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MULTI-OBJECTIVE DAYLIGHT OPTIMISATION OF THE OFFICE BUILDING IN CLIMATIC CONDITIONS OF UKRAINE

***Abstract. The purpose of this paper** is: to analyze the possibilities of multi-objective daylight optimization of an office premise in climatic conditions of Ukraine; to propose academically proven method for daylight optimization in order to achieve optimal values of Daylight factor (DF) and Daylight glare probability (DGP); to reveal optimal values of window-to-wall ratio (WWR), window length-to-width ratio and shading device depth of south façade for two locations – Kyiv & Odesa. **Methods.** Literature review of scientific papers and regulations, as well as computer simulations using computer-aided design software – Rhinoceros, visual programming language – Grasshopper, plugins – Ladybug Tools & Honeybee, and Octopus. **Results.** The multi-objective daylight optimization method of the office space in the climatic conditions of Ukraine was tested; optimal façade design options of office buildings from the point of view of DF and DGP were identified; optimal values of WWR, windows proportions and shading devices depth were discovered; office buildings façade design comparison for two climatic zones of Ukraine was conducted (for Kyiv and Odesa). **Conclusions.** Architects are suggested to use multi-objective daylight optimization at early design stage for façade design. Architectural design on the basis of environmental computer simulations provides rather accurate results for design solutions including: values of WWR, window proportions, shading devices depth, etc. The compromise between environmental design and aesthetical approach can lead to sustainable, environmentally conscious architectural solutions.*
***Key words:** sustainable architecture, public buildings, office buildings, energy-efficiency, passive design strategies, daylighting, daylight factor, daylight glare probability, window-to-wall ratio, solar shading devices, light shelves.*

БАГАТОЦІЛЬОВА ОПТИМІЗАЦІЯ ПРИРОДНОГО ОСВІТЛЕННЯ ОФІСНОЇ БУДІВЛІ В КЛІМАТИЧНИХ УМОВАХ УКРАЇНИ

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Анотація. Мета статті.** Проаналізувати можливості багатоцільової оптимізації денного освітлення офісного приміщення в кліматичних умовах України; запропонувати академічно перевірений метод оптимізації* *денного освітлення приміщення для досягнення оптимальних значень коефіцієнта природного освітлення (КПО) та коефіцієнта відблисків (КВ); виявити оптимальні значення коефіцієнта скління (КС) фасадів офісних будівель, співвідношень довжини до ширини вікон та ширини сонцезахисних пристроїв південного фасаду для двох міст України, що репрезентують різні кліматичні зони — Києва та Одеси.* ***Методи дослідження*. Огляд наукових публікацій, нормативних документів за темою дослідження, а також комп'ютерне моделювання з використанням: програм автоматизованого проєктування — Rhinoceros, мови візуального програмування — Grasshopper, плагінів — Ladybug Tools & Honeybee та Octopus.* ***Результати.*** *Апробовано метод багатоцільової оптимізації денного освітлення офісного приміщення у кліматичних умовах України; виявлені оптимальні варіанти проєктування фасадів офісних будівель з точки зору КПО та КВ; запропоновано оптимальні показники КС фасадів та пропорцій вікон і ширини сонцезахисних пристроїв. На прикладах Києва та Одеси проаналізовані відмінності проєктування фасадів офісних будівель для двох кліматичних зон України.* ***Висновки.*** *Архітекторам рекомендовано використовувати багатоцільову оптимізацію денного освітлення на ранній стадії проєктування для розробки фасадів офісних будівель. Архітектурне проєктування на основі комп'ютерного моделювання навколишнього середовища забезпечує досить точні результати проєктних рішень, включаючи: значення КС, пропорції вікон, ширину сонцезахисних пристроїв тощо. Компроміс між екологічним дизайном та естетичним підходом може привести до сталих, екологічно свідомих архітектурних рішень.* ***Методи дослідження****. Огляд наукових публікацій, нормативних документів за темою дослідження, а також комп'ютерне моделювання з використанням: програм автоматизованого проєктування — Rhinoceros, мови візуального програмування — Grasshopper, плагінів — Ladybug Tools & Honeybee та Octopus.* ***Результати.*** *Апробовано метод багатоцільової оптимізації денного освітлення офісного приміщення в кліматичних умовах України; виявлені оптимальні варіанти проєктування фасадів офісних будівель з точки зору КПО та КВ; запропоновано оптимальні показники КС фасадів та пропорцій вікон та глибин сонцезахисних пристроїв. Проаналізовані відмінності проєктування фасадів офісних будівель для двох кліматичних зон України на прикладах Києва та Одеси.* ***Висновки.*** *Архітекторам рекомендовано використовувати багатоцільову оптимізацію денного освітлення на ранній стадії проєктування для розробки фасадів офісних будівель. Архітектурне проєктування на основі комп'ютерного моделювання навколишнього середовища забезпечує достатньо точні результати проєктних вирішень, включаючи: значення КС, пропорції вікон, глибин сонцезахисних пристроїв тощо. Компроміс між екологічним дизайном та естетичним підходом може призвести до сталих, екологічно свідомих архітектурних вирішень.*

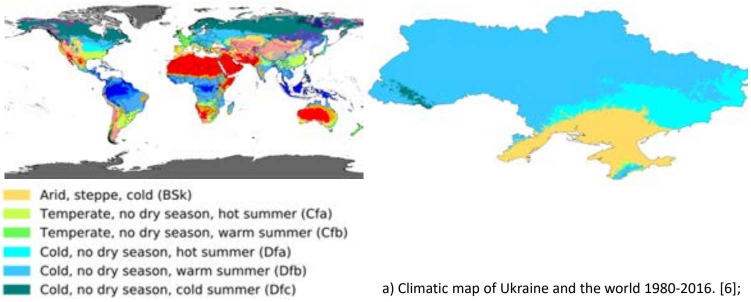
Ключові слова: *архітектура сталого розвитку, громадські будівлі, офісні будівлі, енергоефективність, пасивні архітектурні стратегії проєктування, природне освітлення, коефіцієнт природнього освітлення, коефіцієнт відблисків, коефіцієнт скління, сонцезахистні пристрої, світлові полиці.*

