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Evaluation of the energy consumption mechanism based on urban street orientation

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ABSTRACT: Lack of due attention to the orientation of streets and establishment of urban blocks without regard for climatic characteristics and conditions of the environment have an adverse effect on thermal comfort in open urban spaces. Construction of new settlements without taking any study of climatic requirements undermines thermal comfort for pedestrians and other users, especially in cold regions. Considering the conditions of Khorramshahr city and also its specific climate, the study of the subject of energy as well as the explanation of general and structural principles for future changes need to be studied and evaluated in a sustainable manner. For this purpose, microclimate simulation was performed using ENVI-met software. A sample parcel with six different orientations (With a distance of 30 degrees) were simulated in the hottest day and the sultriest day of year. The results suggest that the orientation mode of the passages at 30 degrees from the north is the best mode resulting from the simulation and compared to the higher modes, the micro-climatic conditions are better and more favorable. Orientation of 60-degree passages is also known to be the worst-case scenario. The final result of this section represents the order of priority orientation of the main thoroughfares for the future development of Khorramshahr city. By using the results of this section in order to select and use the optimal orientation for the passages, as well as molds with optimal shape and density, we will definitely see very visible and tangible results in the short, medium and long term and for the next researches, other approaches of evaluation in micro scale can be done.

Keywords: Urban Micro Climate, Urban Street Orientating, Energy Consumption, Khoramshahr City, Microclimate

RUNNING TITLE: Energy Consumption Mechanism

INTRODUCTION

In recent years, issues related to climate change and energy have become more important and focused in urban studies (Song et al. 2020). Today, cities are responsible for emitting more than 70% of greenhouse gases (Grilo et al. 2020), although cities cover 2% of the biosphere surface (Mukherjee, 2018), their inhabitants consume 60 to 80% of the world's energy. (Perera et al. 2021). As this issue intensifies, energy efficiency is a key factor in urban development (Jafarpur & Berardi, 2021; Aram et al. 2019). This leads governments to make concerted efforts to reduce greenhouse gas emissions (Fernandez-Luzuriagae et al. 2021). In many recent studies, the orientation of streets and blocks has been mentioned as one

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of the most important design factors that affect energy consumption on buildings (Faroughi et al. 2020). Urban morphology and materials properties play a relevant role in assuring a healthy and comfortable living environment (Sudprasert, 2019; Palme, & Salvati, 2016), especially because the recent growth of the population living in cities has caused an increase in the densification of the urban pattern (Wang et al. 2020). On a medium scale, and especially in urban micro-scale, in relation to buildings and the surrounding environment, each building changes the climate around it. These changes take place under the title of micro-urban climate and the impact of factors such as geometry and cross section of the city, shape, height, size of buildings, the direction of streets and buildings and the level of open spaces (Yanxue Li et al 2021). In the topic of micro-structure of urban climate, parameters of urban morphology can be proposed that examine and explain the relations with a morphological approach. Elements such as masses, passages and blocks as the main cases of urban morphology have indicators in which the meaning of this meaningful relationship can be analyzed practically the most accurate effects (Mosteiro-Romero et al. 2020)

