Assessment of the impact of street lighting on usage activity of pedestrian traffic spaces on the example of the square in Saint Petersburg

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Abstract. Lighting is one of the key factors in ensuring the maximum flow of people in traffic spaces. The choice of lighting settings determines pedestrian comfort and safety, which defines the choice of pedestrian’s route. The growth of cities is the reason for finding solutions to the optimisation problem of the lighting settings of traffic spaces to reduce energy costs and ensure comfort and safety of pedestrians. Solving the problem of adaptive lighting requires experimentation. The experiment conducted in the square in Saint Petersburg showed that the shortest routes to the most remote points of the square are in great demand among pedestrians. When the level of illumination of lamps changes by 1-2 steps, a decrease in the colour temperature to 3200 K has the strongest influence on the choice of pedestrians. The preference for a route with normal and reduced to 3200 K temperature varies depending on the day of the week.

1. Introduction

The growth of the population of big cities and the increase in the people flow rate serve as an incentive to develop public spaces in a city. Jan Gehl [1,2], a famous urban designer, classified urban spaces into three types according to the activity of people on the street. He singled out traffic space, recreation space and social interaction space. Traffic spaces are of particular interest as elements of urban space which have the greatest impact on business and social activity of a city. The primary function of traffic spaces is to ensure movement of the maximum number of pedestrians in the shortest time in a comfortable environment. The quality of this function depends on many factors. It is also determined by the frequency with which people choose this or that route.

Lighting is one of the key factors when choosing a route, along with the quality of road surface, the width and congestion of a pedestrian area, adjacent objects, etc. While pedestrians choose a route, the significance of the light environment increases markedly when natural daylight is reduced in the evening and at night [3], especially in places with increased criminal activity. Insufficient lighting makes pedestrians feel unsafe and reduces the usage activity of traffic space. An increase in the level of illumination expands the area of clearly distinguishable objects and contributes to a decrease in criminal activity [4,5], increasing the sense of security [6] and, consequently, increasing the usage
activity of traffic space [7,8]. However, when increasing the level of illumination, it should be taken 
into account that excessive illumination can cause visual discomfort [9,10] and reduce the usage 
activity of a pedestrian area. Along with illumination, colour temperature also influences pedestrian’s 
comfort and choice of a route [11-13]. Besides comfort, when a pedestrian stays in artificial lighting 
for a long time, colour temperature also affects his or her circadian rhythms [14,15], which are directly 
related to the maintenance of human health. Known research results do not allow us to determine an 
optimal combination of illumination and colour temperature, at which the usage activity of a 
pedestrian area will be maximal. This is due to two categories of external factors. The first category 
includes non-reproducible combinations of environmental conditions: the trajectory of a route, the 
location of the objects that attract people (shops, museums, metro, etc.), etc. The second category 
includes reproducible or repeated conditions: time of the day, age, the initial psychoemotional and 
physical states of the subjects (pedestrians), etc.

Another important aspect of the lighting environment of public spaces is the increase in electricity 
consumption for lighting in growing cities. It is caused by the increase in pedestrian areas and the 
general people flow rate. Reduction of the electricity costs for lighting is implemented in two 
directions: the development of progressive energy-saving lighting devices [16-18] and the use of 
adaptive lighting [19] based on intelligent [20-23] control methods. The latter direction provides for 
flexible changes or adaptation of the lighting settings based on the built-in program for managing 
these settings, depending on external factors. Creation of a lighting model for this control program is a 
multi-criteria task that requires numerous field experiments on various types of objects.

2. Object of Study
A square, which is located at the intersection of Engels Prospekt and Parkhomenko Prospekt of the 
Vyborgsky District of Saint Petersburg (Figure.1), was chosen as the object of the study. Entrances 
and exits from the square were numbered and taken as the endpoints of routes. Street intersections 
which correspond to the vertices of the square contour are marked with letters.

![Figure 1. Square layout with the routes and adjacent streets.](image-url)
3. Experimental Conditions
The experiment was carried out with the lighting equipment available in the square under the following weather conditions:

- ambient temperature, °C – +20 ± 10;
- relative humidity, % – from 45 to 80;
- atmospheric pressure, mm Hg – from 630 to 800;
- tests were not carried out if precipitation (snow, sleet, rain) had occurred in the experimental area at least 3 hours before the start;
- test results were considered invalid if precipitation (snow, sleet, rain) occurred during the test;
- tests were not performed at wind speed greater than 11 m/s.

4. Results of the Experiment
To experiment in the most equal conditions, the teams of 2 observers counted the number of pedestrians in the evening hours from 9 p.m. to 11 p.m. Both single pedestrians, as well as groups of more than 2 pedestrians, were counted.

4.1. The first stage of the experiment
A series of observations was made on different days to analyse traffic on routes and choose the most visited route. Based on the results of observations, we calculated the expected value (Figure 2) and the standard deviation (Figure 3) of the number of pedestrians on each route.

