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Backlight on the climber
An exploratory study for the indoor bouldering facility

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BACKLIGHT ON THE CLIMBER
an exploratory study for the indoor bouldering facility

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To the light that has come into my life, enrich my life.
To those who helped, supported, and believed in me during this writing and research time, I can not make it without all your support.
Special gratitude to my tutor, Gerhard Rehm who provided good guidance through conversations on the subject, I also want to thank my friends Jason and Henrik for their help through the process.
I dedicate this work to my family for their love, and support.
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Abstract

The rise of rock climbing is a global phenomenon. Seven out of ten bouldering gyms opened during this decade in Stockholm. With the increasing sports climbing population, the lighting condition of sports facilities should be a concern, especially since electricity demand growth in buildings has been remarkably rapid. However, not much research has been conducted regarding investigating the effect of artificial lighting on indoor bouldering users’ experiences.

This thesis investigates a balance between addressing sustainable development goals number 7.3 and maintaining users’ experiences while exercising, taking Klätterverket Gasverket as a case study. Different research methods have been used to provide a pilot study to be explored by others, including literature review, semi-structured interviews, and empirical study.

This research has shown that it is hard to draw conclusions regarding the perceived qualities of light. The qualitative and quantitative results conclude that we can decrease electrical consumption in a situation that has sufficient daylight without sacrificing climbers’ experience. Adjusting the distance between the luminaire and climbing wall can slightly improve the average illuminance level and user experience.

Keywords:
Artificial lighting, vertical illuminance, indoor sports facilities, indoor bouldering, user experience
INTRODUCTION

Artificial light sources play an indispensable role in the daily life of any human being, and it has dominated humans’ indoor spaces for nearly a century. The use of artificial light cannot be avoided in all indoor areas nowadays, indoor sports facilities as well. Sweden's physical activity factsheet demonstrates that the proportion of women and men in Sweden who have reported exercising regularly has increased since 1980 and is now approximately 60 percent (Physical activity - The Public Health Agency of Sweden, no date). The growth of the sports population has led to an increase in the use of indoor sports facilities.

However, interior artificial light consumes abundant electrical energy, and global electricity demand proliferates. According to Digitalization and Energy – Analysis (IEA), electricity demand growth in buildings has been remarkably rapid over the last 25 years, accounting for nearly 60% of the total increase in global electricity consumption (Digitalization and Energy – Analysis, no date). Among the total building account consumption of electricity, the percentage for lighting in the building sector ranges from 20% to 45% (Minimizing energy consumption for artificial lighting in a typical classroom of a Hellenic public school aiming for near Zero Energy Building using LED DC luminaires and daylight harvesting systems | Elsevier Enhanced Reader, no date). Nowadays, the world faces severe energy and environmental crises. But global electricity demand grew by 5% in 2021. Moreover, almost half of the increasing electricity demand in 2021 is met by fossil fuels, notably coal, threatening to push CO2 emissions from the power sector to record levels in 2022 (Global electricity demand is growing faster than renewables, driving strong increase in generation from fossil fuels - News, no date).

Therefore, improving energy efficiency is a focal point of sustainable development. The 2030 Agenda for Sustainable Development provides the 17 Sustainable Development Goals, which are an urgent call for action, including goals number 7, target 3: by 2030, double the global rate of improvement in energy efficiency (Goal 7 | Department of Economic and Social Affairs, no date). Thus, finding a compromised sustainable lighting solution for indoor sports facilities is a world trend motivated by energy, environmental, and health considerations.

Among all kinds of indoor sports, indoor climbing is one of the biggest growing sports in the world. Sports climbing has experienced a surge in popularity over the past two decades (Michailov et al., 2018; Uvarova et al., 2019). According to the Olympic official website, in terms of the world, 25 million people climb on a regular basis (Sport Climbing - News, Athletes, Highlights & More, no date). The recent surge of sports climbing in popularity is reflected in the decision to add the sport to the 2020 Olympics in Tokyo (Uvarova et al., 2019). With the increasing number of the sports climbing population, the lighting condition of this newly emerging indoor sport should be a concern.
PRIMARY RESEARCH QUESTION

This paper aims to find the balance between addressing sustainable development goals number 7.3 and maintaining users' experiences while exercising.

By studying the perspective of indoor climbers before and after the lighting solution proposed by the author, one can gain insight into how lighting conditions in indoor climbing facilities can be optimized by considering both sustainable development goals and users’ experiences[figure 1].

SUB-QUESTION

In the daytime, can energy be saved on the east wall of the first floor of Klätterverket Gasverket? Without daylight, what is the more sustainable solution for the east wall of the first floor of Klätterverket Gasverket?

Figure 1: Research question with lighting in indoor bouldering gyms and sub-questions
BACKGROUND LITERATURE

INDOOR CLIMBING

Free climbing is the sport in which climbers try to reach the top of their objective using only their physical body (Rock climbing explained, 2019). Traditionally, it took place in natural settings. However, rock climbing gradually changes into an indoor sport [appendix 1].

Among three types of indoor climbing, bouldering is the easiest to get started. Participants do not need any certification or equipment (e.g., locking carabiner and harness, etc.) when they begin their first climbing. As such, indoor climbing facilities have influenced the broader development of the sport of climbing and climbers’ behaviors and perceptions (Eden and Barratt, 2010).

Despite the emergence of bouldering activities that have sparked research interest (e.g., recovery method, injury risk factors, movement behavior, etc.), not much research has been conducted regarding investigating the effect of artificial lighting on indoor bouldering users’ experiences.