Communication networks have different patterns in terms of shape and in terms of size, they have different physical characteristics such as length, width and orientation, which affect the energy efficiency inside buildings. At the macro level, the pattern of the road network affects the fuel consumption in the building by orienting and influencing the orientation of the fabric sections in relation to the best sunlight, and at the micro level by affecting the surface built with the passage (Xu et al. 2018). Street orientation determines the amount of shade, radiation, light and air movement, the intensity of city ventilation and the duration of relative humidity (Chen et al. 2021). However, it is difficult to propose a global model of streets and city configuration that best suits all climatic characteristics. Therefore, some general assumptions can be used as a guide for urban street design. There is very little solar access on North-South Street. There are some design methods to improve the performance of buildings on North-South Streets. Orientation of the shortest view to the street is one of the most obvious methods (Li et al. 2021); It is better to turn the building to the south in the sections located along the diagonal streets. Although it is convenient to orient the facades of buildings parallel to the street, this alternative design provides benefits (In non-row buildings), In east-west streets, high depth of parts is better than shallow depth. Unbalanced retreats cause problems in both summer and winter. Very small rear seats are acceptable, especially if used in a row housing, in areas where more shade is needed, it is best to have taller buildings and trees on the south side of east-west streets (Kouklis, & Yiannakou, 2021). In addition to the above guidelines, streets should be designed to be straight and parallel to each other to support the movement of air in and out of the city. On the other hand, if the conditions are such that the site is prone to storms and dusty winds or low winds and cold and hot winds enter, the streets should be designed perpendicular to each other (Loeffler et al. 2021). The most desirable street direction in terms of external thermal comfort is the northwest-southeast or northeast-southwest direction. East-west streets, on the other hand, are inherently incapable of creating a climate-friendly environment; Because in this model, the block is positioned in relation to the sun's radiation in such a way that it casts the most shadow on the open spaces in winter and reflects the most sunlight on them in summer (Pioppi et al. 2020; Manni et al. 2019). Shading in passages with different directions of size and direction may direct the wind or prevent the wind from reaching the street level (Knowles, 1981). Because the speed and direction of the wind and the way of air flow in the city change according to different obstacles (Habibi, 2014: 216). To improve airflow in valley-like streets, buildings must be retreated, openings increased, and buildings of varying heights constructed (ibid., P. 218). When the direction of the street is perpendicular to the direction of the wind and the buildings are parallel to the street, the main stream of wind passes over the buildings. Wind currents in the street are caused by secondary currents caused by wind colliding with buildings. In such conditions, the ventilation of the urban space is suppressed. The width of the streets has little effect on urban ventilation. When city streets are parallel to the wind direction, wind currents are less likely to hit buildings on the edge of the street, thus improving urban ventilation. The same situation occurs when the streets are at a slight angle to the wind. When the wind hits the street obliquely, the intensity and speed of the wind will be different on both sides of the street. Pedestrians on the windward side experience faster speeds across the street (Nazarian et al. 2019). For maximum access to the ventilation and air movement in the streets, set the direction of the boulevards and main streets 20 to 30 degrees relative to the direction of the prevailing summer winds (Vallati et al. 2018). Narrow, winding alleys are designed to provide comfortable and cool microclimates in hot and dry climates. These alleys protect against hot and cold winds and receive minimal solar radiation, reduce the effect of stormy winds and provide shady spaces during the day. In hot and humid climates, a wide street is needed to provide ventilation. However, in order to reduce the amount of solar radiation, these streets need shading (Piselli et al. 2019). The city of Khorramshahr is located in the vicinity of the Persian Gulf, has a special strategic economic, commercial and political importance and is located at the end of Khuzestan province, which has a high capacity due to the existence of water piers. Khuzestan province and Khorramshahr city, due to their geographical conditions and specific climate, has a very high temperature that the average maximum temperature in the hottest month of the year for all stations is above 40 degrees Celsius, which according to basic studies in Khorramshahr, The interior of the building needs cooling in 41% of the year. Therefore, determining the energy mechanism in the masses forming the physical form of urban settlements is considered important and vital for such cities in order to provide a macro and mid-scale model, strategy and policies by examining the structure and explaining the role of energy consumption.

MATERIALS AND METHODS

Khorramshahr city with an area of 201215 square kilometres between 48 degrees and one minute to 48 degrees and 30 minutes east longitude of the Greenwich meridian and 30 degrees and 19 minutes to 30 degrees and 58 minutes north latitude of the equator at the southwestern tip of Khuzestan province Has been.

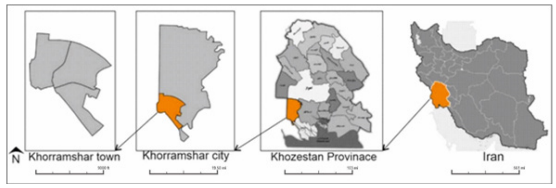

Fig 1: Geographical location of Khorramshahr in the country and Khuzestan province

In terms of topography and natural features of the city, the city is relatively flat in general, in the northern part of the Karun River is the highest point of the city with a height of 4.2 meters above sea level and the lowest point in the southern part with a height of 50 centimeters above sea level. The study of the urban context of the current situation in Khorramshahr indicates that the major central parts of the city include fine-grained fabric and a combination of fine-grained and intergranular. The hybrid and coarse-grained fabric occur mainly in newer development areas, and the coarse-grained fabric is most concentrated in the southern part and parts in the eastern part of the city. It should be noted that the morphology of the studied species based on research indicators and typology in modern urban planning based on LSE sources includes the morphological evaluations, which has been done according to the explanation of the combined scenario based on the principle of sustainability.

