of the population is concentrated in cities due to changing factors, especially social and economic factors. This situation leads to a rapid increase in urbanization. It is estimated that two-thirds of the world's population will be in urban settlements by 2050 with the population concentrated in these cities and the continued increase in urbanization (UN DESA, 2014). However, energy consumption in urban settlements is increasing with the effect of today's living standards. Urban settlements are responsible for 75 per cent of global primary energy consumption and 70 per cent of global carbon emissions (UN-Habitat, 2020).

Considering all these, it is seen that cities play a major role in reducing energy consumption. Energy performance assessments at settlement scale are limited and less developed compared to building scale and regional scale studies. In this case, lack of assessment tools and difficulties in accessing data are the main reasons. However, studies at this scale are important as they consider urban form and energy performance. While energy systems in buildings can be changed in the

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shorter term and occupants' behavior can change, urban form can have a longer lasting impact on energy consumption, both positive and negative. This is because the performance of the energy system depends on the behavior of building occupants, but compact urban forms are not affected by user behavior (Beygo & Yüzer, 2017; Wener & Carmalt, 2006). For this reason, energy saving measures to be taken at urban scale are of great importance in our country where urban settlements are increasing rapidly.

Stromann-Andersen and Sattrup concluded that the geometry of the settlement has an impact of up to 19% in residential buildings and 30% in office buildings on total energy consumption and revealed the importance of design (Stromann-Andersen & Sattrup, 2011). However, since there are many variables in residential design, it is not possible to reach an absolute truth among unlimited alternatives by making generalizations (Oke, 1988). At this point, for each design, location-dependent analyses and planning should be made according to the design parameters. Since the design decisions taken at the settlement scale will have an impact on energy consumption throughout the lifetime of the buildings, it is important to develop solutions that will provide optimum energy performance according to energy efficient design parameters.

Research on this topic in the context of sustainable urban settlement in terms of energy consumption in Turkey and the Mediterranean region: In order to minimize energy demand and environmental impact for a sustainable 'urban balance' and sustainable urban growth in general, significant energy savings can be achieved by combining passive heating, cooling and daylighting techniques as well as the integration of renewable resources to minimize energy demand and environmental impact, taking into account building design parameters such as the location of buildings, building form, orientation relative to each other, as well as environmental data at the design stages (Ascione et al., 2017; Ayçam et al., 2020). Similar studies have evaluated the impact of outdoor microclimate improvements on building energy performance, and studies have been conducted to determine the best building layout size that can optimize building energy performance and energy production (Cardinali et al., 2020).

To address such urban solutions and challenges, the rapid development of computing technology, including Artificial Intelligence (AI), offers new opportunities in various sectors, including urban design (Batty, 2018). Therefore, the use of AI in urban design integrated with the smart city concept not only responds to today's challenges, but also paves the way for developing smarter, more efficient and sustainable cities in the future (Kurniawan et al., 2024). In this context, Forma, Autodesk's next generation architecture software, was used for modeling the case study and performing analysis simulations within the scope of the study. Another main objective here is to investigate the role of technology in supporting sustainable urban planning and the data and services offered by the software to the user.

1.1. Methodology

Within the scope of the study, through literature review, the design parameters affecting the suitability of buildings as energy efficient settlement and form according to different climatic and geographical positioning were determined and the climatic and geographical characteristics of the region where the selected building group is located were specified. In this way, for the buildings considered in the study, certain design parameters have been put forward to ensure energy efficiency at the settlement scale. In line with these parameters, Autodesk Forma, which offers analysis and simulations developed with new architectural software technologies, was used to examine the energy efficiency of the selected building group and its effects on the surrounding settlement. Inferences were made on the suitability and energy efficiency of the buildings in the case study according to the local design parameters, and the energy performance and energy performance of a dense building group, which was created on an almost empty land where there was only one low-rise building before, and which was positioned higher than its surroundings, were analyzed. Thus, the importance of designing buildings on an urban scale, especially buildings that will be spread over a large area as in the example, by taking advantage of the fast data provided by the developing architectural software technologies in this context, by considering the energy efficiency of the buildings according to their climatic and geographical characteristics has been revealed (Figure 1).

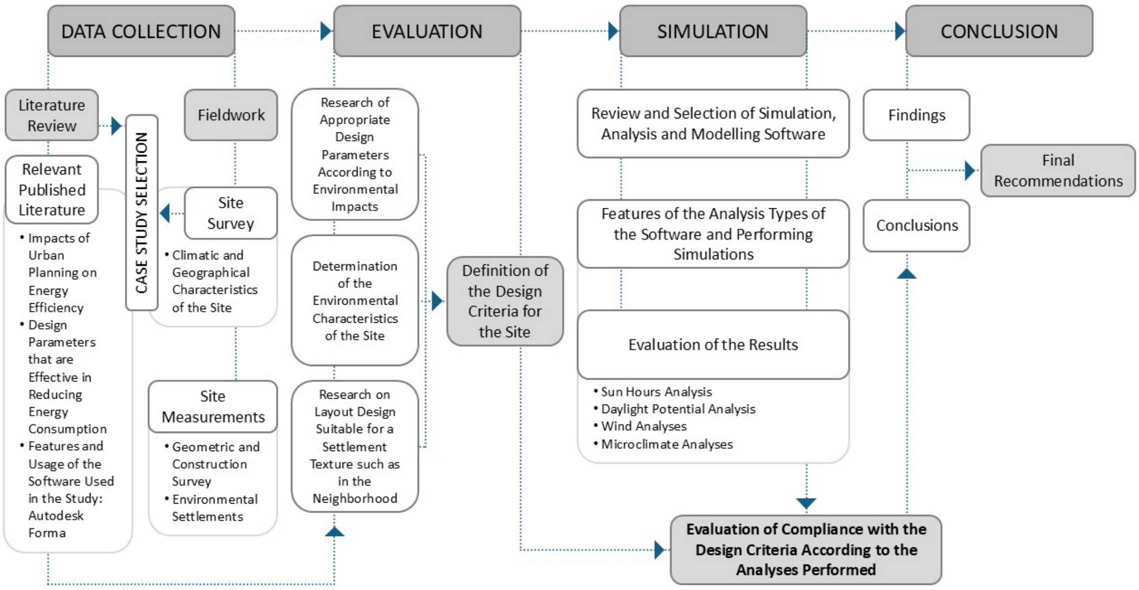


Figure 1 Methodology of the study

1.2. Research Questions

What are the appropriate criteria that can be proposed to ensure the energy efficiency of buildings in different climatic conditions in form and layout scales, according to the characteristics of Sakarya/Serdivan region within the scope of the study, how do today's architectural technologies affect the applicability of these criteria in new or existing buildings, and what kind of strategy can be proposed?

2. Parameters Affecting Energy Efficiency

2.1. Climate

Climate is the name given to the average of meteorological phenomena such as temperature, humidity, air pressure, wind, precipitation, precipitation pattern observed in a place over a long period of time. Climate types can be classified by looking at conditions such as temperature and precipitation regime. However, the most widely used classification system today is the Köppen climate classification (Figure 2) developed by Wladimir Köppen (Climate, 2024). According to Köppen climate classification, Turkey, which is located in the temperate climate zone, is considered as five climate zones as hot-humid, hot-dry, temperate-humid, temperate-dry and cold (Erinç, 1996; Yılmaz & Çiçek, 2016; Zeren, 1978; Zeren, 1987; Koca, 2006).

Figure 2 Map of Turkey's climate zones (Koca, 2006)

Climates are formed by the combination of temperature, pressure, wind, humidity and precipitation. These directly affect the built environment organization as observable and measurable climate variables (Kısa Ovalı, 2009). Accordingly, it can be said that climate should be considered as a leading factor in the context of energy efficiency in the design phase of buildings.

2.2. Location and Orientation

The existing building layout, vegetation, sun and wind are important environmental factors that should be considered in the context of energy efficiency of buildings. The topographical positioning and orientation of buildings, together with the climate factor, directly affect solar gain and indirectly affect heat losses and gains. For this reason, it is necessary to choose a suitable location in the topographical layout according to the climate, taking into account the solar radiation and air currents that constitute natural data in the early stages (Figure 3) (Umaroğulları & Cihangir, 2019; Beygo & Yüzer, 2017).

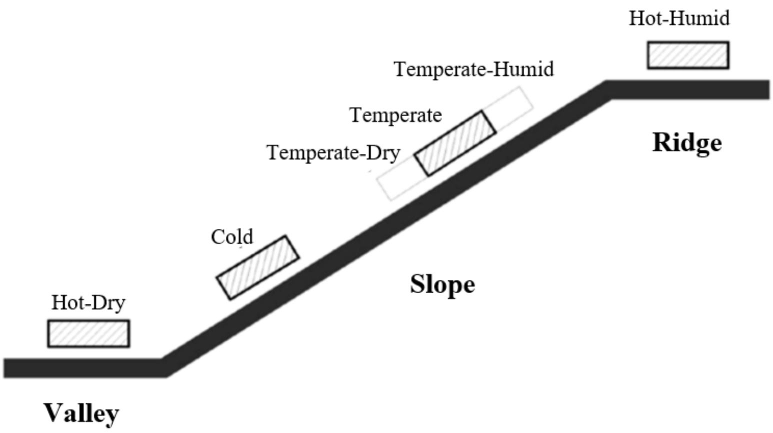


Figure 3 Suitable topographic locations according to climatic characteristics (Zeren, 1978)

When orienting the facades of the buildings, an appropriate orientation created depending on the direction of the sun and wind will minimize the energy loads and the negative effects of the climate (Table 1; Table 2).

