Serrated and Finned Glazed Facades' Impact on the User's Visual Comfort

Marcin Brzezicki(✉)

Faculty of Architecture, Wroclaw University of Science and Technology, Prusa 53/55, 50-317 Wroclaw, Poland
marcin.brzezicki@pwr.edu.pl

Abstract. The spatial modification of the glazed façade is a part of the overall façade's creation scheme. Despite the important aesthetical function, serrated and finned facades are also seen as an important tool of daylight management in buildings, especially when façade is partially glazed and partially opaque. This allows guiding scattered daylight deep into the room, simultaneously reducing the impact of direct solar radiation. The presented paper analyses the impact of different geometries of half-glazed (with shading elements) finned and serrated facades on the user's visual comfort (daylight factor and summer solar exposure). The analyzed façades are of different geometry and south-facing located in 50° latitude in Wroclaw. The calculations were done using the De Luminæ software (DL-Light platform) with SketchUp. The analysis allowed to identify – for different typologies of serrated façade – the risks of glare and overheating and the potential need for sunlight protection. The software also helps to the position shading surfaces to control the potential glare.

Keywords: Facade design · Serrated façade · Daylight comfort · Radiance

1 Introduction

Serrated and finned building envelopes are a very eye-catching element of contemporary architecture. Finned façade is defined as a façade with external fins, located perpendicularly to the façade plane. Serrated façade in plan resembles the edges of a serrated blade, hence the name. Serrated and finned facades substantially influence the building's tectonics understood as the relationship between the structural and the art form. They also have a major impact both on visual appeal and on building physics – the increased surface of heat exchange compared to flat facades and decreased solar gains if properly designed.

This paper concentrates on the issues daylight optimization in office buildings, that feature finned or serrated glass facades. As fully-glazed façades influence the level of daylight in the building in a relatively small manner, therefore partially glazed and partially opaque façade were analyzed. The reason for this was the fact that the opaque part of the envelope serves as a shading device, blocks the sunlight and influences the room's internal daylight level. As use "of solar shading to control solar radiation through the glazed openings is usually essential in office buildings in order to obtain visual comfort, thermal comfort as well as a decreased energy use for cooling" [1]

J. Charytonowicz and C. Falcão (Eds.): AHFE 2019, AISC 966, pp. 179–187, 2020.
https://doi.org/10.1007/978-3-030-20151-7_17

The presented paper features an analysis showing how opaque perpendicular fins and partial façade's serration (façade partially gazed and partially opaque) can influence daylight level and user's visual comfort in the office room. Additionally, if the opaque part of the serrated envelope is correctly placed (e.g. transparent panels might face North, opaque – South) it allows avoidance of direct solar gain [2]. E.g. during the analysis of 25 Ropemaker Place building in London (arch. Arup Associates, 2012) "angled window treatment is stated to reduce solar heat gain by 27% from an equivalent flat façade" [3] because of the proper arrangement of the opaque and glazed parts of the serrated oriels. The opaque flanges of serrated façade work like "static angular selective shading systems" [4] that blocks direct sunlight and admit daylight within a specific range of incident solar angles.

The overmentioned design strategy is called "solar avoidance" and will be discussed herein detail with reference to finned and serrated facades, as the discomfort glare remains one of the most comfort affecting issues in the contemporary full-glazed glazed façade, also in case of shading elements obstructing the view [5].

1.1 Glare and Daylight Optimization

User's visual comfort in an office building depends on two main features: the level of illumination, and the daylight uniformity. As human eye takes a certain amount of time to adapt to new lighting conditions [6] frequent changes of the illumination level can cause discomfort, distraction, glare, and – in some circumstances – could be even dangerous. Perry defines discomfort glare as "related to the presence in the visual field of excess luminance differences" [7]. Glare is a frequent optical/visual phenomenon in case of fully glazed glass envelopes. Excessive sunlight in the room creates areas of excess luminance, that greatly influence the user's visual comfort. Many different thresholds of the glare level have been recently defined (expressed in cd/m^2) that are presented in a paper by Suk et al. [8]. Therefore the glare experienced by the user is assumed to occur where the patches of high luminance are formed on a working plane – basically in the areas of high solar exposure.