Problem setting. Energy-efficiency of office buildings strongly depends on daylighting of office premises. Furthermore, daylight improves wellbeing, reinforces circadian rhythms, improves visual comfort, connects building occupants with the outdoors and improves productivity of office employees. That's why it is important to design building's façades in a way that ensures optimal daylight conditions. In that regard, architects are encouraged to optimise at early design stage following parameters: window orientation, window-to-wall ratios, window shapes and sizes, shading device shapes and sizes, etc. However, efficient, accurate and academically proven methods are required for this purpose. During façade design, while different objectives are being searched for — best case for each objective can be found separately, however, if the objectives can't be determined separately than trade-offs between two or more conflicting objectives should be found by multi-objective optimisation. These trade-offs solutions are referred as — nondominated solutions. In this case nondominated solutions are those in which no one objective function can be improved without a simultaneous detriment to at least one of the other objectives. The author finds out that these kind of studies (multi-objective daylight optimization based on Pareto-Principle) for climatic conditions of Ukraine have not been conducted yet, therefore the knowledge gap exists in this area.

Analysis of the latest studies and publications. Latest studies show interest in the field of energy-efficiency of office buildings and daylight strategies. Journal paper [1] provides an overview on of simulation-based optimization methods in the building sector, aiming at clarifying recent advances and outlining potential challenges and obstacles in building design optimization. Key discussions are focused on handling building optimization issues, the performance and selection of optimization algorithms, multi-objective optimization and the implementation of optimization techniques into architectural practice. Another paper [2] presents a literature review of parametric design in architecture and focuses on its applications in daylighting and solar radiation, which can have an essential impact on improving daylight availability and energy saving. The study [3] investigates the significance of such parameters as: depth of shading, facade offset, location of shading, window-to-wall ratio, count of shading, angle of shading, and height of window in the optimal design of shading for an office space. Variables were designed aiming to improve the values of energy usage intensity, spatial daylight autonomy, daylight glare probability, and thermal comfort in the office space. Parametric design and Wallacei's algorithm were used for the optimisation. The paper [4] explores daylight optimization of light shelf parameters and thermal comfort analysis. Rhinoceros modelling tool, Grasshopper simulation tool and Octopus optimization multi-objective algorithm were applied to find the optimum combination of the parameters based on daylight performance indicators. Thermal comfort analysis was conducted for selected solutions with optimized light shelves using Openstudio. The study provided information for choosing the optimal properties of light shelves and the best design options in analysed locations. Journal paper [5] investigated environmental design of residential buildings is a process involving a large number of parameters and objectives. The study presented a targeted optimization framework for residential buildings based on the adjustment of window-related parameters coupled with various natural ventilation patterns. Multiple phases were carried out in this optimization framework to optimize the objectives (energy consumption, thermal comfort, daylight environment) simultaneously, including the usage of a genetic algorithm to achieve the Pareto optimization of window-related parameters and Multi-Criteria Decision-Making logic.

The purpose of the publication is – to explore the daylighting strategies for office buildings in two climatic zones of Ukraine (Kyiv and Odesa); to propose the method for daylight analysis (Daylight factor and Daylight glare probability) by using parametric modelling; to investigate the results of computer simulations and multi-purpose optimization of window-to-wall ratio (WWR), window proportions and shading device sizes; to define façade design options based on optimal design variables (south window width & height, shading device depth); to compare the façade design options for Kyiv and Odesa.

Main part. According to Coppen-Geiger climatic maps [6], Ukraine, comprises six climate



a) Climatic map of Ukraine and the world 1980-2016. [6];

b) Climatic zones of Ukraine. [7];

	Type of building envelope	Value R q min/m² · K/W For climatic zones:	
		I	II
1	External walls	4,00	3,50
2	External roofs, contacting with external air	7,00	6,00
3	External roofs, of heated technical floors, attics, unheated attics slabs	6,00	5,50
4	Slabs contacting with external air and above unheated basements	5,00	4,00
5	Glazing	0,90	0,70
6	Roof windows	0,80	0,70
7	External doors	0,70	0,60

c) The required minimum value of the of the heat transfer resistance for building envelope (residential and public buildings) ***R q min***. [7];

Premises	Plane (H-horizontal, V-vertical) regulation of lighting and DF, height of the plane above the floor	Category and subcategory of visual work	Artificial lighting					Daylighting		Combined lighting	
			Illuminance of work surface, lux		cylindrical Illuminance, lux	discomfort value, M not more than	pulsation value, K_3,% not more than	DF, %		DF, %	
			combined Illuminance	general Illuminance				average DF d average	min DF d min	average DF c average	min DF c min
1	2	3	4	5	6	7	8	9	10	11	12
Office buildings											
1. Offices, premises for visitors	H-0.8	B-1	400/200	300	–	40	10	3,0	1,0	1,8	0,6
2. Design rooms, drafting bureau	H-0.8	A-1	600/400	500	–	40	10	4,0	1,5	2,4	0,9

d) Required values of lighting for civil buildings. Table D.1. [8]

