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A CORRECT ILLUMINATION OF AN ESCALATOR IS A SET OF RADICAL SOLUTIONS

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ABSTRACT

An analysis of escalator areas illumination of the Moscow underground is given. Disadvantages of the existing illumination system are shown, and ways of their elimination are proposed using upgrading illumination devices with preservation of a “historical” image of the latter.

Keywords: light environment, psychophysiological disorders of vision perseption apparatus, escalator inclination, operation and emergency illumination

1. INTRODUCTION

Illumination of the Moscow underground station space, being most complex system ensuring safety of transportations and maintenance of the railways and all infrastructures with elements of cultural heritage, is a very specific problem, which solution is more similar to museum illumination.

As these objects are a part of the general architectural project, their illumination should be implemented within the context of solving the problem for the whole system as a dual formation. The first subsystem is “external environment – entrance hall – escalator – central hall –platform – car”, and its exposure element is a passenger. The second subsystem is “platform – tunnel” and its exposure element is a train driver, Fig.1.

Here we deal with the first subsystem, in which among the station areas requiring illumination alignment the most contradictory elements are escalators, as shows analysis. It is going on because illuminance at the passengers faces changes repeatedly for a short time interval, for example, more than threefold. Besides, one should notice that such illumination, when all elements of the system are identical by illuminance, is ideal. As _PHAROS-ALEF LLC_ studies together with representatives of escalator service and with power supply service of Moscow underground showed, the situation is complicated by imperfection of the existing principle of the escalator inclination illumination, which does not allow reaching modern illuminance standards predetermined by the requirements [1].

Respectively, due to features of the traditional illumination devices (ID) structures installed on escalators, a principled revision of illumination approach of this station area is necessary.

A complexity of solving this problem is aggravated by the fact that design of escalator luminaries are different and most of them requires a change of the diffuser structure, and in doing so, one should not change their appearance, otherwise, should not distort a “historical” image of the stations.

Implementation of emergency illumination using light emitting diodes isn’t less important, but this requires special developments.

And finally, a support of psychological comfort determined by colour temperature of light environment is necessary: this parameter of light sources should be changed from (3700–4200) K in the morning to (2800–3200) K in the evening (i.e. taking into account the human circadian cycles).

Solution of all specified problems should be implemented along with power consumption decrease, which was a very difficult technological problem

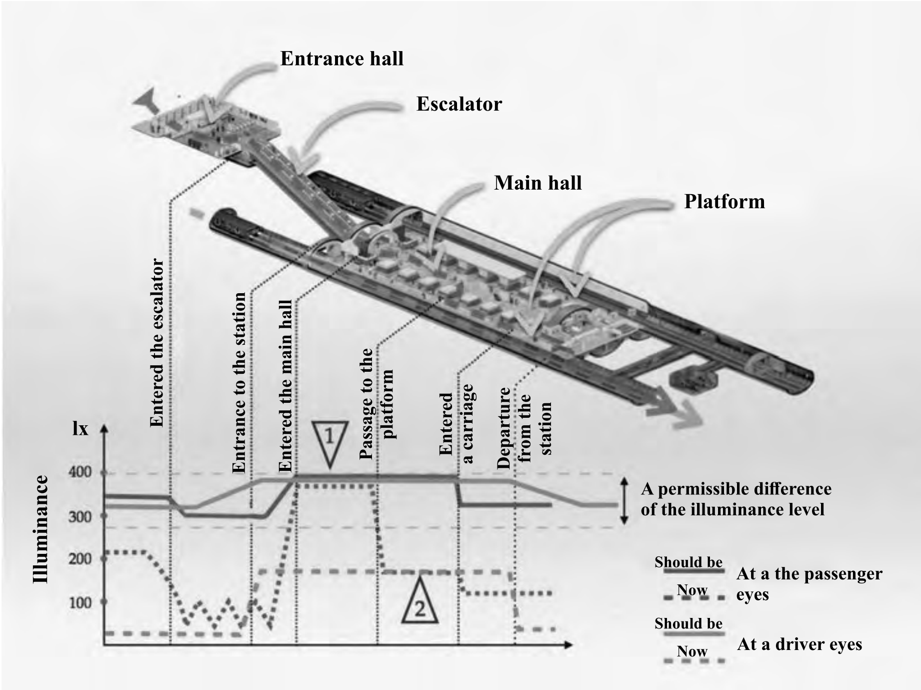


Fig. 1. Layout of illuminance distribution over a station space

until recently. Emergence and quick development of powerful LED light sources allows the successful overcoming obstacles on this way and solving some other problems of illumination upgrade. One of these problems, for example, alignment of illuminance in tunnels, on platforms, and at central halls is already solved based on adaptive IDs of the rolling stock [2], which were developed by PHAROS-ALEF LLC and tested at the Moscow underground.