2 Methodology

Studied room had dimensions of 12.0 × 6.0 m with a height/clearance of 4.0 m (72 sq. m. area). The longer side of the room featured a "floor to ceiling" glazed façade protected by opaque fins or serrated in different rhythms. The façade was facing directly South, and all the calculations were carried out for Wroclaw, located in Poland in Central Europe at the 52° north latitude (including weather data).

For the analysis of visual comfort, three values were measured: DF – daylight factor in %, LU – daylight uniformity (for evenly overcast sky) and the average value of SSE – summer solar exposure (for the appropriate climate data for Wroclaw). The value of SSE was given in hours per day calculated as the average between 21st of June and – 22nd of September in time steps of 60 min. The DF and LU parameters allowed for the estimation of the diffused daylight uniformity, while the SSE allowed for the estimation of the influence of direct solar radiation. All the values were measured on the working surface 0.8 m above the floor level. The diagram of the simulation setup is given in Fig. 1.

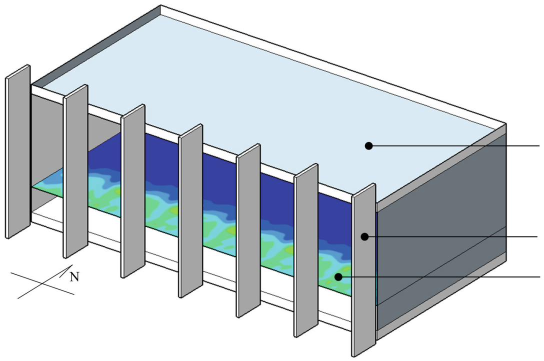

Fig. 1. The layout of computer simulation setup. Studied room had dimensions of 12 × 6 m with a height/clearance of 4.0 m.

All the calculations were done using the De Luminæ software (DL-Light platform) with SketchUp used as 3D-modeling software. The DF was calculated at 72 points in the room (1 sensor per sq. m.) while the SSE was calculated at 7200 points (100 sensors per sq. m.). All the data were imported into the spreadsheet software (Microsoft Excell 2013) and subsequently studied and compared. The data were also visualized in a form of images representing DF – in grayscale – and SSE in false color. The scale is accordingly given at the presented figures and diagrams.

3 Simulated Facade Typology

Two types of facades were studied: *(i)* with opaque fins located perpendicularly to the plane of the façade, and *(ii)* serrated façade that featured one flange opaque and one flange transparent (see Fig. 2). Opaque fins were of different depth (1 and 0.5 m), and located at different spacing along the façade (every 1 or 2 m), in total 4 variations were simulated. Serrated façade was studied in 9 variations: with equal and unequal proportions of opaque and transparent part – further called 1:1, 1:2 and 2:1 (opaque: transparent ratio) – and at different serration angles 45-, 30- and 15° for the first element located on the left. This allowed for a comprehensive study of the serration geometry to be carried out.