Fig. 1. Climate of Ukraine and requirements for energy efficiency of building envelope and daylighting: *a* – climatic map of Ukraine and the world 1980–2016. [6]; *b* – climatic zones of Ukraine. [7]; *c* – required minimum value of the heat transfer resistance for building envelope (residential and public buildings) R q min. [7]; *d* – required values of lighting for civil buildings. Table D. 1. [8]

types, in addition to it, it consists of two climatic zones, hence the requirements regarding the minimum value of the heat transfer resistance for building envelope (R q min) are different for each zone [7]. Therefore, author analyses two different climatic zones of Ukraine with two cities respectively – Kyiv (zone I) and Odesa (zone II). Furthermore, according to table D.1. Normative values of lighting for civil buildings (DBN V.2.5-28:2018 "Natural and artificial lighting". Appendix D) [8], the average Daylight Factor (DF) for office premises is – 3.0%, and the minimum DF is – 1.0% (Fig. 1). State building codes of Ukraine do not regulate the value of glare for daylight, that is why Daylight Glare Probability (DGP) was taken as a benchmark. As per the study [9], DGP is an indication of the percentage of people who would be disturbed by glare. It will be generated as a hemispherical fish-eye image, using the eye and focus positions. The value will be classified as one of the following four categories: imperceptible – less than 35%; perceptible – 35%–40%; disturbing – 40%–45%; intolerable – greater than 45%.

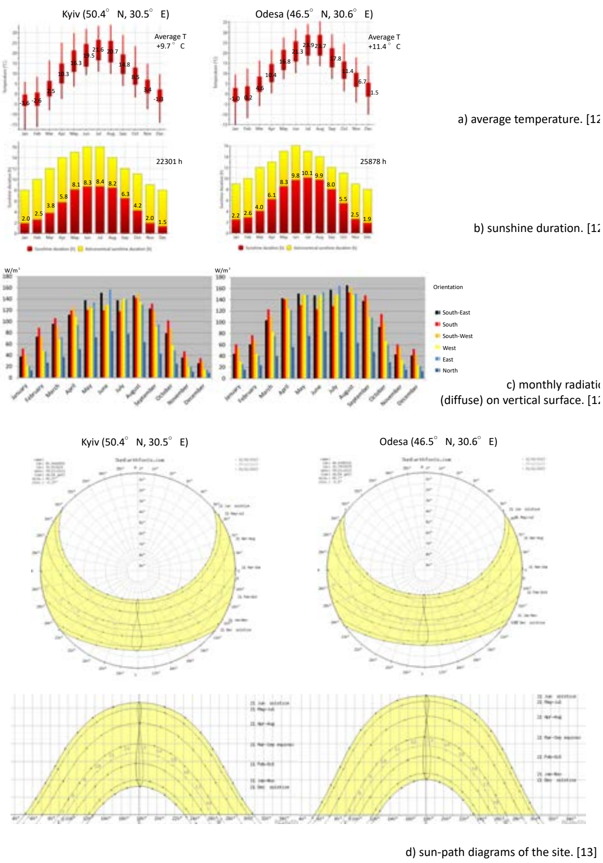


Fig. 2. Weather data for Kyiv and Odesa, Ukraine: *a* – average temperature. *2024.* [12]; *b* – sunshine duration. *2024.* [12]; *c* – monthly radiation (diffuse) on vertical surface. *2024.* [12]; *d* – sun-path diagrams of the site. *2024.* [13]

The author takes into account the following weather data: average monthly temperature, sunshine duration, monthly solar radiation on vertical surface, sun-path diagrams of the site, etc. The main weather data was extracted from Meteonorm 8, Ladybug Tools software and online resource SunEarthTools (Fig. 2).

As specified by the air temperature chart, the average annual temperature in Kyiv is +9.7 C°, which indicates the dominance of indoor heating. As per the graph of solar irradiation on the vertical plane, the highest indicators are on southern orientation (1184 W/m^2), southeast (1153 W/m^2) and southwest (1143 W/m^2), while eastern (972 W/m^2) and western (962 W/m^2) orientations show lower values; and the northern orientation has the lowest figure (513 W/m^2). West, south-west, east and south-east orientations mainly show the highest indicators in the warm period (May–August), it can cause overheating of the interior spaces due to solar heat gains. However, the southern orientation shows the highest values in the cold period (September-April), which can be useful for passive heating. According to the sun path diagrams, in Kyiv in winter (January 21, noon), the angle of the sun above the horizon is quite small – 19°, but in the summer (June 21,

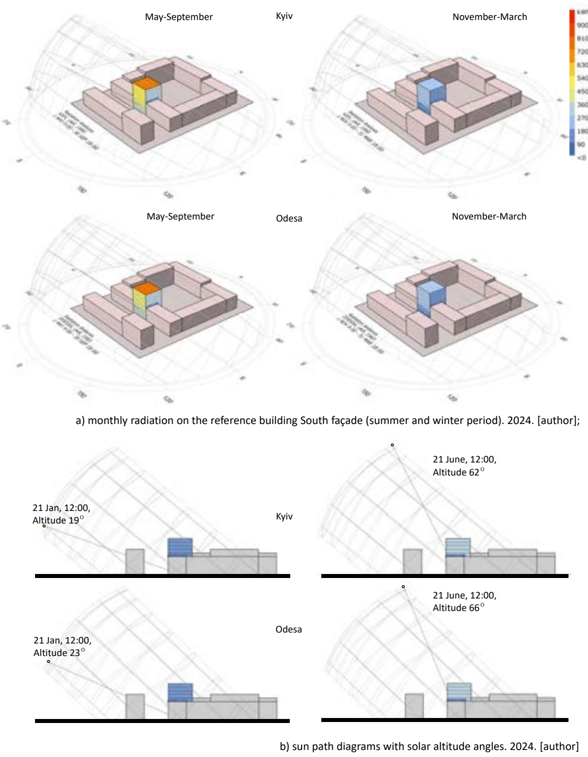


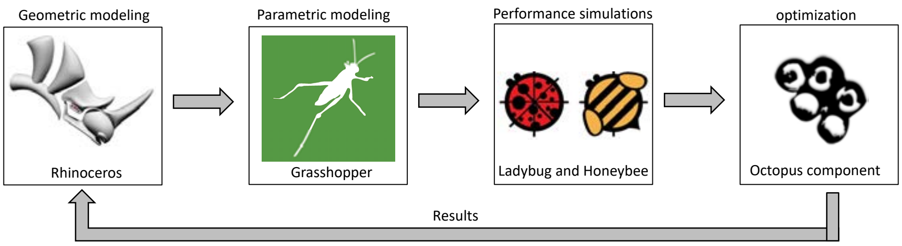
Fig. 3. Environmental characteristics of the site: *a* – monthly radiation on the reference building South façade (summer and winter period). *2024.* [Source: Author]; *b* – sun path diagrams with solar altitude angles. *2024.* [Source: Author]

noon) it is much higher – 62°, and the off-season period (March 22 and September 22, noon) it is – 40° and 39°, respectively.

