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USER RESPONSES TO LED AS A GUIDE FOR ENERGY EFFICIENT LIGHTING APPLICATIONS IN DOMESTIC ENVIRONMENTS

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1. INTRODUCTION

Daylight and its variances throughout the day constitute a fundamental reference point for light and lighting quality all over the world. Incandescent light is the artificial light-emitting technology that is closest to this generally predominant visual lighting preference. Previous studies of light sources that are used in private households indicated a preference for incandescent light bulbs. In relation to these, the more energy efficient light sources that are available on the private market have emerged from a divergent light emitting technology. Significant differences in lighting characteristics, light colour, light distribution characteristics and degree of human visual comfort can be identified when light from incandescent light bulbs is compared with that emitted by fluorescent tubes, fluorescent bulbs, low-energy bulbs and LEDs. These differences risk is making more difficult the transition from using incandescent bulbs to increasing the use of more energy efficient sources of light in private households. There is a pressing need to map out preferences for lighting characteristics, light colour and visual comfort in order to eliminate any obstacles to switching to more energy efficient sources of light in response to the European Commission's directive that phases out the incandescent lamps during the years 2009, 2010, 2011, 2012, 2013 and 2016. More stringent specifications would also be placed on halogen lamps. This EU directive increases the need for more knowledge about general visual preferences and how people in general experience the light from energy efficient light sources in general and especially LED. Working towards sustainability is an individual and global challenge that in a high degree concerns the light sources used in domestic environments. Because of this there is important to know more about similarities and differences in the opinion of men and women and subject´s from different parts of the world.

2. AIM AND PROBLEM FORMULATION

To be able to get a fast acceptance of energy efficient light sources in domestic environments and to predict the use of future lighting techniques and map possible obstacles in the acceptance of new lighting technique there is a need to investigate factors that affect the choice of light sources from a visual consumer perspective. The aim of the study is to record visual lighting preferences among male and female subjects from different parts of the world so as to construct a basis for energy efficient lighting design based on well established preferences. What are the test subjects' preferences for lighting levels on work surfaces and supplementary ambient light levels, light colour, levels of comfort when viewing lit surfaces, the experience of illuminated surfaces and the experience of the atmosphere that is created by light from installations equipped with energy efficient light sources that are available on the private market? Test subjects' experiences are contrasted with those they obtain at home. Are there differences in acceptance when the subjects stay in the two test rooms? What is behind a positive or negative reaction from the subjects?

3. BACKGROUND

In the process of adapting to a sustainable society, significant potential for reducing the current energy consumption has been assessed in the area of lighting. The means by which to achieve this goal is an increase in the use of daylight as a general light source and the design of supplementary artificial lighting consisting of more energy-efficient light sources and lighting control. Incandescent bulbs are the light sources that are currently in widespread use in private households. These bulbs differ from the more energy-efficient light sources that are available on the market in terms of light colour, light distribution and lighting characteristics. There has been a well established following for incandescent light bulbs for the past 100 years in domestic environments. This light source generates a warm, soft, yellowish light that distributes well in a room and easily creates an ergonomic visual atmosphere. In accordance with the European Commission's Ecodesign directive, incandescent light bulbs will be phased out and be replaced with more energy efficient light sources such as low-energy lights, fluorescent bulbs and tubes and LEDs. LEDs provide a visually harsh, white, evenly distributed light in comparison to incandescent bulbs. Because they are small, concentrated light sources, it is difficult to achieve uniformly distributed light in rooms in which they are used. In comparison, fluorescent bulbs provide a greater degree of harshness and uniformity and are less comfortable to view than incandescent light bulbs. Low-energy light bulbs emit a paler light in comparison to incandescent light bulbs. Recording human preferences for room lighting, light colour and lighting levels and studying traditional and historical options for lighting may result in a basis for the future development of an energy efficient light emitting technology and/or applications with a broad level of acceptance among private consumers. The information may serve as a bridge between new technology and predominant traditions and values, which may hasten the conversion to more energy efficient lighting design in private homes. It is hard to find articles written about visual preferences in accordance to energy efficient lighting design, but the question is of great importance and a development theoretically is important. (Foster old et al. 2010)

4. METHOD

4. 1. Test subjects

The test subjects were recruited via e-mail (due to convenience), which was sent to all students at Jonkoping University. From the group that expressed an interest in participating, 100 people were selected based on a desire to obtain as even a distribution in age and geographical origins as possible. 87 people from 23 countries completed all stages of the study. The group consisted of 43 men and 44 women. The average age was 31 years. The subjects attended the study in balanced order of presentation. The average values for the entire group's experiences were arrived at as a first step. The group was then divided into three subgroups: Scandinavians, Central Europeans and non-Europeans. Finally, the group was divided into men and women. The average values for the entire group of test subjects were compared with those of the subgroups. The average values obtained from each subgroup was subsequently compared with those of the other subgroups.