It is clear that the proposed underground illumination upgrade should be provided with a minimum range of as much as possible unified IDs and light sources taking into account features of their service maintenance.

This work is dedicated namely to solving all above listed illumination upgrade problems at the Moscow underground.

2. AN ANALYSIS OF THE LIGHT ENVIRONMENT STATE IN ESCALATOR AND PRE-ESCALATOR AREAS OF THE MOSCOW UNDERGROUND STATIONS

As it was already noticed, a specific position in the underground illumination is held by escalators. It is specific, because illumination of this area practically adapts a passenger either for visual work in the street, or for underground light environment (halls, platforms, etc.). For this reason, considerable differences in illuminance are not desirable for passenger eyes. So, they are not allowed [1]. However, the real situation obviously contradicts this limitation. As the measurements show (Table 1), illuminance on steps and passenger eyes while escalator driving is different at different stations depending on the using ID structure, on their location, on ceiling type, on the vault inclination, and, which is most important, the illuminance does not meet the adopt standards anywhere. So, maximum illuminance at a passenger's eyes (324 lx) is at Baumanskaya station, and minimum (10 lx) is at Kievskaya radial; maximum illuminance on a step (169 lx) is at Baumanskaya, and minimum (4 lx) is at Sportivnaya station.

On one escalator with traditional ID structures, (floor lamps with spherical diffusers), the illuminance fluctuates from 340 lx to 186 lx when moving downwards and from 160 lx to 312 lx when moving upwards, i.e. illuminance at passengers' eyes changes more than 1.7 and 1.95 times respectively when passing one ID. And when using floor lamps with semi-spherical diffuser IDs, it changes from 44 lx to 14 lx when moving downwards and from 53 lx to 19 lx when moving upwards (the changes are 3.1 and 2.7 times respectively). These changes are very much, whereas they should be no more than 1.5 [1], and each such change happens during five seconds

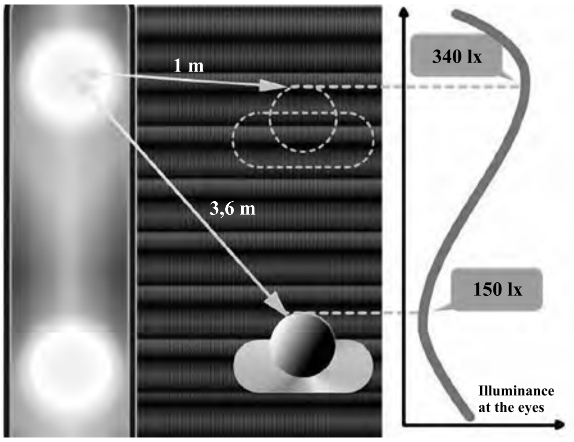


Fig. 2. Layout of illuminance change at passengers' eyes when escalator moving

Fig. 3. Arrangement of escalator area illumination at Sretensky Boulevard station

and total number of the changes for one escalator descent or ascent reaches 15–18.

Similar results were also obtained at escalators using IDs with other types of diffusers: matte long cylindrical, matte short cylindrical and transparent cylindrical. A reason of such illumination changes is in an essential change of the distance between an ID and a passenger when moving along with an escalator. A scheme of illuminance change at a passenger eyes when moving along with an escalator is shown in Fig. 2.

Besides, within a normalised area, (an escalator at the step level should have illuminance no less than 100 lx [1]), the measured illuminance practically at all stations was lower than the standard.

It was also dependent on the following:

– On the distance to the IDs (for example, at VDNKH station it was from 15 lx to 58 lx);

– On the ID types used (for example, when using IDs with spherical diffusers at Elektrozavodskaya station it was from 18 lx to 63 lx, and when using IDs with semi-spherical diffusers at Sportivnaya it was from 10 lx to 28 lx;

– On power of the light sources (for example, for IDs with the same diffuser at Marksistskaya it was from 17 lx to 78 lx, and at Pushkinskaya – from 51lx to 130 lx).