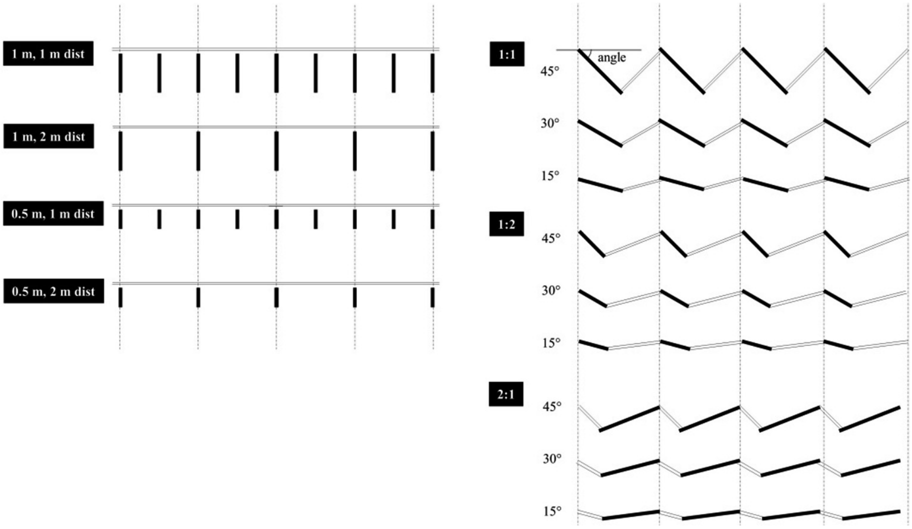

Fig. 2. Diagrams illustrating all studied facades variants. *(Finned shading)* devices on the left and *(serrated façade)* on the right.

4 Results

4.1 Unprotected Facade

For the purpose of comparative analysis of the daylight distribution in the studied room DF, LU, and SSE were calculated for unprotected glazed floor-to-ceiling façade. As expected all results DE, LU and SSE were very high in value. Maximum DF value reached 50.11%, while medium value was 21.15%. LU value was very low – 0.27, meaning the unfavorable high differences in the luminance were present in the room. SSE reached a very high value of 4h43m of solar exposure.

4.2 Finned Facade

Simulation of the finned shading devices produced much lower DF values (from 22% to 54% of the original value of 50.11%) in comparison with the unprotected facade. The lowest DF value was recorded for the fins with the largest depth (1 m) and with the smallest spacing (1 m) – 22.61%; while the largest was recorded for the smallest fins (0.5 m), with the largest spacing (2 m). Those results were obvious and expected. Surprisingly, the LU was very similar in every variant at an approximate factor of 0.28, not significantly different from an unprotected façade.

Results of SE simulation were similar to those of DF. The lowest SSE values were recorded for the fins with the largest depth (1 m) and with the smallest spacing (1 m). The difference between the longest SE time of 3h21 h/day and the shortest SE time of 1h47 h/day was 47%. Images representing the graphical results are given below in Fig. 3.