Table 1 Suitable Building Orientations According to Different Climate Zones (Orhon et al., 1988)

Hot-Humid	Hot-Dry	Temperate-Humid	Temperate-Dry	Cold
Large surface: S → 3° E Open to wind	Large surface: S → 18° E Openings in courtyard direction	Large surface: S → 13° E Giving large surface to the wind	Large surface: S → 27° E Not giving wide openings to the wind	Large surface: S → 24° E Closed to wind

Table 2 Suitable Building Orientations According to Different Climate Zones (Orhon et al., 1988)

Climate Zone	Optimum Direction S E	Good Directions W S E
Hot-Humid	3°	10° 19°
Hot-Dry	18°	0° 40°
Temperate-Humid	10°	13° 35°
Temperate-Dry	27°	10° 56°
Cold	22°	20° 45°

2.3. Building Form

Solar radiation and wind effects should be taken into consideration when determining the form and shape of buildings in order to ensure minimum heat loss and minimum heat gain (Orhon et al., 1988). Compactness in building volumes is one of the most important criteria in energy efficiency (Koca, 2006).

As compact forms minimize heat transfer, they also reduce energy consumption, while building designed by giving a large surface to the optimum direction has more opportunity to benefit from solar radiation than other forms and positioning. In buildings that give a large surface to the prevailing wind, an increase in heat losses and a decrease in heat gain can be achieved compared to compact forms. These variables should be evaluated in harmony with the climate where the building is located (Table 3). Positioning the building elements according to the sun and prevailing wind reduces the heating and cooling loads of buildings (Orhon et al., 1988; Bayraktar & Yılmaz, 2007; Beygo & Yüzer, 2017). For different forms surrounding the same volume, the external surface area of the building and the amount of heat lost and gained from the external surfaces will also be different (Yılmaz et al., 2000).

Table 3 Building Forms Suitable for Different Climatic Zones (Orhon et al., 1988)

Hot-Humid	Hot-Dry	Temperate-Humid	Temperate-Dry	Cold
Surface open to the wind, raised from the ground, close to a long rectangle.	With courtyard, square base, with surfaces open to the interior.	Rectangular or free plan, S, S → 13° E with large surface to the wind at ESD.	Closed to the wind at EASD, S, S → 27° E with large surface, compact form close to square.	Facing the wind with little surface, minimizing the outer surface, giving a large surface to S, S → 24° E, compact, square, etc. based.

2.4. Building Envelope

The building envelope is one of the most important parameters under the control of the architect in providing energy and climatic comfort, consisting of all horizontal, vertical and inclined building components that separate the indoor environment from the outdoor environment, shaped depending on the physical environmental factors (Kısa Ovalı, 2009; Koca 2006). Properties of the building envelope such as absorption, transmittance and reflectivity properties against solar radiation related to heat and moisture transfer, slope of the envelope, total heat transmission coefficient, time delay, amplitude reduction factor are very effective in determining the heating, cooling and lighting energy costs of the building (Zorer, 1992; Umaroğulları & Cihangir, 2019).

For this reason, while designing the building envelope, it is necessary to determine the heat, light, humidity and sound permeability in a way to provide the necessary comfort, considering the climatic and environmental conditions of the region (Table 4).

Table 4 Building Envelope Properties Suitable for Different Climate Zones (Orhon et al., 1988)

	Hot-Humid	Hot-Dry	Temperate-Humid	Temperate-Dry	Cold
Surface Texture	Rough. Shaded (horizontally).	Horizontally and vertically with large indentations and protrusions.	Smooth	Smooth	Smooth

Surface Color	Light color (reflective)	Light color (reflective)	Color lightness at average value	Color lightness at average value	Dark color (absorbent)
Roof Shape and Orientation	Flat or pitched. S → 3° E Shaded Double layered (Cold roof)	Flat or pitched. S → 18° E Shaded Double layered (Cold roof)	Flat or pitched. S → 13° E Double-single layered	Pitched S → 27° E Double-single layered	Pitched S → 24° E Single Layered

2.5. Planning of Settlement Area

Analyzing the settlement areas where the buildings are planned and positioning them in a suitable area constitutes an important design criterion in terms of energy efficiency as it will affect solar and wind gains according to the distances, heights and locations of the surrounding settlement texture and open spaces within itself (Beygo & Yüzer, 2017; Umaroğulları & Cihangir, 2019; Kun, 2005). The location of the buildings in densely built-up areas such as cities and the location of the buildings in rural areas with less built-up areas constitute an important difference in terms of energy efficient design. In addition, it should be taken into consideration that the settlement texture, scales and interrelationships of the buildings, streets, green areas such as parks directly affect the microclimate (Umaroğulları & Cihangir, 2019; Kun, 2005).

Reducing the exposure of buildings to sunlight in summer and increasing it in winter, increasing natural ventilation in summer and providing protection from the wind in winter according to the prevailing wind direction and speed will contribute to reducing the energy required for heating. Preventing wind corridors between buildings in terms of comfort is another point to be considered. Topography, neighboring buildings, vegetation, solar radiation, wind direction and speed have a very important effect on energy efficiency (Beygo & Yüzer, 2017).

Table 5 Suggestions for the Positioning of Buildings in the Formation of the Settlement Texture according to Different Climatic Zones (Orhon et al., 1988)

Hot-Humid	Hot-Dry	Temperate-Humid	Temperate-Dry	Cold
Shifted so as not to interfere with wind direction and spaced greater than 7H apart. Spaced greater than 2 1/2H with no obstruction to sunlight at EASD. Homogenous height.	Compact, with courtyards, blocking the sun's rays on vertical and horizontal surfaces in ESD. Horizontally spread and low-rise.	Spaced less than 5H downwind at EASD, shifted downwind at ESD and spaced greater than 7H. Spaced greater than 3H, not blocking solar radiation at EASD. Homogenous height.	Compact, spaced less than 5H in the wind direction at EASD.	Intermittent to less than 5H in EASD in wind direction. Not obstructing sunlight at EASD. 2 Spaced greater than 1/5H. Homogeneous spread and height.

3. Case Study

The building group selected as a sample is in the middle of a settlement of smaller-scale building units and one similar-scale building with a similar function to the north, located in Sakarya/Serdivan, which has a temperate-humid climate. The project, which includes residential areas, offices, shops and indoor/outdoor car parks in addition to its commercial function, was opened for use in 2021. Consisting of 10 blocks and spread over 52 thousand square meters, the building group divides the land into two areas with the concepts of 'indoor shopping center' and 'street bazaar' at the city ground level (Figure 4).

On the west side facing the boulevard, there are 1 floor above ground 1 floor trade and 3 floors of office blocks above; on the south side facing the axis coming from the city center, there is 1 floor above ground 1 floor trade and 2 floors of apartment units/studio apartments above. The blocks are higher than the other buildings in the neighborhood and are positioned parallel to the street side of the parcel with a 6° deviation from the north-south axis towards the west.

Figure 4 Project site plan and views (Evrenol Architects)

The site's environment and location are design criterion that has an impact on climate control and energy consumption. Near the site, there are 4-5 story apartment buildings with commercial units on the ground floor, 2-3 story villa type residences and education units, although not too many. Serdivan Shopping Mall located in the north of the area is the largest commercial building and with its large car park in the south, it makes the building group open to the prevailing wind coming from the north (Figure 5).

The compact forms and layouts of the building masses, which are generally positioned on the east-west axis around the area, reduce the heat gain of north-south winds, while the low heights of the buildings enable the utilization of solar radiation.

Figure 5 Urban form in and around the selected area

In the study area, the land is orientated towards the west with a deviation of approximately 6°. The plot spreads over a flat area without any slope. The plot continues its commercial function between the shopping center to the north and the bazaar axis to the south, and is framed by smaller commercial units, residential and educational units around the plot. (Permissions were obtained from the relevant authorities and architectural office for the visuals used in the modeling and presentation of the site.)

3.1. Study Area and Climate

Serdivan is located in the west of Sakarya Province center in the Eastern Marmara Region. Serdivan is one of the closest settlements to the transport network. It is built on the hills at the extreme points of the Adapazarı plain. A part of Sapanca Lake is within the borders of the district. While the ratio of forested area to the general area of Sakarya Province is around 44%, this figure is quite low for Serdivan. Serdivan forest and green area ratio is 16,8%. The general quality of the forests is in the type of degraded grove and normal coppice. Oak type trees are predominant. Serdivan has become the fastest growing and most favorite district of Sakarya. The region, which has productive agricultural areas until today, has become a preferred place for residence in recent years (URL2).