4. 2. Test used in the study

Data on the test persons' experiences of light were collected through a combination of semantic scales and questionnaires with freely formulated responses. In the latter case, the number of positive and negative light descriptive words was counted and given one point each.

Fig. 1. Test Room 1

Fig. 2. Test Room 1

Fig. 3. Test Room 2

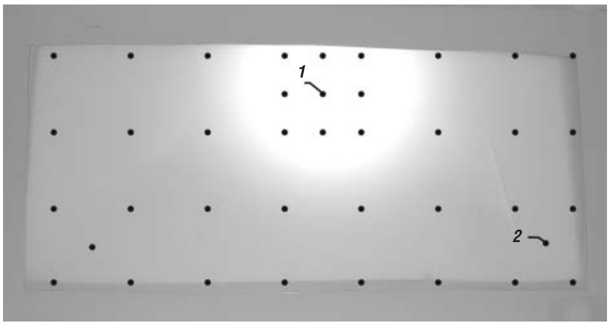

Fig. 4. Test for level of visual comfort, brightness on the wall. Measure point Nr 1. Measured maximum level of brightness Measure point Nr. 2 Measured minimum level of brightness on the wall

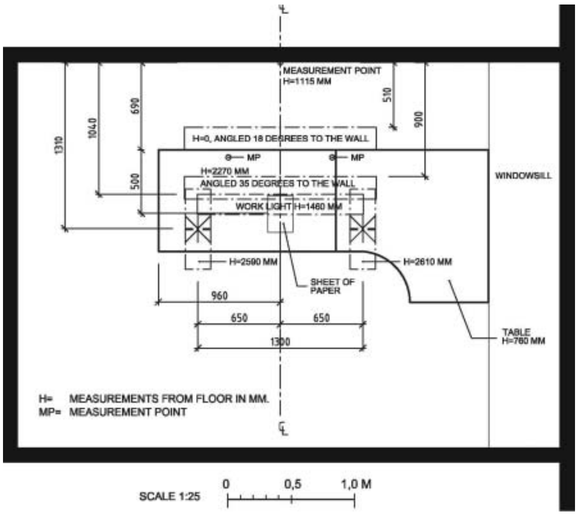

Fig. 5. Floor plan: room for studying individual values obtained from viewing illuminated surfaces with a high level of visual comfort and measured preferences for supplementary levels of ambient light.
(1, 4 Fagerhult Sidelight², 26 W 830. Lamp 2, 1 Fagerhult Closs 2 x54 W Philips 830. Lamp 3, 2 Electroscandia 8047 2 x49 W Philips 830. Control dimmers on table, Helvar 1–10 V converter Digi DIM 470. Lighting control, Fagerhult ATCO PCA 2/54 15 XL one size LP. Lighting control: Fagerhult Sidelight, Osram Quicktronic qt-t/ e1 x26/230–240 dim. Lighting control: Electroscandia Tridonic PCA/49. Light source 80–3950 lx. Working light gives 0 (80)-3950 lx on the working table and 0 (10)-120 to the Ambient light. Ambient light gives 0 (10)- 550 lx on the working table and to the Ambient light 0 (30)-1800 lx. Total on the Working table 0 (90)-4500 lx. Total Ambient light 0 (40)-1930 lx)

The evaluation of the subjects experience of color of light was done in 5 boxes painted in white, NCS 0500 N and with the size of width 72 cm, height 50 cm, dept 53 cm. Box number one was equipped with Philips compact fluorescent light source, 2700 K, 827 13 W 400 cd/ m^2. Box number two was equipped with Optoga, Svea, LED, 22 W, 2950 K. Box number three was equipped with Optoga, Svea, LED, 9 W, 3660 K. Box number four was equipped with Optoga, Svea, LED, 15 W, 4300 K. And Box number 5 was equipped with Optoga, Svea, LED, 12 W, and 5350 K. Box 2–5, 300 cd/ m^2. The subjects stood on a spot at the floor at a distance 200 cm from the wall behind the box. There was no distance between the box and the wall. The subjects then answered the following questions about the light in the boxes. Question: Describe with your own words, your opinion about the light in box 1, 2, 3, 4, 5, Describe the quality of the light with a marker at the 10 degree range low (low=1, high=10.) The test was analyzed with means and compared between subgroups.

