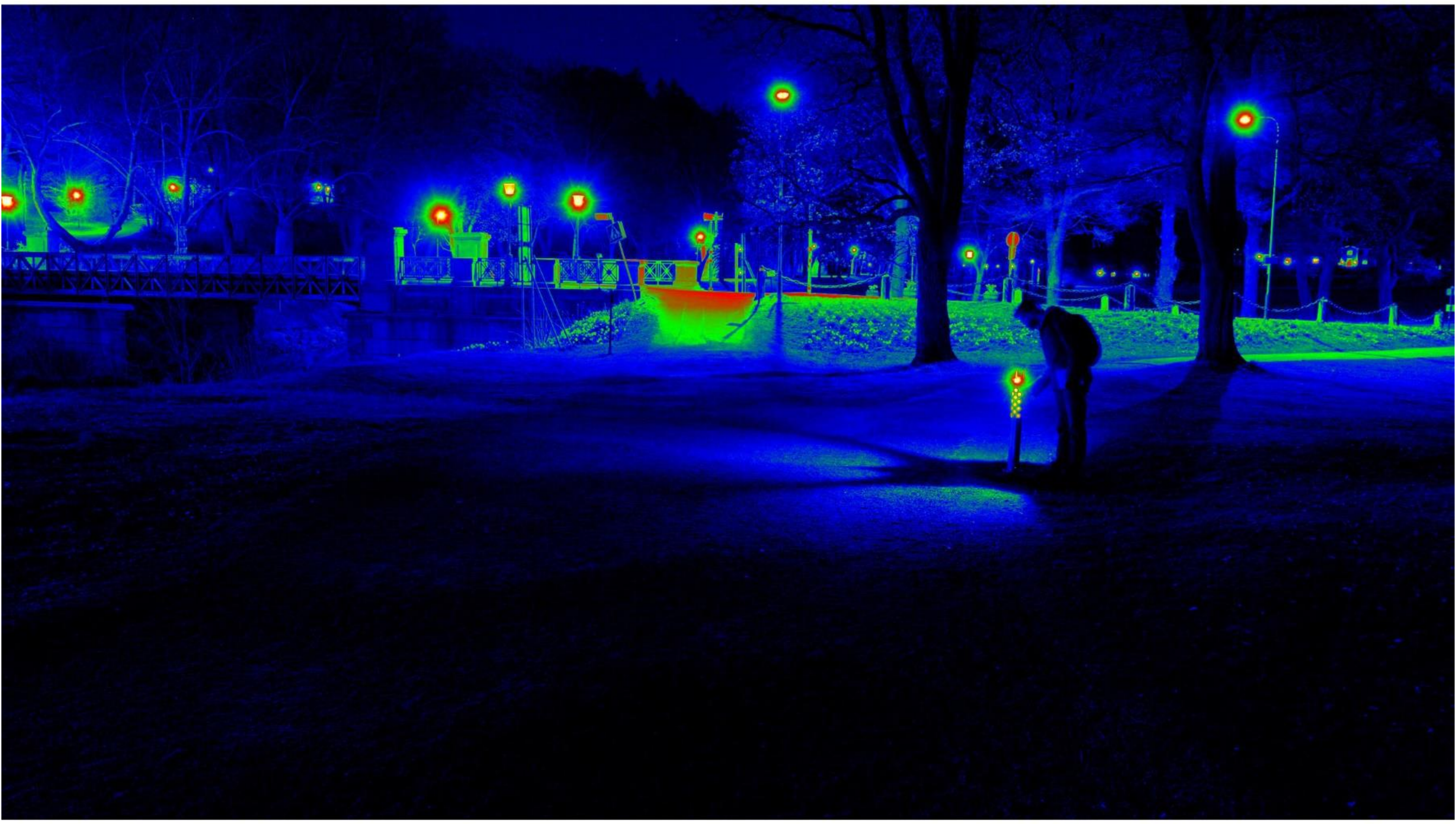
Evaluation of advanced lighting control systems for outdoor lighting

Results from installations at Bromma and Djurgården



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Evaluation of advanced lighting control systems for outdoor lighting

Results from installatons at Bromma and Djurgården

This project was financed by the Swedish Energy Agency as an investigation into the benefits of using Advanced Control Systems in outdoor lighting installations.

The project evaluation is based on observations, interviews and experiences from actual installations part of the public lighting in Stockholm. Installation and evaluation was carried out over the winter 2014-2015

Swedish Energy Agency Project number: *37666-1*

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1. Abstract

The study evaluates the performance of two installations of street-lighting for pedestrians in the Stockholm area. One of the installations "*Bromma*" replaces a standard – static installation with one that can sense motion and adjust the light level according to presence in order to save energy. This installation and the evaluation of it is related to a previous study of an installation: *Advanced Individual Control of Outdoor lighting, Official Final Report - Kungsholms strand project* (STRAGALI & UNDURTY 2013). The other installation "*Djurgården*" is a prototype solar-powered installation which uses an advanced control system and sensors to extend the duration of its battery-powered light. The installations were installed in October/November 2014 and are both accessible by the public, one as a part of the street-grid in Stockholm and the other as a recreational path in the Royal-Park of *Djurgården*. With energy savings in excess of 50% compared to a static installation, without any loss in visual experience shown in *Bromma* and a positive response to the installation in *Djurgården* changing the behavior of users; the benefits of having an advanced control system managing installations are clear and some guidelines are starting to materialize as to how these systems should be set-up in order to achieve the best results.

Den här studien utvärderar två installationer med gatubelysning på gång/cykelväg i Stockholmsområdet. Den ena installationen är i Bromma och ersätter en befintlig installation med en installation som känner av närvaro och kan justera ljusstyrkan efter behov i syfte att spara energi. Denna installation bygger vidare på ett tidigare projekt längs Kungsholmsstrand och de resultat som presenterades i rapporten: Advanced Individual Control of Outdoor lighting, Official Final Report - Kungsholms strand project (STRAGALI & UNDURTY 2013). *Den andra installationen på Djurgården är en solcellsdriven installation som använder avancerad styrning för att förlänga den batteribaserade driftstiden. Båda installationerna blev klara i oktober/november 2014 och är del av den offentliga belysningen i Stockholm och på Djurgården. Resultaten visar att en energibesparing på över 50% utan märkbar effekt på de visuella förhållandena kvällstid i Bromma är möjlig och att en stor majoritet användare på Djurgården är positiva till installationen - vilket också har visat sig i mer besökare kvällstid. Fördelarna med att ha avancerad styrning av gatubelysning är tydliga och vi börjas dessutom förstå hur vi kan ska hantera olika variabler för att få det bästa resultatet.*

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2. Background

2.1 Introduction

Urban-lighting on bicycle/pedestrian paths and in parks is a vital part of the infrastructure of a modern city. In the city of Stockholm there are approximately fifty-thousand luminaires illuminating parks and paths. It would be very difficult for people to go about their daily business without them – as in winter there can be as little as 6 hours of daylight. So there is clearly a need for illumination. But there is also a great drive to save energy on lighting and if the energy consumed by these luminaires could be reduced by 50% it would save 4 000 000 kWh every year.

Energy efficiency is already being improved through the change to LED-luminaires instead of older more inefficient technologies, but can we go even further without reducing the quality of lighting? Changing to LED-luminaires addresses the way the light is created - but it also changes the way we can control the luminaire. Because the LED-light source does not mind rapid changes in intensity, it is of interest to look at how illumination can be matched to the need for it, as a way to further energy savings.

There is a need for illumination but the need varies. The most obvious variation is of course between day and night and this has for decades been addressed with the use of daylight sensors or by setting timers to match the day/night cycle.

To further match the need one can see it as a function of the activity of the people using the path. By declaring certain times of the night “low activity”, and accept lower visual conditions during these hours, one can set all lights to dim down to e.g. 80% in a “night mode” - thereby saving energy.

But if we can measure the real time activity on the path and control the light in real time, then in theory we can always save energy – except when someone needs the path to be lit. To test how this could be implemented and evaluated a project *Kungsholmsstrand* was completed in 2013 with the help of the Swedish Energy Agency using advanced control systems, sensors and LED-luminaires along a pedestrian pathway in Stockholm. The results were promising with a “scenario” resulting in a 40% reduction in energy by using advanced control system - furthermore there was no negative reactions compared to a static installation at 100%.

In order to verify the results and see the reaction of even more energy saving scenarios another project was approved in 2014 – now evaluating two new installations. One similar to the *Kungsholmsstrand* setup but with further integration of components and in a more suburban part of the city where the surroundings are darker at night. In parallel another installation will be evaluated along a recreational path in a nature preserve. This installation is using solar-panels and batteries to generate and provide energy without the need for extensive ground-works for cables, which is felt as too intrusive in this area. In order to optimize the use of available solar-energy an advanced control system is considered a requisite for this type of installation to be able to function throughout the winter as far north as Stockholm.

2.2 Project Partners

Both Installations

Sustainable Innovation - SUST

Sust is founded by leading companies in collaboration with the Swedish Energy Agency. Sust deals with sustainable energy solutions with leading companies, entrepreneurs and researchers aiming for direct results, environmental benefits, cost savings and energy efficiency.

Role:

- Project management and coordination of the project
- Research expertise and research contacts
- Administration of grants from the Energy authorities
- Evaluation (planning, implementation and reporting)
- Common external communication about the project.

Royal Institute of Technology – KTH

KTH Royal Institute of Technology in Stockholm is the largest and oldest technical university in Sweden. The Lighting Laboratory at KTH is responsible for education and research within the area of architectural lighting design.

Role:

- Evaluation of lighting installations
- Research expertise
- Summarizing results into recommendations for the research community and future installations.

Bromma Installation

Fagerhult

A Swedish based company that is one of the leading lighting groups in Europe. They develop, produce and market professional products with a focus on lighting in the public domain.

Role:

- Lighting expertise

- Developing/delivering products as per the project requirements.

Tritech

Tritech is involved in the development, management and production of industrial products in the field of M2M (machine to machine).

Role:

- Development and adaptation of the control system for individual control and presence control.

- Operation and support of control systems during the project period.

- Energy measurements during the project period.

Stockholms stad

The Municipality of Stockholm is responsible for development and maintenance of infrastructure within the city. *Trafikkontoret* is the department responsible for the lighting and both the *Bromma* and the *Kungsholmsstrand* installations are a part of their domain.

Role:

- Construction owners and specifying requirements for lighting solution.

- Responsible for the installation supervision.

- Concerned organization in dealing with the public.

Djurgården Installation

Kungliga Djurgårds Förvaltningen

The park *Djurgården* is a part of the Royal Estate and managed by its own management within the Royal Court.

Role:

- Construction owners and specifying requirements for lighting solution.

- Responsible for the installation supervision.

- Concerned organization in dealing with the public.

Active Lights

Leading Light AB is an independent Swedish company which develops, manufactures and sells high quality luminaires. They are specialized in the area of LED and Solar-powered products.

Role:

- Lighting expertise

- Developing/delivering products as per the project requirements.

- Operation and support of control systems during the project period.

- Energy and activity data collection during the project period.

2.3 Project Structure

Figure 1 – Project partners and respective areas.

2.4 Kungsholmsstrand Report

The project builds on the experiences from a previous study of an installation at *Kungsholmsstrand* and especially the installation in *Bromma* can be seen as a continuation of this study where we use the best scenario from *Kungsholmsstrand* as a benchmark. The report : *Kungsholmsstrand – Advanced Individual Control of Outdoor Lighting* (Undurty, 2013) established that there was an acceptance for sensor driven dynamic scenarios and found a best scenario among a selection for use on that type of path. The variables used to modify the scenario have been kept the same in this study, but since there was no clear indication which effect individual variables had and that the limit for saving power using this setup had been reached, the indication was that there is room for further energy-savings before user opinion is affected. In the new installation at *Bromma* we test the findings from *Kungsholmsstrand* on a different path with regards to intensity, surroundings and users, we can also modify upon the most efficient (saving and user opinion) scenario (#4) to learn even more about individual parameters and what effect they have on energy saving and user opinion. As a rule "any energy saving scenario which does not affect the user opinion compared to a static scenario on full effect" is a good scenario – but it does not tell us anything about the individual parameters effect on users. As the scenarios tested in the *Kungsholmsstrand* study were more or less similar in response and close to that of the 100% scenario – it was decided that we should include more provocative settings in our study in order to get more information from the response of users. In order to equalize the results of the energy-measurements with regards to differences in the length of the night, the results presented from the energy-measurements at *Kungsholmsstrand* were kept between 18:00 and 06:00. This makes the use of energy reflect an average night on the path and will be comparable to the conditions of installations on other latitudes than 59° North. However it does not include the times of day when people are most active on the path – which is when they are going to work and coming home, the time between 06:00-08:00 and 16:00-18:00 are peak hours for activity on the path. In this new study we wanted to be able to directly compare our results to the findings at *Kungsholmsstrand* but we also wanted to have the most accurate measurements with regards to the actual conditions on the path. To exclude the peak-hours would give a better result in the percentage of energy saved, which is how we primarily present the result, but the total energy saved is arguably the more interesting number and as we will see, the installation saves energy at all hours – even during peak intensity. It was decided to increase the interval included in our energy measurements to between the hours of 16:00 – 08:00 with the knowledge that this will affect the comparison with *Kungsholmsstrand*.

3. Installations

3.1 Site analysis

Bromma

A paved path for pedestrians and bicyclists; mainly used by people who live in the surrounding area to get to and from the local transportation-hub which is located in a small square with shops. The path is situated on the fringe of a small forest with dense foliage to one side; together with short visual distances along the path because of turns and elevations this creates a feeling of it being narrow and more rural than the surrounding area. A few people said, in the daytime, that they felt uncomfortable using the path at night. The path has been lit by the municipality using 4m poles with a distance between poles of approximately 24m – these poles will be reused for the new

Figure 2 – *Bromma* before new installation

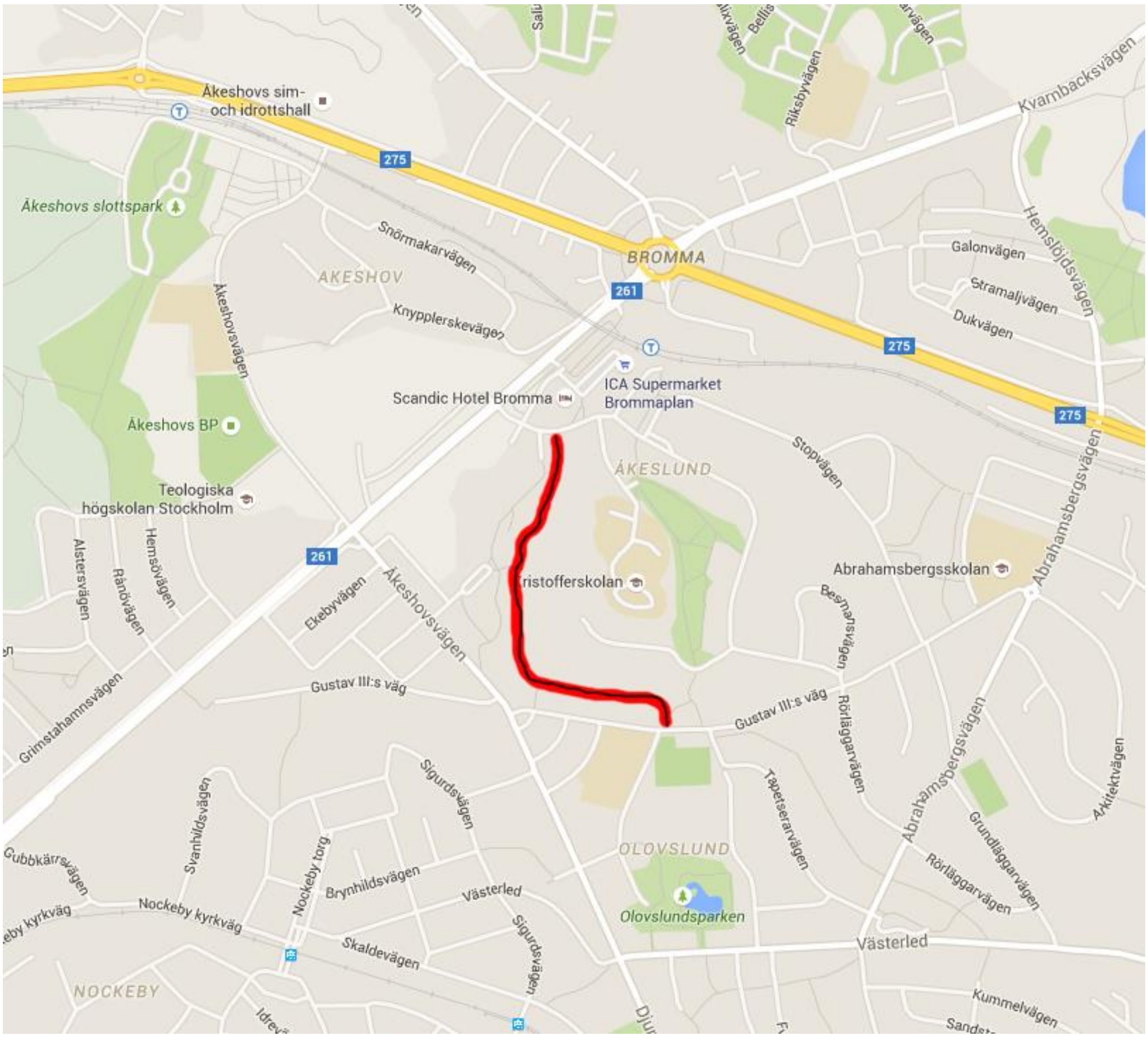


Figure 3 – Map of *Bromma* project

installation. The previous fixtures used mercury-vapor lamps with a slightly asymmetric light-distribution along the path. Apart from the two main entrances to the path, one at either end, there are two connecting paths, plus an area where the path and a residential area are adjacent to each other.

The entrances are both affected by other installations, the northern one by metal-halide street-lamps from the road running at a right angle and the southern from 6m LED-poles that provide extra illumination for the crossing of the street "Gustav III:s väg". The connecting paths are smaller or same size as the path and are illuminated similar to the previous installation; in the area where the residential housing is close to the path there are cooler white LED-poles for the courtyards and parking areas that spill some light onto the path. This is important as light adaptation can differ depending on from where one enters the path and the appearance of the path from a distance, as either dark or bright, may require different levels of light depending on the surroundings. Also the northern entrance is straight with a longer line of sight compared to the southern which curves to the left almost immediately. The appearance of the path changes considerably with the seasons and in summer, when the trees are lush, it is in places walled by vegetation which should perform as a reflector for light extending outside the road surface - providing some illumination on the vertical plane and contributing to a more balanced lighting composition.

Figure 4 – *Bromma* installation (Photo by: Lennart Johansson – Stockholm Municipality)

Djurgården

Recreational path along the water in a natural preservation area. A few houses and some benches along the path. Mostly used by people walking or running in order to exercise and/or experience a bit of nature, users of this path do so by choice rather than necessity. The surroundings are dark at night to the level that on a clear night the moon will provide visible illumination and on an overcast night the sky above Stockholm to the west will appear bright. The path entrances are illuminated by the connecting roads meaning that dark adaption is affected when entering the path from either end. The beginning of the path is fairly open on both ends with respect to sight distance but as one walks along more foliage and turns create a winding path through nature; about halfway along the path there is a long straight with fields on both sides where there is lots of sky overhead - at dusk or at full moon the natural light is enough to see the path and the surroundings if ones vision

Figure 5 – *Djurgården* before installation

is adapted to the dark. There are several points of interest along the path, especially the views across the water which should be considered when designing the installation and the level of illumination. It is the surroundings which makes this path popular, not only that it connects point A to point B; therefore it is important that the illumination should keep with the character of the path.

Figure 6 – Map of *Djurgården* project

Figure 7 – *Djurgården* installation.