EN12193

Lighting represents an essential and complex part of the design of sports environments. The lighting of an athletic movement must meet different requirements for the athlete engaged in the sporting gesture and for the spectators (Di Pede et al., 2017). Diverse lighting requirements are applied to various sports.

Many standards institutions and committees, including the American National Standards Institute, Illuminating Engineering Society, and the European Committee for Standardization, provide technical standards for sports and recreational areas. On a European level, the primary technical standard for lighting sports facilities is EN12193 (Standard - Ljus och belysning - Sportbelysning SS-EN 12193:2018, no date). Limit values for various lighting parameters are imposed in EN12193, especially for horizontal and vertical dimensions maintained average illuminance and illuminance uniformity. The limit values correspond to different lighting classes, specified according to the game level (recreational, training, competition). The lighting requirements imposed for wall climbing are demonstrated in Table 1.

Although the technical standards provide quantitative indications of the leading lighting parameters, they do not offer sufficient, more in-depth information for further exploration of bouldering lighting conditions, especially after considering the variable terrain of the climbing wall and simultaneously horizontal and vertical movement of athletes.

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<td>Horizontal Illuminance</td>
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<tr>
<td>I</td>
<td>500</td>
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<td>II</td>
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Table 1: lighting requirements guided in EN12193 for wall climb environment
Method

Methodology diagram

- Introduction
- Background research
- Research Question

Method - 0
- On-site observation
  - Result - 0: current situation conclusion

Method - 1
- On-site measurement & interview study
  - Result - 1: requirement & preference conclude

Method - 2.1
- Design lighting test based on result 0 & 1
  - Result - 2.1: measurement result

Method - 2.2
- Adjust the details & open participation
  - Result - 2.1: interviewees’ feedback

Discussion

Figure 2: methodology diagram
**Pre-Study**

The first inquiry analyzes Stockholm's current indoor bouldering information, including space prototypes, artificial light settings, and how daylight affects the bouldering area. Second, I choose the first floor of Klätterverket Gasverket (space prototype 1) as the primary study example for further phases. On-site measurements, tests, and interviews are carried out in this bouldering gym.

The semi-structured interview was conducted with the owner of Klätterverket Gasverket. The owner can bring out an in-depth view of the primary intention of the interior lighting design and the energy consumption data, which is different from the users' perspective. The semi-structured face-to-face interview was approximately 30 mins and was audio-recorded and transcribed.

Last, the research zooms into the lighting condition in Klätterverket Gasverket. The measurement was conducted at the east wall area of the first floor and focused on the maintained illuminance, vertical climbing wall uniformity, color rendering index, color temperature over the surface of the climbing wall, and crash pad. The measurement is conducted with the GL Spectis 1.0 Touch spectrometer at 11 AM, 1 PM, 3 PM, 6 PM, and 8 PM.

Reference grids for calculation are applied to both the vertical climbing wall and horizontal crash pad[Figures 3 & 4]. These grids are rectangular, and the illuminances are measured at every node. The grid size is defined as 1-meter width and 1-meter height, which is the easy distance that most climbers can reach next hold. The measuring height of horizontal illuminance on the crash pad is 1.5m above the ground, the most common altitude of horizontal illuminance measuring.
**Interview Study**

I attempt to understand users’ perspectives and preferences of current climbing lighting conditions through interview inquiry. Semi-structured interview questions are applied to four participants separately at 11 PM, 1 PM, 6 PM, and 8 PM [appendix 2]. Four participants all regularly go bouldering at Klätterverket Gasverket, all climbing recreationally.

In the first part of the interview, I asked four participants to describe their experience in bouldering, their experience in other indoor bouldering gyms in Stockholm, and the crucial factor that affect their choice of when to go bouldering.

The second part starts with the participants climbing one specific route on the wall. All participants climb the same route, by which they can rank the environment under the exact prerequisites. Afterward, participants are asked to rate the four lighting parameters: light level, glare, light distribution, and colors from zero to nine based on their experience during the previous climb in an adjusted V/P theory questionnaire and describe their answers. I selected these four lighting parameters based on the semantic scale for lighting: 7 Descriptors of Light(Liljefors and EJh, 1990).

I conducted an affinity diagram from the interview transcripts. Narratives and other responses from the transcripts were grouped into thematic categories, labeling each group into themes. This inquiry seeks to understand what topics users are concerned about while bouldering.

**Lighting Test - Daytime**

The daylight test focuses on reducing energy consumption without affecting users’ climbing experience during the daytime. To make it easier for participants to compare different lighting conditions, I turned off all luminaires at the same period as the interview study phase: 11 AM and 1 PM. The lighting measurement of the vertical climbing wall and horizontal crash pad are conducted the same way as in the pre-study step but only at the left half of the area, which is related to the route participants are climbing. The measurement result determines how long the lights can be turned off without affecting too much users’ experience.

Participants who attended the interview study phase during the daytime partook in the test phase after the turn-off period is defined. They climbed the same route and had interviews to compare the differences between the two lighting conditions.
Lighting test - night

To increase energy efficiency, the artificial light test focuses on finding the ideal distance between the luminaire and the climbing wall. According to CIBSE SLL’s new Technical Memorandum TM66, a full understanding of a scheme’s sustainability must also include the product life cycle, including keeping products and materials in use (CIBSE - Building Services News and Policy, no date). Therefore, I used the Trego luminaire TA6 LED that Klätterverket Gasverket uses rather than other products.

The initial distance from the wall to the luminaires is 5 meters. I blocked the original one with a blackout curtain and hung another unit 2.5 meters from the wall. Starting from this position, I moved the luminaire forward at 0.5-meter intervals [Figure 5] and maintained the original tilt angle. The measurement and participant test are taken after moving the luminaire to the ideal specified position.