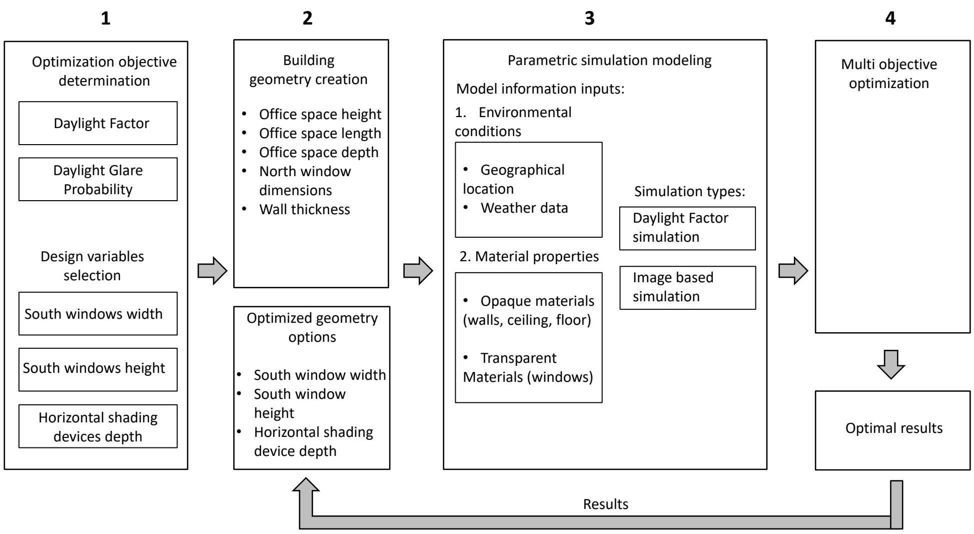
As for the air temperature of Odesa, the average annual temperature is +11.4 C°, which also suggests the dominance of indoor heating. As for the solar irradiation on the vertical plane, the highest values are on southern orientation (1315 W/m²), south-east (1289 W/m²) and southwest (1312 W/m²), while eastern (1097 W/m²) and western (1111 W/m²) orientations have lower values; and the northern orientation has the lowest value (548 W/m²). West, south-west, east and south-east orientations mainly show the highest indicators in the warm period (May-August), it can cause overheating of the interior spaces due to solar heat gains. However, the southern orientation shows the highest values in the cold period (September-April), which can be useful for passive heating. For Odesa, in winter (January 21, noon) the angle of the sun above the horizon is 23°, but in summer (June 21, noon) – 66°, and in the off-season (March 22 and September 22, noon) – 44° and 43°, respectively (Fig. 3).

The methodology of quantitative research is used for the study. Computer simulations using computer-aided design software (CAD) – Rhinoceros, visual programming language – Grasshopper, plugins – Ladybug Tools & Honeybee, and Octopus are applied (Fig. 4, *a*).

The simulation-based multi-objective optimization method consists of 4 steps: optimization objective determination & decision variable selection; building geometry creation; parametric simulation modelling; and multi objective optimization method (Fig. 4, *b*). At the first, the optimization objectives are determined (DF and DGP values) according to climate conditions and functional requirements. Then, the design variables are selected (south window width, south window height, horizontal shading device depth). Secondly, geometric model is created with fixed



a) Software tools used in the parametric simulation modelling and multi objective optimization. 2024. [author];



b) Simulation-based multi objective optimization process. 2024. [author]

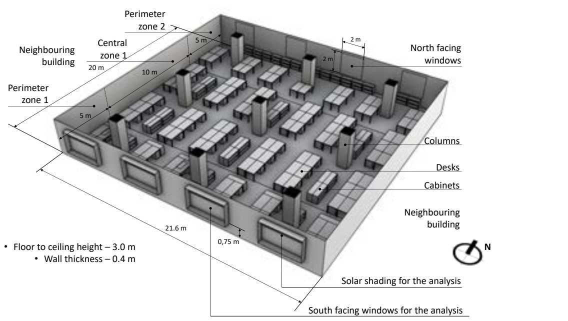
Fig. 4. Simulation-based multi objective optimization process: *a* – software tools used in the parametric simulation modelling and multi objective optimization. *2024.* [Source: Author]; *b* – simulation-based multi objective optimization process. *2024.* [Source: Author]

parameters of building length, width and height, as well as north windows sizes. Thirdly, parametric simulation model is used, which connects geometry with: environmental conditions (geographical location & weather data); material information (opaque & transparent materials), and perform two types of simulations (DF & DGP). Lastly, the multi-objective evolutionary algorithm is used to explore optimal results coupled with the parametric simulation model.