Climate of the Site: It should be noted that in addition to the standards in zoning regulations, the geographical structure and climate play a role in the preference of Serdivan district. In addition, factors such as the ground structure of the hills; the relatively low humidity rate in the climate compared to other districts in the metropolitan area and the wind-receiving situation; the fact that a part of Sapanca Lake is within the borders of the district are effective on preferences (URL3).

Average High and Low Temperature in Serdivan (Figure 6):

- Black Sea climate and temperate climate prevails. Serdivan is generally windy.
- Summers in Serdivan are warm, humid and clear, while winters are cold and partly cloudy.
- The hottest month is August, and the average temperature is 23°C, the coldest month is January, and the average temperature is 6°C. The average annual temperature in Serdivan is 14°C.

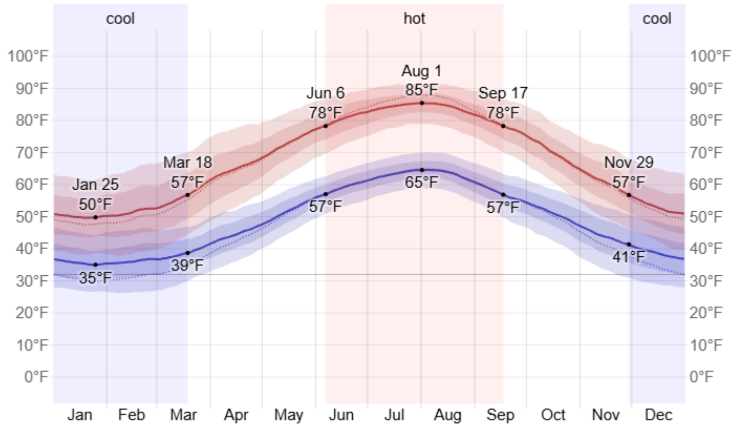


Figure 6 Average high and low temperature in Serdivan (URL4)

Sunny Hours and Cloud Cover: Serdivan day length varies significantly throughout the year (Figure 7).

- In 2024, the shortest day occurs on 21 December with 9 hours and 15 minutes of daylight, while the longest day occurs on 20 June with 15 hours and 6 minutes of daylight.
- The mean percentage of cloud cover in the sky in Serdivan shows extreme seasonal variations throughout the year.
- The clearest month of the year in Serdivan is July; during this month the sky is 95% clear, mostly clear or partly cloudy.
- The cloudiest month of the year in Serdivan is December, during which the sky is overcast or mostly cloudy 62% of the time.

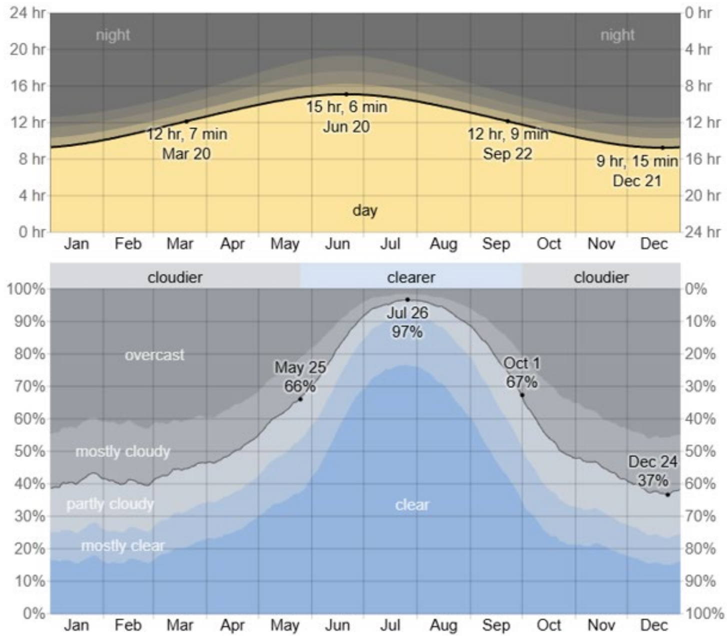
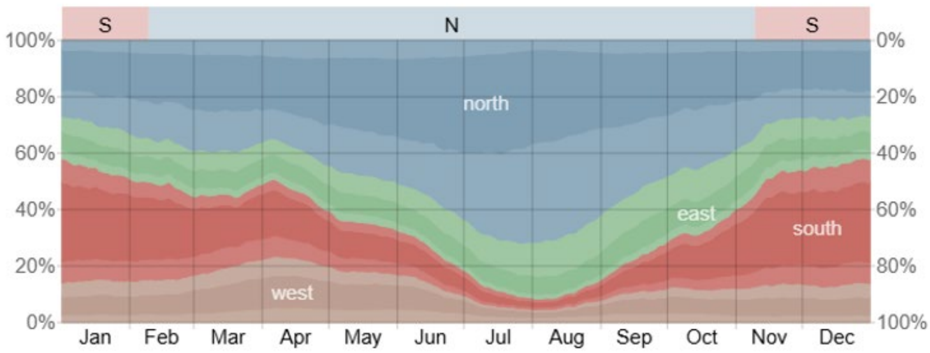


Figure 7 Serdivan sunrise and dawn hours, cloud cover categories (URL4)

Microclimate, Wind and Humidity: Serdivan is generally windy. The prevailing average hourly wind direction in Serdivan varies throughout the year (Figure 8).

- The wind was generally from the north for 9.0 months from 9 February to 9 November with a maximum of 72% on 26 July.
- The wind generally blows from the south with a maximum of 44% on 1 January for 3.0 months from 9 November to 9 February with a maximum of 44%.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wind Speed (mph)	6.8	7.1	6.7	5.9	5.5	5.8	6.6	6.8	6.2	6.0	6.1	6.6

Figure 8 Wind direction and speed in Serdivan (URL4)

There are extreme seasonal variations in the perceived humidity in Serdivan (Figure 9).

- The muggiest period of the year lasts for 3.1 months from 10 June to 14 September, during which time the comfort level is muggy, oppressive or unbearable by at least 13%. The muggiest days in Serdivan are in August, during which the weather is muggy or worse for 13.7 days.
- 21 February is the least muggy day of the year and muggy weather conditions are almost non-existent.

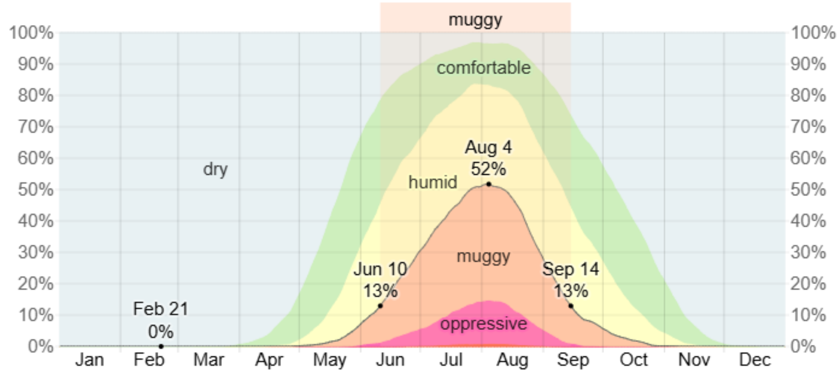


Figure 9 Serdivan humidity comfort level (URL4)

3.2. Appropriate Design Criteria's According to Characteristics of the Site

Due to the temperate-humid climate in Sakarya/Serdivan, where the study area is located, buildings should aim to protect from the wind and benefit from the sun as heat and illumination in the cold period, while in the hot period, wind should be used to break the uncomfortable power of humidity, natural ventilation should be created and designs should be created to provide protection from the sun (Table 6).

These climate zones provide the most architectural solutions. By establishing a close relationship between nature and housing, planning should be organized freely. In particular, the negative effect of humidity should be reduced by organizing the space in a way to create natural air flow (Kısa Ovalı, 2009).

Table 6 Climatic Design Criteria for Buildings in Temperate-Humid Regions (Orhon et al., 1988)

Location and Orientation	Building Form	Building Envelope	Planning of Settlement Area
• Large surface: S → 13° E • Optimum direction: 10° south to south-west • Good orientations: 13º southwest to 35º southeast • Current orientations: 23º south-west - 49º south-east	• Large surface to the wind in ESD. • Rectangular or free plan. • S, S → 13° E with wide surface.	• Smooth surface • Color lightness at average value • Pitched or flat roof types • S → 13° E roof direction • Double-single-element roof form	• Less than 5H in EASD in the direction of the wind, intermittent to intermittent • Shifted in the wind direction at ESD and intermittent greater than 7H • Spaced larger than 3H, not blocking solar radiation in EASD. • Homogeneous height

3.3. Modelling and Analysis Tool Used in the Study: Autodesk Forma

Autodesk Forma is a browser-cloud based conceptual design toolkit that offers AI-powered environmental analyses. Forma also enables modelling in the context of the city, bringing in open city data to place the design on the existing skyline.