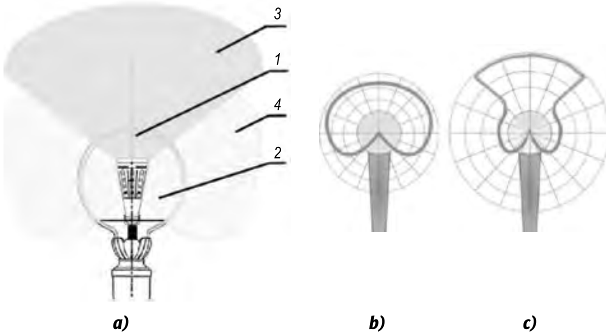


Fig. 4. Escalator standing lamp:
a – a proposed structure; *b* – radiation indicatrix for traditional implementation, *c* – radiation indicatrix for implementation of the proposed structure

3. A CORRECT ESCALATOR ILLUMINATION IS A SET OF RADICAL SOLUTIONS

3.1. A Basic Technological Solution of Escalator Illumination

A desire to reduce illuminance changes led to development of a new principle of escalator illumination and of the structures implementing it at Sretensky Boulevard, Mehzdunarodnaya and Spartak stations.

In these versions, illumination in a reference area is made by radiation of an ID installed on the balustrade re-reflected from of the vault surface inclination, which excludes its of ID direct radiation into passengers' eyes.

By the light distribution nature, balustrade IDs (luminaires) installed at Sretensky Boulevard station (Fig.3) met the requirements [1]. This meeting is not complete, because relation of luminous fluxes in the top and lower hemispheres is not the best. The calculations show that to provide the standard illuminance, ID luminous flux towards the ceiling in this case should be not less than 5000 lm.

An analytical simulation and practical implementation of such a "balustrade" illumination confirm a possibility to solve the set problems but requires new IDs, which are not suitable to be used at old stations because of their stylistic features.

Nevertheless, it turns out possible to solve this problem using all permissible ID versions of an escalator balustrade without changing their historical image [3, 4]. So, in the most widespread escalator ID versions of the first stations of Moscow underground made as floor lamps with spherical diffusers (Fig. 4), top and lower parts of diffusers should have different transmission factors, lower parts should have a small, and top parts should have a big transmission factor. Such diffusers should have two areas, one of which (area *1)* should be almost transparent (with a big transmission factor), and the second one (area *2*) should be matte (with a small transmission factor). In doing so, the light source should direct most part of luminous flux *3* to area *1* illuminating the escalator inclination vault with a minimum attenuation and forming a necessary illuminance on the escalator steps using the reflected light. In this case, a part of luminous flux *4* (5–6 times lesser) should be directed to the diffuser area *2*. As a result, with a switched on ID, the diffuser looks like an entirely luminous body.

Wherein dazzle of the passengers is completely eliminated as most part of luminous flux is limited by a cone, which generators are always located out of passenger eyes (Fig. 5) passing the IDs, and illuminance distribution along the balustrade vault ceiling is uniform enough and comfortable for the perception.

A visualisation of illuminance distribution (Fig. 6) shows that stripes created by the IDs will not be sighted within the visual field.

As it was already noticed, luminous flux reflected from the escalator vault ceiling creates a sufficient illuminance on the escalator steps without visual discomfort (due to the created illuminance of (350–400) lx as it is in the station and in the entrance halls). Absolute illuminance values and their distribution in operation illumination mode were calculated according to the DiaLUX program with use of a specially developed LED lamp, which appearance and technical specifications are given in Fig. 7 and in Table 2.

In the case, when traditional escalators IDs have other structure, such technological solutions are also implemented without special problems (Fig. 8).

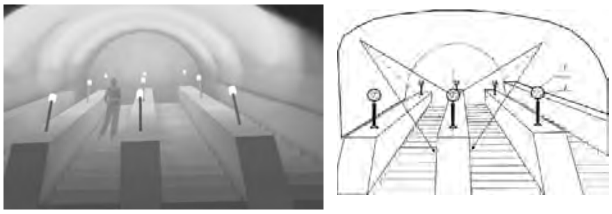
3.2. Emergency Illumination

A specific position in the station escalator area illumination system of the underground is held by emergency illumination, requirements to which assume ID operation based on alternate and direct current in voltage intervals of (60–160) V and 127 V ± 10 %.