(Photo by: LeadingLight AB)

3.2 Technology

The "Advanced Lighting Control System" uses a combination of sensors and the ability to communicate to control a number of variables across the installation. Equipped this way, the extra hardware makes the installation responsive in real-time to changes in its surroundings. The response to these changes is chosen through a number of variables which can be altered by the designer. How these variables affect the use of energy compared to the effect they have on the visual-quality/user-opinion is not fully understood, so we follow what we know from static-installations and what was found in the *Kungsholmsstrand Report*. The basic workings of the installations is that poles have sensors that can detect presence, antennas for communication and that the luminaires can alter individually between levels of light output. The principle uses the following logic for each individual luminaire (figure 9).

Figure 8 – Lunova with antenna & sensor

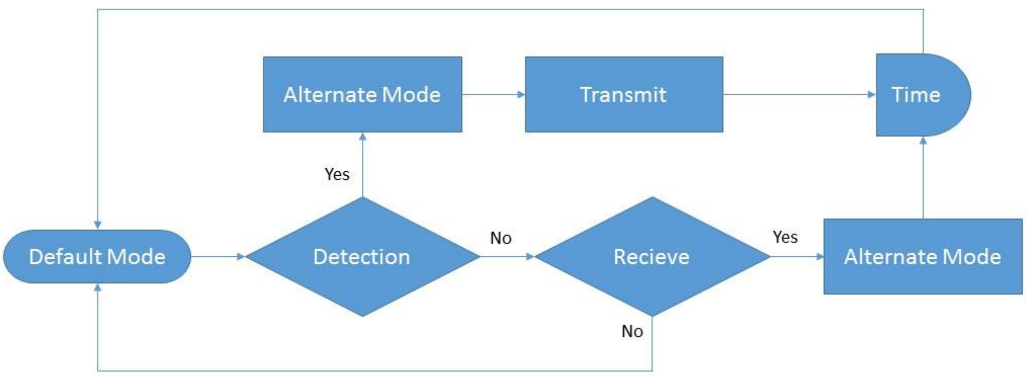


Figure 9 – Logic flow chart

The actions taken after decisions in the flowchart can be altered by variables:

Default Mode = "Low light level" from 1-10

Alternate Mode = "High light level" from 1-10

Time = Time to stay at "High light level" before dimming to "Low light level" in seconds.

Transmit = Number of poles (n) to transmit to in either direction (figure 11).

Delta = Rate of change in light output when switching between the two modes "High light level" and "Low light level".

(The actual software logic is more complicated as transmitted commands are repeated by all poles in the installation and individual poles know the position they have in the installation and can decide if the command applies to them).

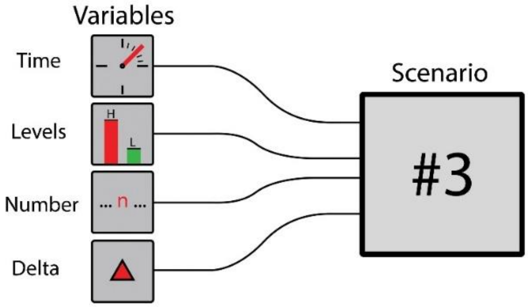


Figure 10 – Scenario variables

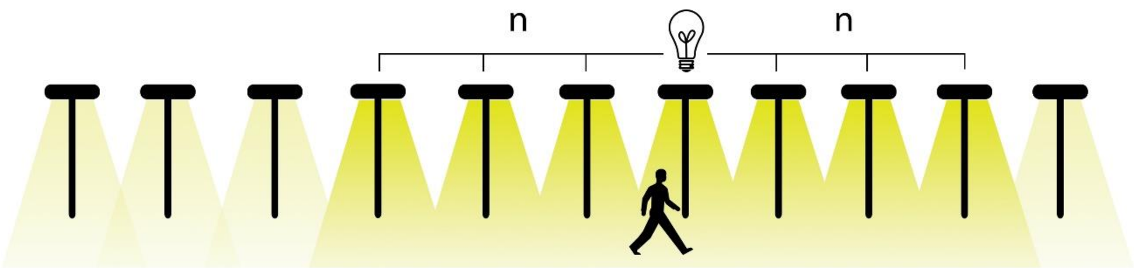


Figure 11 – Number of lights ahead and behind

Bromma

The grid-connected installation in *Bromma* uses "Lunova" LED-luminaires with low glare (indirect illumination) - symmetrical distribution (figure 12) 3000K, 3000lm, 56 W, CRI=81.

Added to the standard luminaire is a small Passive Infra-Red (PIR)-sensor that detects motion in the vicinity of a few meters radius and an internal antenna for short range wireless communication (figure 8 & 14).

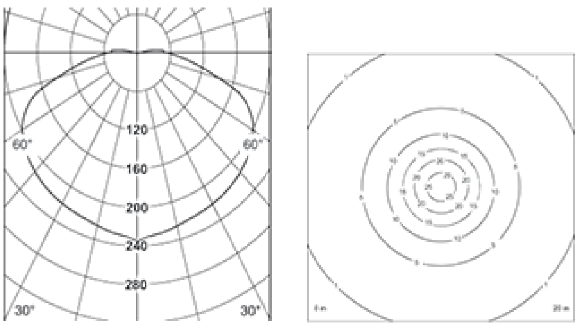


Figure 12 – Light Distribution Lunova

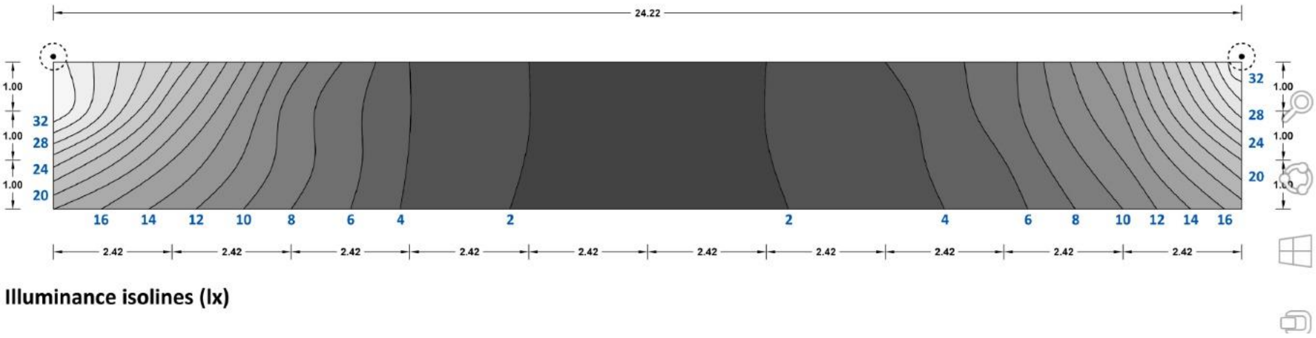


Figure 13 – Isolux diagram of *Bromma* at 100% (lvl 10)

The installation has 32 luminaires, spaced at 24m apart, that can be individually controlled, detect presence and communicate with its nearest neighbors who pass on the information so that the whole installation share information. The protocol for how they should respond is implemented via a central control-unit which is connected to the internet using an interface for changing overall and individual parameters (figure 10). Different protocols are referred to as "Scenarios".

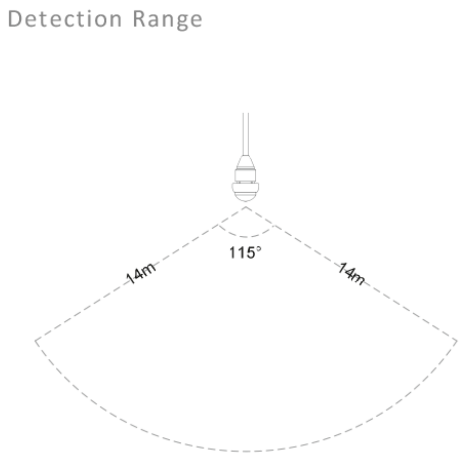


Figure 14 – Detection range of PIR sensor

Djurgården

The solar powered installation in *Djurgården* uses a combination of 42 LED-poles and 32 LED-bollards, they are placed in homogenous intervals where the bollards are used on sections such as an open field or when the path runs next to the water with views of the city or the other shore. Distance between poles is approximately 20m and between bollards 15m. The LED-light source is positioned at 4m elevation on the poles. Both the posts and bollards have a solar-panel and a battery in each fitting, no power connection exist between individual luminaires – so no sharing of power. Two PIR-sensors enable them to not only sense presence, but also direction of the person moving past. Radio communication is used between fittings to light up the path ahead in the direction of motion. The LED-poles

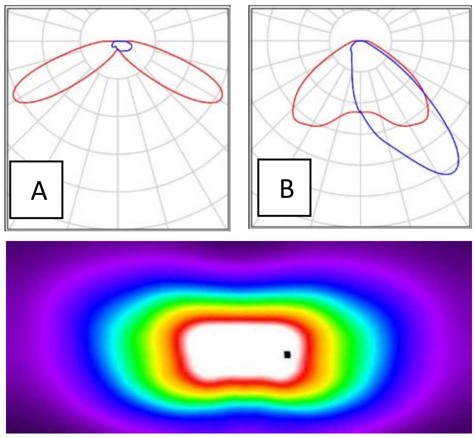


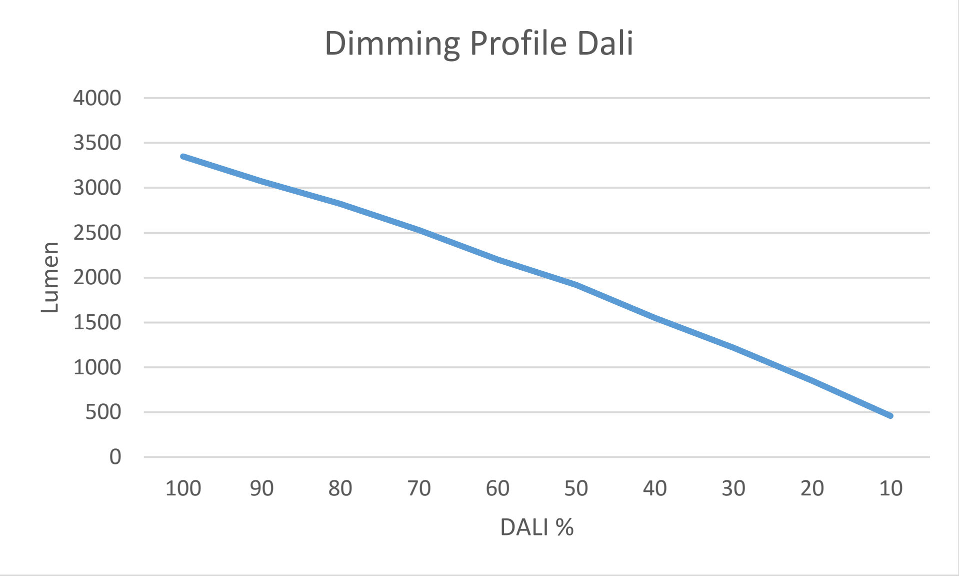
Figure 15 – Light Distribution Leading Light

have a maximum output of 700lm at 10W, 3800K, CRI=76 and the bollards have a fixed output of less than 1W. The LEDs in the luminaire are a combination of type A and B (figure 15) - providing asymmetric light distribution on the path as shown in the false-colour rendering.

3.3 Setup

Bromma

The DALI-controlled dimming was segmented into 10 steps; each corresponding to a decrease of 10% in measured light intensity, meaning that the dimming between 10-0 is approximately linear.



DALI %	V	A	W	LM
100	227	0,267	59,5	3350
90	227	0,243	53,3	3070
80	227	0,221	48,1	2820
70	227	0,195	43,0	2530
60	227	0,173	37,2	2200
50	227	0,152	32,1	1920
40	227	0,129	26,5	1550
30	227	0,109	21,6	1220
20	227	0,090	16,3	850
10	227	0,081	11,0	460

Figure 16 – Dimming Profile and DALI Settings

The time to execute a new dimming command was set to 4s – regardless of the number of steps involved, this means that the rate of change in light intensity can vary between different scenarios.

We have 2-modes for the installation called HIGH and LOW – switching between them is the principle behind saving energy; how these levels should be configured, how we switch between them and when it is best to run one or the other setting is what we are trying to determinate. HIGH will be triggered by sensor detection or by radio command from another pole, LOW will be the default setting that an individual pole will fall back to after not receiving any trigger event or command for a specified TIME.

With scenario #4 from *Kungsholmsstrand* as a benchmark for our scenario #1 at *Bromma*, we have the NUMBER of poles to light-up ahead and behind the pole that detects presence set to 3 – a total of 7 poles (3 ahead, 3 behind, 1 triggered) where possible (figure 11). The exception being where there are intersecting paths, as we cannot detect direction, we light up the connecting paths – 3 poles in all directions to cover all possible routes that can be selected (figure 17).

To handle exceptions to this setup - e.g. where we do not want to dim a certain pole, we have SPECIAL POLES. At *Kungsholmsstrand* the 3 first poles in both ends of the path had a higher LOW - setting in order to create a smooth transition between the connecting installations and not give the impression of a dark path from a distance, before a person enters the path. The installation can be accessed via a web-interface *meshnet* (figure 18) where these variables can be changed for groups or

Figure 17 – Poles ahead at crossings go in all directions – as the direction of users is unknown

individual poles. Energy usage is measured and collected every 15-minutes from the lighting power-usage for the whole area, ideally we would have an independent power supply just for this installation but it was not possible. Because there are other installations on the same power-line we have measured the static-load of these and it is subtracted from the measured in order to obtain the energy consumption for our installation. In practice this means that if the load on the other installations were to change suddenly this could affect our data – to counter for this we monitor the behaviour of the installation with regard to what is reasonable; power usage above or below max-min threshold of the expected load with our current settings is a flag, e.g. if there is a sudden drop in power usage at 4am, when there is no one on the path so we are in LOW-mode, this could indicate a broken lamp in another installation which gives us incorrect data if not accounted for.

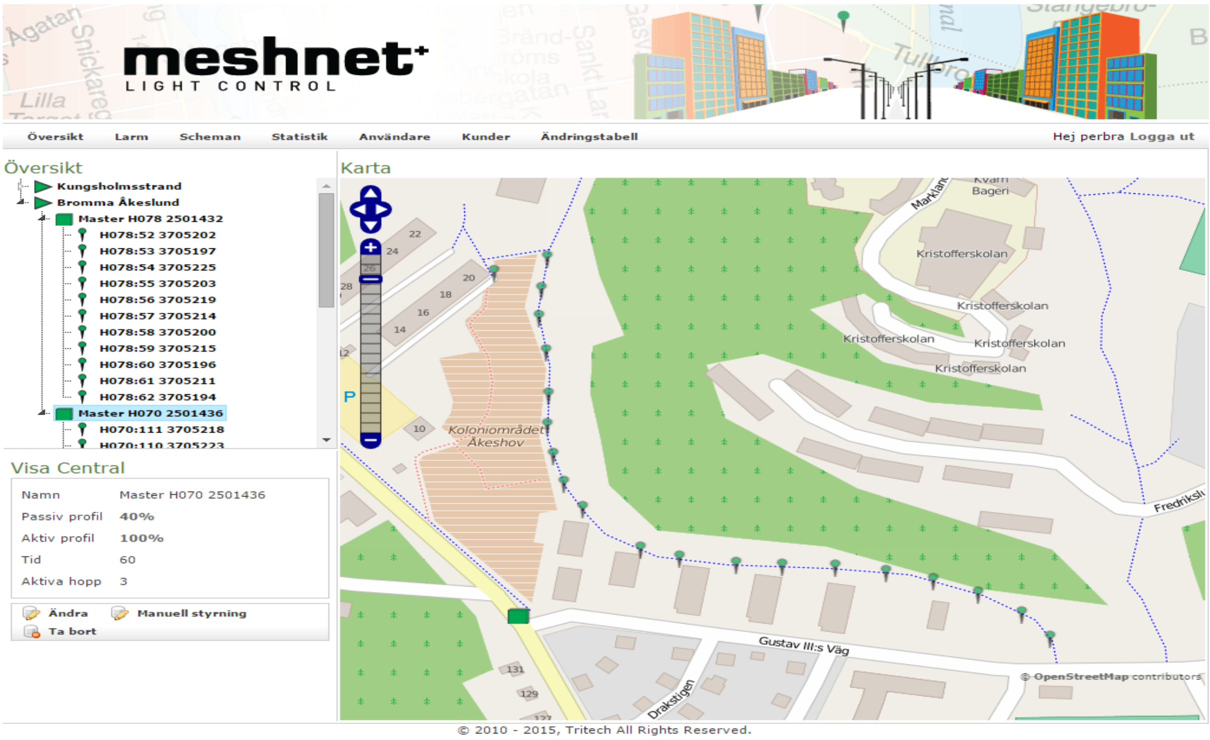


Figure 18 – Control system interface

Djurgården

The installation is a combination of poles and bollards, where poles are the default lighting along the path. Bollards were chosen where the path opens up to views across the water or where the surroundings are open fields with few hiding places and the overhead sky providing some natural illumination on clear nights. Since we do not have a comparable study as a benchmark for this installation, as *Kungsholmsstrand* is to *Bromma*, we did not test different scenarios as such; we tried to find one scenario that balances the available energy from the solar-panels with the usage in order to see how that one scenario is performing. At *Bromma* we tuned the installation to the response from the users – here we tuned the installation to the technical constraints and then looked at the response from the users.

The setup for this installation is more towards power saving compared to *Bromma* and as we can tell the direction that the user is moving in, only 3 poles or bollards light up – the one triggered by movement and two more ahead in the direction of travel. The principle of switching between HIGH and LOW setting in order to save energy is applied but the LOW is at its most extreme setting – OFF. Ideally one would like to have some light at LOW level to signal that the path is lit, even when there is no presence detected, in order to communicate that there is a lighting installation. To mitigate this the first poles at entrances to the path are grid-connected and set to static HIGH – they will "invite" users to enter the path and detect presence without flashing ON from the OFF position which could be a negative user experience when entering an installation without this setup. The time to dim from HIGH to LOW, and vice versa, is 2 seconds for the poles and 1 second for the bollards.

Although the poles have a maximum output of 10W the initial setup was 4W for each luminaire as this provided a longer time of use. Because of higher number of people using the path than expected, combined with low hours of sunlight in the months after installation, it was decided to lower the output for the poles to 2W after eight weeks.

The battery in each pole needs approximately 20 hours of sunlight to reach a full charge (from empty) – but given that individual luminaires can be shaded e.g. by trees or houses; the actual hours of sunlight available to individual luminaires will vary - and even if the variation is small over the course of one day, it can add up over time into large variations in available energy during periods of higher energy demand than supply. A solution to this is to replace the batteries across the installation with fully charged ones during the winter months.

4. Evaluation

4.1 Objective

What makes both these installations advanced is that each individual luminaire can detect motion and is able to adjust its output and communicate with neighbors to create a scenario, involving multiple luminaires, for the lighting which is adapted to the need for illumination. The solar-installation is able to detect direction as well due to the application of two sensors per luminaire.

Light can therefore be projected where and when it needs to be and at a certain amount also – but how does this conform to the requirements of the user?

The focus of the evaluation is to provide a better experience for the user and look at energy saving. In the case of the solar-powered installation, saving energy is directly related to the user-experience as it increases duration of use between charges. It is not an evaluation to see if certain standards are met, but rather to investigate and observe the visual conditions at each location so that the users own experience is taken into account.

We are interested in the user experience as we see this as a direct result of the performance of the lighting installation as a whole (luminaires, control-system, sensors...etc.) and we are interested in what savings in energy we can have using the installations sensor-driven dynamic properties to closer match the users need for illumination thus providing a better experience than other energy saving options.