Looking beyond modelling capabilities, Forma supports real-time environmental analyses across key intensity and environmental attributes such as wind, daylight, sunlight, and microclimate, delivering results that do not require a lot of deep technical expertise. Forma is based on a unified database that can store all data from an AEC project in a 'data lake'. The move from a world managed by files to a single unified database provides a wide range of benefits, not only for collaboration but also for individual users (AEC Magazine).

This software was preferred both to measure the energy performance of the building group at the settlement scale and to evaluate Autodesk's new generation artificial intelligence and cloud-based tool in BIM.

The whole of the buildings in the area were analyzed with Autodesk Forma Artificial Intelligence Based BIM tool in terms of their environmental impacts during the usage phase. The impact of each building unit on the site and its surroundings was evaluated. In Forma, the area to be analyzed and its surroundings were determined on the map, and the buildings in the area and the surrounding settlement were modelled with height and floor area data (Figure 11 & 12). Then, the area was selected as a selection zone and sunshine hours, daylight potential, wind and microclimate analyses were performed for the buildings and their surroundings (Figure 10).

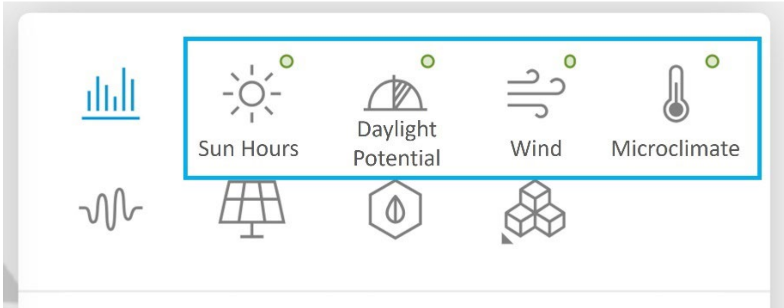
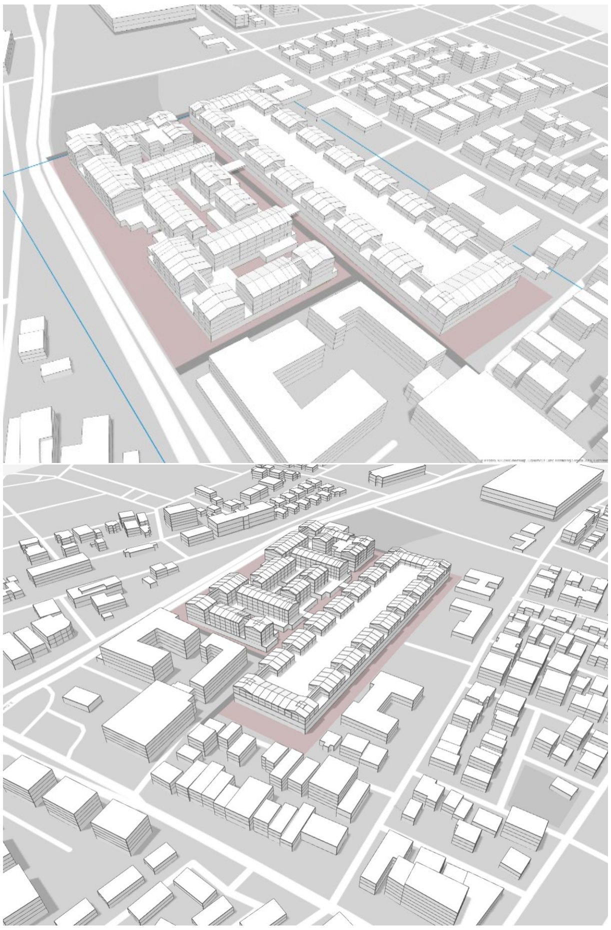


Figure 10 Analyses used in the study context



Figures 11 & 12 Model created in Autodesk Forma

3.4. Performing Analyses

3.4.1. Sun Hours Analysis

With this analysis, sunlight hours on site and in buildings are calculated using ray tracing techniques as well as sun positions throughout the day for the location on earth and the selected date. It is also possible to analyze the percentage of direct sunlight hours on building facades and ground surfaces (Table 7) (Autodesk). The purpose of its use in the study is to ensure that the sunshine hours, which have a negative effect in summer and a positive effect in winter, are evaluated within the scope of all blocks.

Table 7 Characteristics of the Sun Hours analysis (Autodesk)

Areas and objects included	Shading from project surroundings within the model such as buildings or other objects, terrain, vegetation.	**Area coverage**	Buildings within the entire model area or buildings and ground area within the selected site limit or zone.
Technology and calculation	Uses ray tracing technology (OptiX™ Ray Tracing Engine by NVIDIA). Rays are traced from each measuring point in the direction of the sun to determine if the point is in shadow at a given time.	**Assumptions**	• Clouds/weather are not considered in the sunlight calculation. • The analysis accounts for daylight savings time. • Sun rays are sampled every 6 minutes.
Time to complete	30s to 3min depending on the area size.	**Data sources and models**	Sun positions for each time and location is calculated using Bretagnon's VSOP 87 theory.

For this analysis, June 20, the longest day of the year in Serdivan, December 21, the shortest day of the year, and March 21, when the day and night periods are equalized, were selected according to the information on the climatic characteristics of the area in the previous titles in order to analyze the insolation periods of the ground and buildings in the area according to different periods.

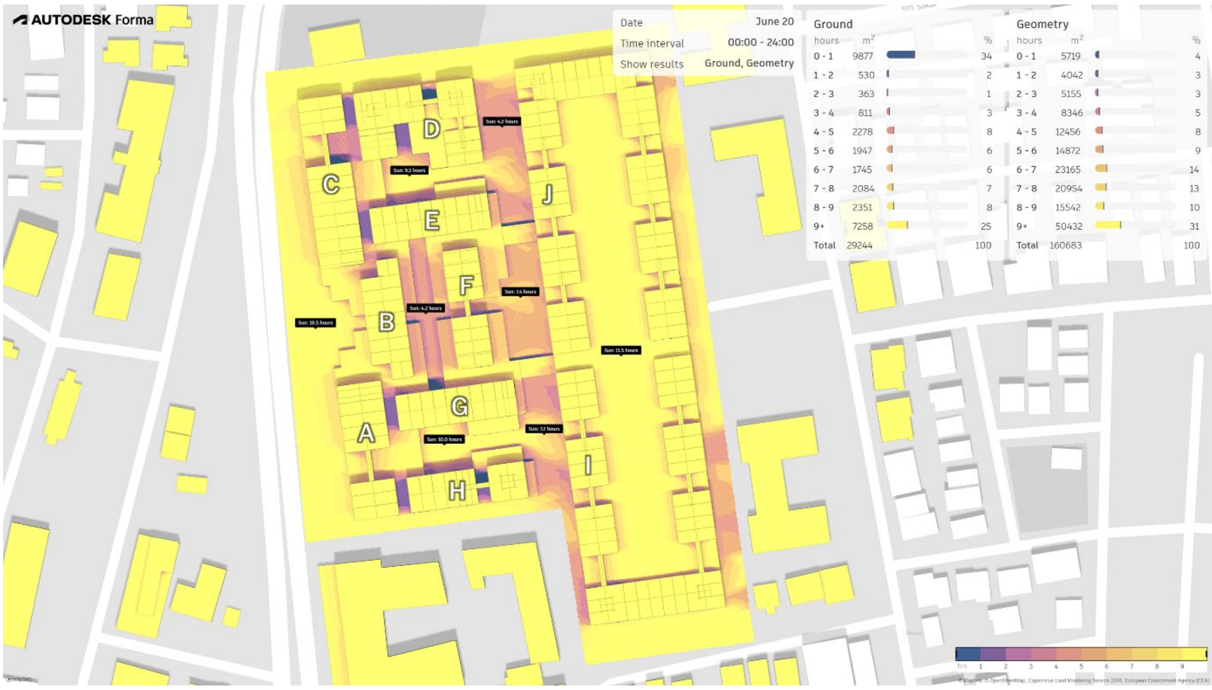


Figure 13 Sun hours analysis for June 20

On this date the day length is 15 hours, and solar gain needs to be reduced (Figure 13);

- The courtyards created offers comfortable open spaces at this date.
- The compact form of block D and the north orientation of its large surface make its summer behavior a little more energy efficient than the other blocks in the area.
- It is seen that heat gain will be high in blocks J and I.
- In blocks J and I, cooling energy consumption is expected to be high due to their relatively empty surroundings and high exposure to solar radiation from the flat roof over the covered shopping center.