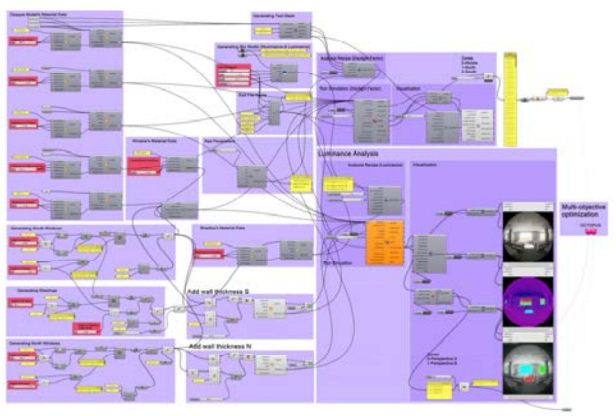
As for the building environmental conditions, two locations in Ukraine (Kyiv and Odesa) with whether data from EnergyPlus database are analysed. Two dates of the analysis are checked (equinoxes): March 22, 12:00 and September 22, 12:00.

Respecting the material properties, reflectance value of the floor is 0.2, ceiling – 0.7, walls – 0.5, columns & furniture – 0.5, surroundings – 0.2, shading – 0.8. Window transmittance is set to 0.7.

Regarding building geometry, the length of the office space is 21.6 m, the width – 20.0 m and the height – 3.0 m. Windows are set in the south and north facades of the building only, there are 4 windows on the south side and 4 on the north. North windows have fixed dimensions 2.0 m × 2.0 m.



a) 3D view of the reference building floorplan. 2024. [author];



b) Simulation-based optimisation model. 2024. [author]

Fig. 5. Geometry of the reference building and parametric model: *a* – 3D view of the reference building floorplan. *2024.* [Source: Author]; *b* – simulation-based optimisation model. *2024.* [Source: Author]

Width of the external walls is 0.4 m. The window-sill height is fixed to 0.8 m. Horizontal shading devices are set for south windows, shading device type – single horizontal canopy (Fig. 5, *a*).

Concerning the design variables, the south window width & height and shading device depth are selected. In the optimization process, the window dimensions and shading device depth were generated automatically on the basis of the decision variables. The values of south window width ranges from 0.5 to 5.4 m and south window height – from 0.5 to 2.1 m. As for the shading device depth, it ranges from 0.0 to 1.5 m and set on the height of 2.1 m.

The parametric simulation is developed to combine the design information and environmental conditions together, and generate the simulation model automatically. Rhinoceros and Grasshopper were used to develop the parametric

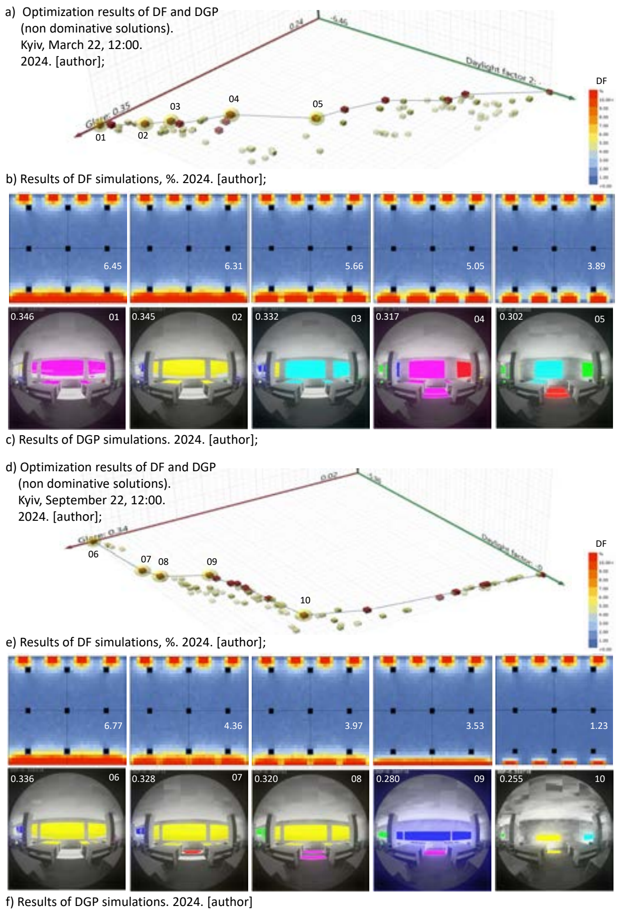


Fig. 6. Daylight Factor (DF) and value of glare (DGP) simulation results for Kyiv: *a* – optimization results of DF and DGP (non dominative solutions). Kyiv, March 22, 12:00; *b* – results of DF simulations, %; *c* – results of DGP simulations; *d* – optimization results of DF and DGP (non dominative solutions). Kyiv, September 22, 12:00; *e* – results of DF simulations, %; *f* – results of DGP simulations. *2024.* [Source: Author]

simulation model. After that, Ladybug Tools & Honeybee plug-ins were used to couple with Grasshopper. Octopus, an evolutionary optimization tool, was used to perform the multi-objective optimization (Fig. 5, *b*), it introduces the Pareto-Principle for Multiple Goals.

Overall, the concept of using evolutionary algorithms for multi-objective optimizations emerged gradually over time, with contributions from various researchers. Early works in the 1990s laid the foundation, and since then, the field developed. The book "Multi-Objective Optimization Using Evolutionary Algorithms", by Kalyanmoy Deb, describes the method in detail [10], this author himself has made a significant contribution to the development of the method.

According to the study [11], during the optimization process, the initial design solutions are generated by evolutionary algorithms and the performances of design solutions are evaluated in the parametric simulation model; the evaluation results are the feedback to the evolutionary algorithm, which supports the generation of design solutions in decision making, and the evolutionary algorithm determines whether the performance of the solutions fits the objectives. If so, the design solutions are the output, and if not, the evolutionary algorithm drives the parametric simulation model to generate new design solutions. After going through a series of iteration optimizations, a Pareto optimal solution set is finally generated. Eventually, the optimal design scheme can be selected from the Pareto solutions according to the preferences of the designers.

Two objectives for optimisation by Octopus were set: to achieve DF for office premises – 3.0% or higher and to achieve the value of DGP – not higher than 0.35. Following parameters were set for the optimization algorithm: Elitism – 0.5; Mutation probability – 0.2; Mutation rate – 0.9; Crossover rate – 0.8; Population size – 10.