The measurement of the climbing wall is conducted the same way as in the pre-study step. The participant who attends the pre-study interview at night is asked to climb the same route again at the same time as in the interview study phase. The participant is requested to describe their experience of this climbing and compare the differences between the two conditions.

Figure 5: Reference grids of luminaire’s position moving test
PRE-STUDY

Pre-study - Current Situation in Stockholm

Although the rise of rock climbing is a global phenomenon (Sport Climbing - News, Athletes, Highlights & More, no date), this paper focuses on the contemporary situation in Stockholm, Sweden. There are ten indoor bouldering gyms in Stockholm. Two started running in the 1990s, and one opened in 2003. The other seven indoor bouldering gyms are opening during this decade. The newest one is opening in 2022. All bouldering areas in Stockholm can be divided into bouldering areas with and without daylight. Half of all gyms have no access to daylight in the bouldering area. The other gyms have different daylight access types [Figure 6].

The green color represents the climbing wall, the blue color represents the window, and the walls without climbing facilities are shown in white color. All 3D models are built without orientation. They are just for illustrating the relationship between windows and climbing walls.

Figure 6: 5 bouldering space prototype with photos
In type one, the windows are opposite the climbing wall, which gives sufficient daylight for the interior environment whether the weather is sunny or overcast. Type two has a whole glass curtain wall in the bouldering area. However, the glass curtain is at the right angle to the climbing wall, which changes the amount of daylight receiving depending on the weather. The relationship between the climbing wall and window in the third one is similar to type number two, but the distance makes the influence of daylight less than the former. The daylight receiving of type four is far less than type three. The last is a semi-outdoor bouldering condition [Figure 6].

Although several space prototypes exist, the artificial light setting in bouldering gyms is similar: backlit. Photos taken on-site demonstrate that all luminaires and natural light sources provide backlit while climbing [Figure 7].

Klätterverket Sickla

klattercentret Gallerian

klattercentret solna

Beta bouldering Copenhagen

Figure 7: the artificial light setting in different gyms
However, the distance between luminaires and the climbing wall and luminaire types is diverse, providing a different lighting experience while climbing. For instance, klättercentret Gallerian, which has a lower ceiling and uses spotlights as its primary light source, has a high contrast light effect on the wall. Climbers can see multi shadows while climbing [Figure 8]. Moreover, when the climber ascends to a height equal to the light, their body becomes the source of shadows [Figure 9].

Because of the restricted bouldering conditions, most light sources in the climbing environment are backlit. In the case of backlighting only, it is essential to discuss the position and the distance between the light and the wall.

According to Henrik, the owner of Klätterverket Gasverket, the ventilation system and sauna account for the most significant electricity usage compared to lighting. Lighting is turned on during the opening hour regardless of the exterior daylight and season. Moreover, all luminaires are controlled by on/off switches. The average electricity consumption for Klätterverket Gasverket is no different between summer and winter, with diverse day lengths.

Moreover, they set all interior light in the bouldering area by their bouldering route setter group. The primary intention of the lighting strategy is to get sufficient light levels on the wall. Henrik thinks that experienced climbers know users’ needs on the wall sufficiently.
The measurement result of the climbing wall and the horizontal area is demonstrated in Figure 10 and appendix 3 & 4. As shown in Figure 10, the average light illuminance is more than the recommended value. All measurement periods except 3 PM reach the recommended value of U2vert (Minimum to Average Vertical Uniformity). The main reason is the window position and sun angle. Windows whose height is only half of the climbing wall cause the uppermost edge of the wall to be the darkest area in every measure period. According to the measure, the closer the time to sunset, the lower the illuminance value. Conversely, the bottom area of the climbing wall, which receives more daylight, has the highest illuminance value during the condition with daylight.

**Figure 10**: Average illuminance at 11 AM, 1 PM, 3 PM, 6 PM, and 8 PM. The max and min lux values are marked with the red circle.
The affinity diagram of the interview results is demonstrated in figure 11 and appendix 5 to 9. This inquiry seeks to understand what topics users are concerned about while bouldering. Four participants had interviews in four focal periods, morning, noon, sunset, and night.

Although participants 1, 3, and 4 indicated that the lighting was not their primary consideration during the climbing, all participants still showed their awareness of natural and artificial light. All participants prefer to exercise in the daytime, especially under the natural light source, and everyone mentioned daylight, whether describing ideal bouldering conditions or preference of exercising time.

When it comes to artificial light dimension, light level and the lighting distribution are the most concerned parameters. All participants proactively mentioned the lighting terms related to light level and lighting distribution. There are two types of preference in light level, preferring a brighter environment and preferring medium light level. Despite their different taste in light levels, participants 1, 2, and 4 perceive the climbing test environment the same. They feel the light level is moderate but bright enough.

Four participants show the same preference for lighting distribution. Everyone illustrates that they like a soft, uniform, and diffuse light while climbing. Participants 1, 3, and 4 mention that spotlights are not diffuse enough. Participant 3 even proactively complains that he perceives the glare when he is on the top of the wall. However, the other three participants feel the environment now is uniform enough.

The third parameter that almost every participant cares about is the correlated color temperature (CCT). Participants 1, 2, and 4 mention the importance of natural light and neutral color. However, their definition of natural light or neutral color is different. This preference reflects on the timing they prefer to come bouldering. The participant who wants higher CCT chose morning as her favorite time going bouldering, and the participant who favors lower CCT chose the afternoon as his favorite.