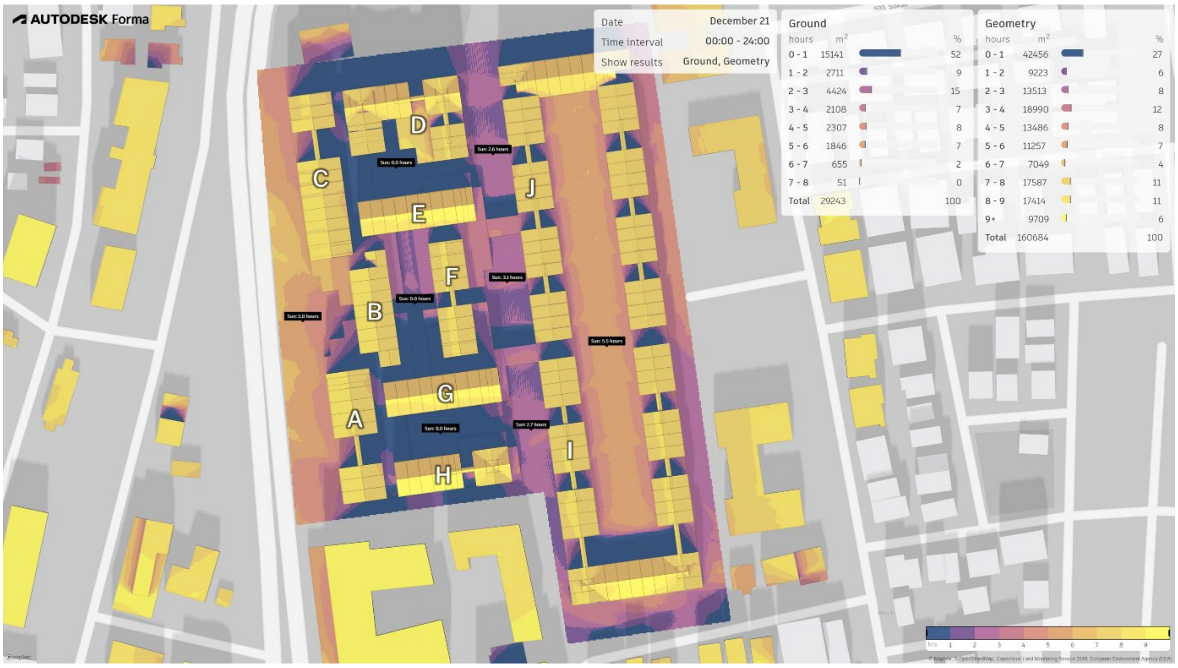


Figure 14 Sun hours analysis for December 21

At this date that solar gain should be increased (Figure 14);

- Heat loss is high in the courtyards and corridors.
- Although D block has a more compact form compared to other blocks, it is clear that the energy consumption required for heating is high in D block and G block.
- The energy consumption will be lower in block I in the cold cycle compared to other blocks in the area.
- It is seen that the building group has reduced the solar gain of the two educational units on the east side.

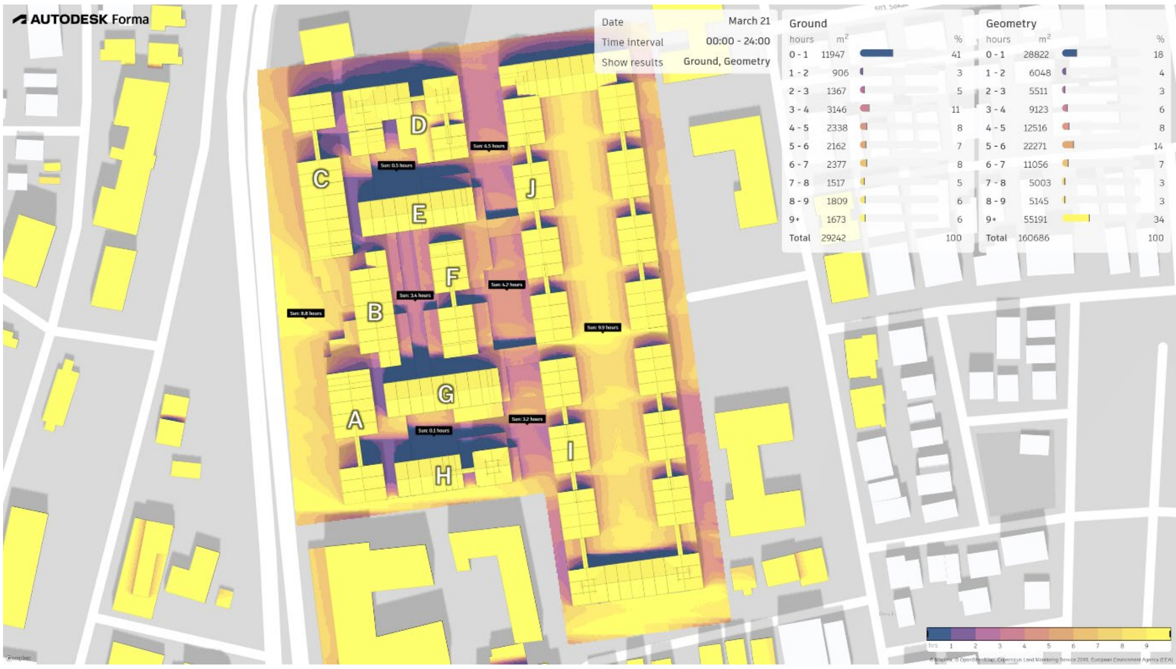


Figure 15 Sun hours analysis for March 21

At this date, when the heat flow is intended to be delayed (Figure 15);

- It is seen that the difference in sun hours between different areas in the landscape is high.

- The courtyards will be cooler during the day.
- The temperature difference between the north and south facing facades of blocks H and I-J will be high.

3.4.2. Daylight Potential Analysis

This analysis visualizes the daylight potential in the context of the surrounding buildings and environment.

This Analysis uses a cloudy sky model and estimates the illuminance on building surfaces using the Vertical Sky Component (VCS) score percentage method. This percentage indicates how much light from the sky illuminates the surfaces in your model relative to the illumination on an unobstructed horizontal surface. The maximum score for the Vertical Sky Component score is approximately 40%. The analysis results are divided into color groups using the thresholds in this table (Tables 8 & 9). For non-vertical surfaces the scores can go up to 100% (Autodesk).

The aim here is to examine the illumination effect of the blocks on each other and on other buildings according to the illumination percentages of the facades of the blocks. Thus, it is to identify the parts of the facade that have less access to daylight.

Table 8 Characteristics of Daylight Potential Analysis (Autodesk)

Areas and objects included	Takes into account shading from project surroundings in the model such as buildings or other objects, terrain, vegetation.	**Area coverage**	Buildings within the model area or selected site limit or zone.
Technology and calculation	The analysis uses a model of an overcast sky and predicts illumination on building surfaces using the Vertical Sky Component (VCS) method. The illumination is predicted using ray tracing technology (OptiX™ Ray Tracing Engine by NVIDIA).	**Assumptions**	• The overcast sky model is independent of the sun and weather conditions and represents a heavily clouded day, September 21st • The geometry of trees is included in the analysis, treated in the same way as other geometries • The terrain outside of the defined map area in the respective project is not considered • The VSC analysis do not take into account window sizes, building materials, room sizes or room functions.
Time to complete	30s to 3min	**Data sources and models**	CIE standard overcast sky model.

Table 9 Vertical Sky Component Scores

VSC < 5%	5%< VSC < 15%	15% < VSC < 27%	VSC ≥ 27%
Achieving reasonable daylight is often impossible.	Difficult to provide adequate daylight.	Larger windows/changes in layout are usually needed.	Conventional window design usually satisfactory.

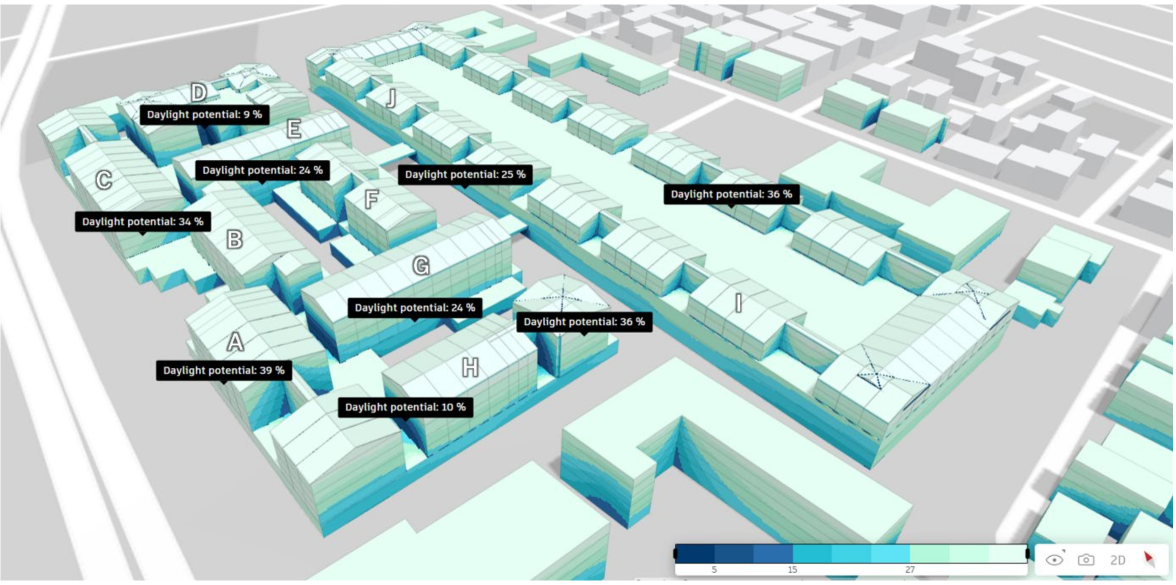


Figure 16 Daylight potential analysis performed in the study area

As a result of the analysis, the forms of the buildings and their positions to each other and the light and shadow areas formed on the facades were determined. The results show that the daylight potential is low on the ground and first floors and in the corridors between the blocks. This shows that cooling energy will be higher on the upper floors in summer and heating energy will be higher on the lower two floors in winter (Figure 16).