The multi-objective optimization consisted of the calculation of 14 generations, approximately 720 solutions were evaluated, including

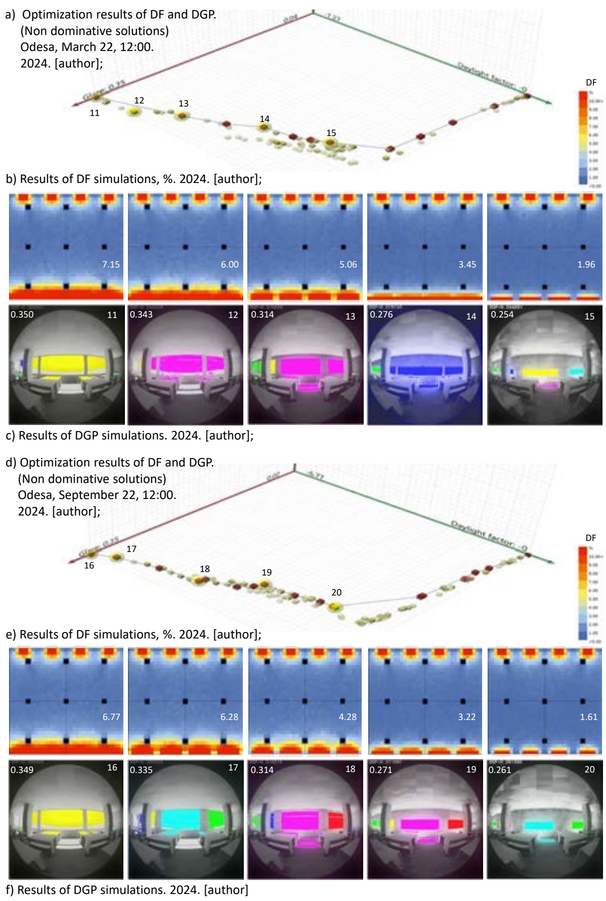


Fig. 7. Daylight Factor (DF) and value of glare (DGP) simulation results for Odesa: *a* – optimization results of DF and DGP (non dominative solutions). Odesa, March 22, 12:00; *b* – results of DF simulations, %; *c* – results of DGP simulations; *d* – optimization results of DF and DGP (non dominative solutions). Odesa, September 22, 12:00; *e* – results of DF simulations, %; *f* – results of DGP simulations. *2024.* [Source: Author]

Kyiv	Case	DF	DGP	width of south window	height of south window	depth of south shading
March 22, 12:00	1	6.459722	0.34623	4.8	1.9	0.1
	2	6.317743	0.345461	4.7	1.9	0.1
	3	5.662187	0.33215	4.4	1.8	0.1
	4	5.054861	0.317494	3.9	1.8	0.1
	5	3.896875	0.302502	3.0	1.8	0.1
September 22, 12:00	6	6.77566	0.349817	4.9	2.1	0.2
	7	4.364653	0.328715	4.9	1.7	0.6
	8	3.975035	0.320782	4.8	1.6	0.6
	9	3.539965	0.280719	5.2	0.9	0.0
	10	1.238438	0.255718	2.5	0.6	0.7

Odesa	Case	DF	DGP	width of south window	height of south window	depth of south shading
March 22, 12:00	11	7.157326	0.350301	5	2.1	0.1
	12	6.009861	0.343426	4.9	2.1	0.4
	13	5.062674	0.314538	4.5	1.7	0.2
	14	3.459306	0.276752	5.1	0.9	0.0
	15	1.961736	0.254031	3.9	0.6	0.2
September 22, 12:00	16	6.77566	0.349817	4.9	2.1	0.2
	17	6.281354	0.335025	4.3	2.1	0.1
	18	4.280243	0.314016	4.2	1.9	0.6
	19	3.224097	0.271697	4.3	1	0.0
	20	1.610243	0.261392	3.1	0.8	0.5

* yellow – acceptable cases, grey – not acceptable cases

a) Optimization results of DF and DGP with corresponding design variables. 2024. [author];

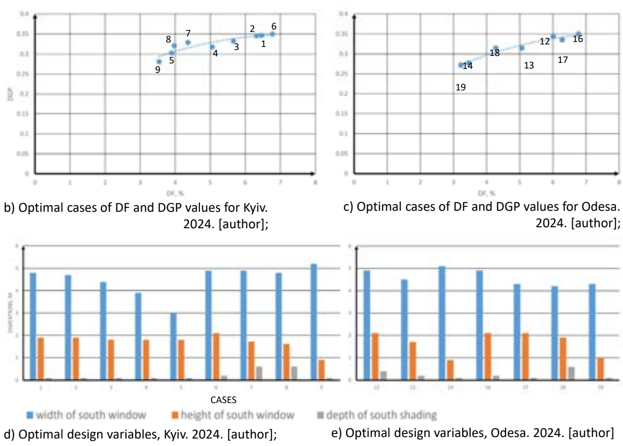


Fig. 8. Optimal values of DF and DGP and optimal design variables: *a* – optimization results of DF and DGP with corresponding design variables; *b* – optimal cases of DF and DGP values for Kyiv; *c* – optimal cases of DF and DGP values for Odesa; *d* – Optimal design variables, Kyiv; *e* – Optimal design variables, Odesa. *2024.* [Source: Author]

