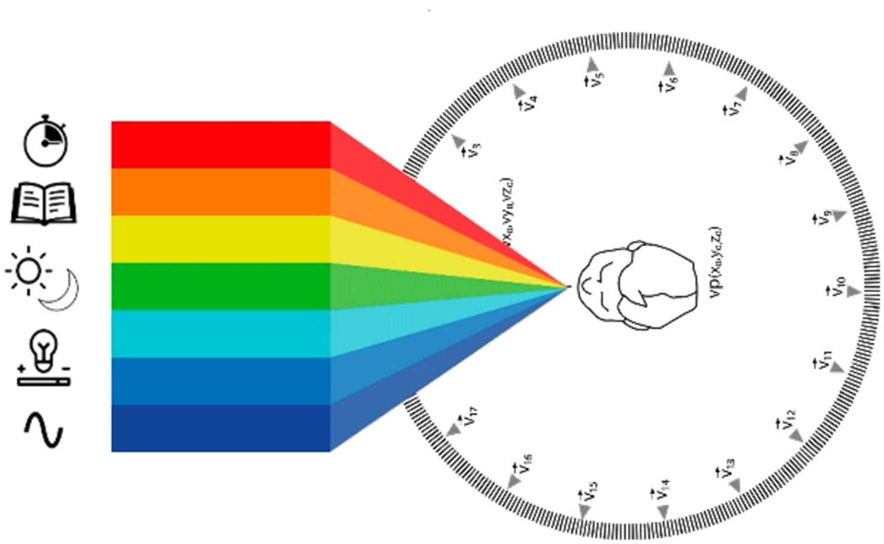

R.E.A.L.

Response-driven Environments for Appropriate Lighting

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Content

REAL
Response-driven Environments for Appropriate Lighting

affects the experience of the space in terms of health, ergonomics, energy and productivity. Digitalization of buildings with focus on healthy lighting and daylight is thus an important step towards healthier indoor environments. Although our knowledge about the spectral-effectiveness of light on productivity by regulating our biological needs is advancing, defining the actual exposure to effective light-ing as result of the building design poses important challenges. A framework that could identify light exposure related to actual human position and orientation (di-rection of the line of sight) in space will lead to healthier indoors costumed for each individual with results in higher productivity as well as effective building per-formance. The effect of such framework for the building occupant and owner are beyond the immediate needs of the society and towards continuous performing results.

The project here, Response-driven Environments for Appropriate Lighting (REAL), sought to develop a pathway towards healthy indoor environments by creating frameworks that relate human subjective response and objective orientation-reflexes to daylight towards informative outputs. In the same context and in an exploratory project, students at DTU were set out to investigate the possibilities of relating these response-driven light exposure levels to human performance. A pre-validated simulation workflow was developed for digitalization of the building based on human responses and aligned with Build 4.0 goals. More importantly, the developed workflow coupled with occupancy sensors can give real-time infor-mation to the occupants regarding their light environment and achievable produc-tivity levels.

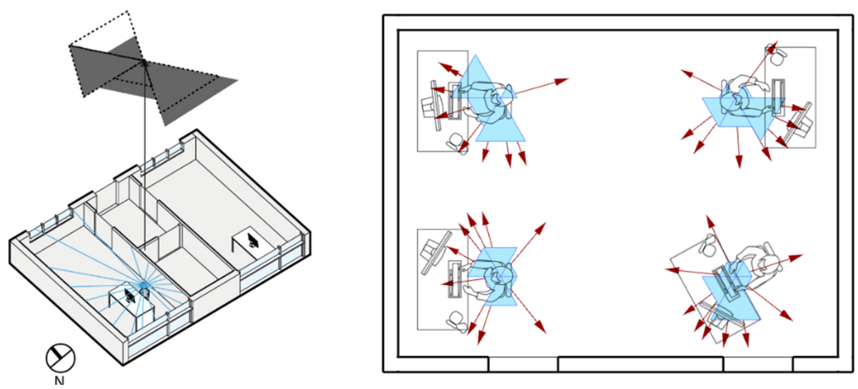
Research Context

Today, humans spend about 90% of their time indoors [Roberts, 2016]. In an educational context, the percentage of hours of compulsory instruction time, that may occur inside the classrooms, ranges between 42%, for secondary students, and 52% for primary students while, the time spent by university students in the classroom is less due to higher individual study time at this level. It is, hence, in our best interest to create high quality indoor environmental conditions to enhance and maximize productivity and performance in such environments. Amongst indoor environmental parameters, as an architectural element light is a highly interdisciplinary topic [1]that affects occupants through different pathways with physiological, psychological and biological [2]responses. In daylit spaces, light characteristics such as sole presence of light and access to natural light were shown to affect students' preferences. Positive effects of window view were seen on attention and concentration in such spaces when relevant tests were used. In a similar way, glare or direct daylight in space has negatively affected the students. Dynamic electric lighting in terms of light intensity or color correlated temperature (CCT), shown to affect students' attention and concentration. Several physiological responses mainly to daylit conditions were also associated with students' mood, sleep and thereby their performance. Studies in daylight have shown that light factors such as intensity, timing, duration, and wavelength affect our circadian rhythm thus our daily lives. As there is a connection between exposure to light, health and performance levels, the lighting environment should be regulated according to the work we have to perform.

Daylight also impact our experience of a space and its intensities can sometimes be so high that it causes discomfort indoors in the form of glare. Our visual comfort is evaluated based on the amount of glare that can be determined from the angle of incidence of daylight. The incidence angle varies with the passage of the sun across the sky, but new studies shows, that it also can vary with dynamic gaze changes and attraction to view outside [Sarey Khanie, 2015]. However, it is important that users have access to daylight and view outside, as this has proven to be of great importance for the perceived comfort in a room.

Despite several existing wavelength-dependent models to predict spectral-effectiveness of light, none includes user behavior into this equation for maximum exposure. These methods only partially can predict the health potentials of the lighting with assumption of static building occupants on fixed pre-defined points. The dynamic human behavior to light exposure has been addressed in fewer studies where photometric measurements and eye-tracking methods have been coupled for observation on gaze responses to light Figure1. There have been many attempts to incorporate discoveries on how light affects human circadian rhythms into a simulation workflow. Lark Spectral Lighting is a plug-inn for Rhino Grasshopper developed as a collaboration of University of Washington and ZGF Architects LLP. Lark spectral lighting can calculate on Equivalent Melanopic Lux (EML) and can also run simulations beyond the normal tristimulus color space [Mehlika Inanici, 2015].

Combining methods and techniques, we worked on two work packages: Firstly we focused on the performance rating for different interior layouts. Secondly, we did an exposure characterization where the dwell and track data were used to define exposure ranges to spectral effectiveness of the space. The results were communicated through student work, publication and two seminars.



a) Results for response-driven orientation reflex to lighting.

b) An example showing the layout intervention based on human responsive principles.

Figure 1 Simulation results from a gaze-repulsive analysis based on human orientation reflexes to light. These results are based on a preliminary mathematical model for prediction of orientation reflexes to light which was developed and integrated in a simulation workflow in Switzerland. The tool highlights the responsive zones in the architectural space where the occupants have the maximum comfort.

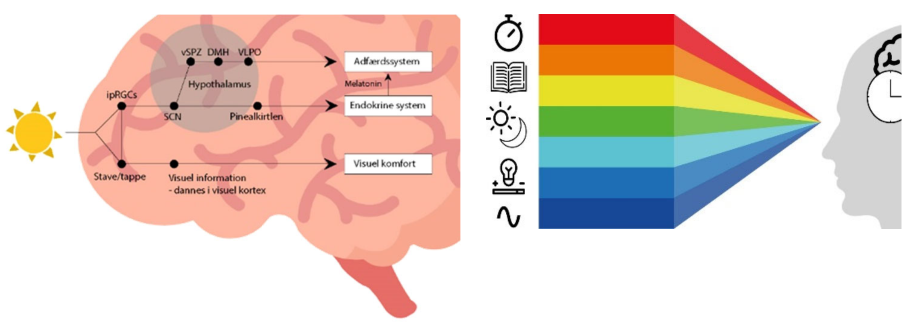
Light, health and performance

Light and Health

Man evolved around a strong light/dark cycle and has since the dawn of time been dependent on the rising of the sun across the sky to wake up and fall asleep. Light design is based on standards and practices developed to meet our visual needs and ahead of our scientific understanding of light's important role in maintaining several human biological functions. In recent decades, interest in research between light effects on human health has increased drastically following the discovery of a third type of photoreceptor in the human retina. It is the human circadian rhythm that is in focus, and especially the connection between light and non-visual effects such as health and performance [3]

Unlike rods and cones which mediates imaging-forming effects at low light and colour vision, a third type of photoreceptor, referred to as Intrinsically Photosensitive Retinal Ganglion Cells (ipRGCs), serves as input in synchronizing the human circadian rhythms to the daily 24h light and dark cycle. The visual system is most sensitive to green light (555 nm) whereas the circadian system's sensitivity peaks in the blue part of the visible spectrum with a maximum sensitivity around 490 nm. Quantities and units that depend on the visual system are thus not good enough to describe circadian effective daylight.