Data about the subject´s opinion of level of visual comfort when looking at an illuminated surface was collected by a test with a box equipped with Optoga LED Svea 15 W 4300 K, Lins 10°. Filter Nr1, 2, 3, 4, Polyesterfilm, 100 gr. Filter Nr5, Lee Filters 228 Brushed Silk. The box was placed on the floor close to a wall. The subjects stood on the floor on a signed spot viewing the box 20 cm from the box. The size of the box was: width 57 cm, height 50 cm and depth 53 cm. The subjects evaluated the level of light starting with looking at five filters covering the light source above each others. The subjects got a questionnaire with the following questions: Describe with your own words how it feels to look into the light in the box and indicate your perception of how pleasant-unpleasant it is to look into the light box with a marker at the 10 degrees range (1=unpleasant, 10=pleasant). The filter number one was evaluated and removed, the level of light on filter number two was evaluated and the same questionnaire was used as for filter number 1. Filter number two was removed and the light level on filter number three was evaluated with the same questionnaire as for filter one and two. Filter number three was removed, and the light level of filter number four was evaluated and the same questionnaire as used as for filter number one, two and three. At last, filter number five was evaluated by the subjects with the same questionnaire as for filter number one, two, three and four. The answers were analysed as a semantic scale with means and the subgroups were compared to each other. Instruments used for measurements of the level of light at the filters were Hanger universal Photometer Model S3 Measured in 90 degree

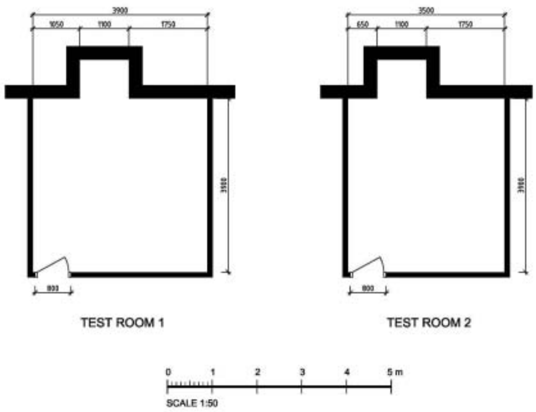

Fig. 6. Floor plan Test Room 1 and 2

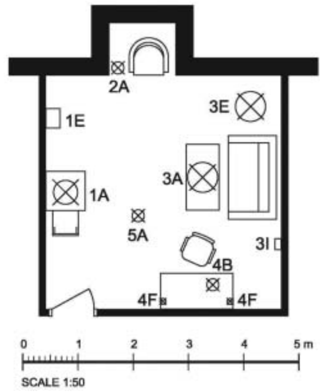

Fig. 7. Coded floor plan, position of luminaries in Test room 1 and 2

Test Room 1, CFLI= Compact fluorescent light integrated			Test Room 2
1 A	Pendant Naxos Markslöjd CFLI Megaman 11 W, E27, 2700 K	1 A	Pendant Naxos Markslöjd LED Energy system 8 W E27
1 E	Wall luminaire Rutbo IKEA CFLI North Light 2 x7 W, E27, 2700 K	1 E	Wall luminaire Rutbo IKEA LED Energisystem 2 x4 W E27
2 A	Reading luminaire Vejle Markslöjd CFLI Megaman 7 W E14, 2700 K	2 A	Reading luminaire Vejle Markslöjd LED Osram Parathom 1,6 W E14 Warm white
3 A	Pendant Saga Markslöjd CFLI North Light 8 W, E27, 2700 K	3 A	Pendant Saga Markslöjd LED Osram Parathom 2 W E27 Warm white
3 E	Floor luminaire Saga Markslöjd LED Osram Parathom 1,6 W E27 Warm white	3 E	Floor luminaire Saga Markslöjd LED Osram Parathom 1,6 W E27 Warm white
3 I	Wall luminaire Orgel IKEA Halogen Osram 42 W 230 V E27	3 I	Wall luminaire Orgel IKEA LED Osram Parathom 1,6 W E27 Warm white
4 B	Reading luminaire Luxo Halogen Osram 35 W 12 V GY 6.35	4 B	Reading luminaire Luxo LED 9 W 18 V 800 mA Warm white
4 F	Two Ceiling luminaire Malmbergs CFLI 7 W GX53	4 F	Two Ceiling luminaries North Light LED 3 W 700 mA
5 A	Ceiling luminaire Lock IKEA CFLI Osram Dulux Super Star micro twist 7 W E27	5 A	Ceiling luminaire Lock IKEA LED Osram Parathom 2 W E27 Warm white