To simulate different conditions of road orientation, the plot is defined as 200 meters by 200 meters with general and standard conditions in most of the current urban contexts. This fabric has two main cross accesses of 20 meters and two axes of 10 meters and is designed with 10 by 20 meters plates, occupancy level of 60% and density of 5 floors. In the 3D simulation image, we see the assumed texture.

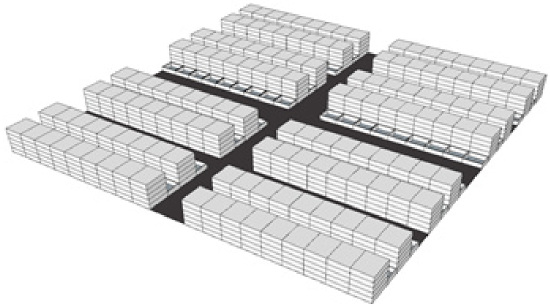

Fig 2: 3D model block mode to simulate different orientation modes

The mentioned fabric to examine different orientation modes, in 6 modes; 30 degrees, 60 degrees, 90 degrees, 120 degrees, 150 degrees and 180 degrees were modeled in the space environment of Envy Matt software and each state was simulated in the hottest and hottest days of the year for 48 hours.

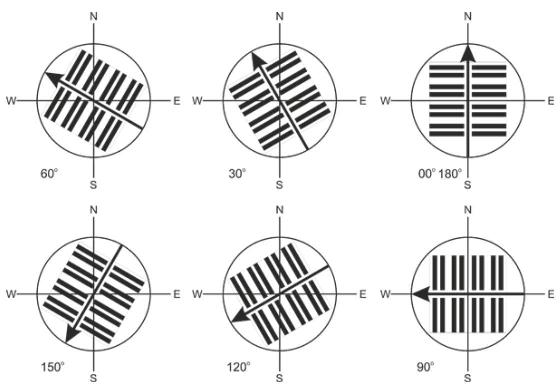

Fig 3: Seven modes of orientation of passages with a difference of 30 degrees in each position relative to the north direction

The model of this simulation is fixed and is the only parameter of the orientation variable defined for the plan. In each case the directions are added at a distance of 30 degrees to the original model and simulated. Below is an example of a temperature map for a sample of 0 and 180 degrees on the hottest day of the year. The general results of this simulation are presented in the form of air temperature maps, average relative humidity and specific humidity on the hottest and sunniest days of the year, respectively.

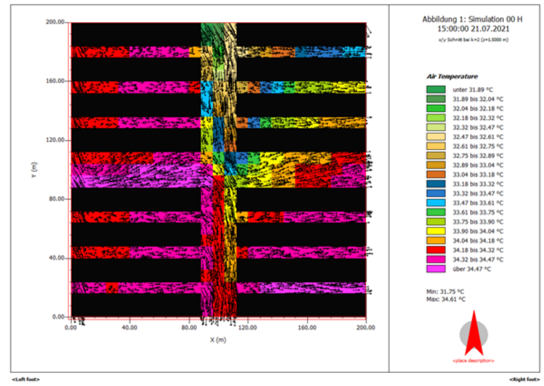

Fig 4: Sample temperature map with directional meter for air temperature on the hottest day of the year for 0 and 180 degrees from the orientation of passages