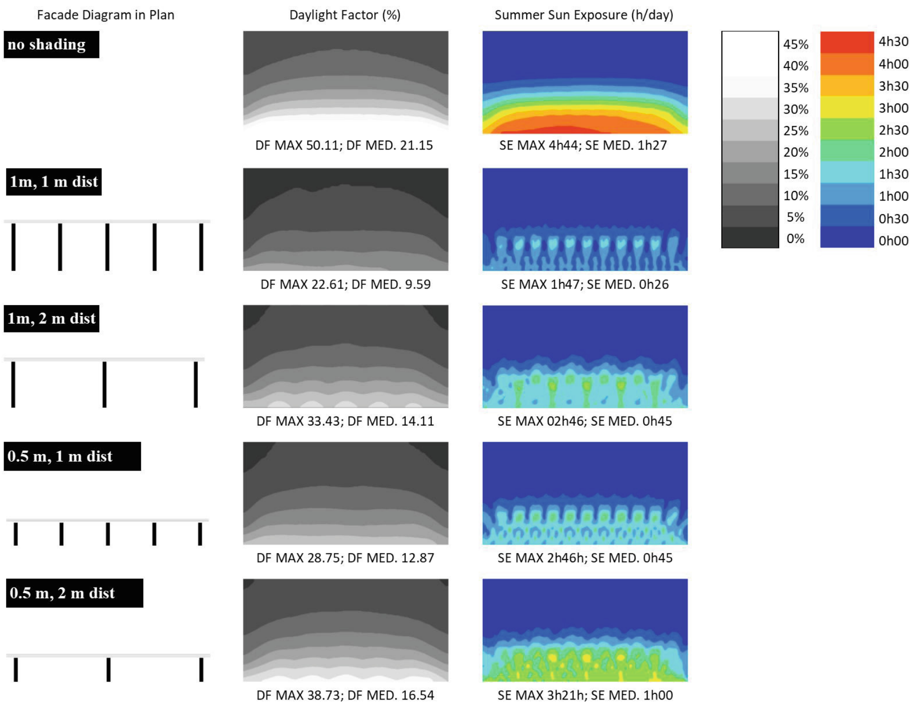

Fig. 3. Diagrams with images generated by the simulation of DF and SSE results for finned shading devices. Façade diagram on the left, DF in the middle, and SSE in the right. The scale is given accordingly.

4.3 Serrated Facades

Contrary to the expectation serrated façade turned out to be less effective in the DF level mitigation. The worst case scenario featured a maximum value of 39.29% that was recorded in the variant with of approx. 60% of façade glazing (variant 2:1, 15°). However, the mean level of DF was almost 30% lower, than in the case of the finned shading devices. Despite this, LU was lower, dropping to the lowest value of 0.16 (compared with the mean value of 0.28 in case of finned shading devices).

The overall performance of serrated façade in SSE turned out to be almost the same as in the case of the façade with finned shading, having the mean value for all cases 2h48 h/day in comparison to 2h40 h/day for finned facades. Images representing the graphical results are given below in Figs. 4 and 5.

5 Discussion

A full comparison of DF and SSE level is limited because of the different geometry of both typologies, however, some general conclusions became evident. The analysis shows overall obvious dependence between the proportion of glazing in the façade