angle towards the filter surface. The maximum value for brightness on the wall was found in point 1, Filter Nr1–5 1130 cd/ m^2, Filter Nr 2–5 1230 cd/ m^2, Filter Nr 3–5 1670 cd/ m^2, Filter Nr 4–5 3700 cd/ m^2, Filter Nr 5 8800 cd/ m^2. Minimum value for brightness on the wall was found in point number two, Filter Nr 1–5 160 cd/ m^2, Filter Nr 2–5 180 cd/ m^2, Filter Nr 3–5 220 cd/ m^2, Filter 4–5 260 cd/ m^2, Filter Nr 5 300 cd/ m^2.

Data about the subjects experience of visual variation when viewing light emitted on a wall from a LED replacement light source was collected. An LED spotlight 30° warm white E27/ 230 V – 2,7 W light source was put on a tripod and was directed towards a white wall at a distance of 120 cm and 160 cm above the floor. The subjects stood on a designated spot on the floor, at a distance of 150 cm from the wall and the lighting was switched off with a lighting switch on the floor. The subject viewed the lit circle on the wall for a minute. A stopwatch was used for the recording of the time. The subjects answered in the test the following question about the brightness on the wall, describe with your own words: If you feel that the light changes during the time you consider the light. If so, describe how the light changes. The data from the test was analysed by counting the number of subjects that experienced that the light on the wall changed or did not change. Data about the subject's opinions about the level of light at the work table and the level

Table 1. Horizontal illumination, test room 1 and 2.

Measurements point		Test room 1, lx	Test room 2, lx
1	Dining table Test Room	300	140
2	Coffee table, Test Room	190	80
3	Writing desk, Test Room	1200	850
4	Middle of the floor, Test Room	100	45

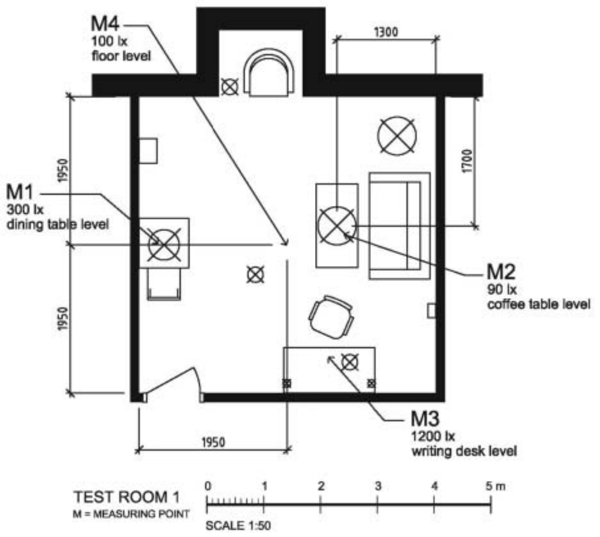

Fig. 8. Coded floorplan.
Horisontal illumination, measurements points in Test room 1

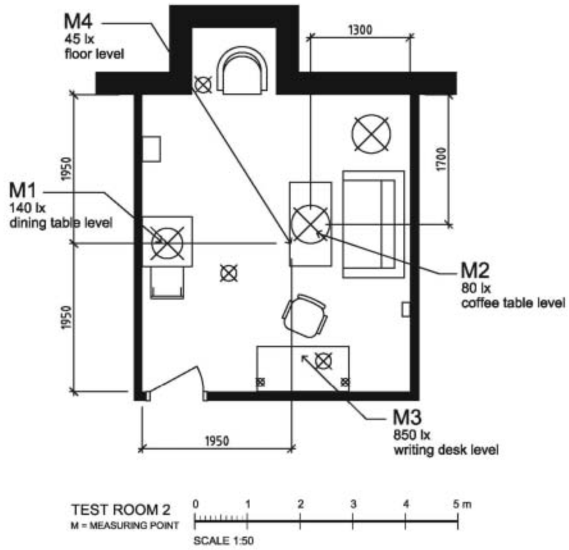

Fig. 9. Coded floorplan.
Horisontal illumination, measurements points in Test room 2

of the complementary ambient light was measured.