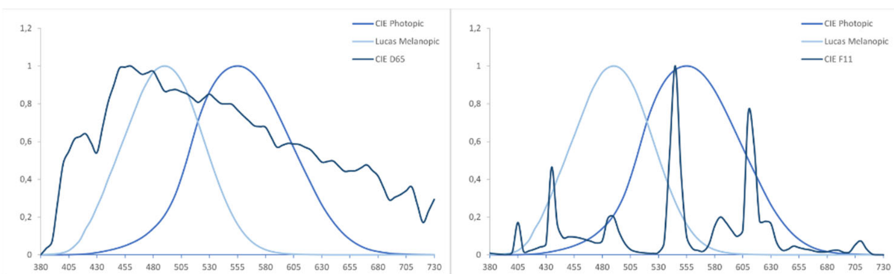
There are several functions in the body that are dependent on circadian rhythms, such as hormone production, sleep/wake cycle, alertness level, and even more. Circadian rhythms basically tell the body to do the right thing at the right time, and (day)light is one of the strongest ques to synchronize these circadian rhythms to the external environment. A lack of a robust stimulation of light and darkness can lead to desynchronization of the circadian system and the external environment - the body does the wrong thing at the wrong time, e.g. as in jetlag or by shift work. Inadequate or mistimed light can also disrupt a normal circadian rhythm and result in negative effects on human performance and health.



(a) (b)

Figure 2 (a) light pathways affecting us visually and non-visually. (b) factors affecting circadian rhythms

As depicted in Figure 2 there are five light factors that affect our circadian system: timing, intensity, duration, wavelength, and prior history of exposure to light [Lockley, 2009]. The internal clock has a period-limited sensitivity to light, such that exposure to light early at night, the circadian phase shifts back, and exposure to light early in the morning advances the circadian phase. The intensity of a light source and duration of exposure is related to the strength at which a phase is shifted. The wavelength of light is also an important factor, as ipRGCs signal through the photopigment melanopsin, whose spectral sensitivity is predominantly bluish, which is why short wavelength light is most effective in stimulating the circadian system. Long wavelength light gives on the other hand minimal circadian stimulus, and therefore supresses little melatonin. Long wavelength light is therefore useful for promoting attention in the late afternoon and the evening without disturbing the circadian system. The circadian system also shows adaptation to exposure to previous light by determination of response to a current stimulus [4].



(a) D65 (b) F11

Figure 3: Comparison of two CIE illuminants

Lucas and colleagues published in 2014 five action spectra's which depends on the photopigment in each class of photoreceptors [Lucas et al., 2014]. These can be utilized to calculate alphaopic illuminance, where especially the curve for melanopsin is used in the description of circadian effects of light. The international WELL Building Institute has developed circadian performance requirements for indoor environment that depends on timing, duration and wave- length in a unit called Equivalent Melanopic Lux (EML) which is based on the action spectra developed by Lucas. The current WELL requirement for "Melanopic Light Intensity for Work Areas," states the following: *75% or more of workstations, at least 200 equivalent melanopic lux is present, measured on the vertical plane facing forward, 1.2 m above finished floor. This light level may incorporate daylight, and is present for at least the hours between 9:00 AM and 1:00 PM for every day of the year* [WELL Standard, 2020]. Despite the fact that it is not required to use daylight to meet these requirements, the designer should make as much use of daylight as possible, and otherwise use it as a guide to where extra lighting is needed. In addition, the electric lighting should strive to mimic the daylight, i.e. high intensities and blue-enriched[5]. In Figure 3 a comparison between CIE F11 and CIE D65 has been made. The first thing that can be observed is that the CIE photopic curve and the melanopic curve are very different, which is why the introduction of new standards and practices is necessary. In addition, the benefits of daylight over a standard fluorescent can also be observed. The D65 has both high intensities and spans a wider spectrum, moreover, the high intensities peak closer to the melanopic curve, whereas F11 peaks at the CIE photopic curve.

Light and performance

There are various ways in which the impact of light on human performance can be measured. Several studies have i.e. evaluated the speed of completion of a task, symptoms of Sick Building Syndrome and absence. In addition, these studies often make use of supplementary questionnaire surveys as an important step in gathering information about the participants and thus gaining representative knowledge within the issue. To examine performance, several studies have used the D2 test of Attention, which is a neuropsychological measure of selective and sustained attention as well as visual scanning speed. The studies with focus on daylighting, have shown that daylight [6,7], daylight levels [8] in most cases is associated with higher satisfaction and behaviours such as amount of time spent in the space or the seating preferences [6], or academic satisfaction [9]. However daylight alone has not shown an effect on student performances [10] or the observed effects were not reproducible [11,12] and in some cases, when glary conditions were present [6,12–15] , negative effects of daylighting conditions have been registered. In absence of daylight, however, severe disturbance on chronobiologic system and consequently concentration levels of the students were observed [16]. On the other hand, view and natural view, important attributes to daylight and window, have been associated both with pleasantness [6] and higher satisfaction [17] as well as on students' performance [18] and learning outcomes [12,15,19] in form of higher grades [17] or better attention [10]. In the formulation of the Light parameter the highest quantity of natural and electric light, but without direct sunlight, was found to be optimum. The quality of view out of the window shows a bivariate correlation with learning progress where window sills are below children's' eye-level [15]. Studies with focus on electric lighting, similarly show higher satisfaction with good electric lighting conditions [8,20]. These studies have also depicted electric lighting attributes such as light levels and CCT affecting student performances when direct performance tests, , e.g. d2 tests, were used as outcome measurement [21–23]. The dynamic changes [22] or variable combination [21] of light levels and CCT have also shown several positive effects on students' directly tested performance [21,24] or reading performance [22]. Lighting perception and lighting levels alone have shown no effect on reading performance [25,26]. Several of these studies indicate towards a need for multi-modal studies for better understanding the effect of light in indoor environment [24–27].

Light, visual scene and visual behaviour

Visual scene is seen through the eyes. For eye movements a number of distinct classes are known[28]. Changes in the line of sight may serve to scan the visual environment or to stabilize gaze (volitional or reflexive movements), while rapid shifts in eye position constitute a prominent class of eye movements in humans [28]. These movements are categorized into categories such as saccades (rapid shifts) and fixations (longer pauses) whose neural control is reasonably well understood [29]. These eye-movement classes coexist with head and body movement to direct our gaze. Therefore, eye movements alone would provide little information about the actual gaze control during real-life behaviour [30–32] . Understanding the natural behaviour of gaze in relation to the real world conditions, e.g. illumination condition or glare, thus requires accounting for all these coexisting movements. Changes in gaze direction and what we see will have a strong impact on the assumed position of the excessive light sources in FOV. Nonetheless, we are aware of only very few studies on the relationship between eye movements and building-induced visual context, such as a window [33–35] and none, which link eye movements to comfort perception indoors. Eye movements as a variable for visual comfort studies can actually not be addressed with psychophysical procedures conventionally used for visual comfort evaluation: the latter rely on subjective occupant perception whereas people are oblivious to their specific head and eye movements. On the other hand, computational models that aim at predicting gaze orientation typically focus on the control of large eye movements by low-level stimulus features, such as luminance contrast, colour, orientation or motion[36,37]. Experimentally, however, gaze is long since known to be influenced by task [38,39] or context [40,41]. Other approaches to eye movements in realistic tasks either used very reduced stimuli or restrained settings, such as driving [42], food preparation[32,43], or sports[30,44,45]. For less constrained scenarios, laboratory data has very limited predictive power for the real-life situation[46]. The focus on gaze behaviour and lighting has largely been on urban street lighting [47,48] or pedestrian lighting [49,50]. In similar context, when viewing static images of natural scenes (streets lit with lamppost at night) observers tend to avoid bright and dark stimulus regions and to direct gaze to regions of medium luminance instead [51]. A fewer studies have investigated the relationship between gaze shifts and building-induced visual context such as the presence of window [52] or light [53–55] . These studies deny the fixed assumption of gaze direction and suggest that during a period of office work gaze rests on vertical and horizontal planes [56]. Moreover, the necessity of limited luminance ratios in FOV to avoid constant re-adaptation for better performance is underlined [53,57]. Some more recent studies have addressed eye movements [54] and its physiological response [58] in relation to glare. However, the natural gaze behaviour in relation to light and glare to our knowledge is still unknown. From previous work demonstrating the profound influence that cognitive factors have on eye movements [59,60], one can hypothesize that there are clear relations between gaze patterns, glare and

luminous environment; the applicant's investigations to test this hypothesis[61] demonstrated the potential of eye-tracking technology [62] to reveal such relationships.
Figure 4, illustrates a simplified response-driven model where avoidance to a directional source $\vec{g}$, e.g. glare, and attraction to the directional source $\vec{a}$, e.g. view, is predicted by the model. The visual scene inputs can be identified using the HDR input data. The iterative model predicts the responsive behaviour, i.e. an angular shift, over the space for all possible directions. Dynamics of light necessitates a dynamic prediction over time. Finally, the model identifies the optimal positions and zones in the building where a clear balance between visual avoidance and attraction behaviour as well as optimal non-visual effects could be obtained. The avoidance-attraction behaviour will depend on the visual scene and particularly light and contrast distribution, view contact (outside the window), scene complexity, and colour contrast, in the room as a function of fixation duration and velocity. Using such model, our simulation workflow incorporates a visual system responses in an indoor environment.