3.4.3. Wind Analyses

Wind analysis shows building and site effects on local air flow patterns. There are two types of wind analysis in Autodesk Forma: Fast Wind analysis and Detailed Wind analysis. In Detailed Wind analysis, results are obtained in a long time compared to computational fluid dynamics simulations, while in Fast Wind analysis, results are obtained in a few seconds compared to previous simulations with artificial intelligence support. In both analyses, wind-related comfort and wind speed data are presented to the user (Autodesk).

The purpose of using this analysis in the study is to evaluate the effects of the air flow created by the blocks between each other and the surrounding structures. Thus, comfort and velocity analyses will be obtained with the north direction wind prevailing in the region during the summer season when the positive effect of the wind will be examined, and with the south and north direction wind prevailing in the region during the winter season when the negative effect of the wind will be examined.

3.4.3.1. Rapid Wind Analysis

Rapid wind analysis can be performed within a circular area with a variable between 150 m and 350 m. It performs a rapid analysis using an Artificial Intelligence-supported predictive wind model. It has been put into use in order to provide instantaneous wind control especially when designing (Table 10).

Table 10 Characteristics of Rapid Wind Analysis (Autodesk)

Areas and objects included	Considers terrain, vegetation, proposal buildings and context buildings in a square centered around the analysis circle - 100m out from the analysis circle in all directions.	**Area coverage**	The rapid analysis area is a circle of variable radius between 150 m (~500 ft) and 350 m (~1100 ft)
Technology and calculation	Uses a machine learning model trained on previously run	**Assumptions (if applicable)**	• The same assumptions as the detailed wind analysis.

	calculations of our detailed wind analysis simulations, to replicate the dynamics of those simulations and hence the physics of wind.
Time to complete	1 second - 3 seconds

	• Buildings taller than 100 m will be clipped at 100 m in the rapid analysis input.
Data sources	Previous runs of the detailed wind analysis.

Figure 17 Rapid wind comfort analysis

Figure 18 Rapid wind speed-direction analysis

With this quickly generated analysis data, there is a state of wind protection in the courtyards, and the wind is felt more in the north-south oriented corridors. This shows that the building group creates wind corridors in the long, north-south axis gaps that it creates within itself and with the surrounding settlement (Figures 17 & 18).

3.4.3.2. Detailed Wind Analysis

In the detailed wind analysis, a circular flood area as same as rapid wind analysis can be determined. This wind analysis provides a more accurate calculation but takes longer to complete. A detailed wind flow and wind comfort analysis is run to obtain a more accurate simulation of different wind directions and speeds (Table 11) (Autodesk).

Table 11 Characteristics of the Detailed Wind Analysis (Autodesk)

Areas and objects included	Considers all elements in the canvas. This means that terrain, buildings both proposal and context, and vegetation all are geometry that impacts results.	**Area coverage**	150m up to 350m radius (492 feet --> 1 138 feet)
Technology and calculation	Computational fluid dynamics (CFD), through the computational tool OpenFOAM.	**Assumptions (if applicable)**	• The volume occupied by the fluid is divided into discrete, hexahedral, cells (the mesh). We make sure that no cells around important areas are larger than 1 meter. However, this means that geometries with more intricate details than 1 meter may not impact the wind flow. Although we make sure that e.g. corners stay sharp also in the analysis. • The height of the wind domain is 4 times higher than the difference in height between the lowest point of the terrain and the highest point on top of the buildings. Max height for our wind domain is 600 meters (1 969 feet) from the highest point on the terrain. • The total coverage (analysis domain) extends at least 350 meters (1 138 feet) beyond the Area coverage described above. • The analysis will not run with high terrain variations
Time to complete	40-200 min	**Data sources**	Wind rose: Global wind atlas Surface roughness: ERA5 surface roughness data.

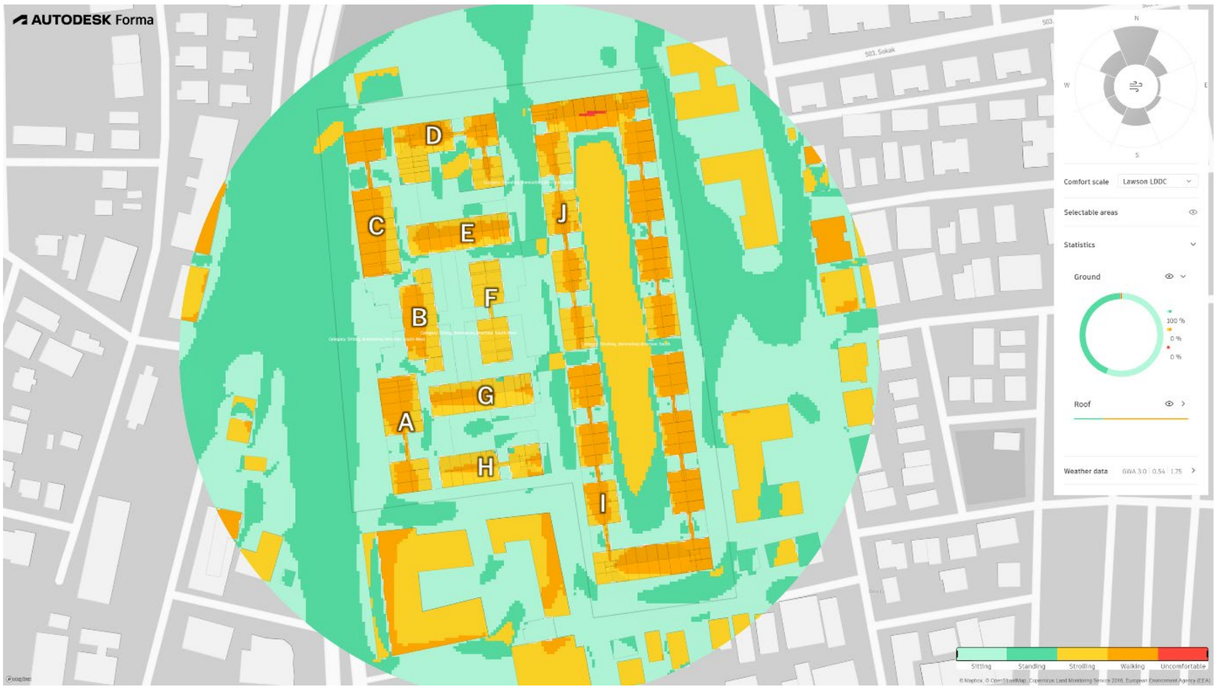


Figure 19 Detailed wind comfort analysis

In the comfort analysis based on the Lawson LDDC scale, it can be said that the courtyards formed by the blocks intersecting the north-south axis are more comfortable. Especially since there is a large parking lot just north of the area and there are no buildings, the winds blowing from the north prevailing wind direction are effective in the corridor designed as Street Market in the project (Figure 19).

Figure 20 Detailed wind speed-direction analysis

In the wind speed analysis, it is obvious that the wind speed is high on the green roof cover of J and I block according to the north wind direction, which is the dominant wind direction. The wind speed, which is higher at the northern entrance between blocks D and J, decreases as it passes to the courtyards. It can also be predicted that the cooling energy in the summer season will be lower than the other blocks because of the D and J blocks, which are orientated towards the prevailing north wind and benefit from the prevailing north wind in summer (Figure 20).

3.4.4. Microclimate Analyses

This analysis combines the results of solar, daylight and wind analyses with local weather conditions to calculate the perceived temperature on site. In this way, it helps to understand the perceived temperature according to the shade and wind conditions created by the design of the local climatic conditions. Microclimate analysis is a hybrid model that combines many different analyses (Table 12) (Autodesk).

The purpose of using this analysis in the study is to understand and evaluate how the local climatic conditions can react to the shade and wind conditions created by the design.

Table 12 Characteristics of Microclimate Analysis (Autodesk)

Areas and objects included	Microclimate considers all elements.	**Area coverage**	Can be run on a circular area with radius between 150 and 500 meters (or 492 and 1138 feet).
Technology and calculation	A hybrid model that combines our sun, daylight, and wind analyses with local weather data.	**Assumptions (if applicable)**	• Does not yet include the effects of surface or ground materials • For wind, sun, and daylight, see respective analysis assumptions
Time to complete	1 min without wind results, 40-200 min with wind results	**Data sources**	The weather data includes information about e.g. solar radiation, and cloud coverage, all from the ERA5 dataset provided by the Copernicus Climate Change Service. Wind roses are retrieved from the Global Wind Atlas, unless a custom wind rose is uploaded in the wind analysis

In the month selection in the analysis settings, August, the hottest month of the year, and January, the coldest month of the year, were selected for Serdivan. In the time selection, the existing 13.00 value in the settings of the analysis was not changed.