Procedures in the visual comfort preference study. 00–00.20: Test subjects were welcomed by research leader and shown into the room. 00.20–2.10: Test subjects sat at a table upon which was white a piece of paper and received instructions on the various stages of the experiment via a tape recording and a loudspeaker. The test subjects began with the control for Dimmer 1 in position 0. They then increased the brightness to the maximum level, before reducing it to a level that they deemed would allow them to comfortably read black letters on a white background that had been affixed to a black fabric. The horizontal illumination strength was measured with a calibrated Hagner luxmeter and recorded by the test leader. The selected level was maintained and the test subject was instructed to increase the brightness of the light in the room by first sliding the control for Dimmer two to its maximum setting before moving it to the level sliding the control for Dimmer two to its maximum setting before moving it to the level with which the test subject felt comfortable. The procedure was done three times.

4.3. Design of the test rooms

All tests were conducted in six rooms. In two of these rooms, light colour, glare and individual preferences for lighting levels were evaluated with regards to levels of light on work surfaces and levels of ambient light. The other four rooms were labelled Test Rooms 1 a and 1 b and Test Rooms 2 a and 2 b. These four rooms will in this text be referred to as Test room 1 and Test room 2. They were completely identical as far as the furniture was concerned, however Room 1 a and 1 b was designed with the same luminaries as Test room 2 a and 2 b, but was equipped with different light sources. The luminaries in Test Room 1 a and 1 b were fitted with LEDs, halogen bulbs and low energy efficient light bulbs, while Test Rooms 2 a and 2 b were fitted solely with LEDs.

4.4. Procedure in the study

The following is the procedure for conducting the study for the test subjects who began in Test

Table 2. Experience of alertness and comfort in Test room 1 and 2 (1=little, 5=much)

	Test Room 1	Test Room 1	Test Room 2	Test Room 2
M=	Alert	Level of comfort	Alert	Level of comfort
The entire group (87)	2,9	3.4	2.5	3.3
Scandinavians (38)	3.3	3.5	3.1	3.2
Central Europeans (22)	2.6	3.4	1.6	3.3
Non-Europeans (27)	2.8	3.5	2.6	3.5
All Women (44)	2,7	3,3	2,5	3,3
All Men (43)	3,2	3,6	2,6	3,3

Room 1. The allotted time was 50 minutes. The test subjects arrived and each were given a folder. They then carried out a test of visual comfort, after which they recorded the light sources they had at home on a questionnaire. They then received oral information about how the trial was to be conducted. An MP3 player in the room gave the test subjects information about the study's activity plan. Evaluation of the fixtures was carried out. Test subjects evaluated whether the light they were seeing in the room matched the light to which they were accustomed at home. They were then asked to state the way in which they were similar and to describe the differences if the light did not correspond with the type they had at home. The test subjects were then asked to record their feelings of alertness, fatigue and well-being using a scale from 1–5 (a little – a lot). The trial was concluded after approximately 50 minutes.

The following is the procedure for conducting the study for the test subjects who began in Test Room 2. The allotted time was 50 minutes. The test subjects arrived and each were given a folder. They then conducted a study of lighting quality by describing the light in boxes 1–5 in their own words. They were asked to evaluate the quality of the light by assigning a score on a scale of 1–10, where 1=low and 10=high. Study of visual variation in the light emitted from the LED replacement light source: The study of visual variation included the test subjects being asked to look at the light source on the wall for 1 minute and then describe, in their own words, whether they felt that the light had changed during the time they had been observing it. They were asked to describe how the light had changed. The test subjects then carried out a glare test. A box with five different filters was placed on the floor. The test subject stood in a marked square, looking at the light in the box. The test subjects were asked to describe their experience of looking at the five alternatively lit surfaces on a scale of 1–10, with 1=uncomfortable and 10=comfortable. The test subjects received oral information about how the trial was to be conducted. An MP3 player in the room provided test subjects with information about the study's activity plan. Evaluation of the fixtures was carried out. Test subjects evaluated whether the light they were seeing in the room matched the light to which they were accustomed at home. They were then asked to state the way in which they were similar and to describe the differences if the light did not correspond with the type they had at home. The test subjects were then asked to describe their feelings of alertness, fatigue and well-being on a scale from 1–5 (a little – a lot). The trial was concluded after approximately 50 minutes. The test subjects then continued to the next room, either Room 1 or 2, depending on where they had commenced the study.