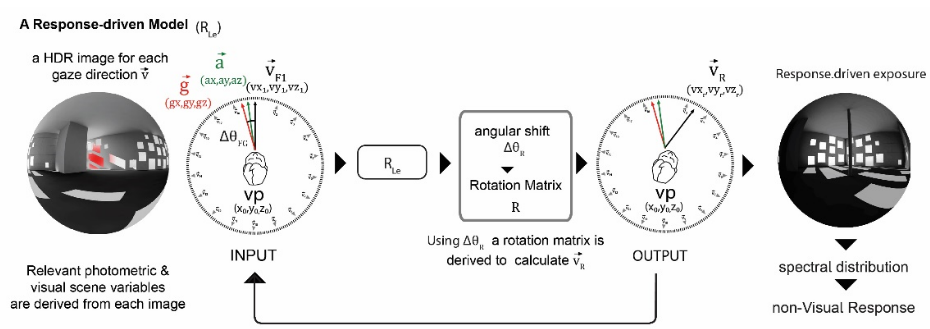
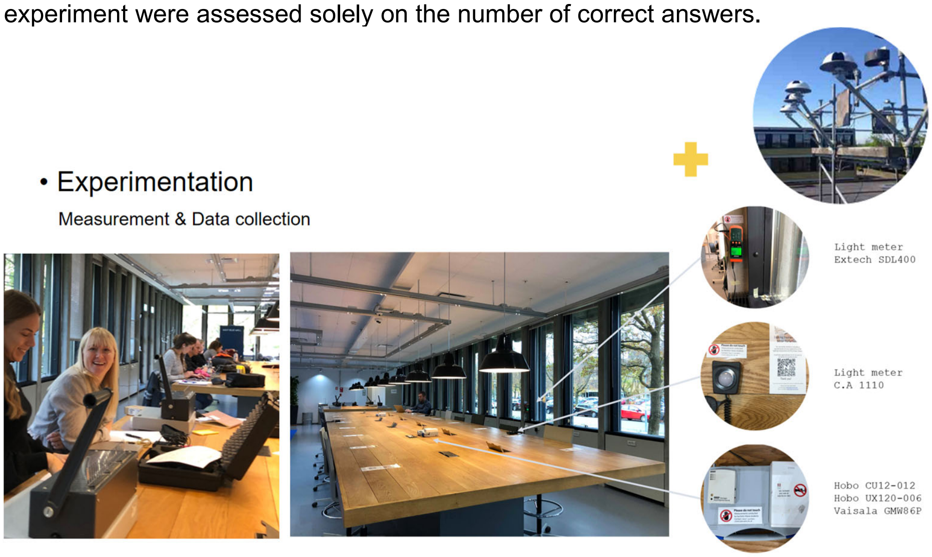


Figure 4 Response-driven model here showing the avoidance to source $\vec{g}$, e.g. glare, and attraction to the source $\vec{a}$, e.g. view, behaviour. The response is depicted by an angular shift $\Delta\theta_R$b where a, initially assumed fixed gaze vector $\overrightarrow{V_{F1}}$, shifts to $\overrightarrow{V_R}$ as a response. The relevant input visual scene variables to predict this behaviour are derived from the 180° -HDR images covering the FOV. Based on this responsive behaviour as function of the visual scene and in interaction with other IEQ parameters non-visual effects can be determined.

Methodology

Experimental phase

The pilot study was done at the SMART Library at Technical University of Denmark between 31th of October until 13th of November where performance and user assessments methods developed at DTU (Attachment A) were coupled with orientation tracking using cutting-edge technologies. All environmental parameters were monitored using different measurement equipment (See placements at Attachment E). The experiment was performed in two selected zones, where physical measurements were recorded, and a questionnaire including a performance test was also prepared[63].The questionnaire was divided into five sections; demographic data, light, mood, purpose and performance tests. The demographic data were collected as people's impact on and expectation of lighting may vary by gender, nationality and age. The sections; light, mood and purpose, were the students' subjective assessments of DTU's library as a study environment with a special focus on lighting. The performance test contained two different test forms; logical test and D2 test. The logical test assumed that the students were able to think logically, which was expected of the engineering students who participated in the experiment. The logical test consisted of three questions that tested the students' ability to concentrate. They were all three different, and tested the students' concentration and readiness for change. The second part of the performance test was a D2 test. A D2 test is designed to measure people's ability to concentrate and perform independently of intelligence ability. The test usually has two parameters; time and number of correct answers. As it was not possible to collect the completion times, the students in this experiment were assessed solely on the number of correct answers.



(a) (b)

Figure 5 (a) DTU library (b) The measurement devices used in the study.

The selected zones

The two zones examined at DTU library have been selected from a previous study. Zone 5 is located on the ground floor, while zone 30 is located on the second floor. In zone 5 the windows are facing west, whereas the windows in zone 30 are facing East and North. Both zones are divided into 6 locations where people have the opportunity to look 360 degrees around. Location layouts as well as the compiled view directions are shown in Figure 6. The hour, view direction, and date are all predetermined based on the questionnaire, and can be used to investigate a momentary picture of health potentials. As shown in appendix C, there were 15 test occupants in zone 5 and 11 test occupants in zone 30. In appendix C, observations of view direction (angle), hour, and date can also be found.

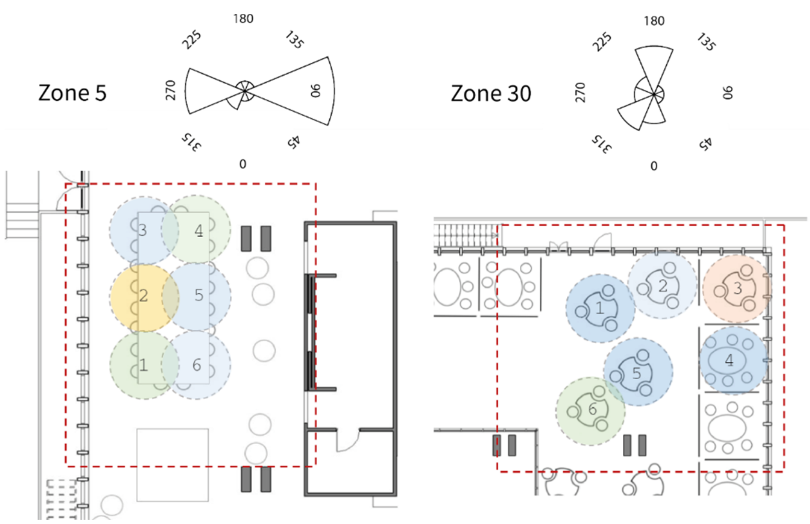


Figure 6 Placement and orientation in zone 5 and zone 30.

Characterization of spectral exposure

A Grasshopper3D tool designed to demonstrate gaze behaviour[64,65], exposure to illumination levels, and spectral illumination, enabling characterization of space-level exposure at any given position. The latter was processed using Lark Spectral Lighting, a plug-in for Grasshopper3D[66] to account for photopic as well as Rea[67] and Lucas[68] circadian brightness. In determining the relationship between the light environment and the test subjects' performance, the human circadian rhythm is used metrically. A circadian rhythm metric is a tool for characterizing light that acts as a stimulus for the human circadian rhythm system, also known as the body clock. This useful simulation workflow can through 3Dimensional modelling of DTU library provide a design standard for a given time of day after which the right amount of melatonin that is suppressed as a result of the light environment can be evaluated.

Figure 7a shows a schematic followed to implement dynamic gaze changes and non-visual effects of daylight in Grasshopper 3D. The setup itself is divided into three parts, where a geometry has initially been built in Rhino. Then material properties are added to the respective surfaces through Ladybug and HoneyBee components. Dynamic gaze changes are added through components from GazeTool [65], which can predict a change of gaze at a location through an implemented formula in Python. In addition, metrics were used to calculate non-visual effects of daylight added through Lark Spectral Lighting. Lark Spectral Lighting is a plug-in for Rhino/Grasshopper that has been used to calculate the health potential of the test subjects' locations in each one (Figure 7b).