They also connect the description of space with the lighting condition. Participants 2, 3, and 4 mentioned the space height while discussing the differences between several bouldering gyms. Participants 1 and 4 illustrate the relation between space height and lighting.

Participant 1 explains that the bigger window may enhance the daylight receiving but risk presenting higher contrast simultaneously, depending on the window's orientation. According to participant 4, a higher ceiling provides a better luminaires position, showing more even lighting distribution.

![Figure 11: Affinity diagram conducted from interview material](image-url)
The measurement result of the climbing wall are demonstrated in Figures 12 to 14, and the horizontal dimension result is illustrated in appendixes 10 and 11. Considering that the participants’ tests concentrate on the climbing process, I focus more on vertical measurement in both the measurement and interview parts. The measurement aims to determine whether the turn-off artificial light proposal is suitable for climbing by measuring the quantitative data.

Compared to the condition with artificial light, the adjusted situation did not present better data at 11 AM. The average light level and the uniformity are farther from ideal [Figure 12]. I consider 11 Am is not a suitable time to turn off the artificial light. Therefore, I postponed the test for one hour and measured the data again at noon [Figure 13].
Most of the indicators at noon are closer to the ideal in the vertical dimension than at 11 AM. However, the cloudy weather with gusty wind causes the instability factor during the measuring. It sometimes blocks the sunlight and dims the light level—the weather influence one vertical data at noon but affects most measurement data at 1 PM and all horizontal measurement data.

I marked out the abnormal data in red and demonstrated two calculations with and without the anomalous data in the vertical dimension result. Even with abnormal data, the average illuminance slightly increases from 312 to 320 lux. Both minimum to maximum and minimum to average vertical uniformity has risen from 0.57 to 0.64 and 0.72 to 0.88.
The afternoon data, which was affected by weather, presented too unsteady that it is hard to separate abnormal data from others. The maximum value declined from 523 to 364 lux. The drop in this value reduced the difference between each measurement point; the vertical uniformity increased from 0.57 to 0.7 (U2vert). Overall, turning off the artificial light during the daytime may sacrifice approximately 200 lux on average but improve the vertical uniformity.

Figure 14: vertical dimension compared results at 1 PM
Lighting test - nighttime

After the first position test, I add one layer of Rosco E-Colour #480 diffusion to reduce the glare, which intensifies because of the closer position [figure 15 & 16], and I definitely hang the luminaire at 2.5 meters from the wall. The measurement data is shown in figure 17. The overall average illuminance slightly increases from 178 to 187 lux, closer to the recommended value. However, the vertical uniformity drops from 0.8 to 0.72.

Figure 15: luminaire with a layer of diffusion

Figure 16: hanging method draft
The measurement data is shown in figure 17. The overall average illuminance slightly increases from 178 to 187 lux, closer to the recommended value. However, the vertical uniformity drops from 0.8 to 0.72.

This inquiry aims to find two things: the better timing for starting to turn off the artificial light during the sunny daytime and understanding how users perceive the modified lighting condition while bouldering. The interview question and the transcription of each interviewee are shown in appendix 12 to 15. Figures 18 to 20 illustrate how participants perceive two lighting conditions by ranking each light parameter. They are required to provide an ideal point for each light parameter and give a definitive score for two lighting conditions afterward. All of them can make comments as much or less depending on their sensation.
Participant 1 feels that the adjusted condition's light level and color rendering are lower than the original condition and his ideal situation but is enough for climbing. The unstable weather, in which sometimes the cloud blocks the sunlight (daylight) and dims the light, is the primary factor that makes him unsatisfied with the no artificial light bouldering environment. Besides, he feels that his perception of color rendering is affected by light level. The lower the light level is, the lower the color rendering is. Conversely, he is satisfied with the elimination of glare. He says that the luminaires hanging on the west wall always glare at him when he is at the wall top.

**Figure 18: how participant 1 perceives two lighting conditions**
Both conditions’ light level is one point away from participant 2’s perfect score. He has a different preference for light distribution from other participants. Although he prefers a stereoscopic environment where he can see diverse layers of shadow and contrast on the wall, current statuses are not uniform enough for him. He also gave positive feedback on the glare parameter that adjusted condition solved the glare problem as participant 1 used to have. He gave two situations on the light distribution and color rendering parameters the same score. According to him, daylight positively affects every parameter, but he thinks the sunny weather is the decisive factor. He considers that the adjusted condition works on the sunny day and the season with a longer duration of possible sunshine, which is not stable enough.

Participant 3’s ideal distribution level is between two conditions; both are one point from her ideal score. She feels little difference in color rendering and glare between the two conditions. Overall, she cares about the light level the most. Although the daylight is adequate for her, she will think the gym is not open if there is no artificial light.

Figure 19: how participant 23 perceives two lighting conditions
Night / Participant 4

Participant 4 feels the adjusted condition’s light level is closer to his ideal condition. He is aware the adjusted condition is more diffuse. However, the color temperature of the testing luminaire is 3000K, which is warmer than the original setting (4000K). Participant 4 indicated that he prefers the CCT between 3000 and 4000K. These two situations do not meet his ideal CCT condition. Therefore, he perceives the two conditions’ light distribution as similar because he feels that the shadows in the original situation are acceptable. He thinks the adjusted condition is better on the glare indicator. Overall, he perceives both conditions as similar and is satisfied with them.
DISCUSSION

The research developed in this study confirmed that the current situation of bouldering gyms in Stockholm could achieve sustainable goal number 7.3 and cater to climbers’ needs simultaneously by adjusting their lighting strategies, including selecting the right luminaires type, adding a diffuser on luminaire to avoid glare, having the opening in the climbing area, and adjusting the distance between luminaire and climbing wall. However, some indicators, which are not directly related to lighting, should be considered essential indicators.