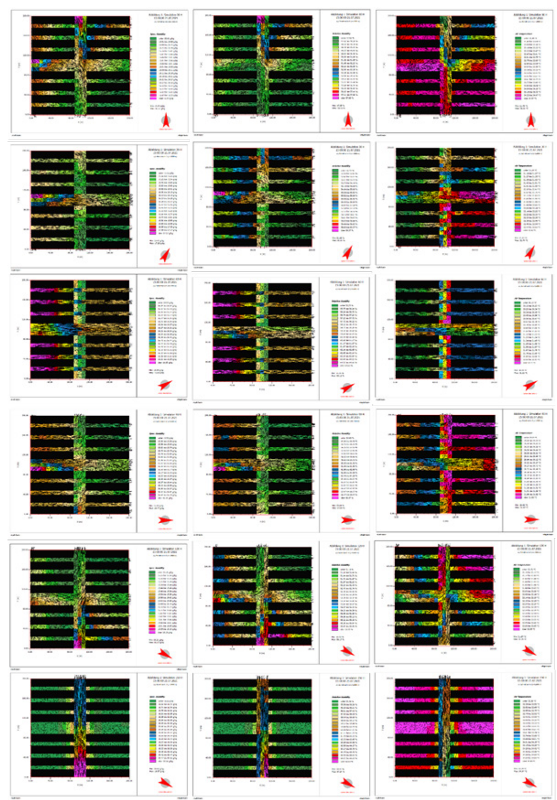

Fig 5: Temperature maps, average relative humidity and specific humidity for all orientation modes on the hottest day of the year

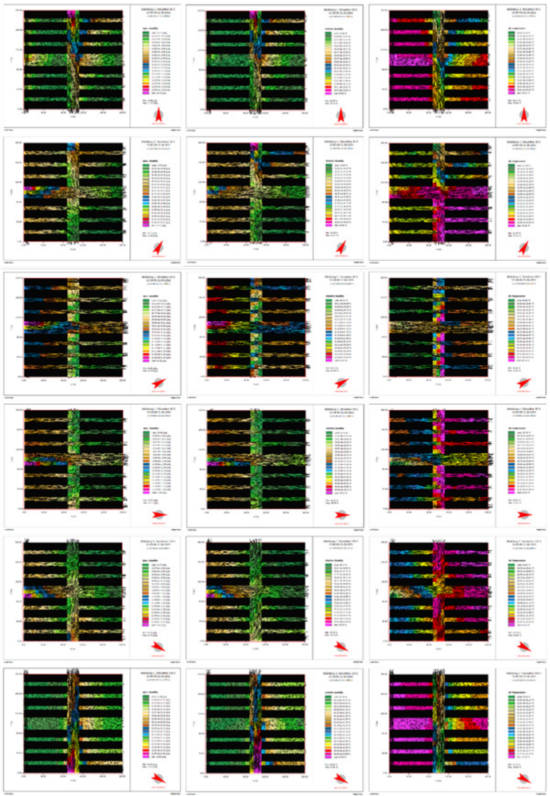

Fig 6: Air temperature maps, mean relative humidity and specific humidity for all orientation modes on the hottest day of the year

RESULT AND DISCOTION

The table below shows the mean values of the numerical results obtained from the simulation performed in Envi-Met software for each mode of orientation. By reviewing and comparing these results, the effects of each state and angle of the orientation of the passages in the assumed designed block on each micro-climatic parameter are determined and finally, considering the overall result of positive and negative effects, the best and worst angles of orientation of the passages for use. In future development in the peripheral sectors.

To achieve this, we first simulate the difference between the values obtained for each parameter separately for two hot and humid days and examine separately for each parameter in each case.

Tab 1: Mean microclimatic parameters in simulating the hottest and hottest days of the year for different orientation modes

		0/180	30	60	90	120	150
S	Air Temperature (°C)	31.6934	31.55756	37.08688	31.30902	30.99252	30.39046
	Wind Speed (m/s)	7.165906	4.60214	5.565277	1.786148	5.099413	8.267231
	Specific Humidity (%)	10.85935	10.28407	59.78425	10.41874	10.44382	11.89733
	Relative Humidity (%)	38.6504	36.88665	107.1545	37.90379	38.64158	45.43225
	Mean Radiant Temp. (°C)	35.84327	35.09213	38.82188	39.26517	38.07475	31.68813
H	Air Temperature (°C)	32.25648	31.61621	31.08623	31.14669	31.29494	31.21517
	Wind Speed (m/s)	4.134713	2.128683	2.117267	15.45425	4.183752	5.756115
	Specific Humidity (%)	15.67694	15.43594	15.66981	15.45425	15.41365	17.26058
	Relative Humidity (%)	53.87738	54.92792	57.53585	56.46748	55.93296	62.56106
	Mean Radiant Temp. (°C)	35.63783	34.75327	37.13994	37.69398	35.89469	32.09888