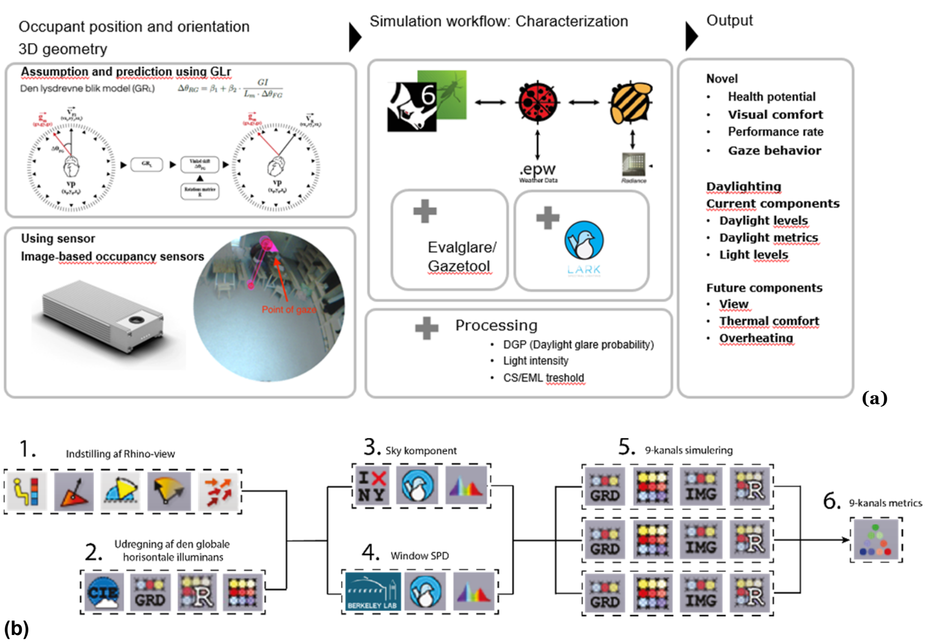


Figure 7 (a) Schematic of the simulation workflow (b) Flowchart of Lark Spectral Lighting

Simulation and case study set up

In a general simulation workflow several steps are made. The 1 step is to set the viewpoint. In the case of the library this is set for each occupant in the 2 zones. Next, the global horizontal illuminance is calculated for either an overcast or sunny sky. In step 3, the spectral sky is calculated through 9-channels based on the horizontal illuminance and the spectral power distribution. In this simulation, a D65 spectral power distribution has been used, which describes the average noon light for Northern / Western Europe. In step 4, the spectral distribution of the glass is calculated, which is calculated through Optics6. In step 5, the 9-channel simulation is started, after which the final results can be collected.

Through the program “Windows” and”Optics6” from Berkeley University, a spectral distribution has been calculated for a window pane type similar to that seen at DTU library. A 2-layer window pane with 4 mm clear glass, 12 mm air layer, and 6 mm energy glass has been used. Since ”Windows” only has a product library for the most common window pane manufacturers, was Pilkington window panes chosen, where we use their 4mm Optifloat ™ Clear and their 6mm Suncool ™ Brilliant 50/25 which has a transmission of 0.5 and a direct transmission of 0.24. Furthermore the general window parameters can, found from Pilkington’s own tool, be seen in Table 1. Table 2 shows the materials used in the simulation study. Table 3 shows the rendering parameters used in the simulations.
A detailed 3D model is designed to ensure that the environment the test participants' face is reflected in the digital format. Tables and movable screens were not included, however, as there is great uncertainty about where they will be placed and will be located in the future. Using Optics6, a window pane setup was chosen to reflect the windows seen in DTU’s library. Finally, simulations have been run, giving the first results for comparison with a d2 performance test. The results consist of a series of 9-channel simulations with results in the EML format and a series of fisheye renderings for general photometric data.

Table 1 Window Property DTU library

Window parameters	Value
Thickness	22 mm
Solar factor	0.49
Daylight transmittance	50 %
Direct transmittance	25 %
Reflectance	39 %
Absorbance	37 %

Table 2 Materials used in the simulation

Materials	Description
Generic Interior Wall -	Diffuse reflectance of 50%
Generic Ceiling -	Diffuse reflectance of 70%
Generic Floor _	Diffuse reflectance of 20%
Generic Exterior Wall _	Diffuse reflectance of 35%
Exterior Ground _	Diffuse reflectance of 10%

Table 3 Radiance rendering parameters

dt	dj	ds	ab	aa	ar	ad	as	lr	lw	pj	ps	pt
0.05	0	0.15	3	0.1	512	4096	2048	8	0.005	2	1	0

Results

36 students answered the questionnaire during the trial period out of which 30 data points were obtained after cleaning the data (Attachemnt C). The distribution between gender, age and nationality can be seen in Figure 7. More results related to the questionnaire can be seen in Attachment D.

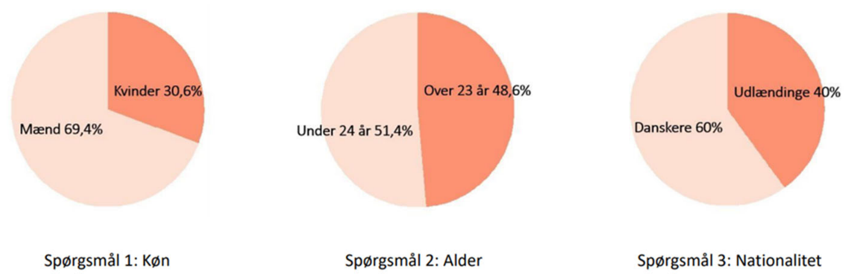


Figure 8 an overview of the demographics of the data sample collected.

We could see that there has been a minimum variations on the temperature, CO2 levels and humidity on the responses as these parameters were kept in a close to constant limits. In some cases the temperature were recorded high possibly due to positioning of laptops and were deleted from the data pool.

While we could see some effects of gender or concentration on the D2 responses or daylight levels outside on occupancy rates indoors, none of these observations were significance or could be explained due to confounding variables. However, an interesting finding was that the majority of subjects who scored above 80% correctly rated on their performance rate fell within certain thresholds (Figure 9). Highest performance was between 300 and 550 lux, and in a few cases men did better in even lower light levels. However, our statistical analysis through a one-way ANOVA shows that the observed differences are not significant for a performance above and below 500 lux. We could also see that people who rated themselves as having a low concentration performed better in light levels between 400 and 550 lux.

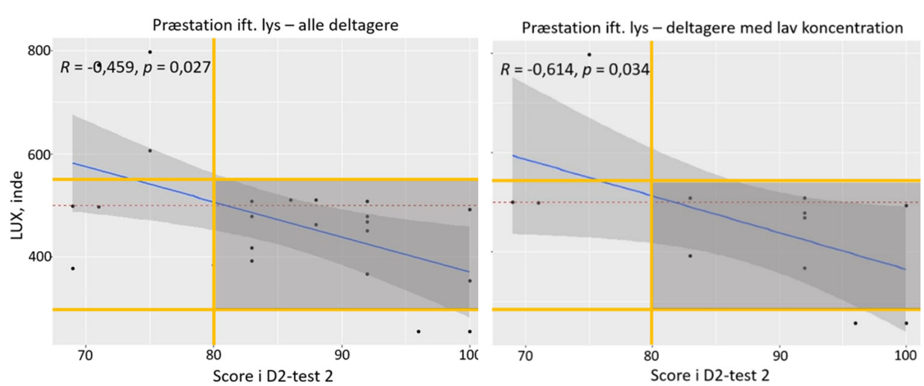


Figure 9 Results for indoor lighting and performance

The simulation study provided a clear demonstration of visual patterns and exposure patterns in different places in space based on the behaviour of the dynamic occupant. Through the Gaze-Tool tool, dominant viewing angles were selected based on the resident's visual pattern over a symmetrical half year. It was seen in the results, in Figure 5, that the gaze changes occurred evenly distributed at all locations in the zone, which means that there is just as much contrast-induced glare at the front as well as at the rear of the zone.

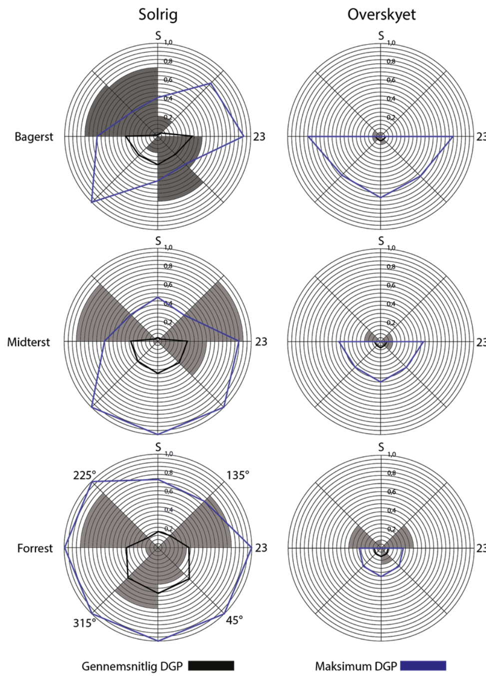


Figure 10 each plot shows the visual scene of 360°, southern façade, with gaze shifts, average and maximum DGP demonstrated. The window facade is at the bottom.