5. RESULTS AND DISCUSSION

The most frequently represented light source in the test subjects' homes was the incandescent light bulb, the least represented was the LED. The test subjects responded more positively than negatively to spending time in Test Room 1, consisting of LEDs, halogen lamps and low energy- light bulbs. The subjects responded less positively when staying in Test Room 2, consisting solely of LEDs. When the subject´s degree of alertness and well-being was evaluated in Test Rooms 1 and 2, the combination of LEDs, halogen lamps and low-energy light bulbs in test room1 resulted in a higher average level of alertness compared to Test Room 2.

Table 3. Values for visual preferences: brightness on a work surface and supplementary levels of ambient light. H=Horizontal illumination, V= Vertical illumination, A= Ambient light

Group	Highest value, H, lx	Lowest value, H, lx	Average value, H, lx	Highest value, suppl. A-light, lx	Lowest value, suppl. A-light, lx	Average value, suppl. A- light, lx
The entire gr. (87)	3900	445	2273	1690	70	453
Scandinavians (38)	3610	445	2122	1620	100	398
Central Europeans (22)	3900	940	2507	1690	100	514
Non-Europeans (27)	3640	520	2257	1000	70	464
All Women (44)	3700	445	2527	1620	100	479
All Men (43)	3900	520	2037	1690	70	428

The results of the study show that the groups, regardless of geographical origin, returned very different individual values with an even spread but similar highest and lowest values when choosing preferred levels of light. The average values for the level of light on the work desk and the supplementary levels of ambient light are also very close. The test subjects' preferences for lighting levels on the work surface, measured as horizontal illumination, indicated a range of 445–3900 lx for the entire group. The range for ambient light was 70–1690 lx.

The results of the study show that when the test subjects assessed the quality of light colour on a scale of 1–10 (low – high), the colours of the light that was measured as 2700 K and 4300 K were ranked as those with the highest quality. Scandinavians deemed the light colour that was measured as 2700 K to have the highest quality, while both Central Europeans and non-Europeans assessed the light colour that was measured as 4300 K as being perceived as having the highest quality.

Differences in evaluation were revealed when preferences for light colour were viewed according to gender. Regardless of geographical origin, women assigned the highest average value for perceived quality at the light colour that was measured as 2700 K. The male subject´s had the highest average for the perceived colour of the light measured as 4300 K.

The level of brightness was assessed on a scale according to the degree of visual comfort, with 1 indicating the lowest degree and 10 indicating the highest degree of comfort. All groups, regardless of division, equated the lowest level of brightness with the highest degree of visual comfort.

Experience of visual variation in the light on the wall

66/84 test subjects felt that the bright LED light source that was used in the study gave a shifting visual pattern on the wall. 18/84 test subjects reported that they did not see any change in the light. The test subjects who reported a change in the light had similar experiences: the light grew in strength, shifted and pulsated.

Evaluation of Test Rooms 1 and 2

Test Room 1 a and b consisted solely of luminaries equipped with LEDs, halogen lamps and low- energy light bulbs. Test Room 2 consisted of the same luminaries but were equipped with LEDs. When the test subjects evaluated their experience of staying in Room 1, half of them reported that the combination of light sources in that room closely resembled the lighting environment in their own homes, while half felt that it was different (41/46). The situation changed when they evaluated Room 2. Fewer thought that a lighting design consisting solely of light from LEDs was similar to the one they had at home and more thought that it was different (36/51).

When test subjects evaluated Test Rooms 1 and 2 based on the lighting environment in which they were staying, their responses to each room were more positive than negative. Test room 2 had a

Table 4. Average values for perceived quality of the colour of the light on a scale of 1–10 (Kelvin)

Mean	2700 K	2950 K	3660 K	4300 K	5350 K
Entire group (87)	7,1	4,8	6,2	7	6,1
Scandinavians (38)	7,8	4,5	6,1	6,8	6,5
Europeans (22)	6,8	5,5	5,8	7,1	5,9
Non Europeans (27)	6,4	4,6	6,7	7,1	5,7
All Women (44)	7,6	4,8	5,7	6,7	6,2
All Men (43)	6,6	4,7	6,7	7,3	6

Table 5. Evaluation of brightness on a surface, 1–10, from unpleasant to pleasant

	1130 cd/ m²	1230 cd/ m²	1670 cd/ m²	3700 cd/ m²	8800 cd/ m²
Entire group (87)	5,5	5,2	4,8	4,2	3,2
Scandinavians (38)	5,1	4,8	4,5	4,3	3,8
Europeans (22)	5,5	5,1	4,8	3,8	2,8
Non Europeans (27)	6	5,8	5,4	4,3	2,5
All Women (44)	5,3	4,9	4,3	4,1	3,3
All Men (43)	5,7	5,4	5,3	4,2	3