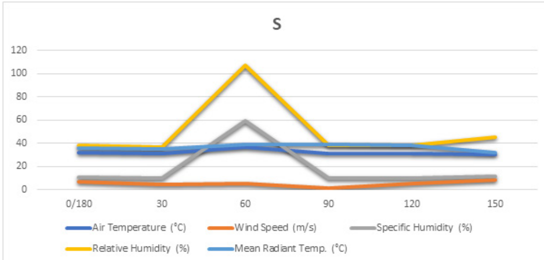

Fig 7: Difference of microclimatic parameters for each of the orientation modes obtained from the simulation for the hottest day of the year

In the chart of the hottest day of the year, slight changes can be seen in all cases except the 60-degree position, which is a significant increase in humidity parameters. Therefore, the initial result is to reject the 60-degree orientation for the passages, and in the next steps, we will get closer to the final result by completing and refining the results

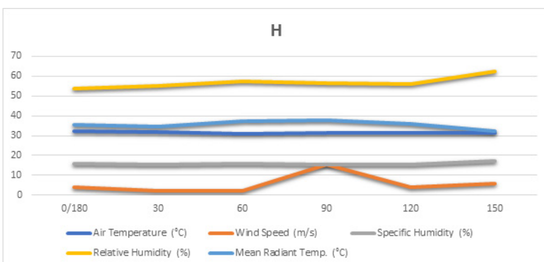

Fig 8: Difference of micro-climatic parameters for each of the orientation modes obtained from the simulation for the sunniest day of the year

In the diagram related to the sunniest day of the year, we see an increase in wind speed in the 90-degree position and also an increase in relative humidity in the passages of 150 degrees. Regardless of the changes and small distances of existence in other parameters and between other states, these two cases are the most important changes in this stage. In order to increase the accuracy of the study and more complete review of the type and number of effects, in this step we evaluate the changes of each parameter separately for each case and each day to become more and better aware of how many and why the effects of these orientations on micro-climatic parameters.

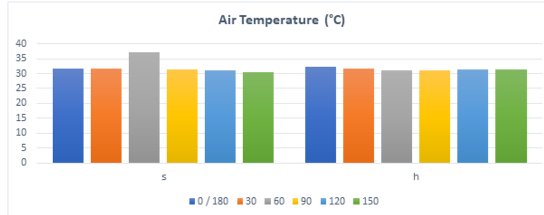

Fig 9: The difference in air temperature on the hottest and sunniest day of the year for each condition of the orientation of the passages

In the study of changes in air temperature in different conditions, not much change is observed. The lowest temperature in the whole results is related to the state of 150 degrees on the hottest day and the highest value is related to the orientation of 60 degrees on the hot day. Regardless of the maximum amount, in general, we see a higher temperature on a sunny day than on a hot day, and by adding other parameters to this assessment and applying their impact on the overall result, we will achieve a more comprehensive result.

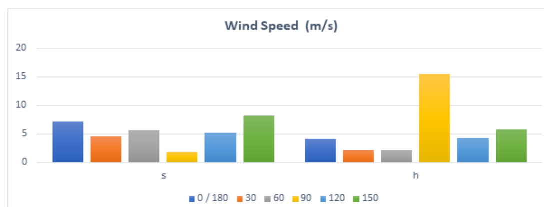

Fig 10: The difference in wind speed on the hottest and sunniest day of the year for each condition of the orientation of the

The wind speed has undergone different changes in the orientation of the passages due to different angles. These changes are so heterogeneous that they can not play a decisive role in their individuality. Therefore, the main effect of the simulation results for this parameter will be in the weighting and scaling section.

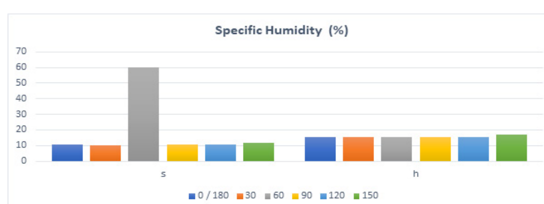

Fig 11: The difference in wind speed on the hottest and sunniest day of the year for each condition of the orientation of the

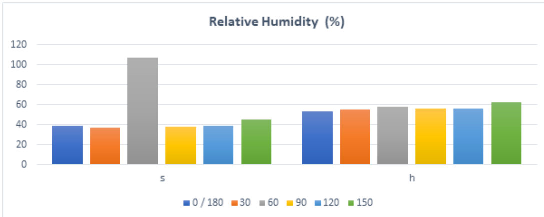

Fig 12: Difference of relative humidity in the hottest and sunniest day of the year for each condition of the orientation of the passages

Changes in moisture values in both parameters between orientation modes on simulated days follow a similar pattern, and as mentioned in the initial evaluation, 60 ° orientation will increase both relative and specific humidity. In contrast, the 90-degree orientation of the passages will bring us the lowest amount of humidity, which is a significant impact.