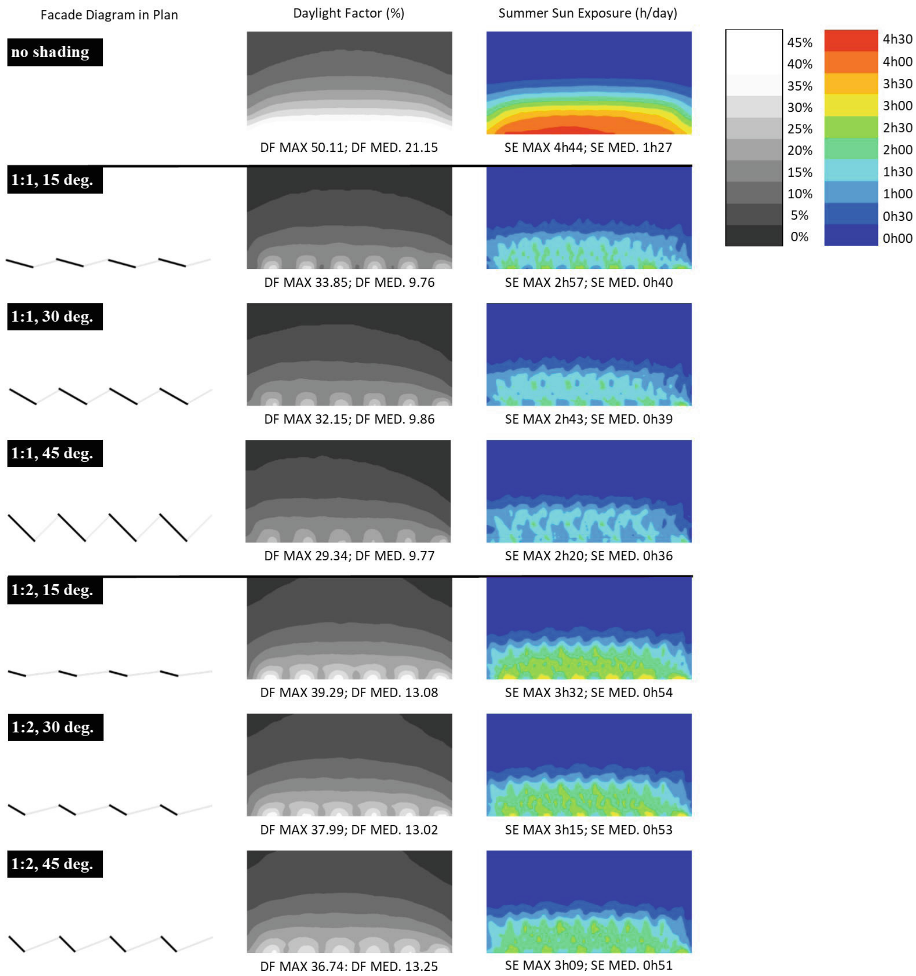

Fig. 4. Diagrams with images generated by the simulation of DF and SSE results for serrated façade variants for series 1:1 and 1:2. Façade diagram on the left, DF in the middle, and SSE in the right. The scale is given accordingly.

(50%, 33%, and 66%) and DF and SSE levels. The more the façade is glazed, the more diffused and direct light is admitted inside the room, increasing the level of illumination. This is true in case of both studied façade typologies for facades oriented directly to the South.

5.1 Scattered Daylight

Fined shading devices seem to be more effective in the mitigation of maximum level of DF the room (mean for all finned cases is 30.88% vs. 32.25% for serrated ones), while much less effective in the mitigation of medium DF (13.28% vs. 10.98%). The most

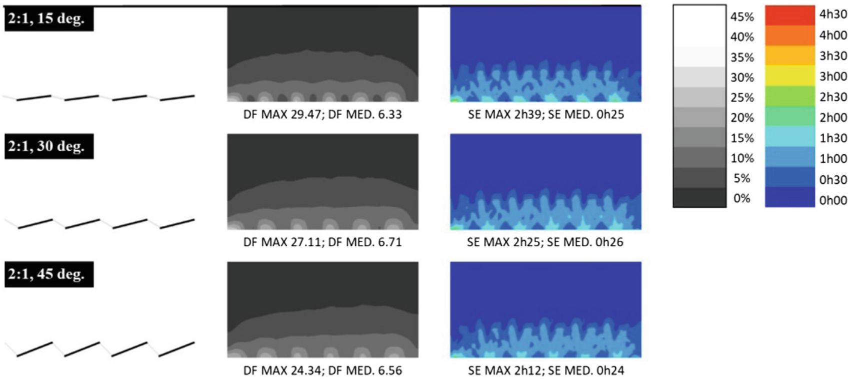

Fig. 5. Diagrams with images generated by the simulation of DF and SSE results for serrated façade variants for series 2:1. Façade diagram on the left, DF in the middle, and SSE in the right. The scale is given accordingly.

surprising were the results of LU in analyzed cases. Serrated typologies turned out to be less effective in the equalization of daylight distribution level ranging from 0.16 to 0.28 in comparison to finned shading devices that featured the mean level of LU of approx. 0.28, regardless of the fin depth and spacing. It was also found, that finned shading devices do lower the DF in the room proportionally but do not substantially affect LU, as it was seen by the comparison of unprotected façade with the façade with finned shading devices (the mean and minimum values remain of very similar proportions – see Fig. 6).

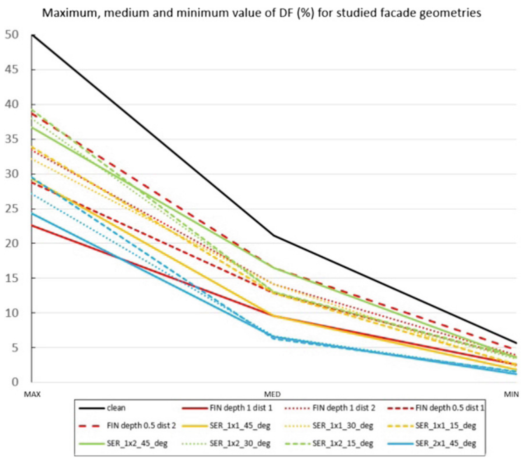

Fig. 6. Graph showing the comparison of maximum, medium and minimum values of DF (%) for all studied geometries. The test series have been discriminated by color.