Table 6. Experience of visual variation in the light on the wall

	Light changes	Glasses, contact lenses	Light does not change	Glasses, contact lenses
Entire group (84)	66	28/66	18	8/18
Scandinavians (35)	26	13/26	9	6/9
Europeans (22)	15	2/15	7	3/7
Non Europeans (27)	25	11/25	2	1/2
All Women (42)	34	13/34	8	4/8
All Men (42)	32	13/32	10	6/10

Table 7. Evaluation of Test Rooms 1 and 2: like or unlike the lighting environment at home

Test Room 1	Test Room 1	Test Room 2	Test Room 2
Like the lighting environment at home	Unlike the lighting environment at home	Like the lighting environment at home	Unlike the lighting environment at home
41	46	36	51

somewhat poorer distribution between the numbers of test subjects who evaluated it positively or negatively. Room 1 got a positive evaluation from 56 subjects and a negative evaluation from 31. Room 2 got a positive evaluation from 49 and a negative evaluation from 38 test subjects.

Record of the light sources in test subjects' homes shows that a majority of the test subjects (57) stated that they had no fluorescent light bulbs at all in the lighting fixtures in their homes. Only 7 stated that they had no incandescent light bulbs at home. 21 test subjects stated that they had no low-energy lights, 30 that there were no fluorescent tubes in their homes and 26 that there were no halogen lamps in their homes.

The registration of test subjects' visual preferences indicate similarities and differences in their experiences of light from energy-efficient light sources

Table 8. Evaluation of Test Room 1 and 2

Test Room 1		Test Room 2	
Number of test subjects		Number of test subjects	
33	Alike, positive	22	Alike, positive
8	Alike, negative	14	Alike, negative
23	Different, positive	27	Different, positive
23	Different, negative	24	Different, negative

Table 9. Use of light sources in test subjects' homes

Entire group (87)	Not at all	Only in a few	In several	In most fixtures	No answer from the subject
Incandescent light bulbs	7	20	23	34	3
Halogen	27	41	13	3	3
Low-energy light bulbs	21	33	19	11	3
Fluorescent tubes	26	47	9	1	4
Fluorescent bulbs	57	21	5	0	4

which may be derived from physiology, gender and geographical origin. The most frequently represented light source in the test subjects' homes was the incandescent light bulb, the least represented was the LED. The test subjects responded more positively than negative to spending time in Test room 1, consisting of LEDs, halogen lamps and low energy light bulbs. But the respons from the subject´s when staying in the light in Test room 2 consisting solely of LEDs, was compared to Test room 1 less positive. When the degree of alertness and wellbeing was evaluated in Test Rooms 1 and 2, the combination of LEDs, halogen lamps and CFL received higher average values compared to Test room 2.

5.2. Discussion of the method

It is difficult to map visual preferences and experiences according to semantic scales. The test subjects have different interests in and knowledge of observing and expressing their experiences. The fact that measurement of electromagnetic radiation with lux and luminance meters lacks the cohesive visual ability of human sight is an additional difficulty that is encountered during data collection. Despite this, the results obtained from the applied methods reveal a trend and provide a rough indication that makes no claims to be precise.

5.1. Discussion of the results

Data from the study exhibited patterns in visual preferences. These patterns may be due to physiological presumptions, gender and geographical origins. The fact that the subjects have a similar span for preferences of level of light on the surface of the work table and a complementary level of ambient light and that men and women evaluate the quality of the colour of the light so different from each other regardless of their geographical background indicates that the physiological basis for visual preferences breaks through differences that may arise due to geographical origins.