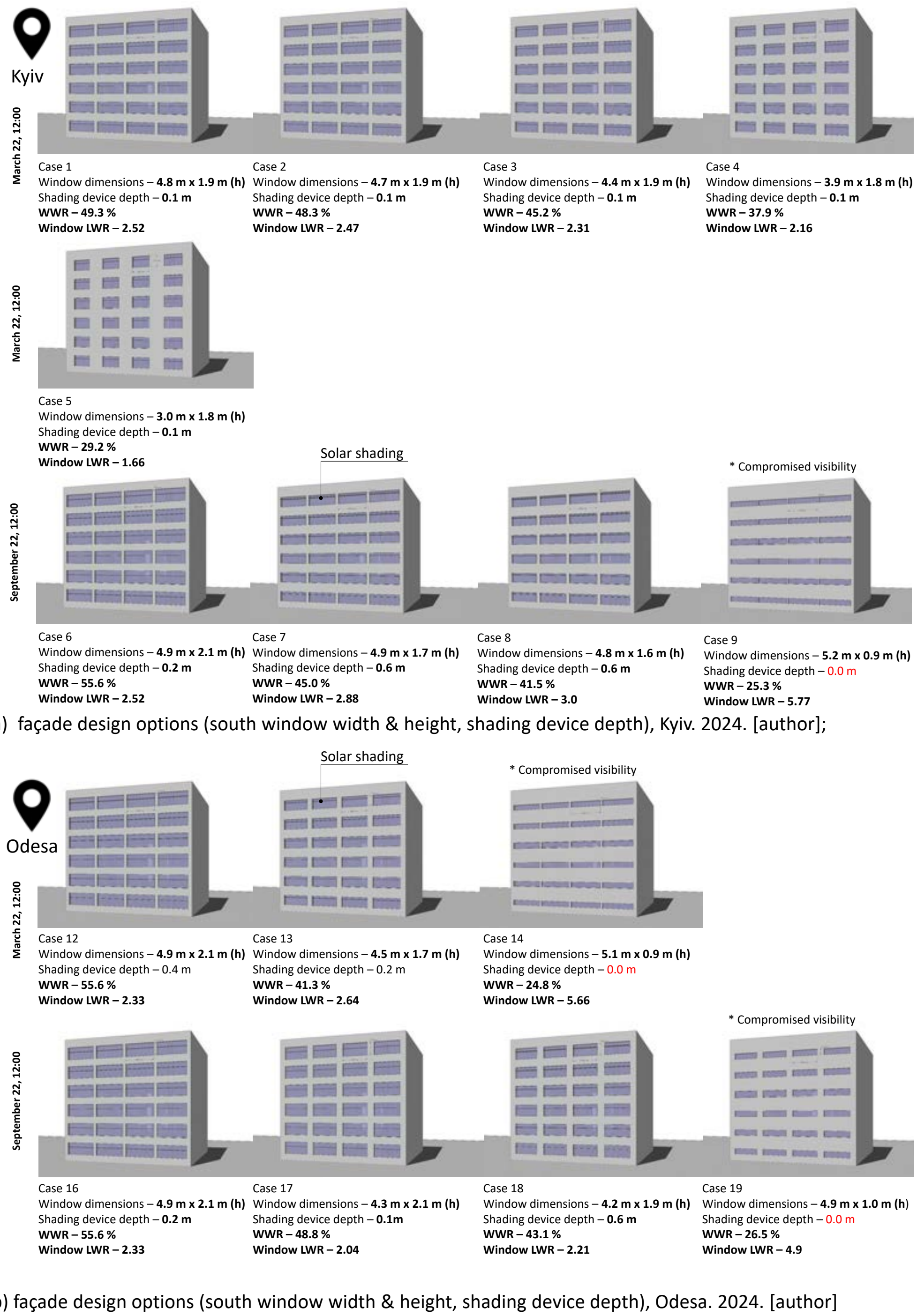


Fig. 9. Façade design options based on optimal design variables: *a* – façade design options (south window width & height, shading device depth), Kyiv; *b* – façade design options (south window width & height, shading device depth), Odesa. *2024*. [Source: Author]

60 non-dominated solutions, which formed a Pareto-optimal solution set expressed by 2D trend-line. In the two-dimension coordinate system, the two axes represent values of DA and DGP. The red-coloured boxes represent 20 solutions with optimal values of DA and DGP (Fig. 6, 7). After verification, 4 solutions were excluded due to the failure to achieve the objectives, so the rest 16 solutions were taken for further analysis and comparison. Solutions (cases 1–9, 12–14, 16–19) demonstrate the results of DF values ranging from 3.22 to 6.77 % and GDP values ranging from 0.27 to 0.34%.

Regarding the results of the design variables, window width ranges from 3.0 to 5.2 m, window height – 0.9 to 2.1 m and shading device depth – 0.0 to 0.6 m (Fig. 8).

Main conclusions and prospects of using the research. According to the simulated façade options based on the optimal design variables (Fig. 9), all cases have windows with horizontal proportions, where length-to-width ratio (LWR) ranges from 1.66 (case 5) to 5.77 (case 9). It suggests the conclusion that windows with horizontal proportions are more suitable in the achievement of optimal DF and GDP. However, cases 9, 14 & 19 have low widow heights of 0.9, 09 & 1.0 m respectively, it can potentially negatively contribute to the window view factor (not analysed in this study). That is why author proposes to exclude these cases from the positive results and to consider only cases: 1–8, 12–13, 16–18. As a result, author recommends following optimal window LWR ratios: from 1.66 (case 5) to 3.0 (case 8).

Concerning the results of window-to-wall ratio (Fig. 9), it ranges from 29.2 % (case 5) to 55.6% (cases 6, 12, 16). It suggests that these values of WWR are more suitable in order to achieve optimal values DF and GDP. Lower values of WWR may cause insufficient DF values but higher values of WWR may cause too high DGP values. Despite that, higher values of WWR can also be applied in case of different shading device design that can reduce DGP values (can be analysed in the further studies).

Respecting the shading device depth, various combinations of window sizes and shading device depth can be applied, ranging from 0.1 to 0.6 m. Most of the results show the minimal shading device depth of 0.1–0.2 m. of However, the correlation between higher values of WWR and larger shading device depth can be observed.