In this case, standard illuminance on the escalator steps should be not less than 10 lx.

It is clear, that solution of this problem requires use of a special equipment to control and connect IDs to operation and emergency circuits.

Fig. 5. A proposed illumination layout of an escalator: visualisation of escalator inclination illumination principle



a) b)

Fig. 6. Illuminance distribution on an escalator balustrade vault:
a – visualisation of illuminance on the vault, *b* – ray path

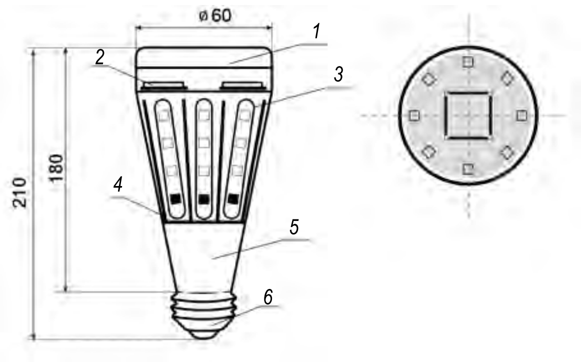
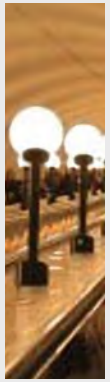
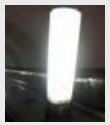
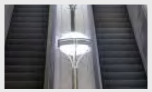


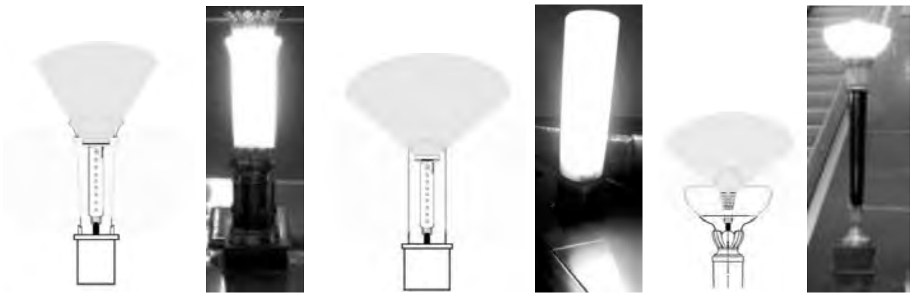
Fig. 7. Appearance of a LED lamp for general and emergency illumination of escalator inclinations:
1 – matte diffuser, *2* – matrix of the main illumination, *3* – line of diffuser decorative illumination, *4* and *5* – case, *6* – socle *E27*

Table 1

№	Station	Light device type		Illuminance, lx											
				Steps (standard: 100 lx at any point)							Passenger eye level				
				At the edge (on the left)		At the centre		At the edge (on the right)			Vertical			Horizontal	
				Min.	Max	Min	Max	Min	Max	$E_{max}/E_{min} \leq 1{,}5$	Min	Max	Relation	Min	Max
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
1	Prospekt Mira-ring		Up Down	26 26	33 33	54 30	40 48	23 23	35 28	2,35 2,08	53 50	80 96	1,5 1,92	52 50	92 76
2	Dinamo		Up Down	20 18	21 52	23 33	34 78	24 19	35 50	1,75 4,3	37 40	140 230	3,78 5,75	45 40	130 105
3	Belorusskaya		Up Down	27 41	34 58	36 64	38 84	27 65	29 70	1,4 2,04	50 190	69 210	1,38 1,1	45 90	42 78
4	VDNKH		Up Down	27 25	43 32	40 37	58 74	15 28	24 33	3,86 2,96	44 37	60 100	1,36 2,7	69 67	95 115
5	Baumanskaya		Down	99 90	120 110	132 120	169 158	87 86	110 105	1,94 1,83	160 186	312 324	1,9 1,74	208 170	363 346
6	Electrozavodskaya		Up Down	33 30	43 44	39 40	63 70	18 23	33 31	3,5 3,04	50 70	134 124	2,68 1,77	76 70	120 115
7	Alekseevskaya		Up Down	21 17	36 26	20 21	22 23	15 17	17 18	2,4 1,52	47 50	85 85	1,8 1,7	45 42	59 60
8	Universitet		Up Down	34 20	40 30	14 22	20 30	12 19	15 33	3,3 1,73	33 49	60 112	1,8 2,28	41 35	52 65
9	Komsomolskaya-radial		Up Down	40 35	57 40	34 35	38 40	36 32	52 34	1,6 1,25	78 89	131 121	1,7 1,35	82 84	126 110
10	Komsomolskaya-ring		Up Down	21 12	22 30	19 17	24 34	22 15	37 25	1,94 2,0	66 73	133 142	2,01 1,94	45 55	126 103
11	Kievskaya-radial.		Up Down	9 8	17 15	13 8	22 15	10 8	15 10	2,44 1,88	20 10	46 23	2,3 2,3	26 26	45 32
12	Prospekt Mira-radial		Up Down	76 64	83 90	83 85	96 97	86 72	110 77	1,45 1,51	160 210	230 280	1,43 1,3	181 186	210 206
13	Semyonovskaya		Up Down	52 35	60 60	52 52	74 87	33 44	77 62	2,49 2,48	80 95	243 216	3,03 2.27	105 92	160 183
14	Sportivnaya		Up Down	10 4	19 15	18 19	28 26	11 11	21 16	2,8 6,5	19 14	53 44	2,7 3.1	16 19	31 47