Some of the areas we want to investigate are: What is the effect of dynamically reduced light-levels by scenario on user opinion or usage? What are the effects of changes in individual parameters of a scenario? How much energy can we save and still have similar performance to that of a static installation with regards to user opinion/experience. What are the effects of different scenarios on different types of users – e.g. cyclists or people walking their dog? At what level do the users detect changes in light from a dynamic installation? What are the effects of dynamic scenarios on the visual appearance of a path from a distance?

4.2 Method

Bromma

In order to obtain both qualitative and quantitative data, and following the same general principle as in the *Kungsholmsstrand*-project, the method of setting different scenarios and measuring variables was chosen. By measuring energy usage, luminance, illuminance, and complementing these with expert-observations and most importantly user-surveys we will try to find out how different variables in a scenario affect the actual conditions on site and user opinion of the visual conditions for each scenario. By only changing one or two parameters between each scenario it is possible to get an idea of their effect on this installation and take that into consideration for future scenarios.

Scenarios include the following variables:

Light level: Light output is linear and divided into 10 segments where: 1=10%, 2=20%...10=100%. Two levels are set - Active (high) and Passive (low)

Number: Number of luminaires that become active in both directions from the "triggered" luminaire: 3=a total of 7 active luminaires when a sensor in the middle of the path is triggered – 3 in front, 3 behind plus the triggered one. (figure 11)

Time: The duration at which a luminaire remains active after being triggered or receiving a command over radio. Also described as *time* in (figure 10).

Special poles: Luminaires that have a different setting to the standard scenario e.g. the entrance or exit of a path can be affected by surrounding lighting installations and in order not to appear dark a higher value is needed for the passive setting.

In the evaluation of *Kungsholmsstrand* none of the scenarios had a negative response from the users so it was decided that we would use the most energy-saving scenario from that study as a benchmark and then be even more aggressive in our approach for this study in order to try to provoke a response.

#	Higher level	Lower level	Special poles (3 at each entrance)	Number of luminaires ahead and behind	Time duration at higher level	Lower intensity at low activity time zone (i.e.23.00-5.00)
#0	100%	100%	n/a	n/a	n/a	no
#1*	100%	50%	Yes (70%)	3	60"	no
#2	100%	30%	no	3	30''	no
#3	100%	20%	no	3	60''**	no

Figure 19 – Scenarios (*This scenario is the same as scenario #4 in the *Kungsholmsstrand* study.)(**Intended to be 30 but changed to 60 after negative result of #2 user survey.)

A parameter not varied in the scenarios but important to the experience of a dynamic installation is the rate of change between different light levels – in our installation time is constant (4s) and "Δ-Light" is variable which will mask small changes compared to large ones. Maximum rate of change (10 to1 or 1 to 10) is 675lm/s and minimum (n to n+1 or n-1) is 75lm/s.

The people using the path (users) are the primary reason for illumination on the path so their opinion carries great weight when evaluating different scenarios. Because this is a path that connects a residential area with communications into the city it is important that the visual conditions are good and that people feel safe as far as possible. When evaluating the scenarios we began with 100% static as Scenario #0 – which means that we are coming down from the highest possible light-levels in order to have this as a reference by those that use the path often. Questioners were used to collect data from people using the path, these were handed out at different times but at a time when the installation was running at approximately the middle of the path and people were informed that they were participating in an evaluation of the lighting installation.

A focus group of experts was chosen for comparing how different levels of light-settings matched up to visual perception, the procedure followed a protocol where we the participants were asked to estimate the level of light from 1-10 of a random setting. Each setting was preluded by 100% for a few seconds then "off" for a few seconds and after this the luminaire dimmed-up to the random setting. All the settings from 1-10 were displayed once in random order.

The focus group was also used to evaluate the lighting conditions at entrances to the path at different settings and the effect this has on the appearance of how the path is perceived from a distance. Conditions at entrances are affected by the light-levels of the path or street they connect to which can be either darker or brighter than the conditions on the path itself. The evaluation was performed by increasing the light level from 0-10 and asking participants, viewing the path from a short distance away in the illumination of the surrounding installation, to note when the light matched the surroundings and the path appeared well lit.

People who chose not to enter the path will not show up in the evaluation, e.g. if the passive-settings are too low, the path could appear dark from a distance at low activity hours and people who avoided using the path for this reason would be excluded leading to a false approval rating. Evaluating the entrances does not eliminate the possibility of this being a factor in the survey, but it gives a reference to how much of a factor it can be for each scenario.

Djurgården

This path is different and so is the evaluation. We did not look at how to maximize energy savings while keeping the same or better visual conditions compared to a static installation as we do in *Bromma*. All the energy is already created by the sun so we are free to use as much as we can but because we are situated as far as 59°N, the mean monthly sunshine hours for December are 33, not enough to provide high levels of light for any duration of time. Here the question is how an installation with very low light-levels and only active for a few hours after sunset will be perceived. Since it is a large park on the outskirts of the city it becomes quite dark at night and there is no need to use the path other than recreational. The need for illumination differs and for this evaluation it can be seen as a case of finding a scenario that works, from a technical perspective, and then see how people experience it. The installation started out at 4W for poles (bollards are static) but it was decided to lower the output to just 2W for each luminaire.

The scenario used is much more abrupt compared to *Bromma*, the biggest difference is that the low-level is 0 (off). 3 luminaires or bollards light up in the direction that you are moving and the time to reach the next sensor is 20 seconds before it turns off. This has the effect that if you stop for a short while or are walking very slowly you can end up in darkness.

Three separate surveys were performed; one in September during daytime before the installation, one in November in the evening, when the installation was newly installed, and running at 4W/luminaire. The final survey was performed 4 months later, during the day, after the installation had been running at 2W/luminaire for 3 months.

4.3 Light measurements

Bromma

The lux levels between two luminaires was measured at 100% and at other settings proving the relationship between the settings in the control system to be proportional to the change in light output. Also the CRI value of 81 did not vary with changes in light output but proved to be constant. Luminance photography at different settings were taken to compare conditions on the path and its surroundings (figure 20).

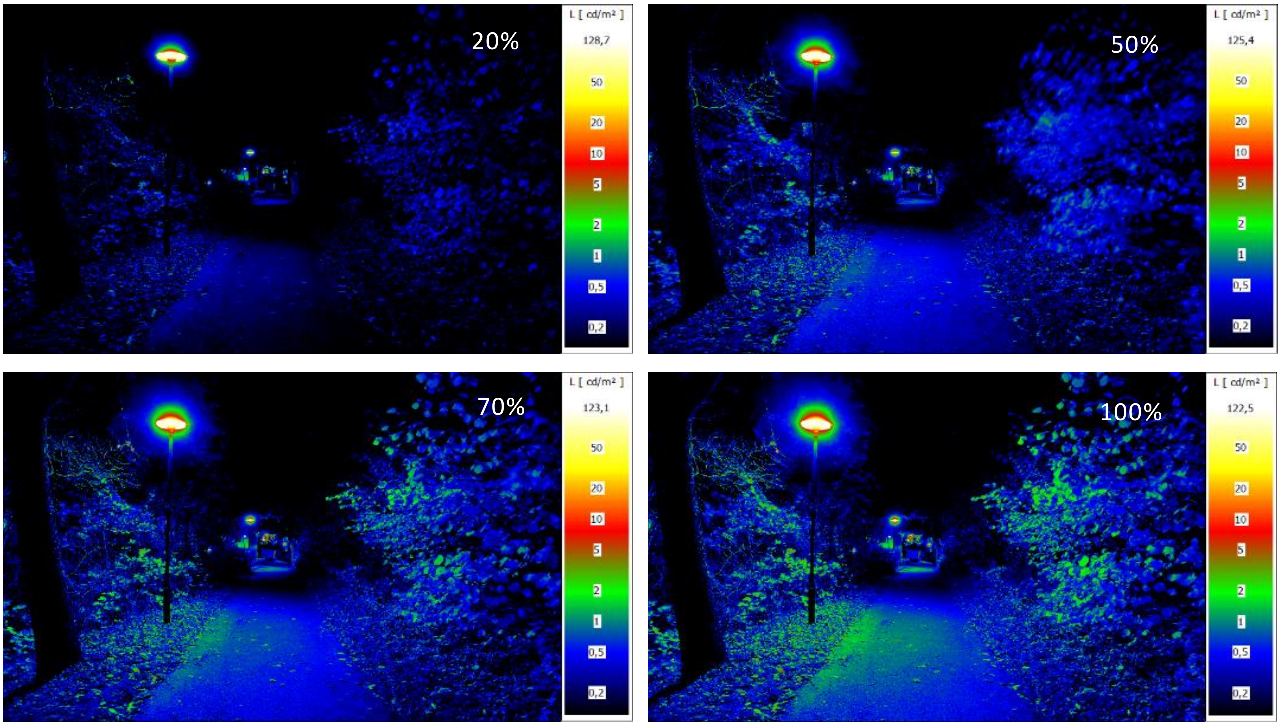


Figure 20 – Luminance photos at levels 2, 5, 7, 10

Djurgården

Luminance photography taken before and after the installation (figure 21) show that although the light levels are low, 2-4W per luminaire, the path is in a relative dark area which gives an illuminated feel similar to that of a full moon on a clear night. Illumination directly underneath a pole is about 2 lx at 2W which is not enough to see colours but enough to see objects on the path and the condition of the surface e.g. if it is dry or wet.

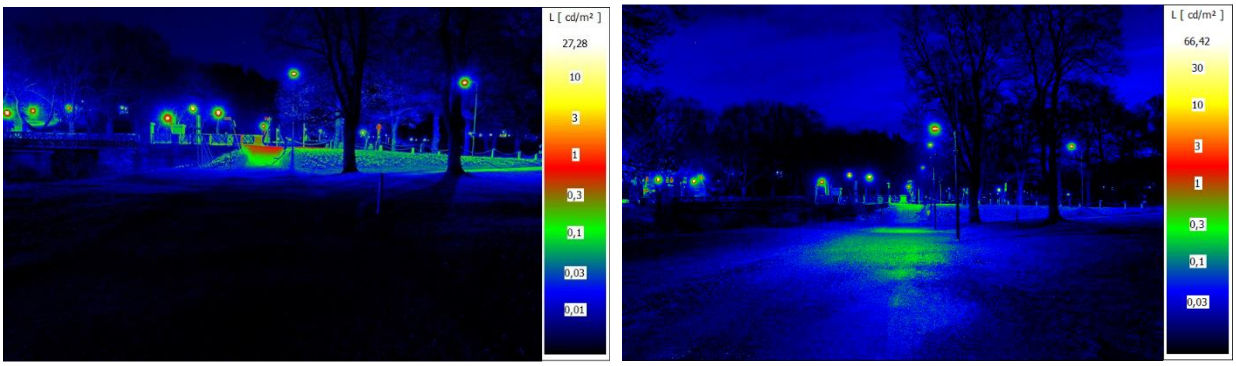


Figure 21 – Luminance photos before and after installation at *Djurgården* (colour scale not matched)

4.4 Surveys

Bromma

The focus group survey, with five participants, of the visual appreciation of light at different levels showed that for light levels below 50% there was a tendency to overestimate (Y-axis) the light output compared to the actual setting (X-axis) (figure 22).

When evaluating the conditions at either entrance it was found that the Northern entrance matched the surroundings at 30%, but the Southern entrance needed 50%-70% before it was judged as “well lit and matching the surroundings”. This shows that although a uniform scenario, without special settings for individual luminaires, is easier to implement and standardize – an optimization of both quality and energy saving cannot be achieved fully and on all paths without it. However what effect this has on the perceived quality of the visual conditions and what the added complexity would mean for the general acceptance and implementation of advanced controlled lighting installations is not known and could be a topic for further study.

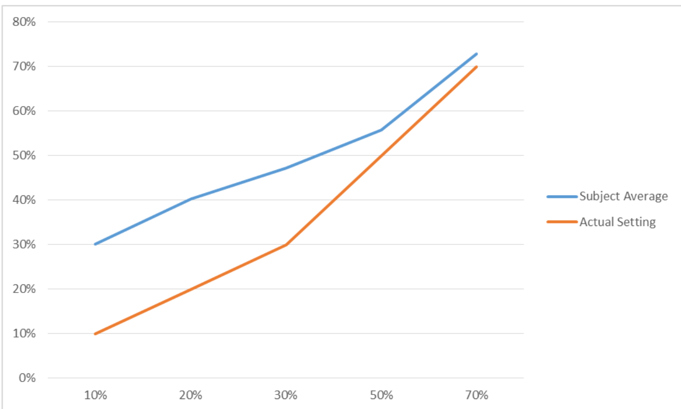


Figure 22 - Focus group evaluation of light levels

The scenario surveys had a participant number (n) of 22 for scenarios #0, #1, #2, and 21 for scenario #3. Surveys were performed in the evening and apart from completing the survey people who used the path sometimes gave spontaneous feedback on the installation and general feel of the path. Pedestrians walking their dogs stood out as good observers of conditions, as they often spend time on the path and are from time to time stationary. This not only makes them more sensitive to shorter intervals of higher light-levels, but they are also more likely to detect the change in light-output "Δ-Light", as motion in an observer makes it difficult to distinguish between the dynamic change by the installation and the variation in light intensity induced by motion through a static and uneven field of illumination.

The feedback they gave during Scenario #2 was that, to hold high level only for 30 seconds duration if no motion is detected was too short, the light dimming down while on the path is experienced frequently. 60 seconds is a better time for this installation and at that time it is rare for the average user to notice any difference between a dynamic - Advanced Controlled Installation and a static one.

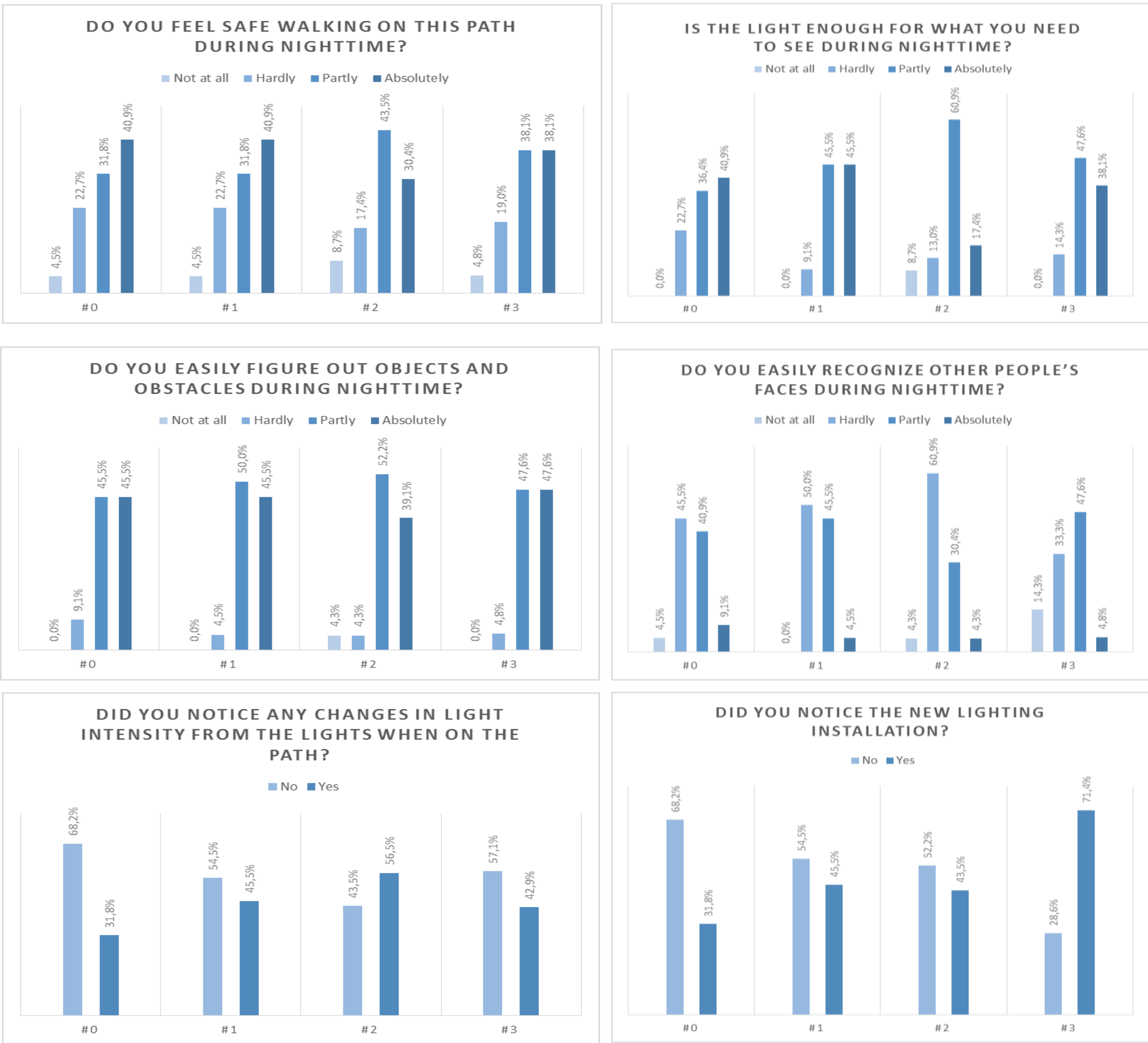


Figure 23 – Results from survey at *Bromma*

Djurgården

The survey before the installation had 27 participants and 83% of them said that they would use the path more if it was illuminated after dark. 60% do not use the path at all after dark, 29% found it difficult to see along the whole path and only 7% found the lighting conditions satisfactory.

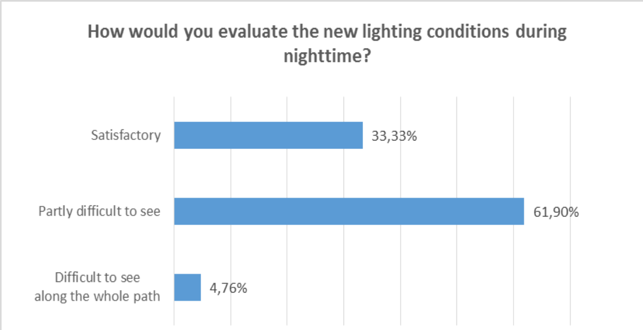


Figure 24 – Results from survey two (4W) at *Djurgården* (Appendix 1c),

Two separate user surveys were performed after the installation, the number of participants were 21 and 22. The first survey was focused on asking about the general conditions on the path and as we can see in *figure 22*, the installation has reversed the opinion of the visual conditions to one third now finding the conditions satisfactory and only 5% found it difficult to see along the whole path. The number of people who believe they will use the path more with the installation in place has gone up from 83% to 95%. The most interesting result is however the fact that 43% of respondents did not use the path at night - before the installation. The third survey expanded the questions to find out more about which of the aspects: "The feeling of safety", "Seeing obstacles on the path" or "Seeing where the path leads" that had changed the most and how important respondents felt they were when compared to one another. It was found that all areas had improved but "Seeing where the path leads" had improved the most, followed by "Seeing obstacles on the path" and the smallest improvement was for "The feeling of safety". When asked about what aspect they found most important "The feeling of safety" was ranked highest followed by "Seeing obstacles on the path". Despite the harsh conditions testing the installation, more than 80% of respondents answered yes to the question "Do you want to see this type of installation on more paths in the area?"

After the power was set to 2W and allowed to run for a couple of months we did another survey which was performed with a few alterations to the questions compared to the 4W survey. We wanted to more specific if and what users found improved on a path lit with this very dim light. Also we wanted to relate this to what they regarded as the most important aspect to improve with lighting the path. This led us to ask respondents to distinguish between 3 aspects: see where the path leads to, see obstacles on the road, and the feeling of safety. We predicted that these aspects require levels of light in ascending order, but we do not know what levels of light they correspond to or what is required in order to satisfy the needs of the users on this path. The 2W survey and results are presented in Appendix 1d (Swedish).