Exposure at participants' position

In the second part of the simulation study, the health potential was evaluated in the selected dominant gaze orientations for each position. A health potential has been calculated for the individual location where a test person has taken the performance test. Figure 11 illustrates at which position and view direction the criteria for EML was, or was not, met. As seen in the illustration there are a great number of subjects which position and view direction doesn't give them, the necessary daylight exposure. This is probably due to the late time of year and the late hours on the day the questionnaire was taken. This calculation is without electric lighting. From the Lark tool[69], the values had to be converted as the selected threshold values used the units Circadian Stimulus (CS) and Equivalent Melanopic Lux (EML). The threshold value CS explained the optimal stimulus throughout the working day, where specific values are given for each hour, while the threshold value EML gave a fixed value over all hours. While most positions in the zone showed satisfactory compliance with the threshold values in summer and under sunny conditions, the results under cloudy skies would only in a few situations achieve the threshold values. It has therefore been shown that climatic regions are crucial for optimized compliance with health potentials. On the north façade, minimal visual discomfort was found, allowing orientations towards the window, which resulted in a higher health potential. It can therefore be concluded that the orientation in space is crucial for the vertical illuminance measured at the eye, however, the visual comfort must still be maintained.

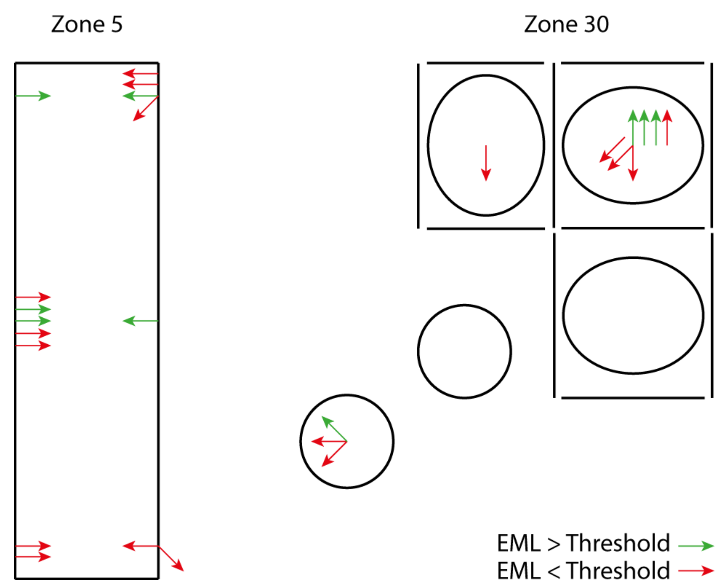


Figure 11 Results for each person in each zone in relation to the specified threshold of 200 EML

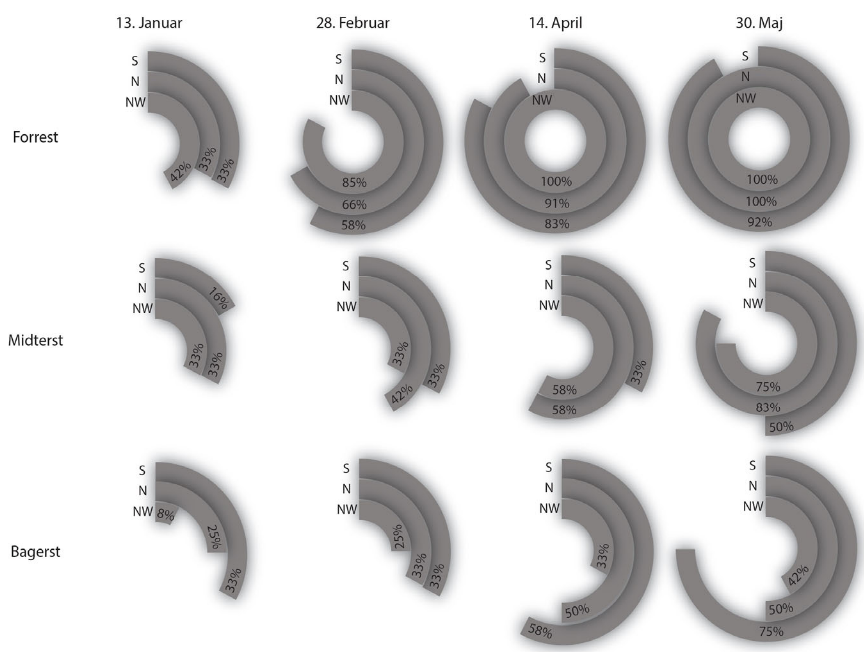
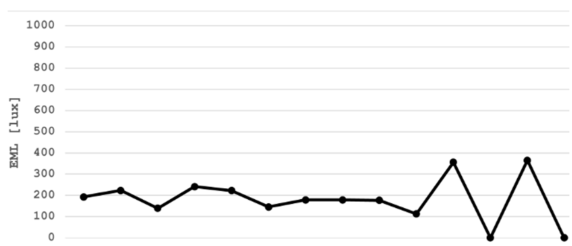


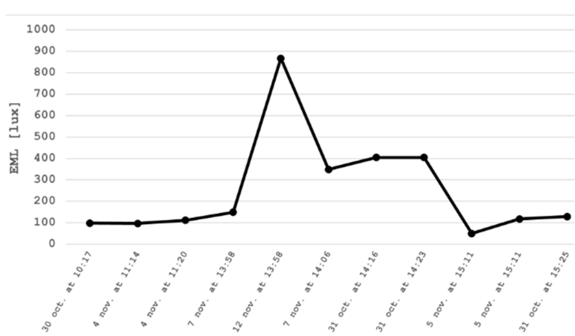
Figure 12 Results of percentage compliance with the threshold value CS for the three positions in the zone (y-axis) over a symmetrical half-year (x-axis). It is further divided according to three different facade orientations.

In Figure 13a and b ,the EML results for each test person in zone 5 and 30, respectively, can be observed. On the x-axis, information on the date and time for answering the questionnaire can be observed, as well as which test person is involved. On the y-axis, the EML value can be read in the unit lux.
In general, relatively stable levels of EML can be seen just below the threshold value for most of the test subjects in zone 5, where the time interval of the day is between 10:00 and 14:00. In addition, a small peak can be observed in the values between 11:30 and 12:00, which may be due to the position of the sun in the sky as well as high intensity levels during this time. Two people seen at 14:04 and 16:49 are exposed to a relatively high amount of EML. In zone 30, low values of EML can be seen early in the day and higher values around 14:00 after which the values fall.

Visual comfort can be evaluated through DGP as seen in Table 5 and 4. As shown in the tables, there are no DGP values above 0.35, which means that it can be assessed as imperceptible glare. This means all test subjects in the 2 zones should have the optimal visual comfort in their view directions. The tables gives further information about a series of photometric quantities which is derived through Evalglare.



(a) EML results for every test participant in zone 5



(b) **EML results for every test participant in zone 30**

Figure 13 EML results for both zones over time and for each participant.

Table 4 Visual comfort results from zone 5

Zone 5	Date and hour	DGP	av lum	E_v	E_v dir
Person 9	31-10-2019 16:49	0.006658	10.81152	35.66948	0
Person 14	05-11-2019 10:17	0.06978	33.86524	152.4439	0
Person 16	05-11-2019 11:33	0.004745	7.586731	21.26878	0
Person 17	05-11-2019 13:00	0.005366	9.343442	26.48076	0
Person 21	05-11-2019 16:40		NIGHT		
Person 22	05-11-2019 17:47		NIGHT		
Person 23	07-11-2019 10:54	0.093782	39.04599	175.6847	0
Person 24	07-11-2019 10:54	0.006218	11.57087	32.74665	0
Person 25	07-11-2019 12:47	0.083894	35.38475	166.1888	0
Person 26	07-11-2019 14:02	0.05287	29.12303	134.6388	0
Person 27	07-11-2019 14:02	0.05287	29.12303	134.6388	0
Person 29	07-11-2019 14:03	0.05287	29.12303	134.6388	0
Person 30	07-11-2019 14:03	0.00414	5.557858	15.51002	0
Person 31	07-11-2019 14:04	0.05548	30.59664	137.5486	0

Table 5 Visual comfort results from zone 30

Zone 30	Date and hour	DGP	av_lum	E_v	E_v dir
Person 1	30-10-2019 14:16	0.177338	123.0589	349.7341	0
Person 2	30-10-2019 14:23	0.177338	123.0589	349.7341	0
Person 3	30-10-2019 16:18	0.147639	66.77434	239.9277	0
Person 7	31-10-2019 15:25	0.194991	170.5959	613.2096	0
Person 11	04-11-2019 11:14	0.194298	165.9173	601.4297	0
Person 13	04-11-2019 11:20	0.154598	95.80975	253.4118	0
Person 19	05-11-2019 15:11	0.057923	47.38753	140.206	0
Person 20	05-11-2019 15:11	0.045347	47.61649	125.7603	0
Person 32	07-11-2019 14:06	0.187609	111.2157	488.7836	0
Person 34	07-11-2019 14:08	0.206077	223.1623	801.9886	0
Person 36	12-11-2019 13:58	0.22648	274.0347	834.799	267.2818

Conclusion

A simulation framework was developed that relates human subjective response and objective orientation-reflexes to daylight, with an informative output in form of light levels and performance rates. The developed simulation workflow makes it possible to identify the exposure to light levels as well as circadian triggers depending on the occupant's position and orientation (direction of the line of sight) in the room. The input to the simulation workflow is occupant position and orientation in space. This can be provided as a presumption or as a real-time data provided by an occupancy sensor or similar.