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
15	Vorobyovy Gory		Up Down	10 11	19 15	18 19	28 26	11 11	21 16	2,8 2,36	19 14	53 44	2,78 3,14	16 19	31 47
16	Cherkizovskaya		Up Down	4530	83 50	34 42	83 110	30 50	70 101	2,77 3,67	95 113	309 551	3,25 4,88	126 110	420 432
17	Kievskaya-ring		Up Down	9 9	11 12	13 13	15 15	9 9	11 11	1,6 1,6	27 30	33 45	1,2 1,5	16 20	17 27
18	Tverskaya		Up Down	78 58	109 62	76 70	106 110	63 45	70 85	1,68 2,4	95 140	240 270	2,5 1,93	150 120	179 195
19	Mayakovskaya (the short escalator)		Up Down	18 17	26 21	34 26	53 35	27 20	48 22	2,9 2,05	46 41	115 105	2,5 2,56	39 49	103 67
20	Mayakovskaya (the long escalator)		Up Down	22 36	32 64	27 61	35 93	28 28	42 43	1,9 3,3	44 65	63 125	1,43 1,9	62 63	82 159
21	Pushkinskaya		Up Down	51 65	73 105	80 85	116 160	85 76	130 127	2,55 1,88	130 171	400 390	3,07 2,28	137 132	319 251
22	Marksistskaya		Up Down	17 23	60 45	18 26	66 41	13 22	78 25	6,0 2,04	41 47	230 125	5,61 2,66	37 32	138 60
23	Okhotny Ryad		Up Down	52 13	85 20	43 24	76 50	35 23	60 51	2,4 3,9	45 67	161 261	3,57 3,9	60 79	180 148
24	Kitay-gorod		Up Down	54 81	58 104	76 100	104 152	79 66	105 115	1,94 2,3	145 153	210 235	1,44 1,53	149 107	167 185
25	Lubyanka		Up Down	36 57	42 98	51 54	78 88	37 60	78 113	2,16 2,1	85 137	279 310	3,28 2,26	121 117	239 216
26	Sukharevskaya		Up Down	38 27	82 75	48 77	79 143	31 52	45 109	2,64 5,3	114 121	404 369	3,54 3,05	108 100	178 200
27	Belyaevo		Up Down	11 11	27 15	31 13	42 31	35 15	49 39	4,4 3,54	49 63	231 157	4,7 2,49	53 33	77 73
28	Sretensky Bulvar		Up Down	35 27	43 30	36 32	47 52	32 40	38 48	1,46 1,92	45 59	61 70	1,35 1,18	90 95	115 110
29	Spartak		Up Down	19 29	26 50	24 65	61 123	17 19	50 51	3,5 6,4	54 60	94 114	1,74 1,9	52 84	92 170
30	Mezhdunarodnaya		Up Down	52 50	90 91	75 63	93 115	76 84	95 109	1,82 2,3	41 94	67 200	1,63 2,13	50 107	85 214

(**Red** – does not meet the standards, black – normal, **blue** – not normalised)



a) b) c)

Fig. 8. Layout of a special LED lamp operation in structural versions of traditional escalator luminaires in the operation illumination mode:
a – with a matte diffuser closed from top, *b* – with a matte diffuser opened from top, *c* –with a semi-spherical diffuser

Functioning of such IDs with light emitting diodes in illumination operation mode assumes a shared use of areas *1* and *2* of the diffusers and lamps (Fig. 4 and 8), and illumination emergency mode supposes use of area *2* only.