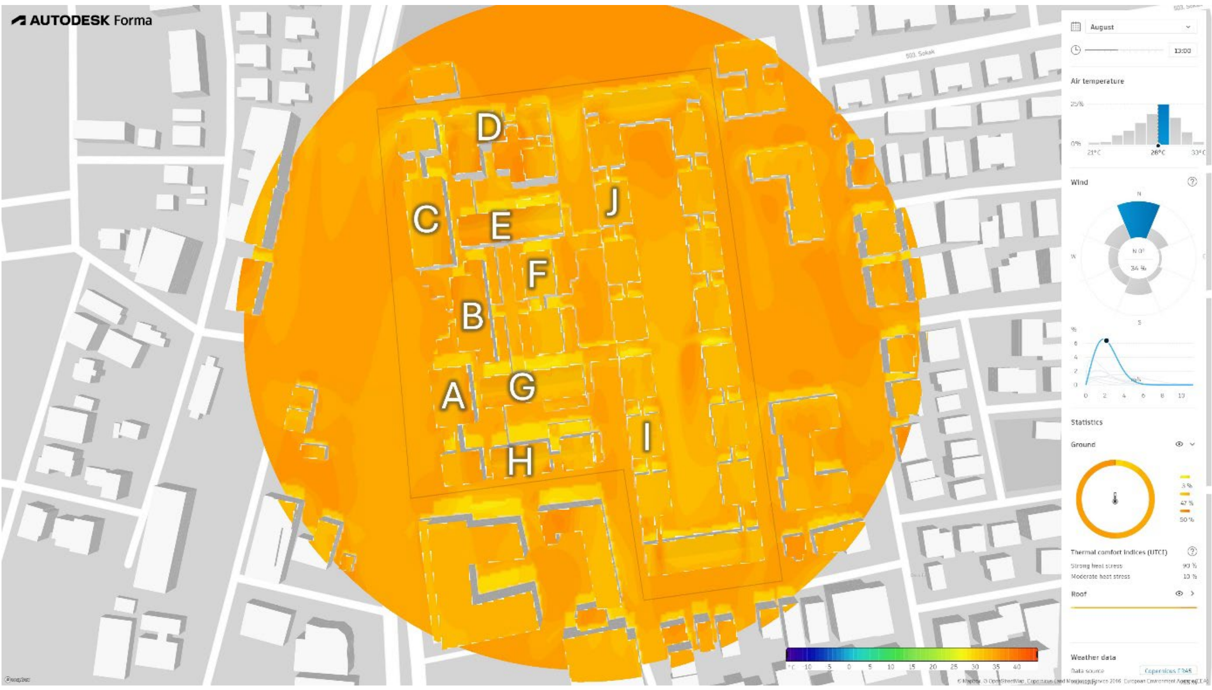


Figure 21 Microclimate analysis for august

Except for the northern facades of the blocks, high temperature stress was observed in general. Although the corridors created take the prevailing north wind into the area, it is seen that the sweltering effect cannot be prevented in the summer period in the area with high humidity. It can be said that the courtyards created in this picture do not make a big difference in the felt temperature (Figure 21).

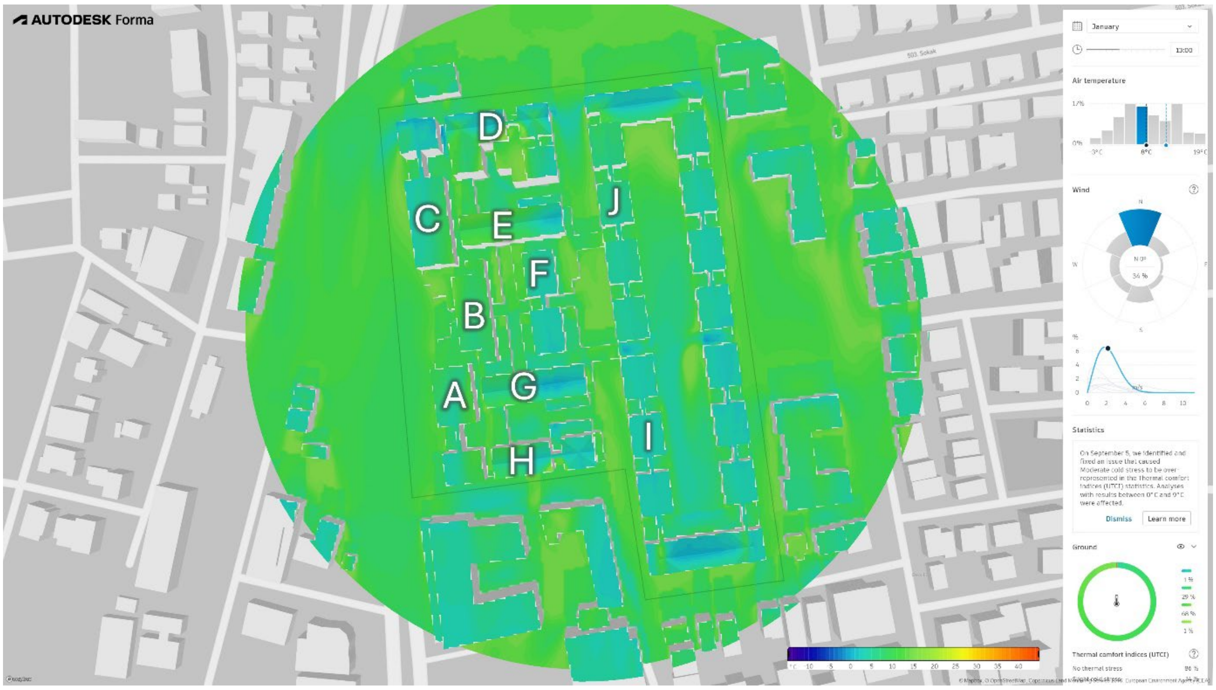


Figure 22 January microclimate analysis

It is seen that there is no high cold stress, and the temperature felt in the area is balanced. The colder temperatures are not felt in the openings but in the gorges between the masses (Figure 22).

According to the results of the microclimate analysis, the presence of the building group does not have any significant effect on the surrounding settlement in this context, as the humidity balances the perceived temperature.

4. Results and Findings

The building group was evaluated as a result of the analyses made within the framework of climate, location and orientation, layout of the settlement area, building form and building envelop parameters.

In terms of compliance with temperate-humid climate design criteria: The buildings comply with most of the criteria in this context with their good orientation range, not blocking the sunlight of each other and the buildings around them, homogeneous heights, rectangular plans and appropriate envelope form.

According to solar and wind analyses: It was found that the courtyard layout reduces the heat gain for the blocks located in the central region and the openings in these areas, the green roof above the mall of blocks J and I increases the heating-cooling energy load since it is clearly exposed to the sun and wind, the heating energy consumption is high in winter in blocks D and G, and the cooling energy consumption is high in summer in blocks H, I and J.

And according to microclimate analyses: Except for block D, the masses where large surfaces are not positioned against the prevailing north winds have created an uncomfortable effect for the user and a negative effect for ensuring energy efficiency due to the high humidity and solar radiation in the summer season. The passages that create the possibility of wind corridor formation with north winds in the winter season do not pose a major problem due to the prevailing wind direction being south in this season, and it has been observed that a settlement form that reduces energy consumption and increases comfort has been created.

The existing building group selected for analysis, according to the design parameters obtained as a result of literature research and according to the analysis made with Forma, it has been seen that it may create some negative aspects for users and energy consumption due to its layout. However, it has been concluded that it does not have much impact on the surrounding residential fabric, except for blocking the illumination and creating wind corridors.

Evaluation about the software: Forma contributes to the provision of energy efficient designs with environmental analyses in the early design phase. Compared to some design criteria required by the climate, it is possible to evaluate energy performances and make suggestions about the values of building parameters and building forms with Forma's settlement scale analyses. However, in the Rapid Wind analysis and Microclimate analysis, data cannot be obtained in the modelled geometry, and evaluation cannot be made in the open spaces created on the first level and on the roof of the indoor shopping mall as in this example. This may cause problems for the designer during the form design phase.

5. Conclusion and Recommendations

This research seeks to answer the research question and thus highlights the importance of collaboration between energy efficient layout, form design, artificial intelligence (AI) and architectural technologies in the process of sustainable urban design. It reveals the potential of next-generation architectural tools to increase efficiency and innovation in urban design creation for existing or future developments. Thus, the study reveals the importance of the effects of the decisions taken at the building and settlement design stages on energy efficiency in future large-scale projects. Furthermore, energy efficiency assessments at the design stages of urban planning are likely to be more efficient than interventions at later stages.