The experimental pilot survey was conducted at DTU Smart Library, where indoor environmental parameters as well as occupants' performance and movement behaviour were monitored. The experiments were done to facilitate the developed workflow towards more informative output in relation to human performance and productivity rates. The experiments were done for a period of 2 autumn months. The pilot study resulted in a relatively small data sample of 30 participants. In order to relate light exposure to the participants' performance, a 3D model of the DTU library was made with close details in order to simulate the daylight conditions the participants were exposed to during the experiments. The simulations themselves were performed using the developed simulation workflow in Grasshopper3. Finally, relating the exposure levels and performance, we derived a preliminary performance rate which can be shown using the simulation workflow.

The take away message from the experimentation phase is that participants achieved higher performance rates, within certain light levels. These results showed that the majority of the subjects performed better at certain light thresholds within the short period of the test. However, for long-term exposures, such threshold might not be relevant. Moreover, the results obtained regarding the effect of lighting on performance are not decisive due to smaller sample size.

Development of tools and studies that can integrate occupants' actual exposure to daylight throughout time and longer exposures can resolve and enhance our understanding on how to create more affective spaces for higher performance. In the context of Smart solutions, such approach can be used to design consciously for human-centric solutions in the design phase where the designed architectural design can be evaluated for higher human performance as result of light. In an applicable smart solutions, adopting such concept to relate occupants' dwell and track data to their real-time light-driven performance output could enhance the use of space where occupant performance can have great advantages.

Future Steps

The project seeks future steps in three categories. Further dissemination of the project is being done through journal and magazine articles. For marketing purposes, we will further distribute the developed simulation tool to our network in form of an assessment protocol, a manual and a video tutorial. Several advances to the tool can be made which are listed below and will be seen in the future upgrades of the tool. These immediate steps are to initiate and integrate solutions in the developed tool for better prediction of occupant orientation in the room in relation to light and views. To estimate residents' performance levels based on the exposure characterization of light, a more comprehensive study needs to be conducted.

Disseminations

- An abstract has been send to the International Building Simulation Association conference 2021, Bruges, Belgium.
- A journal paper has been written together with one of the partners (VELUX A/S) and in final stage of submission to LEUKOS.
- The developed simulation workflow has been developed using visual scripting methods, was published on an open source platform. Its current version is accessible on the following link: https://zenodo.org/record/4039562

Marketing

- Development of a protocol for studies on performance and occupant behavior (position and direction) in space.
- A video and written tutorial is made for further promoting the tool.
- The simulation workflow has been debugged and re-written for ease of use. In its current state, the user only needs a 3D geometry of the building to be assessed.

Future Plan

- The developed simulation workflow will be extended to include the view outside the window as an important attribute of daylighting. An algorithm will be incorporated in the simulation workflow in order to consider the position of the window in the occupants' field of view and its effect on the direction of line of sight and seating position of the occupants.
- The simulation workflow currently is based on an algorithm and model that accounts for gaze (occupant direction in space) behavior based on a preliminary model. It does not include the position of occupants in relation to view outside the window. This will be an addition to the simulation workflow.
- The results from the exposure characterization and performance will be combined for further findings. Performance data from the d2 test needs to be analyzed more in-depth to make a comparison possible.
- The algorithm introduced in the simulation workflow will then need further study for validations.

Compare accuracy of simulations with global horizontal illuminance values derived from DTU weather station and use for Lark Spectral Lighting simulations.

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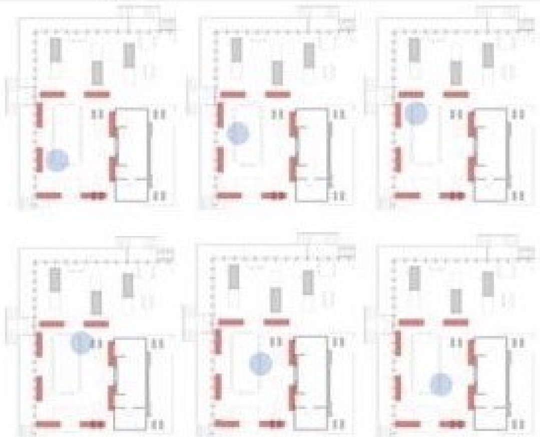
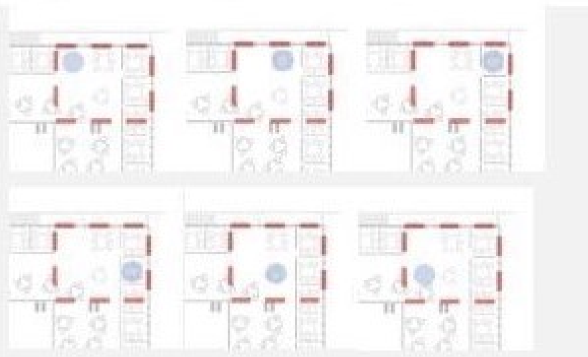
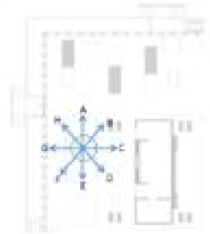
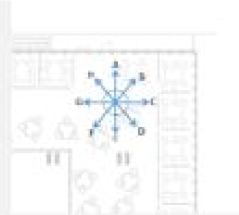
Attachment A The Questionnaire

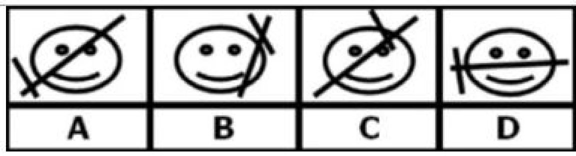
Nedenstående viser de spørgsmål og svarmuligheder, der indgik i spørgeskemaundersøgelsen for forsøgsperioden i efteråret 2019.

Spørgsmål	Svarmulighed
1. *What is your gender?*	o Female o Male o Other orientations
2. *What is your age?*	Type your answer ...
3. *What is your mother tongue?*	Type your answer ...
4. *Which field are you studying or working with?*	Type your answer ...
5. *Do you frequently use the library?*	o It is my first time o Rarely o Occasionally o A moderate amount o A great deal
6.1. *Pick the location you are sitting currently. (If you are located on the second floor, please skip this question)*	
6.2. *Pick the location you are sitting currently. (If you are located on the ground floor, please skip this question)*	

7.1. From your sitting position, please select select the direction you are oriented at more dominantly. (If you are located on the second floor, please answer next questions)	
7.2. From your sitting position, please select select the direction you are oriented at more dominantly. (If you are located on the ground floor, please answer next questions)	
8. How do you feel about the overall lighting condition where you are located at?	*Range from* **Dissatisfied** *to* **Satisfied**
9. Do you consider yourself as sensitive to bright light?	o Yes, I am sensitive o Just a little o Not at all
10. Do you suffer from any of the following eye conditions?	o I use glasses o I use contact lenses o I am color blind o I have tunnel vision o I am night blind o No, I do not suffer from any of these conditions
11. Do you have access to outside view? Are you able to look out of a window at your working position?	o Yes, I have a good landscape view from my working position o Yes, but I need to rotate o Yes, but my view is disturbed by another building o No, the window is too far away
12. When you are looking outside the window, do you experience that your view is restricted by the shading devices?	*Range from* **Very much** *to* **Not at all**
13. When you are looking out of the window, do you experience that your view is restricted by the window size?	*Range from* **Very much** *to* **Not at all**
14. How do you find the level of light where you are located?	*Range from* **Too dark** *to* **Too bright**
15. How do you feel today?	*Range from* **Very sad** *to* **Very happy**