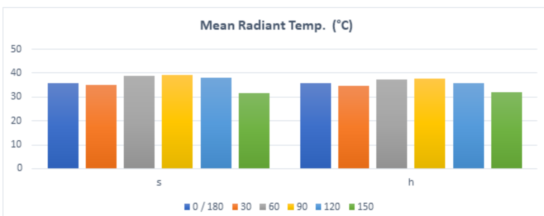

Fig 12: Mean difference of radiation temperature in the hottest and sunniest day of the year for each condition of the orientation of the passages

The average irradiated temperature evaluated in the simulation results shows the best radiant temperature at 150 degrees compared to the north, and this reduces the air temperature as well as the closed temperature. The 60- and 90-degree modes also cause the highest average radiation temperature, respectively, and therefore will have a low desirability.

In order to be sure about the optimal orientation of passages in hot and humid climate of Khorramshahr and detailed analysis of simulation results, orientation modes based on the results obtained from micro-climatic parameters are first weighted and then assigned based on weights. The final ranking is given. In the following equation, we see the mean values of the parameters for each state and each day, as well as the weight of each rank in comparison with similar cases.

Tab 2: Ranking and weighting of Envy Matt evaluation results in orientation modes

		0/180	30	60	90	120	150
S	Air Temperature (°C)	31.6934	31.55756	37.08688	31.30902	30.99252	30.39046
		5	4	6	3	2	1
	Wind Speed (m/s)	7.165906	4.60214	5.565277	1.786148	5.099413	8.267231
		5	2	4	1	3	6
	Specific Humidity (%)	10.85935	10.28407	59.78425	10.41874	10.44382	11.89733
		4	1	6	2	3	5
	Relative Humidity (%)	38.6504	36.88665	107.1545	37.90379	38.64158	45.43225
		4	1	6	2	3	5
	Mean Radiant Temp (°C)	35.84327	35.09213	38.82188	39.26517	38.07475	31.68813
		3	2	5	6	4	1
H	Air Temperature (°C)	32.25648	31.61621	31.08623	31.14669	31.29494	31.21517
		6	5	1	2	3	4
	Wind Speed (m/s)	4.134713	2.128683	2.117267	15.45425	4.183752	5.756115
		3	2	1	6	4	5
	Specific Humidity (%)	15.67694	15.43594	15.66981	15.45425	15.41365	17.26058
		5	2	4	3	1	6
	Relative Humidity (%)	53.87738	54.92792	57.53585	56.46748	55.93296	62.56106
		1	2	5	4	3	6
	Mean Radiant Temp (°C)	35.63783	34.75327	37.13994	37.69398	35.89469	32.09888
		3	2	5	6	4	1

Based on the results of the table above, the final ranking is shown in the next table, and according to these results, which are the result of the weighted average result applied to the micro-climatic parameters in each case, the final ranking of each case of orientations is as follows.

Tab 3: The final ranking status of the 7 modes of orientation of the passages

	S					H						
	AT	WS	SH	RH	MRT	AT	WS	SH	RH	MRT		
0/180	5	5	4	4	3	6	3	5	1	3	3.9	4
30	4	2	1	1	2	5	2	2	2	2	2.3	1
60	6	4	6	6	5	1	1	4	5	5	4.3	6
90	3	1	2	2	6	2	6	3	4	6	3.5	3
120	2	3	3	3	4	3	4	1	3	4	3	2
150	1	6	5	5	1	4	5	6	6	1	4	5