Although the software used in this study contributes to the development of architectural software that will help designers who are interested in sustainable and energy efficient urban planning mentioned in the introduction of the study to predict some environmental impacts at the design stages while planning at the settlement scale, the fact that an existing building group was analyzed in this study showed that it would be useful in identifying advantages and disadvantages for existing settlements/building forms and taking necessary precautions.

This research reveals great opportunities for future urban design for more innovative and efficient planning processes, considering environmental factors and collaborating with a new generation of architectural tools. The use of artificial intelligence in urban design integrated with the sustainable city concept not only responds to today's challenges, but also paves the way for developing more efficient and sustainable cities in the future. This analysis provides recommendations on the tools and methodologies necessary to achieve results in energy efficiency and adaptation at the settlement scale for the studied region and can be compared with similar examples of medium-sized cities at the international level.

References

Ascione, F., Bianco, N., De Masi, R., F., Dousi, M., Hionidis, S., Kaliakos, S., Mastrapostoli, E., Nomikos, M., Santamouris, M., Synnefa, A., Vanoli, G., P., & Vassilakopoulou, K. (2017). Design and performance analysis of a zero-energy settlement in Greece. *International Journal of Low-Carbon Technologies*, Volume *12*, Issue 2, June 2017, Pages 141-161. https://doi.org/10.1093/ijlct/ctw003

Autodesk, *Articles of analyses: Sun hours, daylight potential, wind, microclimate.* https://help.autodeskforma.com/en/collections/4005990-analyses

Ayçam, İ., Akalp, S., & Görgülü, L. S. (2020). The application of courtyard and settlement layouts of the traditional Diyarbakır houses to contemporary houses: A case study on the analysis of energy performance. *Energies*, *13*(3), 587. https://doi.org/10.3390/en13030587

Batty, M. (2018). Artificial intelligence and smart cities. *Environment and planning B: Urban analytics and city science*, vol.*45*, pp. 3-6. doi: 10.1177/2399808317751169

Bayraktar, M., & Yılmaz, Z. (2007, October 25-28). Bina enerji tasarrufunda pasif akıllılığın önemi. *VIII. National Plumbing Engineering Congress*, Izmir, Turkey.

Beygo, K., & Yüzer, M. A. (2017). Early energy simulation of urban plans and building forms. *A|Z ITU Journal of the Faculty of Architecture*, *14*(1), 13-23, Istanbul, Turkey. https://doi.org/10.5505/itujfa.2017.67689

Cardinali, M., Pisello, A. L., Piselli, C., Pigliautile, I., & Cotana, F. (2020). Microclimate mitigation for enhancing energy and environmental performance of Near Zero Energy Settlements in Italy. *Sustainable Cities and Society*, Volume *53*, 2020, 101964, ISSN 2210-6707. https://doi.org/10.1016/j.scs.2019.101964

Climate. (2024, April). In Wikipedia. https://tr.wikipedia.org/wiki/%C4%B0klim

Erinç, S. (1996). *Climatology and methods* (4. Edition), Alfa Press, İstanbul, Turkey.

Kısa Ovalı, P. (2009). *Forming ecological design criteria systematics in terms of climate regions in Turkey: Kayaköy settlement sample*. Trakya University, Institute of Science, PhD. Thesis (Thesis no. 244933), Edirne, Turkey.

Koca, Ö. (2006). *An approach of determination of energy efficient settlement and building design principles in hot dry and hot humid regions*. *İstanbul Technical University, Institute of Science and Technology*, Thesis (MSc.) (Thesis No. 172102), Istanbul, Turkey.

Kun, F. (2005). *Evaluation of tourism purpose buildings in terms of cooling load in the scope of climate balanced design: The case of Kuşadası*. Master Thesis (Thesis No. 168496), Yıldız Technical University, Institute of Science, Istanbul, Turkey.

Kurniawan, A., Wiranti, A., Rahmadi, D., & Poerbo, H. W. (2024). Revealing the Future of Urban Design: Exploring Human and Artificial Intelligence Collaboration in Planning and Design for the Sustainable Built Environment (Case Study: IKN Nusantara), *3RD-ICUDEP, IOP Conf. Series: Earth and Environmental Science 1394* (2024) 012032, IOP Publishing. doi:10.1088/1755-1315/1394/1/012032

Oke, T. R. (1988). Street design and urban canopy layer climate. *Energy and Buildings*, *11*(1-3), 103-113. https://doi.org/10.1016/0378-7788(88)90026-6

Orhon, İ., Küçükdoğu, M. Ş. & Ok, V. (1988). Doğal iklimlendirme. *Project Planning and Design Handbook for Housing Enterprise*, TUBITAK, Publication No. U.9, Ankara, Turkey.

Stromann-Andersen, J., & Sattrup, P. A. (2011). The urban canyon and building energy use: Urban density versus daylight and passive solar gains. *Energy and Buildings*, *43*(8), 2011-2020. https://doi.org/10.1016/j.enbuild.2011.04.007

Umaroğulları, F., & Cihangir, C. (2019). Evaluation of Mass Houses According to Climatic Comfort Design Parameters: ''Temperate Humid Climate Zone: Edirne Binevler (Part 1) Mass Housing Example''. *Journal of Architecture and Life*, *4*(1), (105-122). https://doi.org/10.26835/my.661363

UN-Habitat. (2020). *World cities report 2020: The value of sustainable urbanization*.

United Nations Department of Economic and Social Affairs, Population Division. (2014). *World urbanization prospects: The 2014 revision, highlights* (ST/ESA/SER.A/352).

Wener, R., & Carmalt, H. (2006). Environmental psychology and sustainability in high-rise structures. *Technology in Society*, *28*(1-2), 157-167. https://doi.org/10.1016/j.techsoc.2005.10.016

Yılmaz, E., & Çiçek, İ. (2016). Thornthwaite climate classification of Turkey, *Journal of Human Sciences*, *13*(3), 3973-3994. Retrieved from https://www.j-humansciences.com/ojs/index.php/IJHS/article/view/3994

Yılmaz, Z., Koçlar Oral, G., & Manioğlu, G. (2000). *Determination of thermal insulation value of building envelope depending on building form in terms of heating energy saving executive*: Prof. Dr. Zerrin Yılmaz, (Since September 1999, Assoc. Prof. Dr. Gül Koçlar Oral has been the coordinator of the research.) Institution: I. T. U. Faculty of Architecture, Supporting Institution: I. T. U. Research Fund (Project no. 985), (April 1998-January 2000).

Zeren, L. (1977). Climate-Balanced Architectural Practice in Turkey. Paper presented to *TUBITAK VI. Science Congress*, Izmir, Turkey.

Zeren, L. (1978). *Solar Control in Architecture*. ITU Publications, Istanbul.

Zeren, L. (1978). Architectural Built Environment Design and Solar Energy. *Solar Energy and Environmental Design National Symposium*, ITU Faculty of Architecture, Istanbul.

Zeren, L. (1987). A study on regulation model related to new settlements and buildings energy conservation in Turkey. Istanbul Technical University, *Urban and Environmental Planning and Research Center*, Istanbul, Turkey.

Zorer, G. (1992). Principles of thermal design in buildings. *YTU Faculty of Architecture Publications*, University Publication No: 264, Faculty Publication No: MF-MIM 92.045, Istanbul, Turkey.

URL2: Republic of Turkey Governorship of Sakarya, Serdivan. http://www.sakarya.gov.tr/serdivan

URL3: Serdivan Municipality, Geographical Area of Serdivan. https://serdivan.bel.tr/serdivan-in-cografi-alani

URL4: Weather Spark, Climate and Average Weather Year - Round in Serdivan. https://weatherspark.com/y/96519/Average-Weather-in-Serdivan-Turkey-Year-Round

URL5: Day, M. (2023, June 5). Autodesk Forma: a deep dive into the data lake. https://aecmag.com/features/autodesk-forma-a-deep-dive-into-the-data-lake/#link

Resume

Ceren Aydan Nasır is currently pursuing her master's degree in architecture at Gebze Technical University in Kocaeli, Turkey. She started her architectural education at Sakarya University in 2018 with a Bachelor of Architecture degree and graduated in 2022. In 2023, she started her master's degree at Gebze Technical University in Kocaeli to continue her studies in the field of Building Information Modeling and Artificial Intelligence in Architecture, where she is still studying. Her research focuses on Building Information Modeling, Artificial Intelligence in Architecture, energy efficient buildings and sustainable buildings, revealing her commitment to technological solutions in developing environmentally conscious architectural practices.

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Seher Güzelçoban Mayuk completed her bachelor's degree in architecture at Yıldız Technical University between 2001-2005 as the top student. She had completed her doctorate and master's degrees on Building Science Programme of Architecture. She has been working in various positions since 2012 at Gebze Technical University. Her interests are detail design of building elements, and digital technologies use in construction phase and use in building science education of architecture. She is also interested in how to improve existing buildings in Turkey by a sustainable way. Building science education related to generation Z is one of her interests.