INDICATORS DIRECTLY RELATED TO LIGHT

Through the interview study and on-site observation, I found that climbers gave positive feedback to the more diffuse luminaire type rather than the spotlight. However, there is potential for using both types of luminaires simultaneously in the bouldering environment, which is not common in the current situation.

In addition to the type, the distance also has a significant impact. Bouldering gyms in Stockholm have various distances between the luminaire and climbing walls, which create a different light level on the wall. However, climbers are more sensitive to light levels than other light parameters. To comply with TM66 and maintain the product life cycle rather than replace all existing luminaries, adjusting the distance of the luminaire is essential to solving this issue. Through several on-site adjustments and tests, participant feedback shows that the ideal distance should be 2.5 meters with the diffuser on the luminaire.

Third, participants’ light distribution and color temperature preferences vary, which is hard to meet everyone’s needs. More statistical data from masses of participants need to be collected and analyzed to find the range of CCT and light distribution, which is acceptable for the majority.

LIGHTING CONTROL SYSTEM & INTELLIGENT SENSOR

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ENERGY-SAVING TRADE-OFF BETWEEN LIGHTING AND INDOOR TEMPERATURE

The interview with Henrik, the owner of Klätterverket Gasverket, made me re-consider the electric consumption issue from a different standpoint and brought out a different perspective. Klätterverket Gasverket is trying to get Miljöbyggnad certification during these years. Miljöbyggnad contains 15 indicators related to human well-being and ecologically friendly (‘Vad är Miljöbyggnad?’, no date). Daylight receiving is one of the indicators; more openings bring out more daylight for the interior. However, maintaining the desired temperature indoors is also one indicator as well. Large window areas affect solar radiation, which will cost more energy consumption for keeping the indoor climate in winter.

This issue is rare for me, who comes from low-latitude regions. The tropical weather requires better natural ventilation (Biket, 2006; Azzmi and Jamaludin, 2014; Aflaki et al., 2015). Moreover, every participant prefers to exercise under natural light and considers the windows an essential factor influencing their satisfaction with the environment. The interview with Henrik broke my internal thinking and made me consider the balance between temperature maintenance and daylight receiving. I believe it’s vital to consider lighting and other indicators simultaneously if I want to achieve the sustainability goal in reality. Otherwise, gyms may consume more energy to compensate for the thermal loss.

CROSS-REFERENCING INFORMATION FROM USERS AND OBJECTIVE DATA

I found interesting paradoxical information by cross-referencing information from users with objective measurement data. For instance, participant 1 felt the color rendering index declined without artificial light because the light level was lower than in the previous condition. Nevertheless, the objective data shows a contrary result. The average color rendering index is 88 in original condition and 96 in adjusted condition.

Participants 2 and 3 have converse preferences on light distribution, and they perceived the contrast of the adjusted condition was higher than the original. However, participant 2, who prefers a stereoscopic environment, perceives two conditions were not uniform enough. Participant 3, who prefers a uniform environment, perceives the original condition was too uniform for her. It is contrary to the common-sense deduction. I assume participants 2 and 3 will give me opposite feedback.

Last, cross-referencing participants’ descriptions and the score they gave provides a clear viewpoint in interpreting their feedback. Participant 2 said that he did not know I turned off the light until I turned it on after finishing his test. However, he decreased the adjusted condition score because of the unstable weather control. This kind of attitude-changing process is ordinary during almost every participant’s interviews. Cross-referencing the description and score is necessary for further understanding their implied meaning.
Conclusion

This thesis explores the possibility of reducing the energy consumption of the Klätterverket Gasverket without sacrificing users’ exercise experience and providing a pilot study to be explored by others. The research results conclude that the Klätterverket Gasverket’s daylight receiving exceeds the requirement, but the average illuminance at night is insufficient. Therefore, the proposal is to decrease the light level during the daytime and raise the light level at night, simultaneously maintaining the luminaire life cycle and avoiding energy waste.

According to the interview results after the test, participants’ satisfaction with the environment dropped slightly without artificial light during the daytime. However, the main reason for declined satisfaction could be adjusted. By adding an intelligent sensor or control system which can compensate for the unsteady weather factor and adjust the light level more subtle, the daytime proposal can be more in line with participants’ needs. On the other hand, the participant at night gave positive feedback on the adjusted condition. The result demonstrates that I improved the light level and part of the user experience by adjusting the distance between luminaires and the climbing wall to 2.5 meters.

Although it’s hard to meet every user’s preference and need more exploratory test, the result concludes that it is possible to decrease the electrical consumption without replacing the original luminaire and sacrificing climbers’ satisfaction.
References


Biket, A.P., 2006. ARCHITECTURAL DESIGN BASED ON CLIMATIC DATA. Built Environ. 7.


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Photo source:
1. researcher herself
2. https://swiftr.se/studios/klattercentret-akalla
5. BLX bouldering club website: https://www.blx.rocks/.

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Appendix 1

Outdoor to indoor climbing trend and its influence

Traditionally, rock climbing took place in natural settings. However, in the early 1990s, it was decreed that international events would take place on purposely designed infrastructures only, leaving the natural environment without impact (Sport Climbing - News, Athletes, Highlights & More, no date). Minimizing the constraints of unfavorable weather is the second reason sport climbing is now being made available to people in artificial settings (Eden and Barratt, 2010).