As for the differences between office building façade design for Kyiv and Odesa, informed by optimal values DF and GDP, the author observes similar trends regarding WWR, window LWR and shading device depth. In order to observe larger variations in façade design, further analyses have to be conducted, for example, solar radiation and energy consumption should be considered.

To some up, the author proposed efficient, accurate and academically proven method for daylight optimization of the office building premise to achieve optimal values of DF and DGP by means of parametric modelling and multi-objective optimization. Findings revealed optimal values of WWR, window LWR and shading device depth. However, conduction of spatial Daylight Autonomy (sDA) analysis instead of DF analysis could have led to more accurate results, as it is required by LEED certification. sDA assesses whether a space receives sufficient daylight on a work plane during standard operating hours on an annual basis. The target is 300 lux for 50% of the occupied period. Further studies can be done by multi-objective daylight optimization including sDA analysis.

References

1. Nguyen, A., Reiter, S., & Rigo P. (2013). A review on simulation-based optimization methods applied to building performance analysis. *Applied Energy,* 113, 1043–1058 [in English].
2. Eltaweel, A., & Su, Y. (2017). Parametric design and daylighting: A literature review. *Renewable and Sustainable Energy Reviews*, 73, 1086–1103 [in English].
3. Hakimazari, M., Baghoolizadeh, M., Sajadi, M., Kheiri, P., Moghaddam, Y., Rostamzadeh-Renani, M., Rostamzadeh-Renani, R., Hamooleh, M. (2024). Multi-objective optimization of daylight illuminance indicators and energy usage intensity for office space in Tehran by genetic algorithm. *Energy Reports*, 11, 3283–3306 [in English].
4. Ziaee, N., & Vakilinezhad, R. (2022). Multi-objective optimization of daylight performance and thermal comfort in classrooms with light-shelves: Case studies in Tehran and Sari, Iran. *Energy & Buildings,* 254 [in English].
5. Wang, J., Mae M., Taniguchi, K., Cheng Y., Yagi, S., Saito, K. (2020). Multi-phase framework for optimization of thermal and daylight performance of residential buildings based on the combination of ventilation and window design, *Journal of Asian Architecture and Building Engineering,* 20, 785–805 [in English].
6. Beck, H., Zimmermann, N., McVicar, T., Vergopolan, N., Berg, A., Wood, E. (2018). Present and future Кцppen-Geiger climate classification maps at 1-km resolution. *Scientific Data,* (5) [in English].
7. DBN V.2.6-31:2021. *Teplova izolaciya ta energoefektyvnist budivel* [*Thermal insulation and energy efficiency of buildings*]. (2022). Minregion Ukrainy [in Ukrainian].
8. DBN V.2.5-28:2018. *Pryrodne i stuchne osvitlenna* [*Natural and artificial lighting*]. (2018). Minregion Ukrainy [in Ukrainian].
9. Wienold, J., & Christoffersen, J. (2006). Evaluation methods and development of a new glare prediction model for daylight environments with the use of CCD cameras. *Energy & Buildings,* 38, 743–757 [in English].
10. Deb, K. (2011). Multi-Objective Optimization Using Evolutionary Algorithms. Wiley & Sons [in English].
11. Han, Y., Yu, H., Sun, C. (2017). Simulation-based multi-objective optimization of timber-glass residential buildings in severe cold regions. *Sustainability*, 9 (12) [in English].

12. Meteonorm Version 8. (n. d.). *Meteonorm*. Retrieved from https://meteonorm.com/en/meteonorm-version-8 [in English].
13. SunEarthTools.com: [Website]. (n.d.). Retrieved from https://www.sunearthtools.com/ [in English].

Список використаних джерел

1. Nguyen A., Reiter S., Rigo P. A review on simulation-based optimization methods applied to building performance analysis. *Applied Energy*. 2013. № 113. P. 1043–1058.
2. Eltaweel A., Su Y. Parametric design and daylighting: A literature review. *Renewable and Sustainable Energy Reviews*. 2017. № 73. P. 1086–1103.
3. Multi-objective optimization of daylight illuminance indicators and energy usage intensity for office space in Tehran by genetic algorithm / Hakimazari M., et al. *Energy Reports*. 2024. № 11. P. 3283–3306.
4. Ziaee N., Vakilinezhad R. Multi-objective optimization of daylight performance and thermal comfort in classrooms with light-shelves: Case studies in Tehran and Sari, Iran. *Energy & Buildings*. 2022. № 254.
5. Multi-phase framework for optimization of thermal and daylight performance of residential buildings based on the combination of ventilation and window design / Wang J., et al. *Journal of Asian Architecture and Building Engineering*. 2020. № 20. P. 785–805.
6. Present and future Kцppen-Geiger climate classification maps at 1-km resolution / Beck H. E., et al. *Scientific Data*. 2018. № 5.
7. ДБН В.2.6-31:2021 «Теплова ізоляція та енергоефективність будівель». Київ : Мінрегіон України, 2022.
8. ДБН В.2.5-28:2018 «Природне і штучне освітлення». Київ : Мінрегіон України, 2018.
9. Wienold J., Christoffersen J. Evaluation methods and development of a new glare prediction model for daylight environments with the use of CCD cameras. *Energy & Buildings*. 2006. №. 38. P. 743–757.
10. Deb K. Multi-Objective Optimization Using Evolutionary Algorithms. Wiley & Sons, 2011. 497 p.
11. Han Y., et al. Simulation-based multi-objective optimization of timber-glass residential buildings in severe cold regions. *Sustainability*. 2017. №. 9.
12. Meteonorm Version 8. *Meteonorm*. URL: https://meteonorm.com/en/meteonorm-version-8 (дата звернення: 29.11.24).
13. SunEarthTools.com: [сайт]. URL: https://www.sunearthtools.com/ (дата звернення: 29.11.24).

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