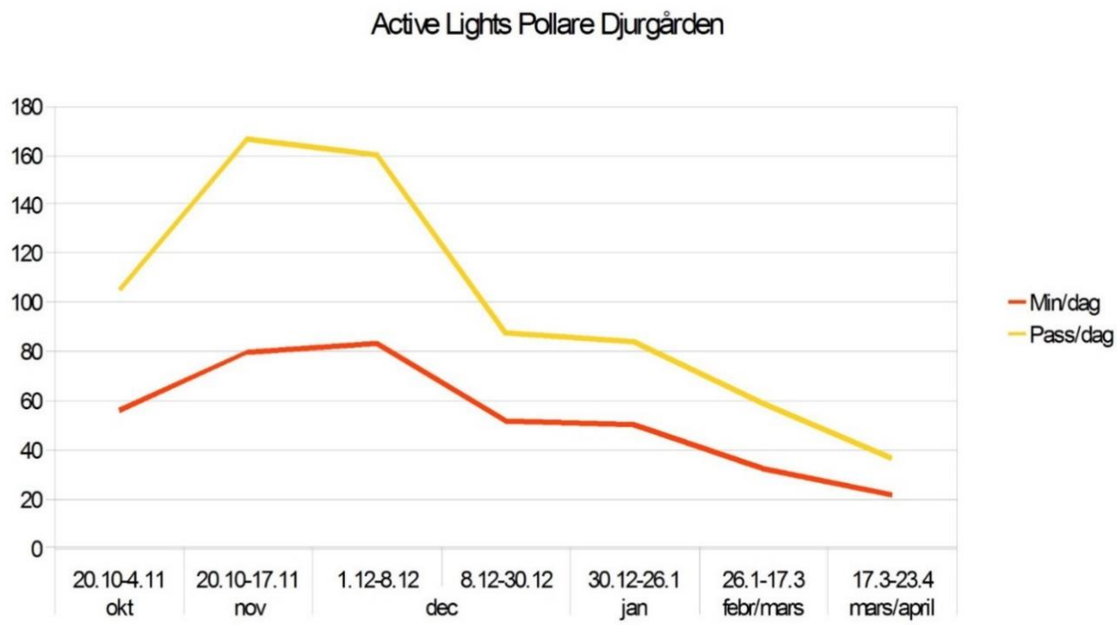


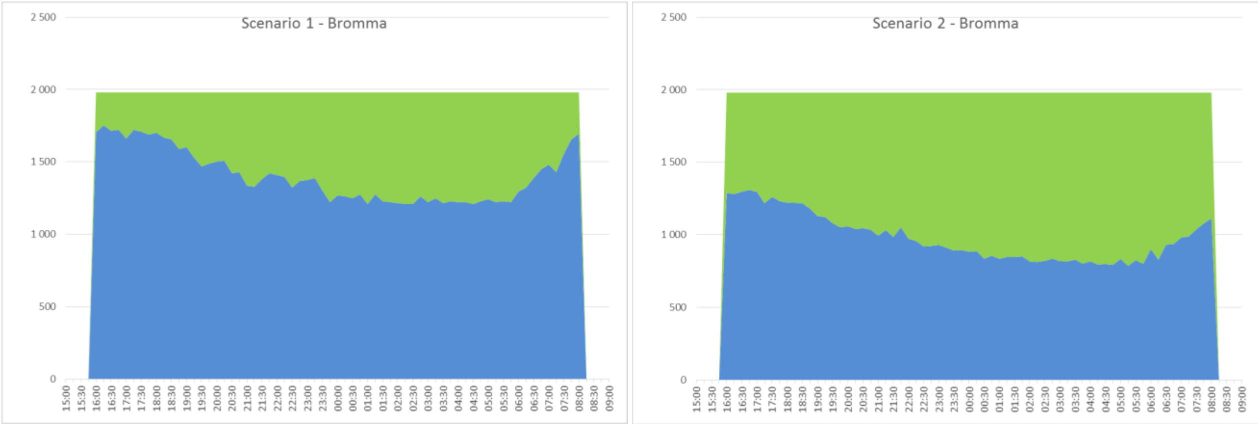
Figure 25 – Activity on the path over time seen as users (yellow) and minutes in "HIGH" (red).

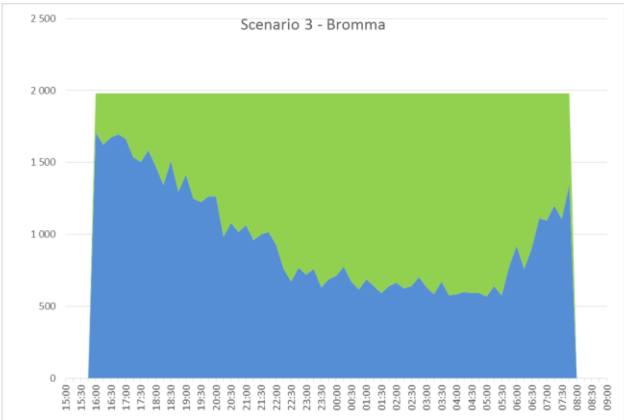
4.5 Energy measurements

Bromma

The measurements period chosen here is between 4 pm and 8 am and measurements are taken every 15 minutes. Results will differ slightly depending on which times are chosen because of the level of activity on the path will typically be higher at certain hours and cutting these hours out can have a significant effect on the result. The measurement period for Scenario #2 was extended because it ran across Christmas holidays. At full power (Scenario #0) the installation uses 1980W. Measurements are collected every 15 min. We see a 30% energy saving for scenario #1 and a 50% saving for both scenarios #2 and #3 respectively on this path. Activity on the path can be seen according to time of day in the energy graphs (figure 26).

We ran Scenario #4 which reduced levels further during the observed periods of low activity between 23.00-06.00 (HIGH: 10, LOW 5 then at low activity HIGH 7, LOW 3; NUMBER 3, TIME 60s) and it saved 46% energy. The reason to do this was to find out what impact we had on the energy saving by using a traditional "Night-Mode" within the scenario; the whole point of the sensors and scenarios is to avoid a general reduction in light and to have the best conditions on the path for users regardless of the hour, but it is important to see to what extent the effects of these two methods are additive. This scenario was not part of the user-evaluation, only energy measurements.

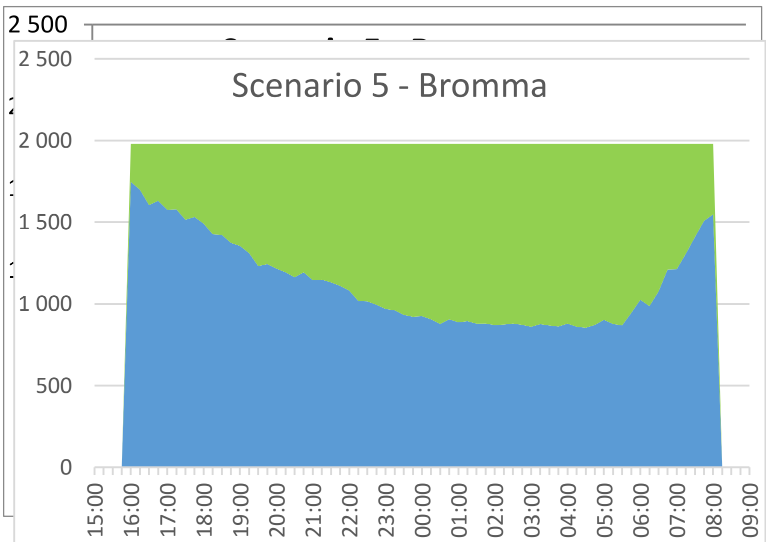




#	Max period power (W)	Min period power (W)	Saving compared to full power (%)
1	1752	1208	29
2	1309	785	51
3	1710	568	51

Figure 26 – Energy graphs for Scenario 1-3 between 16:00 – 08:00

Taking the findings from our evaluation into consideration, we introduced a Scenario #5 after completing the user surveys. The municipality wanted to try a scenario without SPECIAL POLES that regards to the surroundings at the entrances. With the insight that people tend to overestimate light-levels below 50% and that the southern entrance ideally would need 50%-70% of light to match the surroundings; it was decided to set the LOW level to 40% for this scenario. The other parameters were kept the same as Scenario 3: HIGH was kept at 100%, TIME to 60s and NUMBER of poles ahead and behind to 3. This scenario has been running as a long-time study in order to verify that the data



Over the period	
Min period power (W)	854
Max period power (W)	1 731
Max energy/night (Wh)	32 175
Used energy/night (Wh)	18 342
Saving (%)	43,0%

~~Figure 27 – Energy graph for Scenario #5 (HIGH 10, LOW 4) 16:00 – 08:00 over a 6-month period.~~

collected over one or two weeks is similar to that over longer periods of time. Data was collected from the 12th of January to the 26th of June 2015 (figure 27).

Djurgården

The energy use is not measured but the amount of charge (sunlight) received per day is monitored and it is not until March that we had favourable conditions for these two positions. The winter was exceptional with regards to sunlight hours, November got 5 hours as compared to the average of 56. The activity in November had the installation running for an average of 100 minutes a night with an average of 150 detections registered (minimum 150 people). It was clear that there was too little sunlight compared to the activity on the path between November and February for the installation to function all night, the battery lasts about a month during this period using the 2W scenario. Because of this it was decided that the batteries would be replaced once a month with fully charged ones – this takes approximately 2-4 min for each pole and is seen as acceptable by the park management. 3-4 replacements of the batteries are predicted as necessary at this location during winter for the installation to function properly at all times. The option not to change batteries would lead to short intervals of illumination depending on how much sunlight that was available during that day and individual luminaires would run out of power depending on how favourable their position is, creating a non-uniform performance which, without information, could be interpreted by users as a broken installation.

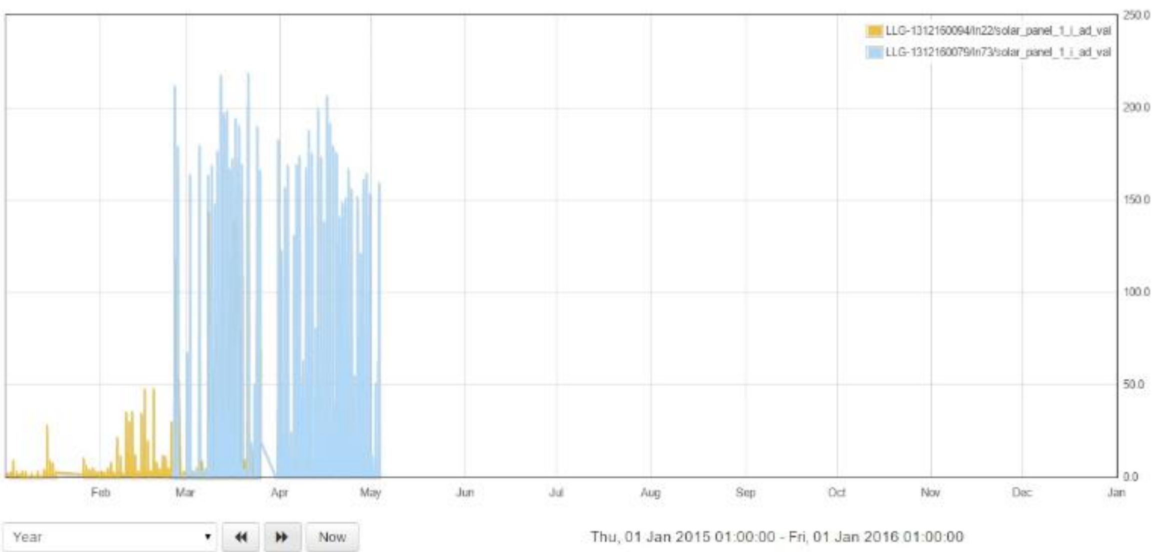


Figure 28 – Charging for two different poles between January and May.

5. Results

Bromma

With an Advanced Control System - energy saving results are connected to the conditions on each individual path. When we talk about specific results e.g. a 40% saving in energy for a scenario; this result is true for this path and it is likely what we can expect to find on paths with similar conditions – foremost with respect to the number of users and distribution of users over time. The saving in percent is important, but of equal importance is to look at the trend - what happens to the scenario and the energy saving if we increase or decrease a certain variable. When a trend or result from *Bromma* is compared to the findings at *Kungsholmsstrand* and they are similar - we can assume that this result is highly probable on other paths in the Stockholm area.

Scenario#1

Our path is not as busy as *Kungsholmsstrand* so we expected similar or better performance than their Scenario #4, but after the first measurement we had a saving of 28%, which was considerably lower than the 42% reported from the *Kungsholmsstrand report*. We checked our installation and found that one of the PIR-sensors was faulty and triggered continuously; causing 7 luminaires to stay in permanent HIGH mode. After changing the faulty sensor we achieved a 32% saving for Scenario #1 which is better – but still 10% away. With the maximum theoretical saving, assuming zero activity on our path, being 46% (50% and 6 poles at 70%) and if we disregard dimming times between HIGH and LOW what is the ratio between "HIGH/LOW" with a saving of 32%? - If we divide the cumulative energy saving 32% with our factor of saving 46% we get that approximately 70% of time was in LOW mode and 30% in HIGH; which sounds reasonable compared to a 42% saving where we would need to be in LOW mode more than 90% of the time (see image 15). The measurement period being from 16.00-08.00 this means that at a 46% saving in energy the installation spent around 11h in LOW and 5h in HIGH during that time. A static time-based "Night-Mode" scenario with a reduction of 50% in output between 23.00 and 06.00 - yields a result of approximately 22% in energy-saving for the same period but with a 50% reduction in light on the path during the night. The user response to our Scenario #1 is similar to our Scenario #0 (100%), the only noticeable shift is that people to a greater extent see changes in the light intensity from the lights – but since 27% of users in the static Scenario #0 also claimed to see changes in intensity; it is hard to make any conclusions other than that we see an increase in people who say they saw this aspect. With only 9% of respondents answering that they "hardly" had enough light on the path and no one that it was "not at all" enough - the scenario agrees with the findings from *Kungsholmsstrand* that there few if any changes in the visual conditions on the path for users compared to a static 100% installation and that this is reflected by user opinion.

$$x = \frac{Actual\ Saving}{LOW\ Saving}$$

Figure 27 – Ratio of Activity on path

Scenario #2

By shortening the time to stay in HIGH after being activated by half to 30s and reducing the LOW output to 30%, this scenario has two variables changed in order to drastically reduce the energy used. We wanted to push the scenario into an area where we believed we would see some change in response from users. The energy saving was 51% and we are starting to see a negative trend in survey answers. The feeling of safety among users is down slightly and their view on whether they have enough light or not went down drastically among users who were happy with the previous scenarios. The way that respondents answered the questions regarding “what” they could see, (obstacles vs faces) indicates that something is negatively effecting complex tasks such as recognizing faces and together with the answers in Question 5 and Question 9 points to users experiencing changes in the visual conditions while on the path. What was even more apparent was the spontaneous comments from people that they now noticed changes in the light. As we interviewed people on the path - the lights would dim down as we spoke, unless there was other activity on the path, meaning that walking slowly or stopping briefly would often expose users to the LOW -mode.

Scenario #3

This is a scenario where we are looking at probably the lowest “LOW-setting” that we can have without making the path look like it is neglected – 20%. Light at 10% was judged, visually, as not reaching but a few meters from the pole and make the path look gloomy. But still at 20% it is a test of the robustness of the installation as e.g. in the event of a sensor not detecting properly - it will be obvious to anyone moving from 100% into 20% over the course of 20m that the light is becoming very dim. After running the scenario we see that the energy saving is excellent at almost 60% with user surveys showing similar results compared to Scenario #0. Question 8 - the ability to recognize faces, what we see as a complex task, scored lower which can be seen as a negative indicator, but when looking at user opinion on Questions 5, 6 and 7 regarding basic task ability and the subjective feeling of light and safety on the path - they do not support a negative opinion overall.

Scenario #4

We tested a “night-mode” on top of a conservative scenario in order to see the effects we would get from lowering the HIGH value as well as the LOW? With little traffic on the path during these hours the effect is not visible and we see few benefits of having more light in LOW mode for a few hours as this is when no user is on the path. One of the entrances could be better matched to this level and if the LOW is set very low there could be a benefit in having a higher setting around dusk or dawn to communicate that the path is lit when in LOW-mode. To lower the HIGH value is not recommended as the benefit of having an advanced control system is to have the best conditions for users as they are using the path and on this path most time is spent in LOW.

Scenario #5

A long term scenario that balances the biggest energy saving we can have while matching the conditions at the entrances. At 40% LOW-setting it was judged that we have enough light to manage the conditions at each entrance without special poles and that in the case that a sensor would not trigger or a person would remain on the path stationary the user would still have enough light on the path to see. It was not included in the user survey so only the energy data is gathered, it is still running as the default scenario on the path and no complaints have been received by the municipality. The energy saving over 6-months was 43%. The time spent in LOW 72% and HIGH 28% shows a similar activity on the path as earlier scenarios.

Djurgården

Because the energy we save is put into the duration of time that the installation can provide illumination, measuring energy-saving is not applicable for this installation. The advanced control system is part of the general performance of the installation as a whole and we therefore focus on the user response to the new conditions and how the installation can handle the conditions.

The results from both the 4W survey and the one at 2W show that people are in general very positive to the installation. At 4W a majority of users found that they had some difficulties to see in parts of the path (Q 8,9) but they were almost in unison when answering that they would use the path more often now that it was lit (Q 11). In the 2W survey we asked more specifically about how different aspects had been affected by lighting the path. The three aspects were: to see where the path is going, to see obstacles on the path, and the feeling of safety. Users found that all aspects had improved with the level of improvement being the highest for seeing where the path is going and lowest for safety.

There was a number of spontaneous comments by users, either walking by or participating in the survey, that some of the luminaires were not working (likely because the batteries were out). The people commenting on the performance were, despite this, positive to having the installation on the path.

6. Discussion

In the start-up of both installations there were a few technical issues like: a broken driver or a sensor that was faulty, in our case these problems were related to separate pieces of hardware that when replaced eliminated the problem. The user however cannot distinguish between a broken driver and a systems design flaw; compared to a static installation, where a fault is most likely seen as a broken lamp and this is an easy fix, installations using advanced control systems could see negative experiences fall on the installation as a whole. This together with the fact that it is not immediately apparent if all aspects of the installation are working by turning on the power, means that it is important to allocate resources to verify the functionality of the whole system after installation – possibly aided by a *test setting* as standard scenarios are time consuming to check by nature of their design.

Bromma

How do we look at energy saving on a path as part of the overall concept of quality? How do we compare a 10% reduction in energy on a path with 50 users, to a 50% reduction on one with 10 users? If we look at other methods of energy-saving they have negative effects on the lighting condition on the path, we also know that: more traffic equals less energy saved by having an advanced control system. For *Bromma* we evaluate scenarios based on the overall energy saved and look for results that do not have a negative impact on the visual quality and the user experience of the lighting, but we do not take into account the number of users. The benefits of using Advanced Control Systems on paths with low intensity are clear – it saves more energy than other energy-saving solutions while providing better visual conditions. On paths with high intensity - the energy saved can be smaller, but as we are still maintaining good visual conditions this saving is made without a possible negative experience for a large number of users.

When the installation is set-up and running a scenario which is moderate e.g. #1 or #5, the changes that occur are virtually undetectable in the eyes of the average user because they happen so far ahead. As we saw in the study, most people were unaware that the installation was responsive and dynamic even when altering between 20% and 100% output in Scenario #3. We said early in the project that walking on a path that saves energy without noticing any difference to a 100% static installation is the benchmark we are aiming for. Since the effect of changes in light intensity are masked by motion in an observer, it would be interesting to investigate further the impact of a dynamic installation on people close to but not on the path itself. Inhabitants of the surrounding houses could be aware of the changes in the installation even if people on the path are not. We see that the conditions were different at either entrance to the path and that they require different levels of light in order to match the surroundings – mostly because we want to communicate that this is a lit path. The appearance of the entrances are affected by our adaptation to the conditions so this also would apply to dusk and dawn - when the available light is higher than the required values on the road, but we are experiencing a degradation of light as compared to our adapted state. Lower levels of light that are enough for night-time could go unnoticed at dawn or dusk, thereby missing out on its communicative value and any effect on the feeling of safety by the user. The indirect LED solution of the luminaire used on the path is designed so that the light inside the housing is visible from the side as one approaches the luminaire; this light is not as powerful as the light directed down towards the path but it makes the installation visible from a distance even at lower light levels, which is a positive feature provided that it is, as in our case, glare free.