CONCLUSION

Therefore, based on the knowledge and evaluation of Khorramshahr urban fabric with regard to energy in urban morphology and the principle of urban fabric stability, to present the optimal model of urban design, the findings of the current research show the energy consumption status according to the evaluation of morphological variables. It is the morphotypes as well as the climatic parameters that have determined the specific results of each case and also provided the appropriate type and ratingThe orientation mode of the passages at 30 degrees from the north is the best mode resulting from the simulation and compared to the higher modes, the micro-climatic conditions are better and more favorable. Orientation of 60-degree passages is also known to be the worst-case scenario. It should be noted that the basis of weighting in the final two stages of large and medium scale climate in the Khorramshahr region and also the standard climate comfort for humans and since the results are generally higher than the values of climate comfort range, so the lowest value in Each parameter has the highest rank (lowest weight). Therefore, in the final ranking, the lowest numerical value indicates the best microclimatic state. The final result of this section represents the order of priority orientation of the main thoroughfares for the future development of Khorramshahr city. By creating a more favorable micro-climate in the passages, they will both provide more climatic comfort for users of urban spaces during the day and will significantly reduce the amount of energy required for buildings on both sides of the urban corridor. If realized, this will lead to lower energy consumption and consequently reduced pollution, thermal islands and, on a large scale, environmental sustainability and sustainable development. By using the results of this section in order to select and use the optimal orientation for the passages, as well as molds with optimal shape and density, we will definitely see very visible and tangible results in the short, medium and long term. This can be considered as a suggestion for future research. A combined study of the orientation of the passages, taking into account the location of different species or different proposed densities, in order to achieve more accurate and definite results in this field.

REFERENCES

Aram, F.; Higueras García, E.; Solgi, E.; Mansournia, S. Urban green space cooling effect in cities. Heliyon 2019, 5.

Chen, C., Ding, L., Zhang, Y., Qiu, H., & Li, Y. (2021). The Impacts of Morphology of Traditional Alleys on Thermal comfort: A case study of Da Long Wang Xiang in Zhenjiang, China. E3S Web of Conferences 283, 02045 (2021). ICCAUE 2021. https://doi.org/10.1051/e3sconf/202128302045

Chen, S., Cui, P., & Mei, H. (2021). A Sustainable Design Strategy Based on Building Morphology to Improve the Microclimate of University Campuses in Cold Regions of China Using an Optimization Algorithm. Mathematical Problems in Engineering. Volume 2021, Article ID 2304796, 16 pages. https://doi.org/10.1155/2021/2304796

D. Mukherjee, “A Review Study on the Thermo Physical Properties and Storage Applications of Phase Change Materials,” World Scientific News, vol. 98, pp. 185-198, 2018.

Faroughi, M.; Karimimoshaver, M.; Aram, F.; Solgi, E.; Mosavi, A.; Nabipour, N.; Chau, K.-W. Computational modeling of land surface temperature using remote sensing data to investigate the spatial arrangement of buildings and energy consumption relationship. Eng. Appl. Comput. Fluid Mech. 2020, 14, 254–270.

Fernandez-Luzuriaga, J., del Portillo-Valdes, L., &

Flores-Abascal, I. (2021). Identification of cost-optimal levels for energy refurbishment of a residential building stock under different scenarios: Application at the urban scale, Energy and Buildings, Volume 240, 110880, ISSN 0378-7788, https://doi.org/10.1016/j.enbuild.2021.110880.

Grilo, F., Pinho, P., Aleixo, C., Catita, C., Silva, P., Lopes, N., Freitas, C., Santos-Reis, M McPhearson, T., Branquinho, C., 2020. Using green to cool the grey: Modelling the cooling effect of green spaces with a high spatial resolution. Sci. Total Environ. 724, 138182 https://doi.org/10.1016/j.scitotenv.2020.138182.

Jafarpur, P., & Berardi, U. (2021). Effects of climate changes on building energy demand and thermal comfort in Canadian office buildings adopting different temperature setpoints, Journal of Building Engineering, Volume 42, 102725, ISSN 2352-7102, https://doi.org/10.1016/j.jobe.2021.102725.