This is the beginning of the development of indoor sports climbing. Over the past two decades, artificial climbing walls have been built in schools, homes, shopping malls, and gyms. Therefore, indoor climbing facilities have increased (Kulczycki and Hinch, 2014). While the development of outdoors climbing is still thriving, the focus of this study is on indoor bouldering situations.

There are several different types of indoor climbing in the Olympic games: leading, bouldering, and speed climbing. Bouldering is the most common form of indoor climbing in cities because it does not require tall walls or complex terrains for route settings. Besides, participants do not need any certification or equipment (e.g., locking carabiner and harness, etc.) when they begin their first try of climbing. Indoor bouldering facilities are settings where many climbers are introduced to rock climbing and practice their skills that can be applied to climbing at natural sites (Morgan, 1998). As such, indoor climbing facilities have influenced the broader development of the sport of climbing and climbers’ behaviors and perceptions (Eden and Barratt, 2010).
### Appendix 2

**Semi-structured interview questions (pre-study phase)**

<table>
<thead>
<tr>
<th>Question</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. What's your experience in bouldering?</td>
<td>1.1 when are you starting bouldering, what is your level now? how frequently do you go bouldering?</td>
</tr>
<tr>
<td>2. What's your ideal bouldering condition?</td>
<td>2.1 if only considering the lighting?</td>
</tr>
<tr>
<td>3. What time do you prefer to go bouldering?</td>
<td>3.1 why? 3.2 does lighting affect your choice? 3.3 what time is your favorite time going bouldering if considering only lighting? 3.4 why? 3.5 how do you feel the light at the time you choose?</td>
</tr>
<tr>
<td>4. Have you been to other bouldering gyms in Stockholm?</td>
<td>4.1 can you describe each bouldering area in different gyms? 4.2 which gives you a better overall experience? 4.3 which gives you a better lighting experience?</td>
</tr>
<tr>
<td>5. Rank lighting condition using these four light parameters from 0 to 9</td>
<td>5.1 light level: 0 means dark, 9 means bright 5.2 light distribution: 0 means dramatic, 9 means uniform 5.3 glare: 0 means disturbing, 9 means none glare 5.4 the stone’s color on the wall: 0 means color presented unreal, 9 means color presented real 5.5 overall lighting condition: 0 means dissatisfied, 9 means satisfied</td>
</tr>
</tbody>
</table>
APPENDIX 3

The measurement result of the climbing wall
Appendix 4

The measurement result of the horizontal area
## Appendix 5

### Four interviewees' keywords related to light

Four different colors (yellow, green, red, and blue) represent various participants. Brighter color represents a positive attitude to the keyword they mentioned, while darker color indicates a negative feeling.

<table>
<thead>
<tr>
<th>Interviewee 1</th>
<th>Interviewee 2</th>
<th>Interviewee 3</th>
<th>Interviewee 4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>sports guy</strong></td>
<td><strong>jog outdoor</strong></td>
<td><strong>rock climbing outdoor</strong></td>
<td><strong>focus on indoor</strong></td>
</tr>
<tr>
<td>bright</td>
<td>morning</td>
<td>natural light</td>
<td>route style</td>
</tr>
<tr>
<td>diffuse light</td>
<td>uniform</td>
<td>sunny day</td>
<td>space height</td>
</tr>
<tr>
<td>recognize stones clearly</td>
<td>route style for beginner</td>
<td>see outside</td>
<td>windows</td>
</tr>
<tr>
<td>sunlight</td>
<td>artificial light</td>
<td>route style</td>
<td>see outside</td>
</tr>
<tr>
<td>window</td>
<td>natural light</td>
<td>warm</td>
<td>neutral color</td>
</tr>
<tr>
<td>direct sunlight on climbing wall</td>
<td>colder</td>
<td>sleepy, study</td>
<td>warm light</td>
</tr>
<tr>
<td>backlit</td>
<td>overcast</td>
<td>cherish</td>
<td>diffuse</td>
</tr>
<tr>
<td>luminaires position</td>
<td>daylight</td>
<td>daylight</td>
<td>spotlights</td>
</tr>
<tr>
<td>luminaires type</td>
<td>light is the main reason</td>
<td>light before noon</td>
<td>window &amp; climbing wall in right angle</td>
</tr>
<tr>
<td>artificial light</td>
<td>light is not main reason</td>
<td>bright, sufficient</td>
<td>can’t remember if there is window</td>
</tr>
<tr>
<td>climb in morning</td>
<td>less window</td>
<td>no glare</td>
<td>have windows</td>
</tr>
<tr>
<td>medium light level</td>
<td>every wall lit by sunlight</td>
<td>natural color</td>
<td>not uniform light</td>
</tr>
<tr>
<td>enclosed space</td>
<td>short period light too strong</td>
<td>natural color</td>
<td>medium light level</td>
</tr>
<tr>
<td>dark corner</td>
<td>spotlight too focus</td>
<td>glare on the top of wall</td>
<td>prefer warmer CCT</td>
</tr>
<tr>
<td>high ceiling</td>
<td>uniform</td>
<td>eye’s comfort</td>
<td>prefer diffuse, soft</td>
</tr>
<tr>
<td>luminaires in right position</td>
<td>no glare</td>
<td></td>
<td>necessary light level</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>no daylight</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>no glare</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>strong contrast</td>
</tr>
</tbody>
</table>
**Appendix 6**