Figure 2 shows that Route 3-4 was chosen by the largest number of pedestrians who visited the square. The diagram in Figure 3 proves that Route 3-4 has the smallest standard deviation compared to the other routes. This can be explained by the fact that the endpoints of Route 3-4 are closer to points A and C of the square contour vertices. They correspond to diagonally located intersections of the neighbouring streets and areas of attraction of people: the centre for physical education, sport and health of Vyborgsky District is adjacent to point C; grocery stores are adjacent to point A.

The results for Route 1-4 and other routes are not shown in Figures 2 and 3 because there were no pedestrians during the allotted time interval. This can be explained by the fact that the excluded routes perform the walking function.

4.2. The second stage of the experiment
The task was to identify the influence of various lighting factors on the preference of pedestrians when choosing a route. During the experiment, we studied the influence of changing the lighting scenarios on the number of pedestrians walking along the selected Route 3-4. Hence, the following factors were identified: the average illumination of the road surface and colour temperature. These factors were varied by applying light filters to the lighting equipment available in the square.
The maximum and minimum values of average illumination on the lampposts were achieved by using light filters "No. 211 Chris James Neutral Density 0.9 (ND8)." This filter reduces the light intensity by 3 steps without changing the colour. It has a transmittance of 13.7% and an absorption coefficient of 0.86.

To vary colour temperature, we used conversion filter, "No.204 Chris James 204 Full C. T. Orange." This filter changes the colour temperature from 6500K to 3200K. It has a transmittance of 55.4% and an absorption coefficient of 0.26.

To compensate for the absorption of light flux by the light filters, filter "No. 209 Chris James Neutral Density 0.3" was used. This filter reduces the light intensity by 1 step without changing the colour. It has a transmittance of 51.2% and an absorption coefficient of 0.29.

Based on the results of the observations, the total number of pedestrians on all previously selected routes was calculated (1-2, 1-3, 2-3, 2-4, 3-4). The percentage of the total number of pedestrians who chose Route 3-4 when using lighting scenarios with different filters was determined (Figure 4).

The bar chart in Figure 4 shows that the most preferred lighting scenario for pedestrians was without using filters. In this case, more than 60% of all the pedestrians chose Route 3-4. The lighting scenario of Route 3-4 using filter No. 204 Chris James Full C. T. Orange was chosen by 45% of the pedestrians. It was also the least preferred. In this lighting scenario, the decrease in light intensity is comparable to filter No. 209 Chris James Neutral Density 0.3. Figure 4 illustrates that a one-step decrease in light intensity when comparing filters No. 209 and No. 204, has less effect on pedestrian choice than a change in its colour temperature when using filter No. 209. Thus, in the evening hours of a working day, a decrease in the colour temperature of the surrounding lighting reduces the comfort level of pedestrians which can be explained by an increase in anxiety when the colour temperature drops to 3200K. Hence, the colour temperature in the experimental conditions was the factor that had the strongest influence on the choice of a route by pedestrians.

![Figure 4. Percentage of the total number of pedestrians who chose Route 3-4 when using various filters: without a filter – lighting devices without any filters; 209 – when using filter No. 209 Chris James Neutral Density 0.3; 204 – when using filter No. 204 Chris James Full C. T. Orange; 211 - when using filter No. 211 Chris James Neutral Density 0.9 (ND8).]

4.3. The third stage of the experiment

The task was to determine the influence of colour temperature, as the most powerful factor (based on the results of the second stage of the experiment), on the choice of pedestrians at weekends and working days. The observations were made under conditions similar to the previous stages of the experiments. The results of the observations are presented in the bar chart in Figure 5.

Figure 5 shows that pedestrian preferences in choosing a route at weekends and working days under the same lighting scenarios were opposite, but they did not differ significantly. For example, at the weekend for the lighting scenario with filter No. 204, the traffic on Route 3-4 was only 8% higher, while on a weekday the traffic was 17% lower. Figure 5 illustrates that reduction of the colour
temperature of lighting to 3200 K contributed to the choice of a route by the majority of pedestrians at the weekend than on a weekday.

5. Conclusion
The analysis of pedestrian area activity in the considered square allowed us to establish the fact that the number of pedestrians on different routes varies significantly. This is the basis for reviewing the existing scheme of electricity distribution between the lighting devices of the square to improve energy efficiency of the street lighting.

The relative location of pedestrian areas and streets should be taken into account when designing lighting systems for public spaces.

Lighting and colour temperature settings have varying influence on the usage activity of the pedestrian route in question. Moreover, the experiment showed that the colour temperature has the greatest influence.

Changing the colour temperature of outdoor lighting has the opposite effect on the activity of using a pedestrian route at weekends and working days. This shows differences in pedestrian perception to changes in the colour temperature of a tired and rested body. This fact supports the use of a biodynamic approach to lighting pedestrian areas of the urban environment.

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