Knowing the ratio between LOW and HIGH, for this path, being about 70% means that we know that this is the maximum we could save with LOW set to a not advisable 0% and we can predict the saving for Scenarios not tested. Scenario #2 has a LOW setting that saves 70% and if that is “on” 70% of the time we predict a saving of 49% - the measured saving for Scenario #2 was 51%. If we were to run a fictional Scenario #6 with 10% as LOW setting we should see a saving in the order of 60%. It is a rough estimate and it will differ from the actual result as we are approximating several factors – but it will give us a clue to what we can expect with other settings kept the same.

Including SPECIAL POLES in a Scenario will match the installation to the conditions on the path the closest and will enable the lowest LOW-settings, thus the highest energy savings. But in the surveys we have conducted it seems that they do not have a big impact on user preference, so it is possible that a compensating with a higher LOW-setting could be acceptable on installations where a uniform behaviour is preferred. But because our surveys were conducted on the path we do not include people who chose not to take the path so in order to verify this more studies would be needed on how light levels at entrances and their surroundings, from a distance, affect our impressions and decisions. In this study we have followed in the footsteps of the *Kungsholmsstrand Report* and we have learnt even more regarding the individual factors combining into a scenario. As a recommendation, it is not advisable to set the TIME below 60 seconds with a similar distance between the poles and the NUMBER should be set to 3 poles ahead and behind. It is possible that we could have used only 2 poles ahead and behind on this path as sight-distances are relatively short, but it reduces the lit distance by 30% and the potential energy saving is much smaller as it affects only a fraction of time that individual poles spend in HIGH-mode. It is advisable to keep the HIGH on 100% as this is when the light is needed. Other factors are more flexible to adjustment based on the requirements of the specific location or path

Djurgården

The number of spontaneous comments regarding luminaires that were "broken" seem to have a more negative impact on the impression of this installation than the low level of light when going down to 2W from 4W. That the lighting installation was thought of by some as giving a positive contribution to the area even during daytime suggests that people are passionate about the idea of having a lighting installation on this path, even when it is not in use. Even the low light levels at 2W, similar to a full moon, are seen as positive by the users on the feeling of safety. When given the information that it was a solar powered installation running on batteries, there was a tendency by users to be more positive in their general opinion; especially when they had expressed comments regarding the lighting conditions. This indicates that other factors, than the lighting conditions, have an impact on our opinion of lighting installations or at least the opinion we chose to communicate. The installation would likely benefit from a protocol to handle the discrepancies in available power for each of the individual luminaires in order to avoid having "broken" luminaires in the installation which have run out of power before their neighbours. The light on the path at 2W being comparable to the light from the full-moon is still considered to have increased the feeling of safety by close to 70% of users. It is doubtful whether~~I do not think~~ we would find that 70% of the population feel safer walking on nights with a full-moon, so this seem to support~~also hints at~~ that the mere presence of a lighting installation makes people feel safer on the path. It is however good to know that "some light" seems better than "no light" and not only are users very positive to the installation in the survey – the fact that 43% of users in the 4W survey (Q7) have not used the path prior to the installation and that 90% (Q5) are using the path on a regular basis, suggests that users have altered their behaviour with the new lighting installation.

The Future

As of today there are no standards taking into account the adaptive nature of installations run by advanced control systems, hence they can be both below and above standard depending on which mode they are operating in at the time, LOW or HIGH. However the CIE are working on a new standard for pedestrian lighting (TC4-52) that is most likely going to include exceptions on light levels for dynamic installations and through this study we can see that the LOW level has little effect on user opinion or how they experience the conditions on the path as long as the TIME and NUMBER of poles ahead are set within reasonable levels. *Kungsholmsstrand* and this study points in the same direction – there are few if any drawbacks on the visual quality for the users while saving almost 50% on energy.

7. Conclusion

Advanced lighting control systems can save energy without negatively affecting the visual experience of the users. Detectors on every luminaire and radio-communication between luminaires can create a scenario where higher light-levels are made available only when and where they are needed. Savings of 50% were possible in the *Bromma* installation without any change in user-opinion when compared to the same installation static at 100%. The amount of energy saved was mostly dependent on to what level the lights would dim when there was no detected user (LOW); which in turn should be set with consideration to the surroundings, as it is rarely or never experienced by the average user on the path in a well configured installation. The installation at *Djurgården* shows that Advanced Lighting Control Systems can also be used to extend the range where we can use solar powered lighting. Despite a more aggressive scenario, in terms of power saving, compared to *Bromma* – it was well received by the users.

8. References

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9. Appendix

1. Survey results

a. Survey + answers Bromma:

KTH STH | LJUSLABORATORIET | AVANCERAD STYRNING AV UTOMHUSBELYSNING

Brommaplan

1. Gender:

Male ☐ Female ☐

2. Age:

<20 ☐ 20-40 ☐ 40-60 ☐ >60 ☐

3. Usually, you use this path as:

A pedestrian ☐ A cyclist ☐

4. How often do you use this path?

Everyday ☐ Once a week ☐ Once a month ☐ Rarely ☐

5. Do you feel safe walking on this path during nighttime?

Absolutely ☐ Partly ☐ Hardly ☐ Not at all ☐

6. Is the light enough for what you need to see during nighttime?

Absolutely ☐ Partly ☐ Hardly ☐ Not at all ☐

7. Do you easily figure out objects and obstacles during nighttime?

Absolutely ☐ Partly ☐ Hardly ☐ Not at all ☐

8. Do you easily recognize other people's faces during nighttime?

Absolutely ☐ Partly ☐ Hardly ☐ Not at all ☐

9. Did you notice the new lighting installation?

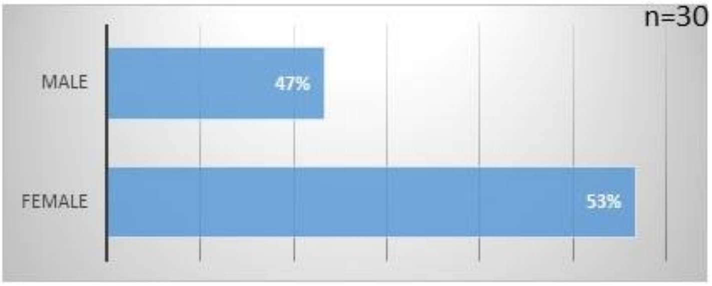
Absolutely ☐ Partly ☐ Hardly ☐ Not at all ☐

10. Please express shortly your comments about the new lighting of the path or your suggestions for improvements:

....
....
....
....
....
....
....
....

Bromma survey Question 1: Gender

Before



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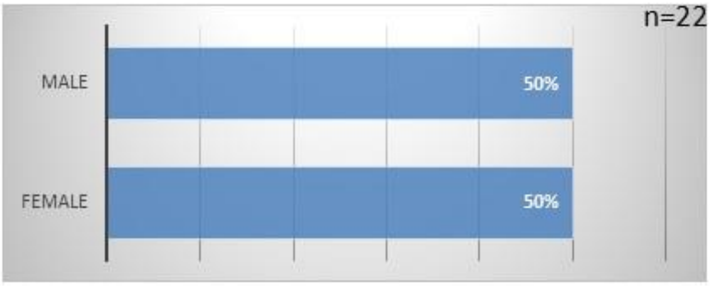

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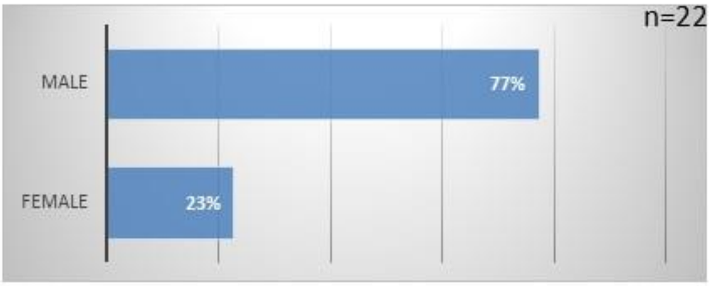

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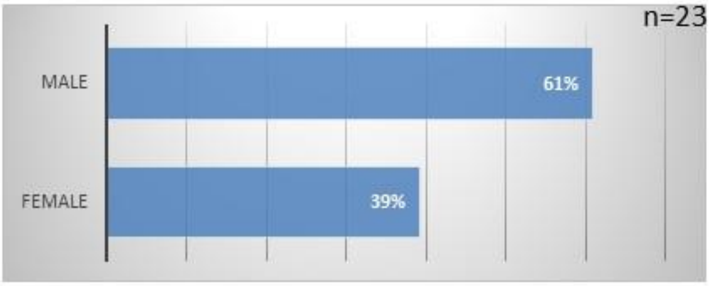

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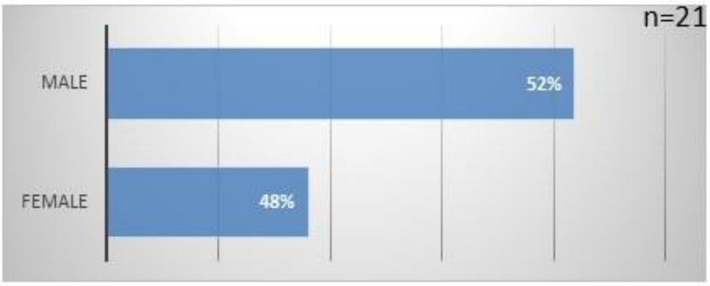
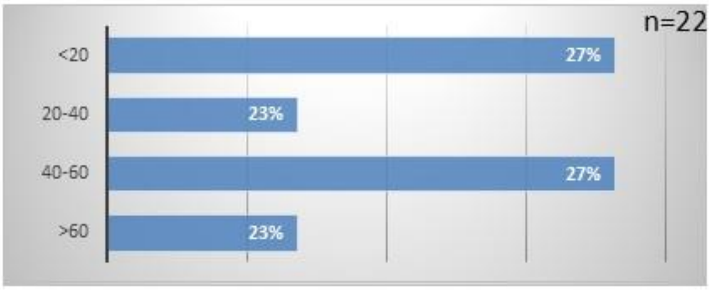


Bromma survey Question 2: Age

Before

100% (#0)



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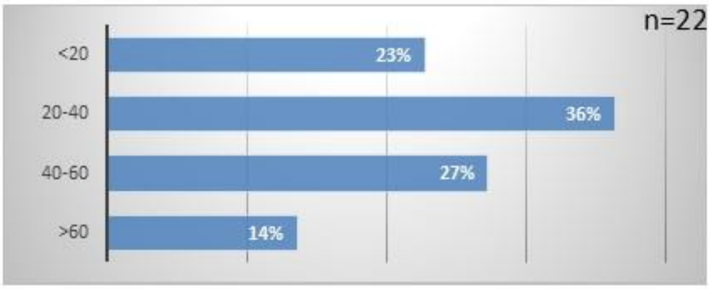

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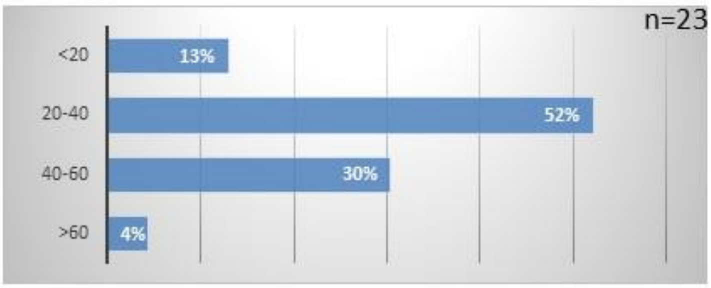

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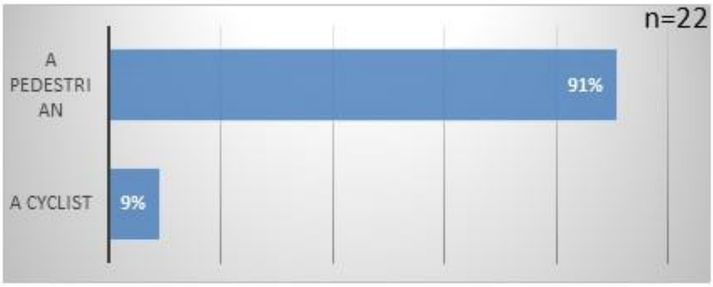
Bromma survey Question 3: How do you usually use this path ?

Before

100% (#0)

#1



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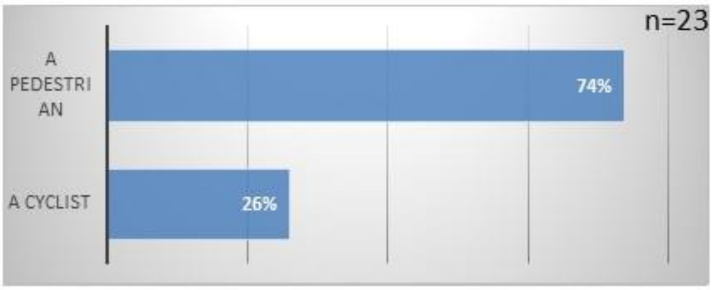

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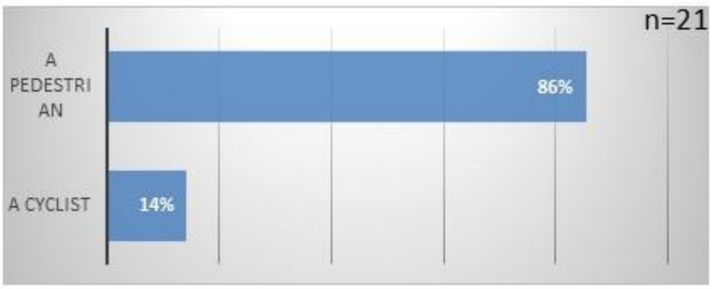
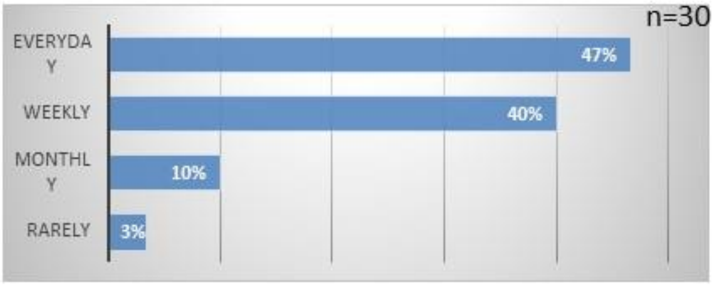


Bromma survey Question 4: How often do you use this path ?

Before



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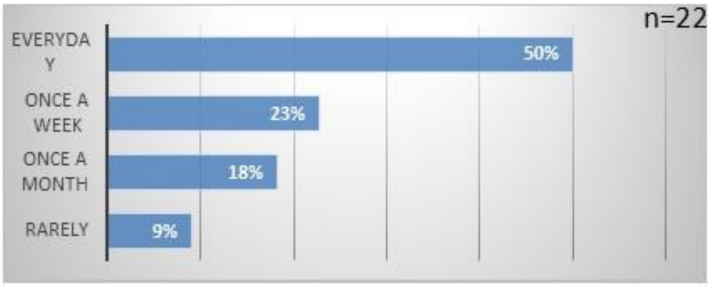

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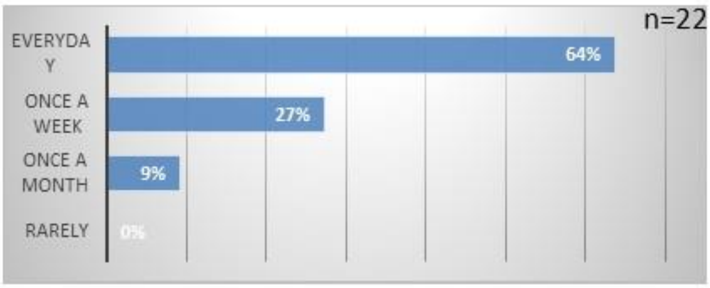

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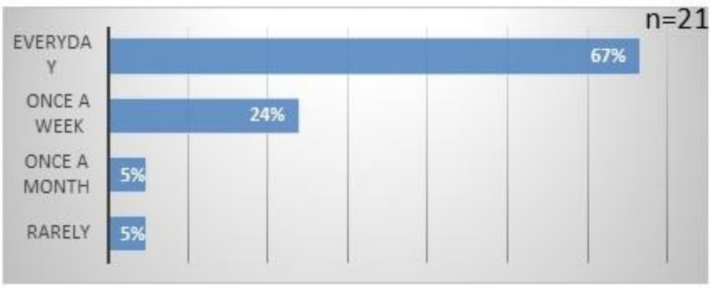
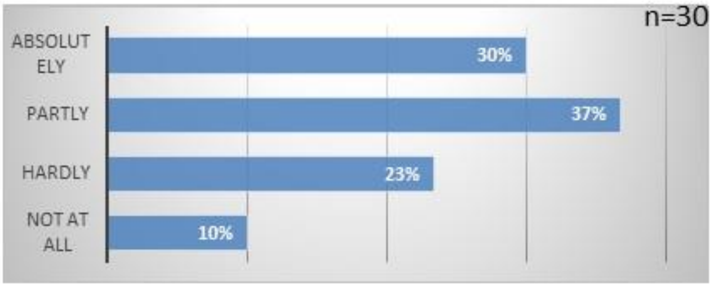


Bromma survey Question 5: Do you feel safe walking on this path during nighttime ?