*Users’ consideration: exercise habit dimension*

<table>
<thead>
<tr>
<th>Prefer outdoors</th>
<th>Prefer sunny day</th>
<th>Prefer natural light source</th>
<th>Prefer daytime</th>
</tr>
</thead>
<tbody>
<tr>
<td>rock climbing outdoor</td>
<td>sunny day</td>
<td>natural light</td>
<td>morning</td>
</tr>
<tr>
<td>jogging outdoor</td>
<td>overcast</td>
<td>windows</td>
<td>morning</td>
</tr>
<tr>
<td></td>
<td></td>
<td>feels like outdoor</td>
<td>morning</td>
</tr>
<tr>
<td></td>
<td></td>
<td>sunlight</td>
<td>around noon</td>
</tr>
<tr>
<td></td>
<td></td>
<td>direct sunlight on the wall</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>artificial light only</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>outside view seeing</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>outside view seeing</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>windows</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>artificial light only</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>neutral color</td>
<td></td>
</tr>
</tbody>
</table>

**Appendix 7**

*Users’ consideration: spatial dimension*

<table>
<thead>
<tr>
<th>Prefer high ceiling</th>
<th>Prefer space with window</th>
<th>Relationship between window &amp; space</th>
</tr>
</thead>
<tbody>
<tr>
<td>high ceiling</td>
<td>have window</td>
<td>can’t even remember if there’s a window in classroom</td>
</tr>
<tr>
<td>high ceiling</td>
<td>have window</td>
<td>direct sunlight on the climbing wall</td>
</tr>
<tr>
<td>spacious</td>
<td>outside view seeing</td>
<td>backlit</td>
</tr>
<tr>
<td></td>
<td>outside view seeing</td>
<td>window orientation cause high light level</td>
</tr>
<tr>
<td></td>
<td>have window</td>
<td>every wall lit by sunlight</td>
</tr>
</tbody>
</table>

window & climbing wall in the right angle
Appendix 8

Users’ consideration: lighting dimension

<table>
<thead>
<tr>
<th>Color Rendering on Site</th>
<th>Luminaire Position</th>
<th>Luminaire Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural color</td>
<td>Luminaire in wrong position</td>
<td>Spotlights</td>
</tr>
<tr>
<td>Not purely white, a little bit green, affect color</td>
<td>Luminaire in right position</td>
<td>Disco lights</td>
</tr>
<tr>
<td>Dark corner</td>
<td>Uniform everywhere</td>
<td>Spotlights</td>
</tr>
<tr>
<td></td>
<td>Window orientation</td>
<td>Diffuse light</td>
</tr>
<tr>
<td></td>
<td>Short period light too strong</td>
<td>Spotlights</td>
</tr>
<tr>
<td></td>
<td>Strong contrast</td>
<td>Diffuse light</td>
</tr>
</tbody>
</table>

- **Color Rendering on Site**
  - Natural color
  - Not purely white, a little bit green, affect color
  - Dark corner

- **Luminaire Position**
  - Luminaire in wrong position
  - Luminaire in right position
  - Uniform everywhere

- **Luminaire Type**
  - Spotlights
  - Disco lights
  - Spotlights
  - Diffuse light

<table>
<thead>
<tr>
<th>CCT</th>
<th>Light Level</th>
<th>Light Distribution</th>
<th>Glare on Site</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural color</td>
<td>Bright</td>
<td>Uniform</td>
<td>Glare on the top of wall</td>
</tr>
<tr>
<td>Natural light</td>
<td>Medium light level</td>
<td>Uniform everywhere</td>
<td></td>
</tr>
<tr>
<td>Cold, energetic, exercise</td>
<td>Brighter daylight</td>
<td>Diffuse light</td>
<td></td>
</tr>
<tr>
<td>Artificial light</td>
<td>Medium light level</td>
<td>Uniform</td>
<td></td>
</tr>
<tr>
<td>Warm, sleepy, study</td>
<td>Recognize stone clearly</td>
<td>Diffuse, soft light</td>
<td></td>
</tr>
<tr>
<td>Natural color</td>
<td>Bright, sufficient daylight</td>
<td>Strong contrast</td>
<td></td>
</tr>
<tr>
<td>Neutral color</td>
<td>Necessary, medium light level</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Warm light</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **CCT**
  - Natural color
  - Natural light
  - Artificial light
  - Natural color
  - Neutral color
  - Warm light

- **Light Level**
  - Bright
  - Medium light level
  - Brighter daylight
  - Medium light level
  - Recognize stone clearly
  - Bright, sufficient daylight
  - Necessary, medium light level

- **Light Distribution**
  - Uniform
  - Uniform everywhere
  - Diffuse light
  - Uniform
  - Diffuse, soft light
  - Strong contrast

- **Glare on Site**
  - Glare on the top of wall
  - No glare at all
  - No glare at all
  - No glare at all
**Appendix 9**

Users’ consideration: other dimensions

- **crowd**
  - not crowded
  - less crowded

- **proximity**
  - close proximity
  - proximity is a consideration

- **climbing route**
  - route for beginner
  - parkour route style
  - amount of route

**Appendix 10**

Users’ consideration: exercise habit dimension

<table>
<thead>
<tr>
<th>Measurement (Light on → off)</th>
<th>11 AM with light</th>
<th>12 AM without light</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evert Min: 134 → 91 lx</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evert Max: 1005 → 1012 lx</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evert Ave: 351 → 129 lx</td>
<td></td>
<td></td>
</tr>
<tr>
<td>U1vert (min-max): 0.13 → 0.08</td>
<td></td>
<td></td>
</tr>
<tr>
<td>U2vert (min-ave): 0.38 → 0.7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Test On-site Average Illuminance: 200 lx
Original On-site Average Illuminance: 351 lx
Recommended Average Illuminance: 129 lx