5.2 Solar Exposure

SSE for both typologies proved to be largely dependent on the fin depth and spacing and – in case of serrated facades – the area occupied by the glass. In case of finned shading devices, the maximum level of SSE was 3h21 h/day for fin depth of 0.5 m and of 2 m spacing. In serrated facades, the largest results were calculated for the 60% glazed facades, accordingly 3h09, 3h15; 3h32 h/day. Obviously, the reduction of the area of glass produced lower SSE results, although it must be stated, that medium values of SSE were approx. 10% higher in case of the façades protected by fin shading devices of than in the serrated facades. This shows a better performance of serrated facades in protection against potential glare produced by the areas of high luminance value on the work plane (Table 1).

Table 1. Table showing all DF, LU, SSE computer simulation results. Maximum results in each series were marked in red, the lowest results were marked in green.

	no shading	1 m, 1 m dist	1 m, 2 m dist	0.5 m, 1 m dist	0.5 m, 2 m dist	1:1, 15 deg.	1:1, 30 deg.	1:1, 45 deg.	1:2, 15 deg.	1:2, 30 deg.	1:2, 45 deg.	2:1, 15 deg.	2:1, 30 deg.	2:1, 45 deg.
DF MAX (%)	50.11	22.61	33.43	28.75	38.73	33.85	32.15	29.34	39.29	37.99	36.74	29.47	27.11	24.34
DF MED. (%)	21.15	9.59	14.11	12.87	16.54	12.87	14.11	9.59	13.08	13.02	16.54	6.33	6.71	6.56
DF MIN (%)	5.65	2.60	3.98	3.63	4.64	2.59	2.30	1.89	3.68	3.41	3.54	1.58	1.51	1.24
LU	0.27	0.27	0.28	0.28	0.28	0.20	0.16	0.20	0.28	0.26	0.21	0.25	0.22	0.19
SSE	04h44	01h47	02h46	02h46	03h21	02h57	02h43	02h20	03h32	03h15	03h09	02h39	02h25	02h12
SSE med.	01h27	00h26	00h45	00h45	01h00	00h40	00h39	00h36	00h54	00h53	00h51	00h25	00h26	00h24

One of the most important results of this analysis is the fact, that large area of the test room (and tested work plane) was devoid of any direct solar radiation, what resulted in very low uniformity of daylight in the room. In the case of SSE, the narrow strip parallel to the façade was highly illuminated, while the rest of the room is totally devoid of the direct solar exposure. In tested case, a light-shelf system should be considered as daylight distribution device into the depth of the working office room.

6 Conclusions

Both façade geometries provide some protection against the excess levels of luminance in the tested office room (measured as DF for scattered light), but remain quite unsatisfactory in the equalization of the level of daylight (LU – light uniformity), especially in case of direct solar exposure. SSE produces on the work plane the areas of elevated luminance for a relatively long time during the day, what results in high potential glare and user's visual discomfort. It is justified to state, that vertical shading devices (either in the form of vertical opaque fins or the opaque flanges of the serrated facade) improve the visual user's comfort in a South oriented room to a very limited scope. Definitely, research considering other orientations of the facade (West and East) shading systems of different geometry – supposedly horizontal – is required to optimize the solutions for the sake of the user's comfort and health.

Acknowledgments. This research was supported in part by a grant from the Polish Ministry of Science and Higher Education (S80401-0067-10-K0106 granted through the mechanism of dotation by Wroclaw University of Science and Technology). The author thanks the manufacturers of the De Luminæ software (DL-Light platform) for the test version, that was made available for the research.

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