Before



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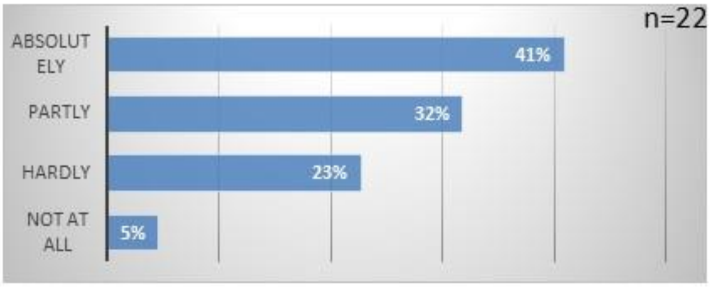

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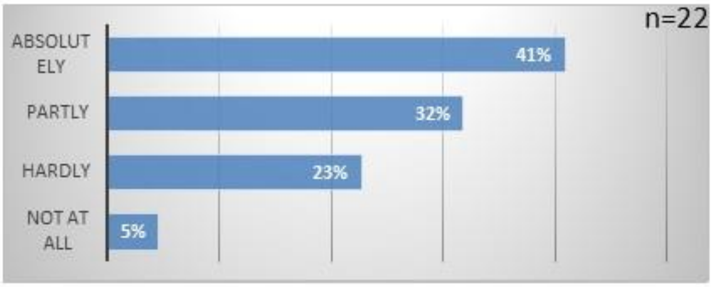

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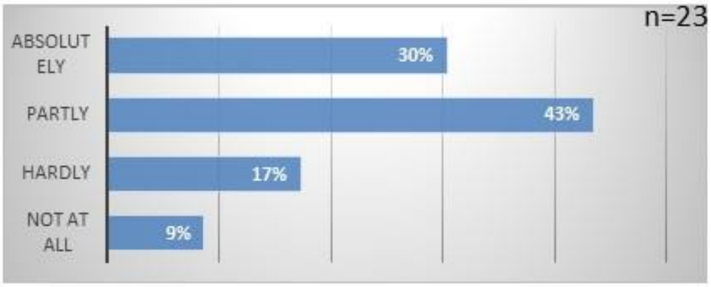

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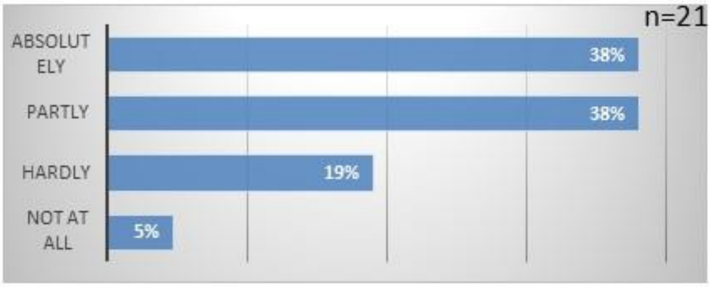
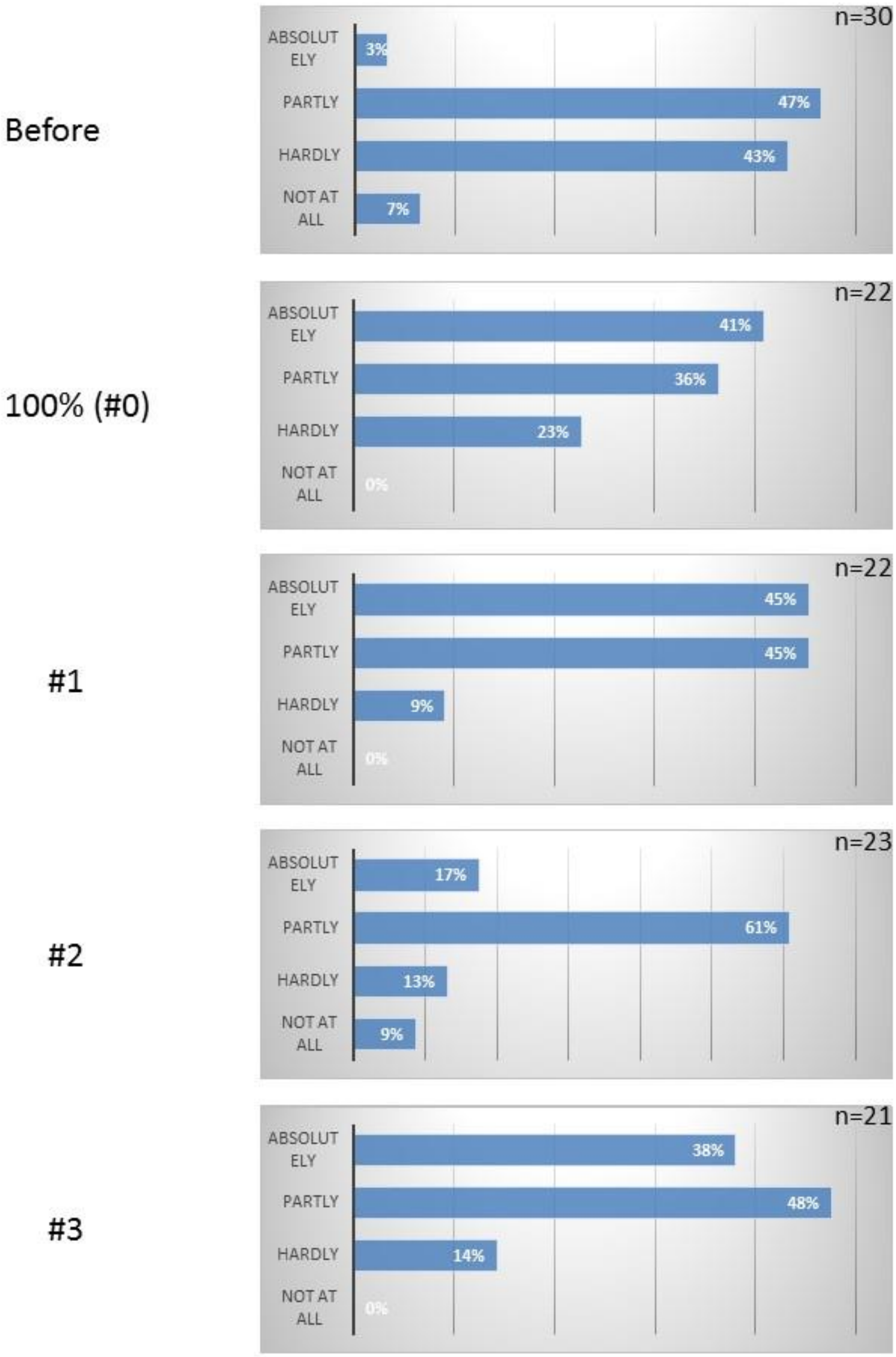
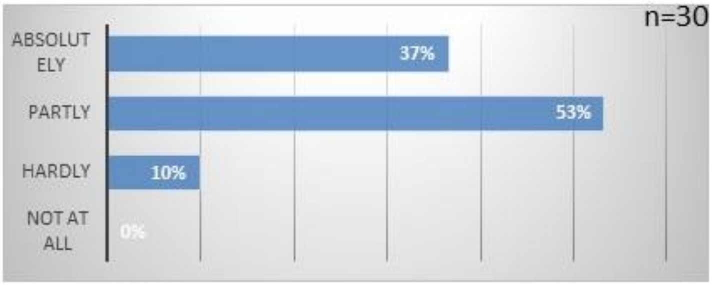


Bromma survey Question 6: Is the light enough for you to see during nighttime ?



Bromma survey Question 7: Do you easuly figure out objects and obstacles during nighttime ?

Before



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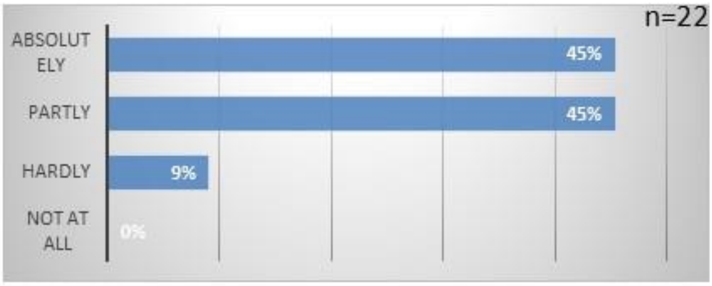

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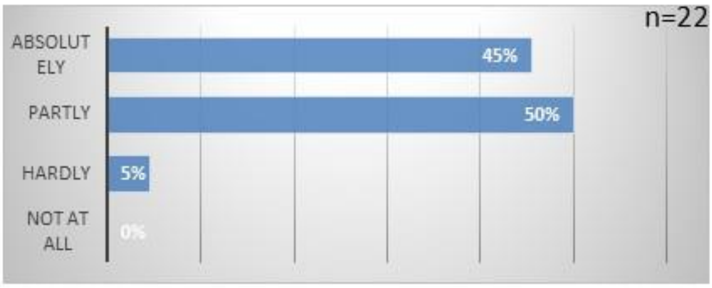

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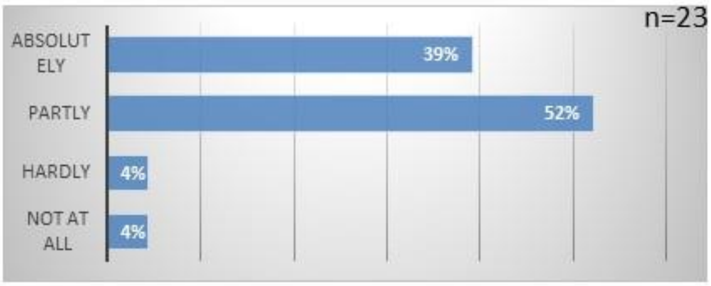

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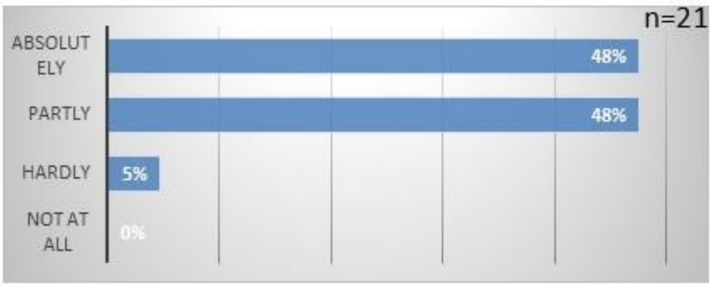
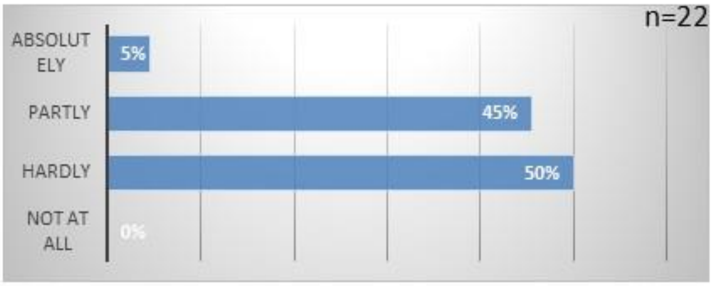


Bromma survey Question 8: Do you easily recognize other people´s faces during nighttime ?

Before

100% (#0)

#1



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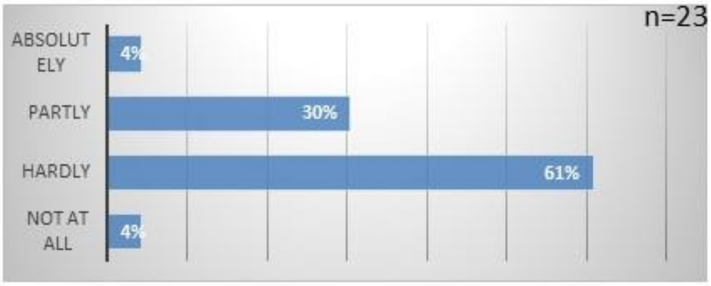

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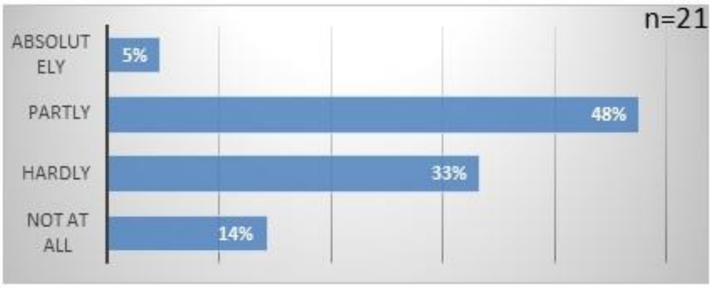
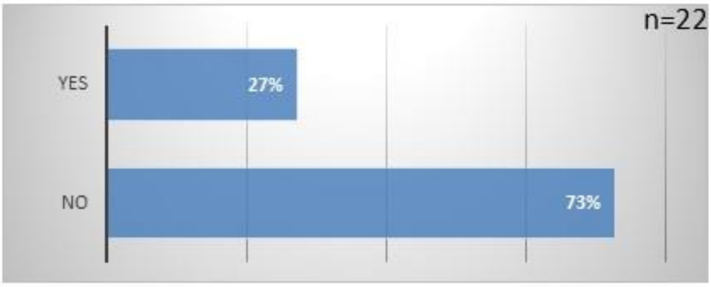


Bromma survey Question 9: Did you notice any changes in light intensity from the lights when on the path ?

100% (#0)



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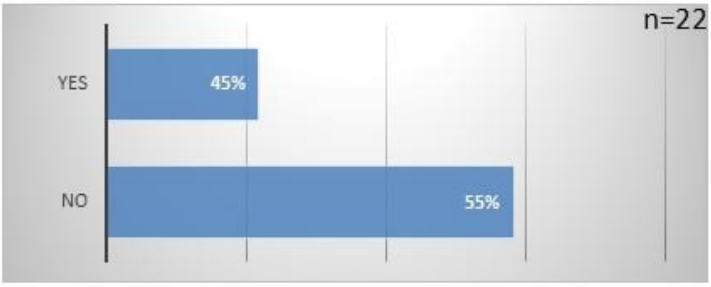

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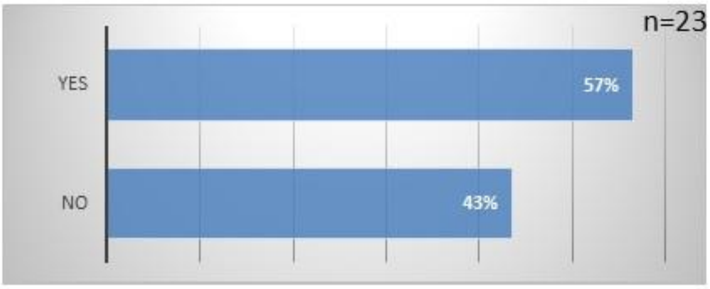

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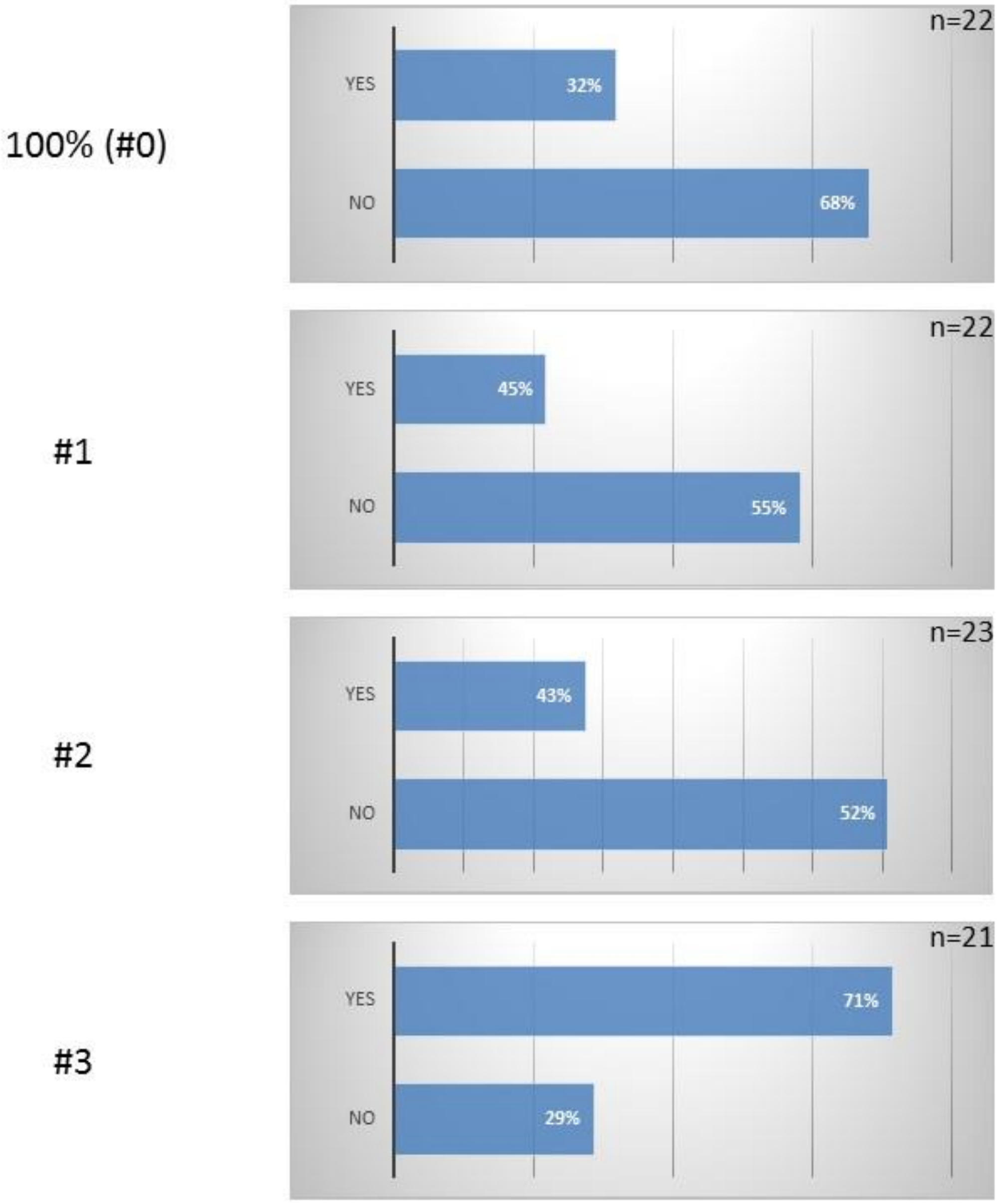
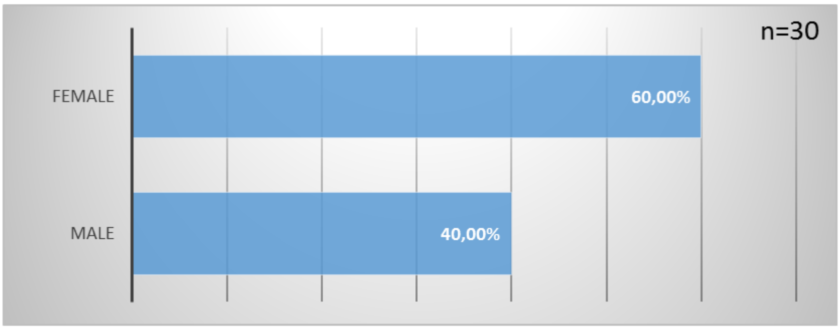
Bromma survey Question 10: Did you notice the new lighting installation ?

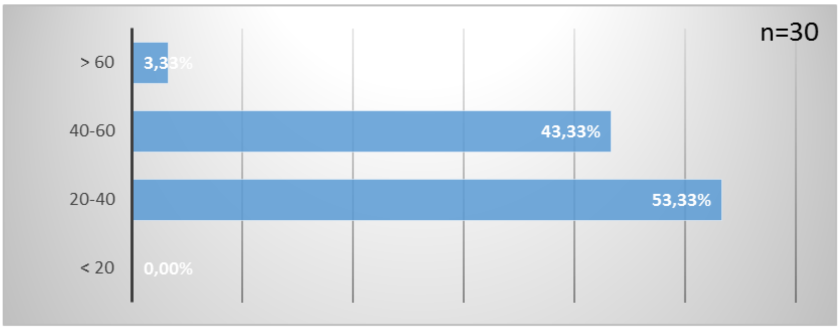


b. Survey + Answers Djurgården (Before installation)

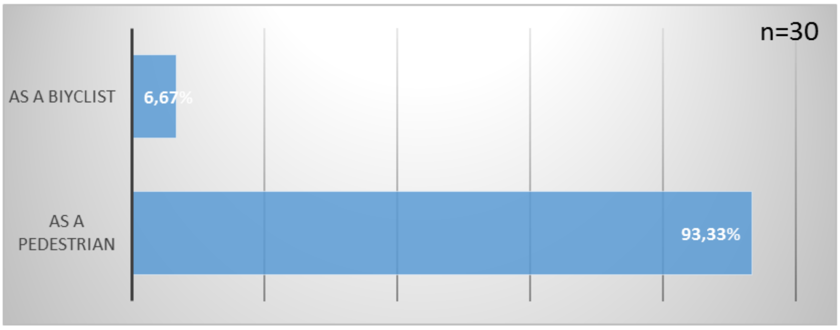
Djurgården survey Question 1: Gender



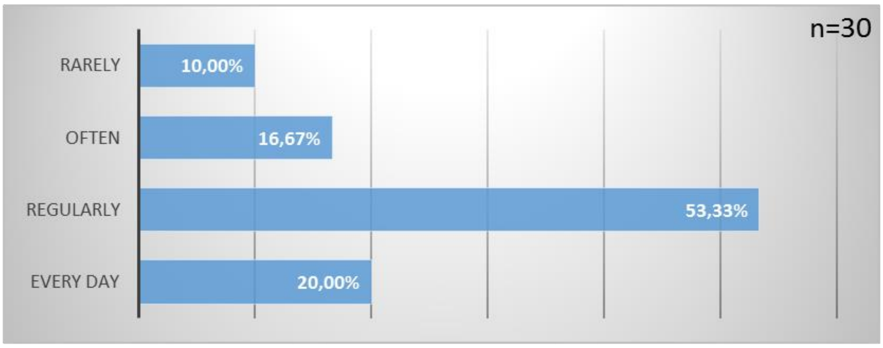
Djurgården survey Question 2: Age



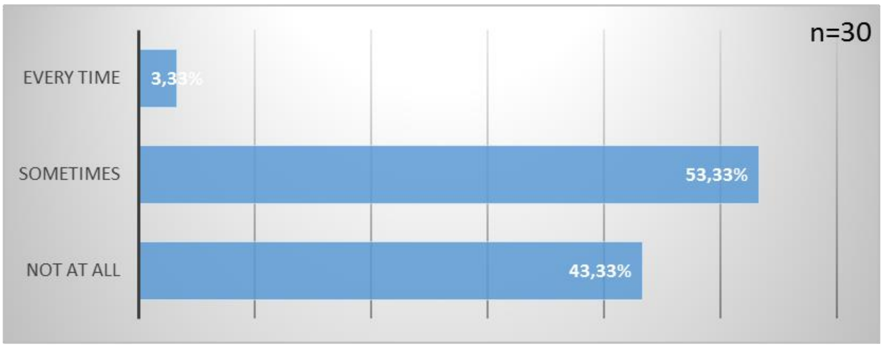
Djurgården survey Question 3: How do you usually use this path ?