Kouklis, G.R., & Yiannakou, A. (2021). The Contribution of Urban Morphology to the Formation of the Microclimate in Compact Urban Cores: A Study in the City Center of Thessaloniki. Urban Sci. 2021, 5, 37. https://doi.org/10.3390/urbansci 5020037

Li, Y., Wang, D., Li, S., & Gao, W. (2021). Impact Analysis of Urban Morphology on Residential District Heat Energy Demand and Microclimate Based on Field Measurement Data. Sustainability, 13. https://www.researchgate.net/publication/349322209_Impact_Analysis_of_Urban_Morphology_on_Residential_District_Heat_Energy_Demand_and_Microclimate_Based_on_Field_Measurement_Data

Loeffler, R., Österreicher, D., & Stoeglehner, G. (2021). The energy implications of urban morphology from an urban planning perspective – A case study for a new urban development area in the city of Vienna, Energy and Buildings, Volume 252, 111453, ISSN 0378-7788, https://doi.org/10.1016/j.enbuild.2021.111453.

Manni, M., Bonamente, E., Lobaccaro, G., Goia, F., Nicolini, A., Bozonnet, E., Rossi, F., 2020a. Development and validation of a Monte Carlo-based numerical model for solar analyses in urban canyon configurations. Build. Environ. 170, 106638 https://doi.org/10.1016/j.buildenv.2019.106638.

Mosteiro-Romero, M., Maiullari, D., Pijpers-van, M., & Schlueter, A. (2020). An Integrated Microclimate-Energy Demand Simulation Method for the Assessment of Urban Districts. Built Environ., 17 September 2020 | https://doi.org/10.3389/fbuil.2020.553946.

Nazarian, N., Dumas, N., Kleissl, J., Norford, L., 2019. Effectiveness of cool walls on cooling load and urban temperature in a tropical climate. Energy Build. 187, 144 –162. https://doi.org/10.1016/j.enbuild.2019.01.022.

Palme, M., & Salvati, A. (2021). Urban Microclimate Modelling for Comfort and Energy Studies. Springer International Publishing. Print ISBN: 978-3-030-65420-7. Electronic ISBN: 978-3-030-65421-4.

Perera, A., Javanroodi, K., Wang, Y., & Hong, T. (2021). Urban cells: Extending the energy hub concept to facilitate sector and spatial coupling, Advances in Applied Energy, Volume 3, 100046, ISSN 2666-7924, https://doi.org/10.1016/j.adapen.2021.100046.

Pioppi, B., Pigliautile, I., Piselli, C., Pisello, A.L., 2020. Cultural heritage microclimate change: Human-centric approach to experimentally investigate intra-urban overheating and numerically assess foreseen future scenarios impact. Sci. Total Environ. 703, 134448 https://doi.org/10.1016/j.scitotenv.2019.134448.

S. Sudprasert, "Evaluation of energy savings by retrofitting of the building envelope of air-conditioned row house," Journal of Architectural/Planning Research and Studies (JARS), vol. 1, no. 16, pp. 83-92, 2019.

Song, S., Leng, H., Xu, H., Guo, R., & Zhao, Y. (2020). Impact of Urban Morphology and Climate on Heating Energy Consumption of Buildings in Severe Cold Regions. Int J Environ Res Public Health. 2020 Nov; 17(22): 83-54. Published online 2020 Nov 11. doi: 10.3390/ijerph17228354.

Vallati, A., Mauri, L., Colucci, C., 2018. Impact of shortwave multiple reflections in an urban street canyon on building thermal energy demands. Energy Build. 174, 77–84. https://doi.org/10.1016/J.ENBUILD.2018.06.037.

Wang, W., Lin, Q., Chen, J., Li, X., Sun, Y., & Xu, X. (2021). Urban building energy prediction at neighborhood scale, Energy and Buildings, Volume 251, 111307, ISSN 0378-7788, https://doi.org/10.1016/j.enbuild.2021.111307.

Xu, X., Gonzalez, ′ J.E., Shen, S., Miao, S., Dou, J., 2018. Impacts of urbanization and air pollution on building energy demands — Beijing case study. Appl. Energy 225, 98–109. https://doi.org/10.1016/J.APENERGY.2018.04.120.

Yanxue Li & Dawei Wang & Shanshan Li & Weijun Gao, 2021. "Impact Analysis of Urban Morphology on Residential District Heat Energy Demand and Microclimate Based on Field Measurement Data," Sustainability, MDPI, Open Access Journal, vol. 13(4), pages 1-17, February. https://www.mdpi.com/2071-1050/13/4/2070