Fig. 9 shows illuminance distribution on escalator steps in emergency mode according to the proposed solution. It is clear from the figure that the solution provides a comfortable illuminance for passenger evacuation and for recovery work, which is six times higher than the current limit [1].

3.3. Designation of an Escalator Moving Part Dimensions

Modern requirements to safety demand a designation of escalator moving part. Today this requirement in some cases is implemented using installation of a blue LED stripe, which use is inadmissible by medical parameters [5] and is forbidden due to fulfilment form [1]. For example, such a stripe is installed at the ring station Prospect Mira.

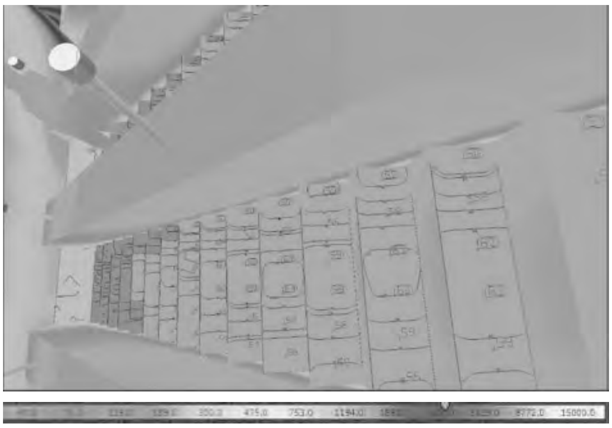


Fig. 9. Illuminance distribution (lx) on an escalator step in the emergency illumination mode

To eliminate the negative effect, replacement of the radiation colour with the correspondent green LED stripe in a diffusing shell can be used.

3.4. Adaptive Illumination of Escalators

The general trend of developing illumination systems is adaptation of the formed light environment towards psychophysiological functions of a person. So, in view of the light sources development level, construction of such systems changing ID colour temperature depending on day time, i.e. of the systems, which take into consideration psychophysiological state of a passenger, is possible already today.

Such a system can be implemented based on LED matrices with a variable correlated colour temperature (Fig. 10).

4. DEVELOPMENT OF THE REGULATORY BASE

An analysis of the stated in paragraph 3 shows that today, there is a technological basis to upgrade illumination of all areas of underground station space including escalators. However, its implementation is impossible without development of the correspondent standards taking into consideration not only the labour protection requirements of the underground personnel but also the passengers' protection requirements. And it is obvious that the set of the controlled lighting parameters should be considerably expanded in this regard. For example, along with escalator step illuminance, this set should include illuminance at the passengers' eyes.

Besides, it is advisable to exclude eye contact with direct radiation of an observer not only from LED light sources but also from fluorescent lamps,

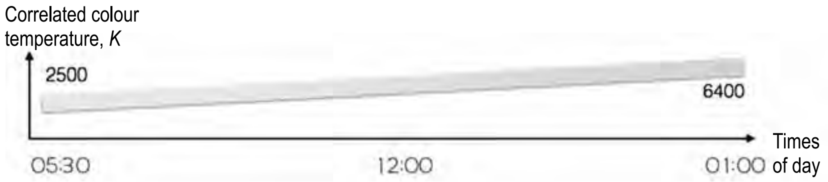


Fig. 10. Time change of correlated colour temperature T_{cc} of LED lamps for adaptive illumination systems

which, due to the luminous flux ripple, are much more harmful than LED light sources. And there are many such reasons and recommendations concerning comfort of the passengers.

5. CONCLUSION

• The presented materials confirm a possibility to upgrade illumination of all areas of the station space, including escalators based on the existing technology facilities.

• Illumination upgrade of the escalator areas requires a revision of the light environment formation methods.

• The proposed escalator space illumination version and the correspondent structural solution allow preserving historical image of the used IDs.

• The modernisation work of the specified illumination requires a revision of sanitary standards and of service regulations of the underground.

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