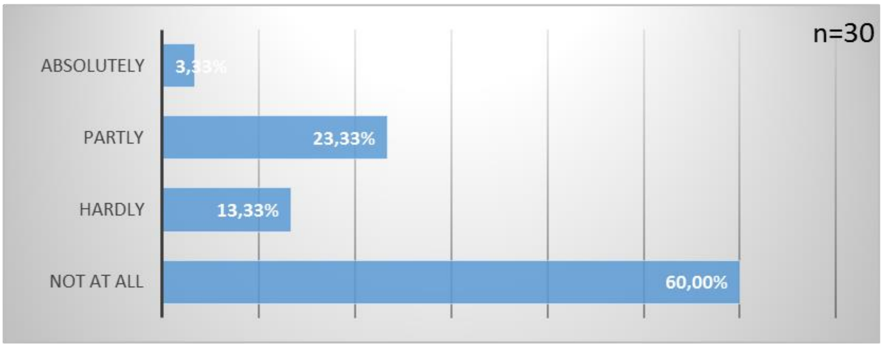
Djurgården survey Question 4: How often do you use this path?



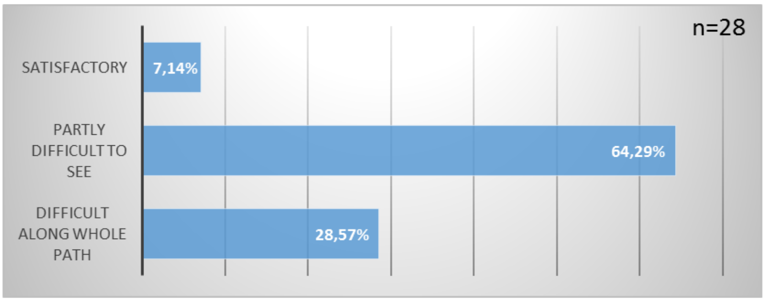
Djurgården survey Question 5: Do you spend time at the resting areas and the benches on the path?



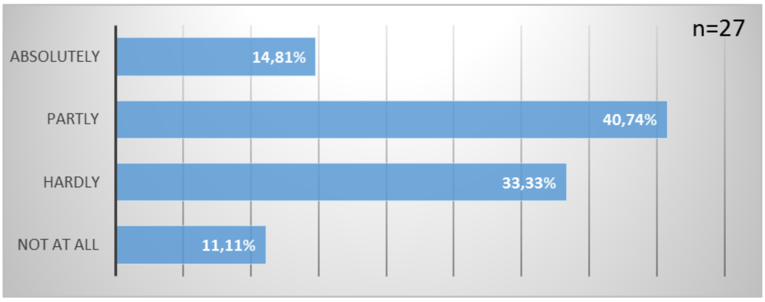
Djurgården survey Question 7: Do you use this path after dark?



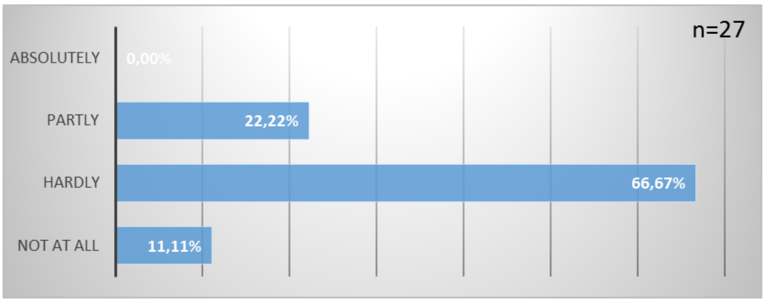
Djurgården survey Question 8: How would you evaluate the lighting conditions during nighttime?



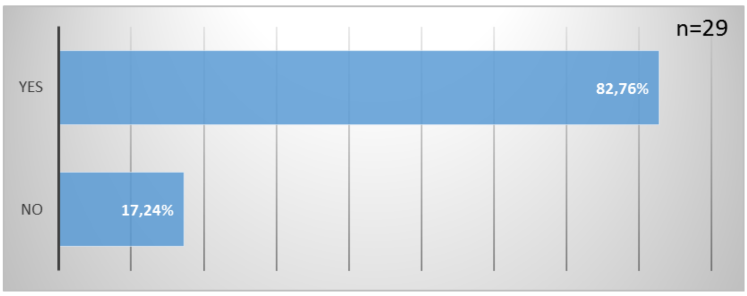
Djurgården survey Question 9: Do you easily figure out objects and obstacles ?



Djurgården survey Question 10: Do you easily recognize other people's faces with this lighting installation?



Djurgården survey Question 11: Would you use this path more during the nighttime if it had artificial lighting?



c. Survey + answers Djurgården (4W):

KTH STH | LJUSLABORATORIET | AVANCERAD STYRNING AV UTOMHUSBELYSNING

Djurgården

1. Gender:

Male ☐ Female ☐

2. Age:

<20 ☐ 20-40 ☐ 40-60 ☐ >60 ☐

3. Usually, you use this path as:

A pedestrian ☐ A cyclist ☐

4. How often do you use this path?

Everyday ☐ Regularly ☐ Often ☐ Rarely ☐

5. Do you spend time at the resting areas and the benches on the path?

Every time ☐ Sometimes ☐ Not at all ☐

6. What do you think are the positive and negative aspects of this path?

(+)	(-)
....	....
....	....
....	....

7. Did you use this path during nighttime before the new lighting installation?

Absolutely ☐ Partly ☐ Hardly ☐ Not at all ☐

8. How would you evaluate the new lighting conditions during nighttime?

Satisfactory ☐ Partly difficult to see ☐ Difficult to see along the whole path ☐

9. Do you easily figure out objects and obstacles with this lighting installation?

Absolutely ☐ Partly ☐ Hardly ☐ Not at all ☐

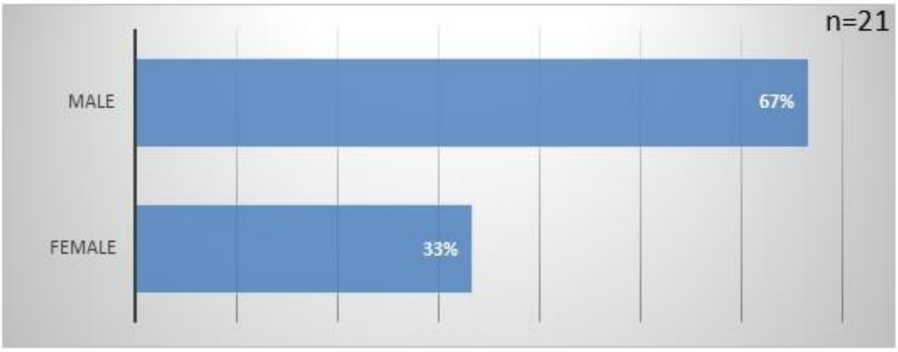
10. Do you easily recognize other people's faces with this lighting installation?

Absolutely ☐ Partly ☐ Hardly ☐ Not at all ☐

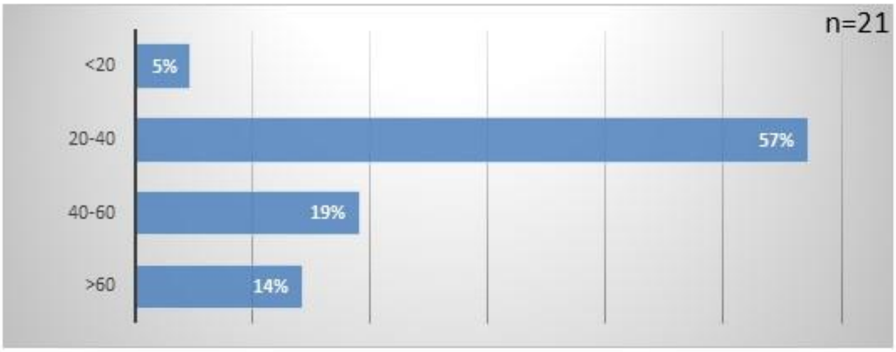
11. Will you use this path more often during nighttime with this lighting installation?

Yes ☐ No ☐

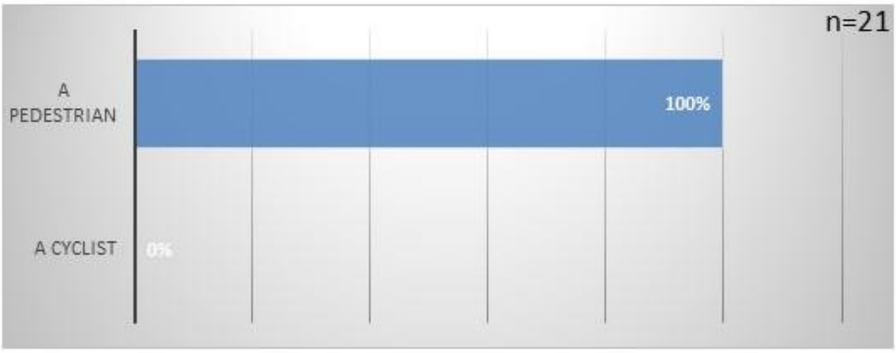
Djurgården survey Question 1: Gender



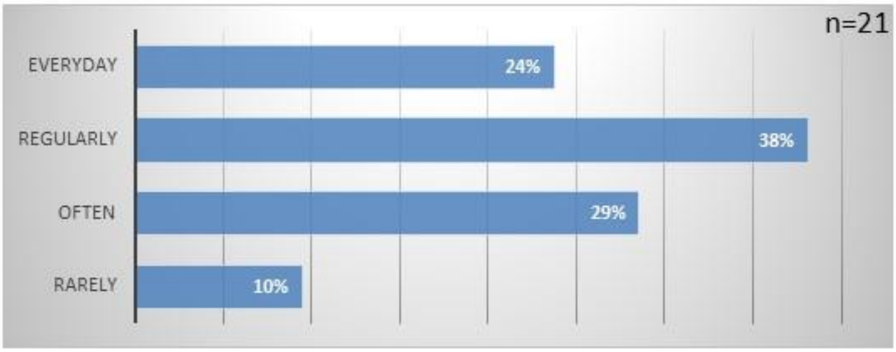
Djurgården survey Question 2: Age



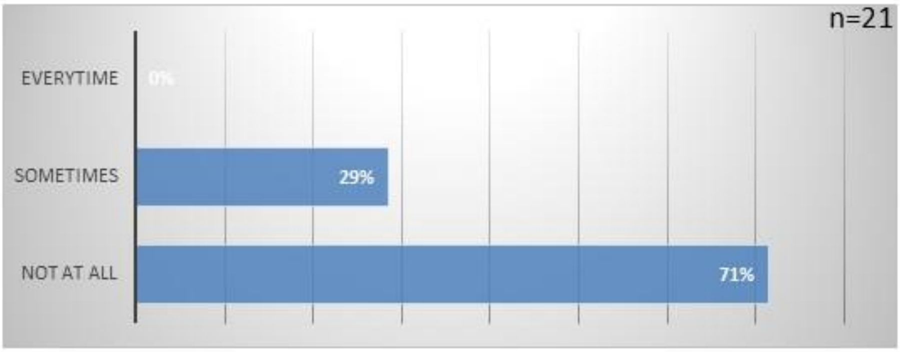
Djurgården survey Question 3: How do you usually use this path ?



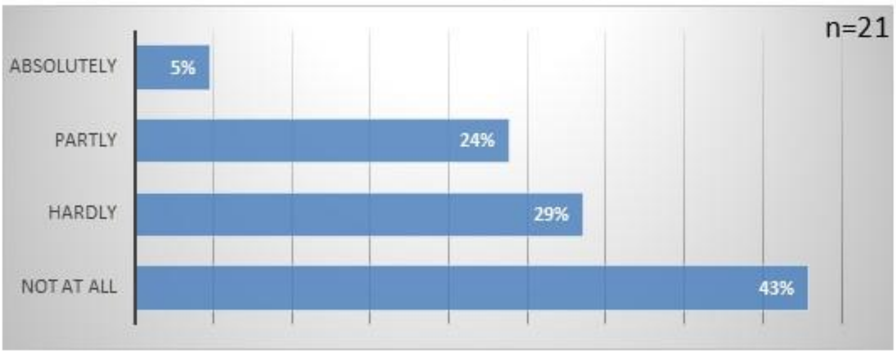
Djurgården survey Question 4: How often do you use this path?



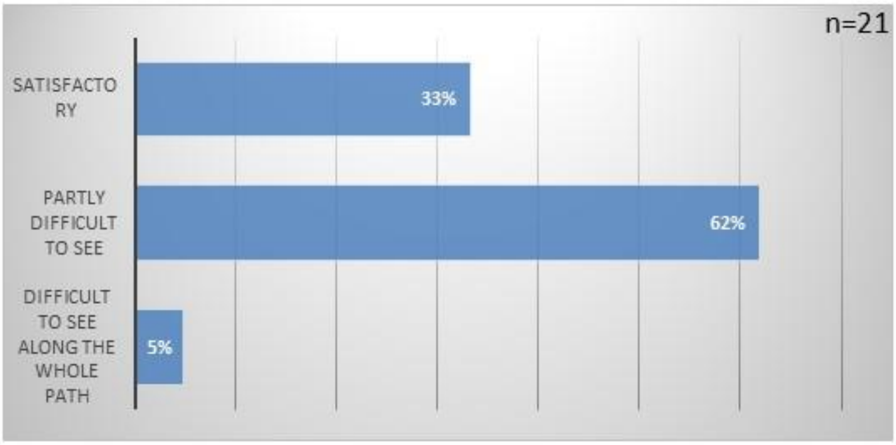
Djurgården survey Question 5: Do you spend time at the resting areas and the benches on the path?



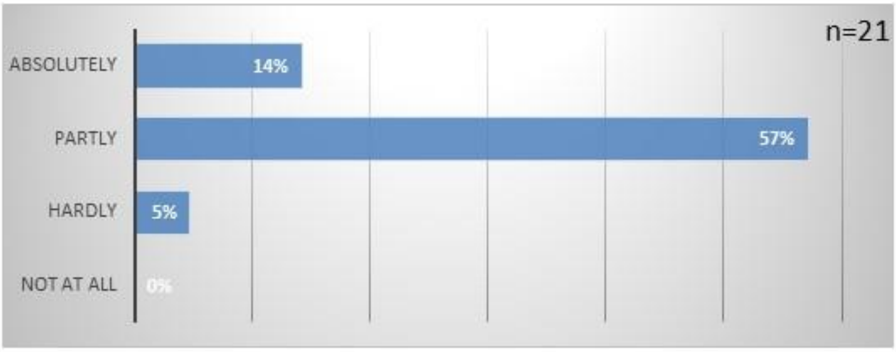
Djurgården survey Question 7: Did you use this path during nighttime before the new lighting installation?



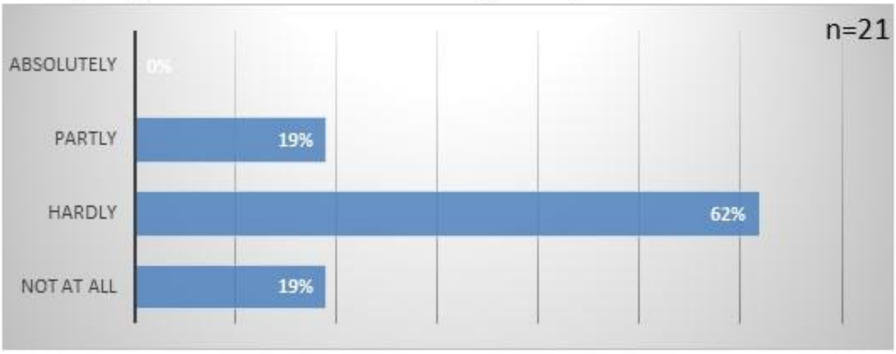
Djurgården survey Question 8: How would you evaluate the new lighting conditions during nighttime?



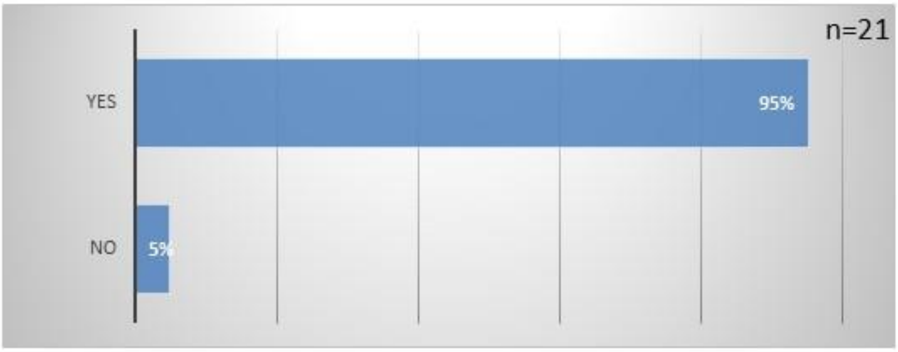
Djurgården survey Question 9: Do you easily figure out objects and obstacles with this lighting installation?



Djurgården survey Question 10: Do you easily recognize other people's faces with this lighting installation?



Djurgården survey Question 11: Will you use this path more often during nighttime with this lighting installation?



d. Survey + answers Djurgården (2W):

KTH STH | LJUSLABORATORIET | AVANCERAD STYRNING AV UTOMHUSBELYSNING

Djurgården

1. Kön:

Man ☐ Kvinna ☐

2. Ålder:

<20 ☐ 20-40 ☐ 40-60 ☐ >60 ☐

3. Hur brukar du använda den här vägsträckan:

Som fotgängare ☐ Som joggare ☐ Som cyklist ☐

4. Hur ofta använder du den här vägsträckan ?

Varje dag ☐ Varje vecka ☐ Varje månad ☐ Mer sällan ☐

5. Brukar du använda bänkarna som finns utplacerade längs sträckan ?

Varje gång ☐ Ibland ☐ Inte alls ☐

6. Är det bra att sträckan är upplyst kvällstid ?

Ja ☐ Nej ☐ Vet ej ☐

7. Hur har följande aspekter förändrats med belysning (sätt ett kryss på linjen)?

Trygghetskänslan:

Mycket sämre ——————————— *Mycket bättre*

Se hinder på vägen:

Mycket sämre ——————————— *Mycket bättre*

Se vart vägen leder:

Mycket sämre ——————————— *Mycket bättre*

8. Rangordna hur viktiga de olika aspekterna är för dig (skriv en 1:a i rutan för den viktigaste, en 2:a för den näst viktigaste...osv.):

Trygghetskänslan ☐

Se hinder på vägen ☐

Se vart vägen leder ☐

Något annat (skriv) ? ☐

....