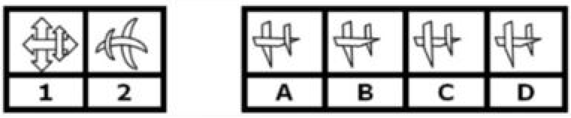
16. *Describe your current fatigue level using the nine options below*	○ Extremely alert ○ Very alert ○ Alert ○ Fairly alert ○ Neither alert nor sleepy ○ A little tired ○ Sleepy, but no effort to keep awake ○ Sleepy, some effort to keep awake ○ Very sleepy, great effort to keep awake
17. *Did you have a good night sleep?*	○ Yes, I slept all night ○ No, I did not get enough sleep
18. *Were you able to concentrate while being in the library?*	*Range from* **Hard to concentrate** *to* **Easy to concentrate**
19. *Please rate how satisfied you are with the overall indoor environment in the library right now*	*Range from* **Dissatisfied** *to* **Satisfied**
20. *What is the medium you are using the most while carrying on your task today here?*	○ Screen ○ Paper ○ Conversation ○ Others
21. *The light at your working spot are mostly from*	○ Daylight ○ Artificial light ○ Both daylight and artificial light
22. *Describe the daylight conditions at your working spot*	*Range from* **Little daylight** *to* **Too much daylight**
23. *Describe the lighting conditions at your working spot*	*Range from* **Too dark** *to* **Too bright**
24. *Do you experience any glare (bright light or unbalanced light in your field of view)?*	*Range from* **Not at all** *to* **Very much**
25. *Where does the glare come from?*	○ Daylight ○ Artificial light ○ Reflections ○ Others
26. *How satisfied are you with your working area?*	*Range from* **0%** *to* **100%**
27. *Right now, you are able to work:*	*Range from* **0%** *to* **100%**

28. *All four shapes have something in common, except one. Find the odd one out.*



29. *Which one of the figures in the boxes on the right is the missing figure?*

30. *Which one of the figures in the boxes on the right is the most similar to the ones on the left?*



31. *How many letter "d" with only two dots on top do you count in the following image?*

32. *How many letter "d" with only two dots below do you count in the following image?*

Attachment B The simulation workflow: description and manual

R.E.A.L.

Response-driven Environments for Appropriate Lighting

A Simulation Workflow

author November 2020

Contents

1 Introduction

This document presents a workflow that can analyse gaze shifts and health potential for buildings using a Gaze Tool and Lark Spectral Lighting - they will be referred to as Gaze and Lark in this document. The basis of the analysis is HDR fisheye images generated by Radiance. The Gaze and Lark workflows are independent meaning that the user can choose a single analysis or both. In the presented workflow both analyses share common Grasshopper components.

In this document several Grasshopper components/user objects will be presented. The names of Grasshopper components will be displayed with `typewriter` font. The name of input and output of the components will be displayed in *italic*.

1.1 Requirements

The requirements for the workflow shown in this document are listed below. For all plugins and programs the newest version has been used in the development and testing of the workflow (as of December 2020).

Table 1: Required plugins and additional programs.

Plugin/Program	Description
Honeybee-Legacy	Plugin for Grasshopper
Ladybug-Legacy	Plugin for Grasshopper
Radiance	Light rendering program
Daysim	Light rendering program

1.2 Notes on presented workflow

The workflow presented is intended to iterate over multiple inputs by the user. These are:

- Point: 3D point of a location to be simulated.
- Number of angle divisions: An integer that defines the number of view directions centered around each point.
- Point-in-time: A specific hour of the year to be simulated which is given by month, day, and hour.
- Sky types: A sky type following the CIE standard skies.

For each of the above parameters, there will be an integer slider selecting a item by the slider value. The sliders are connected to `BatchRun` (see section 2.7), which will iterate over all slider value combinations.

If the user does not need to iterate over a specific input, then the slider for that parameter should not be connected to `BatchRun`.

2 Setup

2.1 Folder structure

Before diving into the workflow, the folder structure will be presented since this is essential due to folder name dependency post simulation. Two Python scripts has been made to make it easier for the user. The first `projectFolder` simply joins the two paths (*workingDir*, *projectFolder*) and outputs the path of the project. The second `folderStructure` takes the *project path*, *subfolder*, and *imageName* as input as well as optional input for *LarkFolder* and *GazeFolder* - if no input it will be "Lark" and "Gaze". The input *subfolder* is a name specifying the month, day, hour, and sky type. The input *imageName* is a name specifying the analysis point and angle rotation (view direction). A schematic illustration of the folder structure is visualized in Fig. 2.

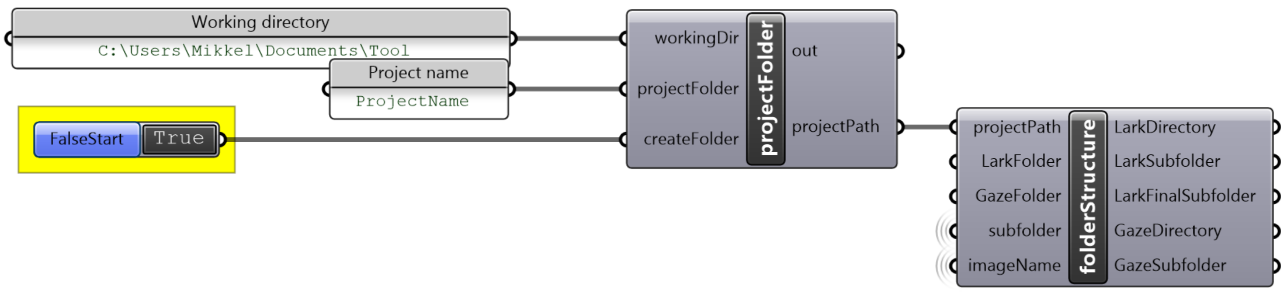


Figure 1: Folder creation using the two Python scripts `projectFolder` and `folderStructure`. In the presented workflow the paths created by `folderStructure` is important.

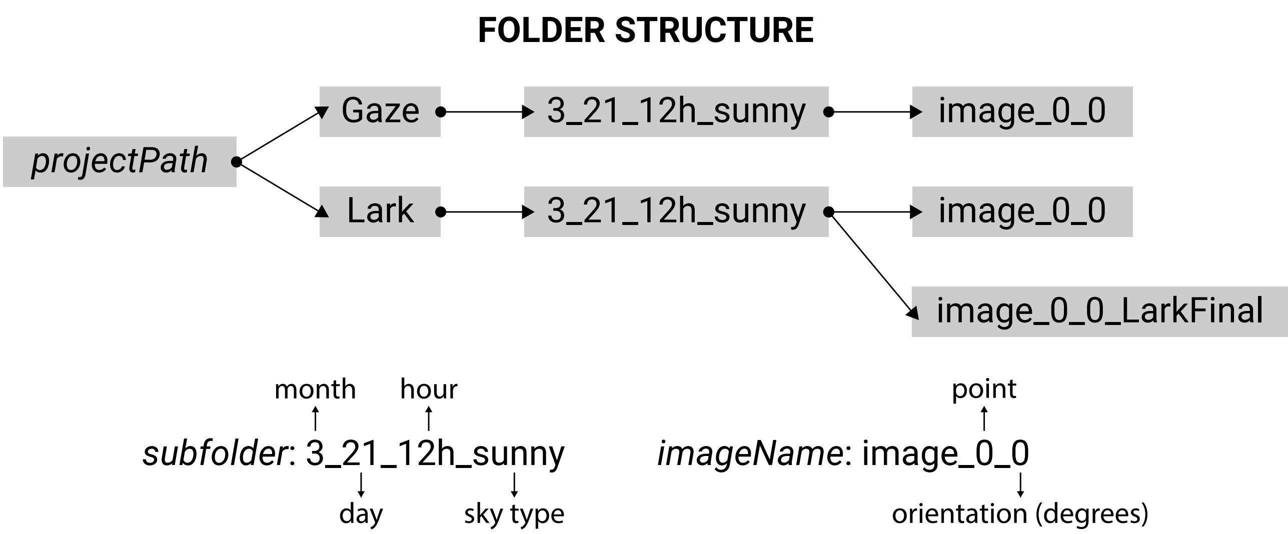


Figure 2: Folder structure of both Gaze and Lark workflows.

2.2 3D geometry

The 3D Rhino model must be imported to Grasshopper. To use the model for daylight simulation with Honeybee, the geometry must be converted to Honeybee surfaces by using `createHBSrfs`. The geometry is connected to *_geometry*, and surface properties, i.e. Radiance material, can be assigned to the geometry by *_RadMaterial_*. The other inputs are not important for daylight simulation.

The Radiance materials is created by either `radOpaqueMaterial` for opaque surfaces or `radGlassMaterial` for transparent/glass surfaces. There are other material components for more advanced properties. An example is shown in Fig. 3 - both opaque and glass materials. The steps must be repeated for each different material in the model.