---

35
Appendix 11

Horizontal dimension compared results at 1 PM
(affected by weather)

<table>
<thead>
<tr>
<th>measurement (Light on → off)</th>
<th>1 PM with light</th>
<th>1 PM without light</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evert Min : 230 → 38 lx</td>
<td>38 lx</td>
<td>38 lx</td>
</tr>
<tr>
<td>Evert Max : 1042 → 892 lx</td>
<td>616 lx</td>
<td>111 lx</td>
</tr>
<tr>
<td>Evert Ave : 481 → 203 lx</td>
<td>469 lx</td>
<td>63 lx</td>
</tr>
<tr>
<td>U1vert (min-max) : 0.2 → 0.04</td>
<td>243 lx</td>
<td>187 lx</td>
</tr>
<tr>
<td>U2vert (min-ave) : 0.47 → 0.18</td>
<td>250 lx</td>
<td>230 lx</td>
</tr>
</tbody>
</table>

Recommended Average Illuminance: 200 lx
Test On-site Average Illuminance: 203 lx
Original On-site Average Illuminance: 312 lx
### Semi-structured interview questions (test phase)

1. Rank lighting conditions using these four light parameters from 0 to 9

   A. Light level: 0 means dark, 9 means bright
      1) What is your ideal score?
      2) What is the score of the condition?

   B. Light distribution: 0 means dramatic, 9 means uniform
      1) What is your ideal score?
      2) What is the score of the condition?

   C. Glare: 0 means disturbing, 9 means no glare
      1) What is your ideal score?
      2) What is the score of the condition?

   D. The stone’s color on the wall: 0 means color presented unreal, 9 means color presented real
      1) What is the score of the condition?

   E. Overall lighting condition: 0 means dissatisfied, 9 means satisfied
      1) What is the score of the condition?

2-1. Compare two conditions and give a score from 0 to 9 for each situation

   1) with artificial light
   2) without artificial light

2-2. Describe the differences
Appendix 13

Interview transcription 1

12 AM / Participant 1

Light Level: I would say three to four. It’s not that dark

Light distribution: it’s pretty uniform for me

Glare: it’s no glare at all, better than before. When I climb to the top of the wall, I always get the glare from the luminaire hanging on the other side.

Color rendering: it’s above the adequate level, I can still recognize the color well, compared to two conditions, the stone is not as bright as the situation with artificial lights, I think it’s the reason why I perceive it a bit unreal than the original situation

Essential difference:

stability is the main focus. The light effect depends on the weather outdoor. It is not stable enough. Although I can see very clearly on sunny days, the forecast weather will be too dark for me. The artificial light always provides the same light level, making me perceive the environment as stable.

The situation without artificial light is not that bad. I feel the environment is natural with the sunlight. 2 points less than the original situation is because of the lower light level and stability.
Appendix 14

Interview transcription 2

1 PM / Participant 2

**Light Level:** I like today’s sunlight. I perceive the environment nicely. But I am not sure of other days’ weather.

**Light distribution:** I have a film background. Therefore, I prefer a stereoscopic environment. I like to see the shadow and layers in the background. I think the daylight has a good effect on the wall.

**Glare:** I used to climb the cave terrain (at other bouldering gyms), so I always get glare from the light from the lower place while I start climbing a route. This environment makes me feel good. Moreover, I don’t get the glare from the other side of the wall while climbing above some position when you turn the light off.

**Color rendering:** It’s natural because the sunlight positively affects it.

**Essential difference:**
I don’t even know that you turn off the light before turning it on. However, I think this is because of the good weather today and also because of the season (spring and summer with a longer duration of possible sunshine).
Appendix 15

Interview transcription 3

1 PM / Participant 3

Light Level: I feel a little bit dark. I would give it four, though I feel satisfied with this light level. My ideal light level is six.

Light distribution: The condition with artificial light is more uniform than the turning off situation. Because the sun is the only light source and it creates the different light levels on the climbing wall, which has diverse terrain (overhang, slab, and vertical combined wall).

However, it doesn’t matter cause it’s not bothering me at all. I feel comfortable even if this environment isn’t that uniform.

Color rendering: I feel the two conditions have no differences in color rendering.

Essential difference:

Turning off the artificial light doesn’t affect me a lot. I can recognize everything. I will feel that the gym doesn’t open yet when the light is turned off. I prefer a brighter space.

The main difference that affects how satisfied I am is the light level. I feel that Asian prefer brighter conditions. Overall, turning on and off the light doesn’t matter to me; I think the daylight is adequate for climbing.
Interview transcription 4

Night / Participant 4

Light Level: I would say 5.5 is the ideal score for the light level. I don’t feel that super bright is a perfect condition for me.

Light distribution: The ideal score is 8. These two conditions are similar for me; I would give it the same score as last time. The contrast was higher last time, but it’s still okay cause the shadow edge isn’t too sharp.

Glare: The light is covered by diffusion, so it’s less glare than last time. I used to see the glare while I finished the route, turned around, and jumped off the wall. However, I noticed glare, and I don’t like it that much, but it’s not a decisive factor for me. I care about the light while climbing than the moment I jumped off.

Color rendering: I would give 9 for the ideal score. I would say 8 as well, although the color is a bit warmer, which I like more, my ideal color will be in between two conditions. The previous one is too cold, and this one is too warm.

Essential difference:

Both settings have advantages and disadvantages, and they are relatively similar. The new setting is more diffuse now, which I like. But I would like to have a colder color temperature though it seems natural. And less glare is a good thing as well.

The essential difference is color temperature. In terms of brightness, it is enough, but it couldn’t be darker than now, I would say.