7. Hur tycker du att belysningsinstallationen påverkar områdets karaktär ?

DAGTID

☐	☐	☐	☐	☐
Mycket Positivt	*Positivt*	*Inte alls*	*Negativt*	*Mycket Negativt*

KVÄLLSTID

☐	☐	☐	☐	☐
Mycket Positivt	*Positivt*	*Inte alls*	*Negativt*	*Mycket Negativt*

8. Vill du se den här typen av belysning på fler sträckor i området ?

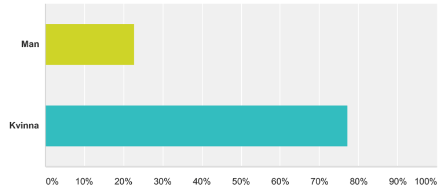
Ja ☐ Nej ☐ Vet ej ☐

Är något som borde förbättras med den nya belysningen?

....
....
....

Q1 Kön

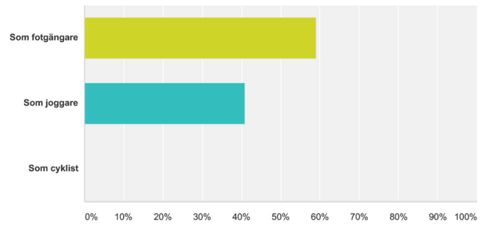
Svarade: 22 Hoppade över: 0



Svarsval	Svar	
Man	22,73%	5
Kvinna	77,27%	17
Totalt		22

Q3 Hur brukar du använda den här vägsträckan ?

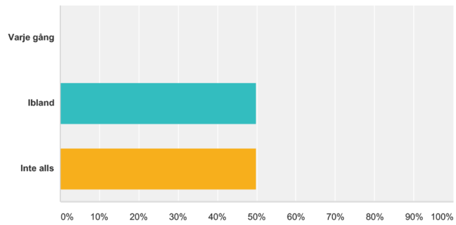
Svarade: 22 Hoppade över: 0



Svarsval	Svar	
Som fotgängare	59,09%	13
Som joggare	40,91%	9
Som cyklist	0,00%	0
Totalt		22

Q5 Brukar du använda bänkarna som finns utplacerade längs sträckan ?

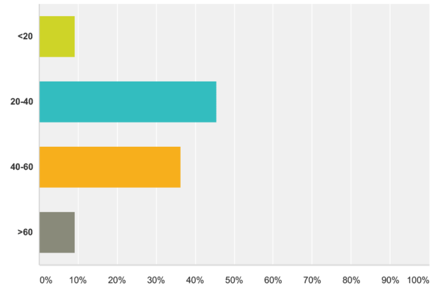
Svarade: 22 Hoppade över: 0



Svarsval	Svar	
Varje gång	0,00%	0
Ibland	50,00%	11
Inte alls	50,00%	11
Totalt		22

Q2 Ålder

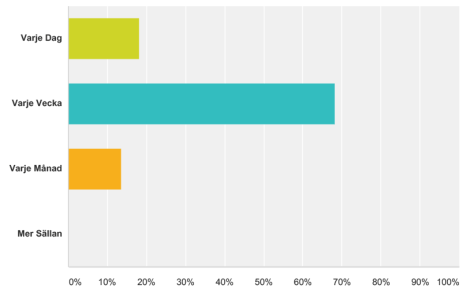
Svarade: 22 Hoppade över: 0



Svarsval	Svar	
<20	9,09%	2
20-40	45,45%	10
40-60	36,36%	8
>60	9,09%	2
Totalt		22

Q4 Hur ofta brukar du använda den här vägsträckan ?

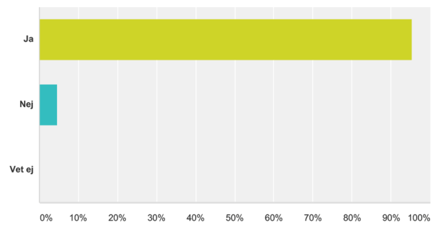
Svarade: 22 Hoppade över: 0



Svarsval	Svar	
Varje Dag	18,18%	4
Varje Vecka	68,18%	15
Varje Månad	13,64%	3
Mer Sällan	0,00%	0
Totalt		22

Q6 Är det bra att sträckan är upplyst kvällstid ?

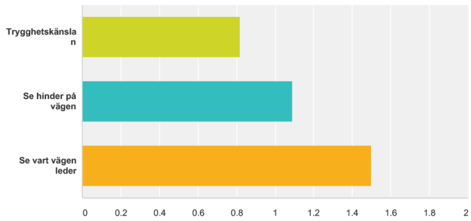
Svarade: 22 Hoppade över: 0



Svarsval	Svar	
Ja	95,45%	21
Nej	4,55%	1
Vet ej	0,00%	0
Totalt		22

Q7 Hur har följande aspekter förändrats med belysningen ?

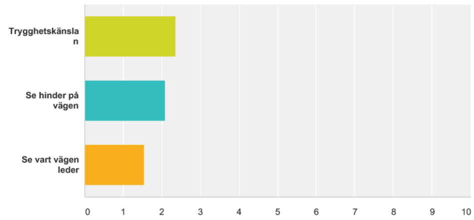
Svarade: 22 Hoppade över: 0



	Mycket sämre	Sämre	Oförändrat	Bättre	Mycket bättre	Totalt	Viktat genomsnitt
Trygghetskänslan	9,09% 2	13,64% 3	9,09% 2	40,91% 9	27,27% 6	22	0,82
Se hinder på vägen	4,55% 1	13,64% 3	18,18% 4	27,27% 6	36,36% 8	22	1,09
Se vart vägen leder	4,55% 1	9,09% 2	13,64% 3	22,73% 5	50,00% 11	22	1,50

Q8 Rangordna hur viktiga de olika aspekterna är för dig

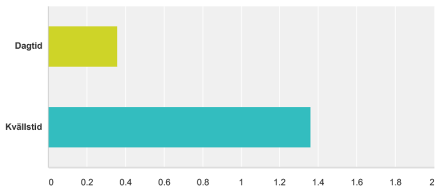
Svarade: 22 Hoppade över: 0



	1	2	3	Totalt	Score
Trygghetskänslan	59,09% 13	18,18% 4	22,73% 5	22	2,36
Se hinder på vägen	27,27% 6	54,55% 12	18,18% 4	22	2,09
Se vart vägen leder	13,64% 3	27,27% 6	59,09% 13	22	1,55

Q9 Hur tycker du att belysningsinstallationen påverkar områdets karaktär ?

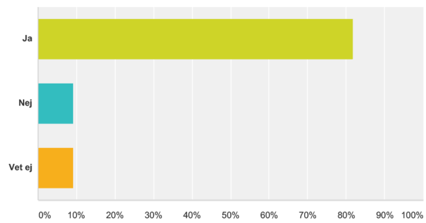
Svarade: 22 Hoppade över: 0



	Mycket positivt	Positivt	Inte alls	Negativt	Mycket negativt	Totalt	Viktat genomsnitt
Dagtid	9,09% 2	13,64% 3	72,73% 16	4,55% 1	0,00% 0	22	0,36
Kvällstid	45,45% 10	31,82% 7	9,09% 2	4,55% 1	9,09% 2	22	1,36

Q10 Vill du se den här typen av belysning på fler sträckor i området ?

Svarade: 22 Hoppade över: 0



Svarsval	Svar	
Ja	81,82%	18
Nej	9,09%	2
Vet ej	9,09%	2
Totalt		**22**

2. Student survey + answers (Part C) Bromma:

KTH STH | LJUSLABORATORIET | AVANCERAD STYRNING AV UTOMHUSBELYSNING

PART A

Level 1

1. The light on this path compared to the surrounding lighting is:

Darker ☐ Same ☐ Brighter ☐

2. Compared to its surroundings does the path appear to have good visual conditions?

Not at all → Absolutely

1 2 3 4 5

3. How comfortable would you feel while entering this path?

Not at all → Very

1 2 3 4 5

Level 2

1. The light on this path compared to the surrounding lighting is?

Darker ☐ Same ☐ Brighter ☐

2. Compared to its surroundings does the path appear to have good visual conditions?

Not at all → Absolutely

1 2 3 4 5

3. How comfortable would you feel while entering this path?

Not at all → Very

1 2 3 4 5

Level 3

1. The light on this path compared to the surrounding lighting is?

Darker ☐ Same ☐ Brighter ☐

2. Compared to its surroundings does the path appear to have good visual conditions?

Not at all → Absolutely

1 2 3 4 5

3. How comfortable would you feel while entering this path?

Not at all → Very

1 2 3 4 5

1

Level 4

1. The light on this path compared to the surrounding lighting is?

Darker ☐ Same ☐ Brighter ☐

2. Compared to its surroundings does the path appear to have good visual conditions?

Not at all	→		→	Absolutely
1	2	3	4	5

3. How comfortable would you feel while entering this path?

Not at all	→		→	Very
1	2	3	4	5

Level 5

1. The light on this path compared to the surrounding lighting is?

Darker ☐ Same ☐ Brighter ☐

2. Compared to its surroundings does the path appear to have good visual conditions?

Not at all	→		→	Absolutely
1	2	3	4	5

3. How comfortable would you feel while entering this path?

Not at all	→		→	Very
1	2	3	4	5

PART B

Compared to 100% output, estimate the level of brightness from 1 to 10 for each of the following five scenarios:

Level 1

1 2 3 4 5 6 7 8 9 10

Level 2

1 2 3 4 5 6 7 8 9 10

Level 3

1 2 3 4 5 6 7 8 9 10

Level 4

1 2 3 4 5 6 7 8 9 10

Level 5

1 2 3 4 5 6 7 8 9 10

PART C

1. Is the light enough for what you need to see?

Absolutely ☐ Partly ☐ Hardly ☐ Not at all ☐

2. Do you easily figure out objects and obstacles?

Absolutely ☐ Partly ☐ Hardly ☐ Not at all ☐

3. Do you easily recognize other people's faces?

Absolutely ☐ Partly ☐ Hardly ☐ Not at all ☐

4. Did you notice any changes in light intensity from the lights when on the path ?

Yes ☐ No ☐

5. What is your overall impression of the installation at the current scenario?

Poor	→			Very good
1	2	3	4	5

6. Do you have any suggestions for changes or improvements of the installation / scenarios?

....

....

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PART D

Level 1

1. The light on this path compared to the surrounding lighting is?

Darker ☐ Same ☐ Brighter ☐

2. Compared to its surroundings does the path appear to have good visual conditions?

Not at all → Absolutely

1 2 3 4 5

3. How comfortable would you feel while entering this path?

Not at all → Very

1 2 3 4 5

Level 2

1. The light on this path compared to the surrounding lighting is?

Darker ☐ Same ☐ Brighter ☐

2. Compared to its surroundings does the path appear to have good visual conditions?

Not at all → Absolutely

1 2 3 4 5

3. How comfortable would you feel while entering this path?

Not at all → Very

1 2 3 4 5

Level 3

1. The light on this path compared to the surrounding lighting is?

Darker ☐ Same ☐ Brighter ☐

2. Compared to its surroundings does the path appear to have good visual conditions?

Not at all → Absolutely

1 2 3 4 5

3. How comfortable would you feel while entering this path?

Not at all → Very

1 2 3 4 5

Level 4

1. The light on this path compared to the surrounding lighting is?

Darker ☐ Same ☐ Brighter ☐

2. Compared to its surroundings does the path appear to have good visual conditions?

Not at all		→		Absolutely
1	2	3	4	5

3. How comfortable would you feel while entering this path?

Not at all		→		Very
1	2	3	4	5

Level 5

1. The light on this path compared to the surrounding lighting is?

Darker ☐ Same ☐ Brighter ☐

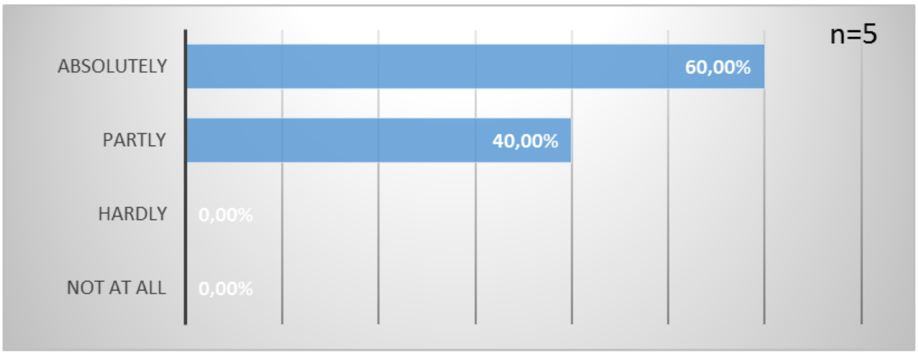
2. Compared to its surroundings does the path appear to have good visual conditions?

Not at all		→		Absolutely
1	2	3	4	5

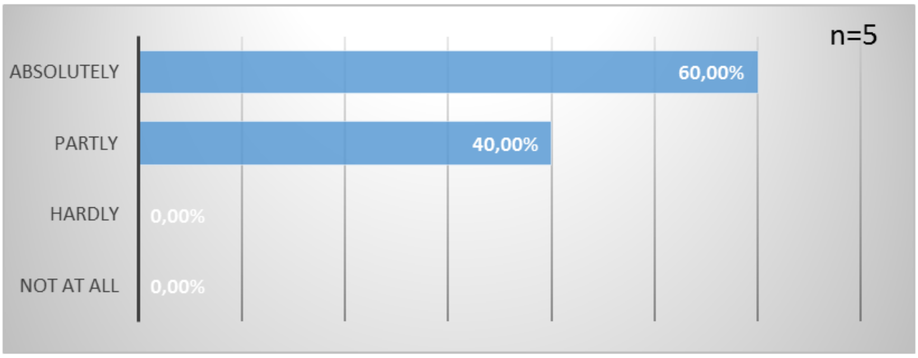
3. How comfortable would you feel while entering this path?

Not at all		→		Very
1	2	3	4	5

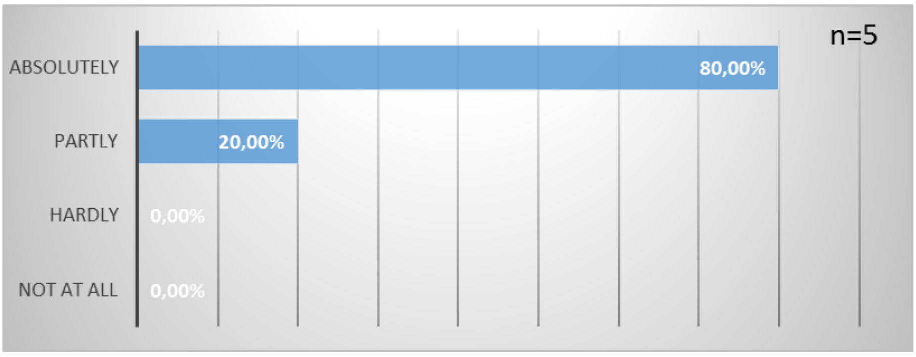
Bromma Student survey Question 1: Is the light enough for what you need to see?



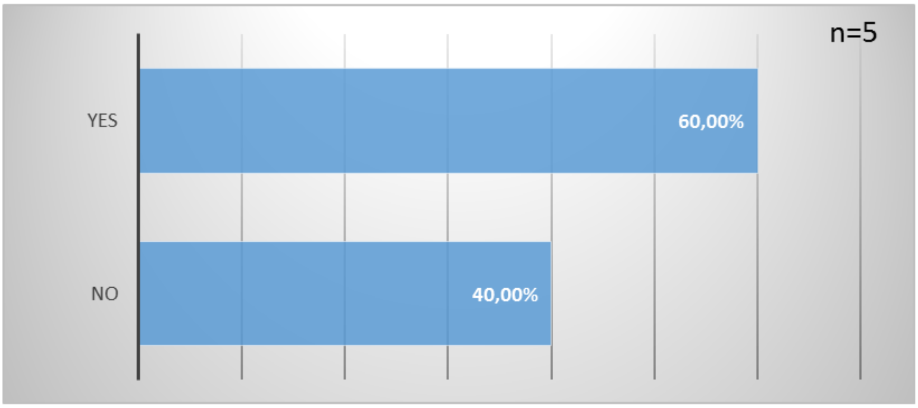
Bromma Student survey Question 2: Do you easily figure out objects and obstacles?



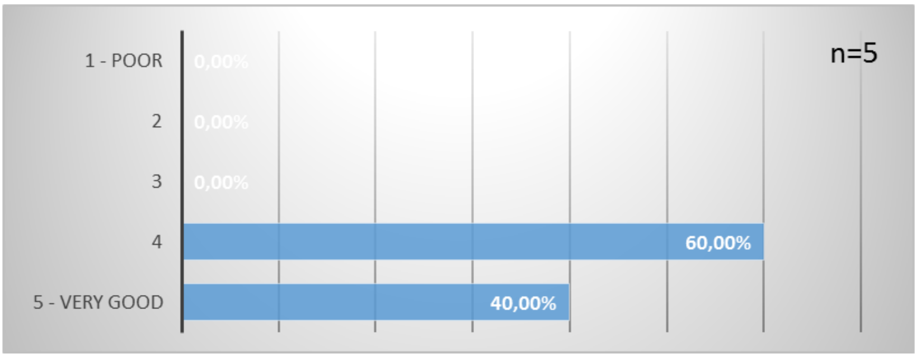
Bromma Student survey Question 3: Do you easily recognize other people's faces?



Bromma Student survey Question 4: Did you notice any changes in light intensity from the lights when on the path?



Bromma Student survey Question 5: What is your overall impression of the installation at the current scenario?



3. Energy measurements Bromma

Power consumption - Bromma

Report date 2015-06-24

Scenario nr	Description	Start	End
#0	High 10, Low 10, Time 60 sec, nr of neighbour luminars 3	14-10-13 12:00	14-10-18 10:00
#1	High 10, low 5, time 60 sec, number of neighbour luminars 3, low set to 7 on 3 ending luminars	14-10-21 12:00	14-10-25 12:00
Level 5	High 5, Low 5	14-10-27 22:00	14-10-27 22:15
Level 3	High 3, Low 3	14-10-27 22:45	14-10-27 23:00
#2	High 10, low 3, time 30 sec, number of neighbour luminars 3. No special endings	14-10-28 12:00	14-11-01 12:00
#3	High 10, low 2, time 60 sec, number of neighbour luminars 3. No special endings	14-11-10 12:00	14-11-15 12:00
Journalist demo	High 10, low 3, time 30 sec, number of neighbour luminars 3. No special endings	14-11-19 12:00	14-11-20 21:00
#4	High 10, low 5 from 06 - 23, high 7, low 3 other time, time 60 sec, number of neighbour luminars 3. No special endings	14-11-20 21:45	14-11-22 12:00
SvT ABC-nytt	High 10, low 2, time 30 sec, number of neighbour luminars 3. No special endings	14-11-24 15:00	14-11-26 21:00
#4 - (more)	High 10, low 5 from 06 - 23, high 7, low 3 other time, time 60 sec, number of neighbour luminars 3. No special endings	14-11-27 23:00	14-12-09 15:00
#1 - after 7 pole correction	High 10, low 5, time 60 sec, number of neighbour luminars 3, low set to 7 on 3 ending luminars	14-12-09 16:30	14-12-15 08:30
#2 - after 7 pole correction	High 10, low 3, time 30 sec, number of neighbour luminars 3. No special endings	14-12-15 22:00	15-01-12 12:00
#5	High 10, low 4, time 60 sec, number of neighbour luminars 3. No special endings	15-01-12 18:00	15-06-23 08:00