6. CONCLUSION

The study's mappings of the test subjects' lighting preferences reveal that patterns in visual preferences exist. The fact that all groups show a higher estimated average of level of being alert and at comfort in Test Room 1 than in Test Room 2 is a basic pattern of preference. There is also a pattern in the range of preferences for highest and lowest values of lighting levels on the surface of the work table and level of complementary ambient light. Averages from each group that are close in value constitute another visual preference pattern, as

Table 10. Use of light sources in test subjects' homes

Scandinavians (38)	**Not at all**	**Only in a few**	**In several**	**In most fixtures**	**No answ. from the subj.**
Incandescent light bulbs	1	5	15	16	1
Halogen	10	21	6	0	1
Low-energy light bulbs	10	17	7	3	1
Fluorescent tubes	5	29	2	0	2
Fluorescent bulbs	24	10	2	0	2
Europeans (22)	**Not at all**	**Only in a few**	**In several**	**In most fixtures**	**No answer. from the subj.**
Incandescent light bulbs	2	3	7	10	0
Halogen	9	8	4	1	0
Low-energy light bulbs	7	6	6	3	0
Fluorescent tubes	9	9	4	0	0
Fluorescent bulbs	19	3	0	0	0
Non Europeans (27)	**Not at all**	**Only in a few**	**In several**	**In most fixtures**	**No answ. from the subj.**
Incandescent light bulbs	4	12	1	8	2
Halogen	8	12	3	2	2
Low-energy light bulbs	4	10	6	5	2
Fluorescent tubes	12	9	3	1	2
Fluorescent bulbs	14	8	3	0	2
All Women (44)	**Not at all**	**Only in a few**	**In several**	**In most fixtures**	**No answ. from the subj.**
Incandescent light bulbs	2	10	12	20	0
Halogen	10	25	8	1	0
Low-energy light bulbs	12	17	9	6	0
Fluorescent tubes	15	25	4	0	0
Fluorescent bulbs	34	9	1	0	0
All Men (43)	**Not at all**	**Only in a few**	**In several**	**In most fixtures**	**No answ. from the subj.**
Incandescent light bulbs	5	10	11	14	3
Halogen	17	16	5	2	3
Low-energy light bulbs	9	16	10	5	3
Fluorescent tubes	11	22	5	1	4
Fluorescent bulbs	23	12	4	0	4

is the broad distribution within the light preference range. Another readable pattern for visual preference is the assessment of brightness in terms of the degree of comfort and discomfort it engenders. All groups, regardless of composition, equated the lowest degree of brightness on the studied surface with the highest average value for comfort. On average, this degree of comfort was consistent for all groups.

The average value for the judgment of the quality of the colour of the light revealed a gender-related pattern. Women, regardless of grouping, assigned the highest value for quality for the light colour that was measured as 2700 K, while men, regardless of grouping, assigned their highest average value for quality of the colour of the light that was measured as 4300 K.

Geographical origin can in this group not be verified as a factor that influences preferences for working light and supplementary levels of ambient light in the group of subjects. Nor can it be verified as a factor that influences visual preferences for the colour of the light; instead, it is gender that plays a role in that case. Similarly, based on the results of the study, it cannot be said that geographical origins play a decisive role in determining levels of comfort derived from regarding an illuminated surface. Instead, the study reveals broad similarities with regards to general visual preferences, as well as clear, consistent patterns based on gender and human neurophysiology.

In evaluating energy efficient lighting environments, when patterns are detected in the study's data, a stronger preference for staying in light from a combination of LEDs, halogen lamps and CFL rather than staying in light solely from LED fitted fixtures is revealed. This evaluation, in which Test Room 1 is deemed to more closely resemble the lighting environment in the test subjects' home environments than Test Room 2 matches the registration of the actual light sources that the test subjects have at home. LEDs, halogen lamps or CFL is in wide use in their home environments. LEDs constitute the light source that is used the least in the subject's home. In this regard, Test Room 2 also assessed to be least like the test subjects' home environment and the most different. The test subjects who felt that the lighting environment was different from the one they had at home were more negative in their evaluations than those who felt the opposite. This is an important indicator of how energy efficient lighting ought to be designed in order to achieve a high level of acceptance among private users. Patterns for visual preferences lay the foundations for continued work with normal distribution of values for what humans generally perceive as well functioning lighting levels, glare and colour temperature. Together, these become a "human area for visual comfort". This lighting's equivalence to human preferences for temperature or air quality should be further investigated in order to improve knowledge of the issue and to distinguish between physiological and neurological responses, aesthetic preferences, and tradition and individual habits. Increased knowledge of visual preferences may function as a tool for both lighting design and technical development and the private customer at the moment of purchase. The practical consequences of increased knowledge of users' individual preferences for lighting environments may be the further development of lighting design technology. In particular, it may lead to a wider degree of acceptance for energy efficient light sources and lighting applications among private users. It may also lead to a reduction in electricity usage; the reduction target of energy consumption may be achieved sooner than estimated. The results of the study should be regarded as a basis for further studies with a similar focus, but with a refined selection of test subjects, in order to guarantee results that can be applied to general cases.

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