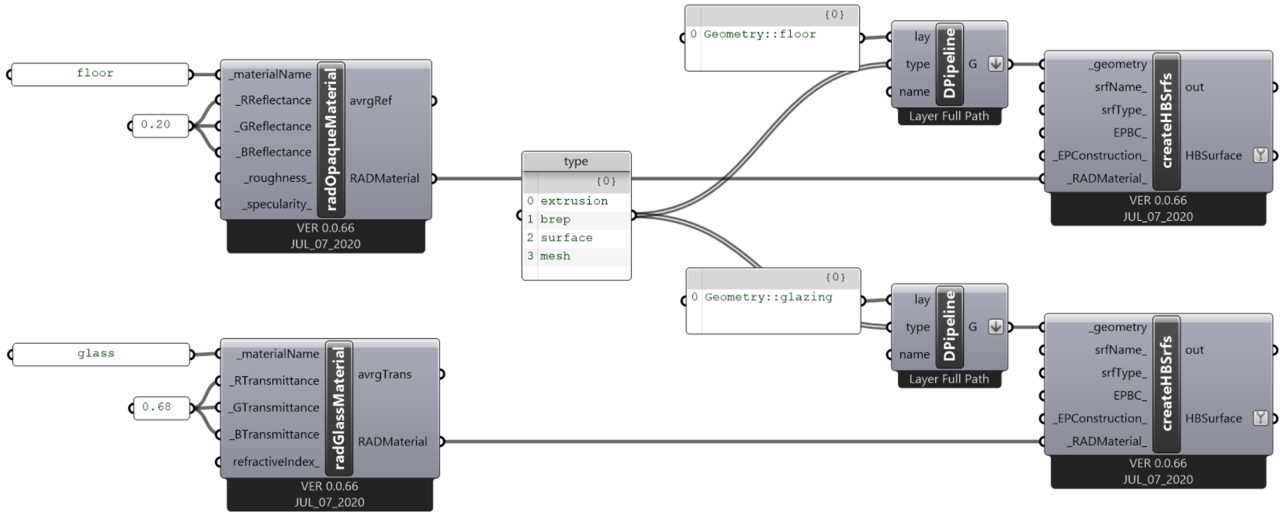


Figure 3: Creation of Honeybee surfaces by `createHBSrfs`. The surface properties are assigned to the geometry by using `radOpaqueMaterial` or `radGlassMaterial`.

2.3 Analysis points and gaze zones

In order to create the view points for the simulations, there must first be generated a set of points (or one point). A total of eight gaze responsive zones (surfaces) are generated around each point. The user has two options, the first being `calculationGrid`, in which a surface is divided into a set of grid points. The inputs U and V determines the number of points in each direction of the surface.

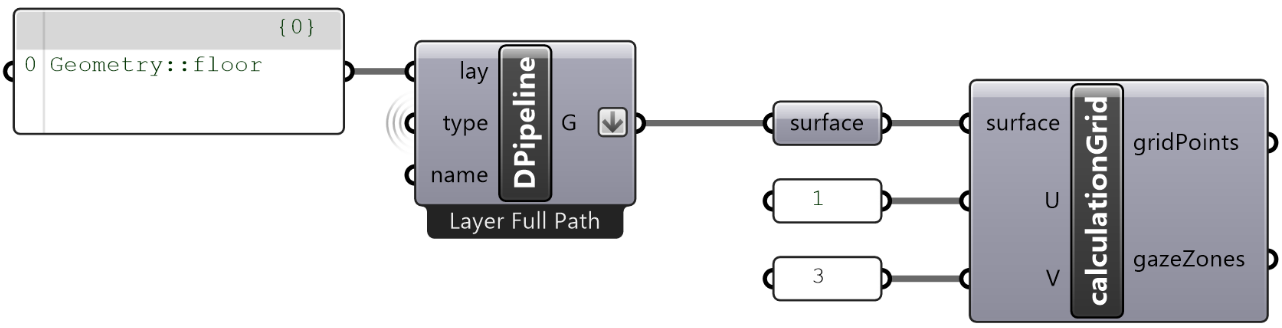


Figure 4: Creation of eight gaze responsive zones centered around a grid point by using `calculationGrid`. U and V is the number of points to be generated in each direction of the surface.

The other option is to use `analysisPoints`. This is useful if the user needs to analyse a very specific set of points in a room, as shown in Fig. 6b, where six points are selected. The component needs a *size* input defining the overall dimensions of each group of gaze zones.

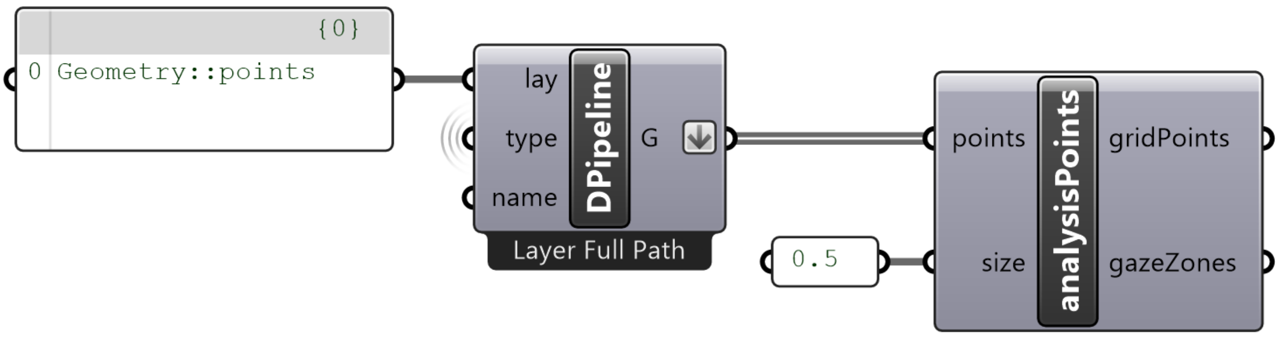
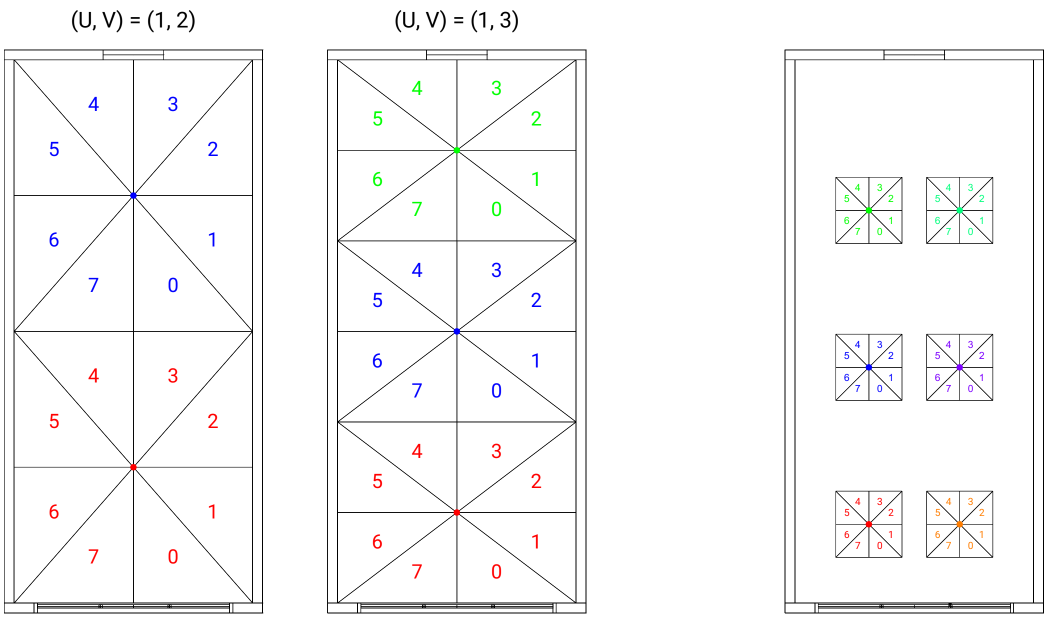


Figure 5: Creation of eight gaze responsive zones centred around a user defined point by using `analysisPoints`. The user can control the over dimension of each group of gaze zones by *size*.



(a) Creation of eight gaze responsive zones centered around a grid point by using `calculationGrid`. The gaze zones are ordered counter-clockwise as shown by the numbers.

(b) Creation of eight gaze responsive zones centered around a user defined point by using `analysisPoints`. The gaze zones are ordered counter-clockwise as shown by the numbers.

Figure 6: Output of both `calculationGrid` (a) and `analysisPoints` (b).

2.4 View direction

The component `imageBasedSimulation` from Honeybee renders an image based on the Rhino view specified in the recipe. The Rhino view is created by `viewDirection` (Fig. 7). A point is inserted in *gridPoint* and an angle in degrees in *angle*. This is the counter-clockwise angle of rotation relative to south. `viewDirection` will pass on a *viewPoint*. The vertical distance (in z-direction) between *gridPoint* and *viewPoint* can be specified by the user with the optional input *offset*. The default displacement is 1.168405 metres which is based on the seated mannequin in `ComfortMannequin` from Ladybug. A vector, *viewVector*, is generated by using the input *angle* - it rotates a south-facing vector (0, -1, 0) counter-clockwise. At last a Rhino view will be created. It will use the default 'Perspective' view and set it based on *viewPoint* and *viewVector*. The Rhino view name ('Perspective') will be outputted as *viewName*.

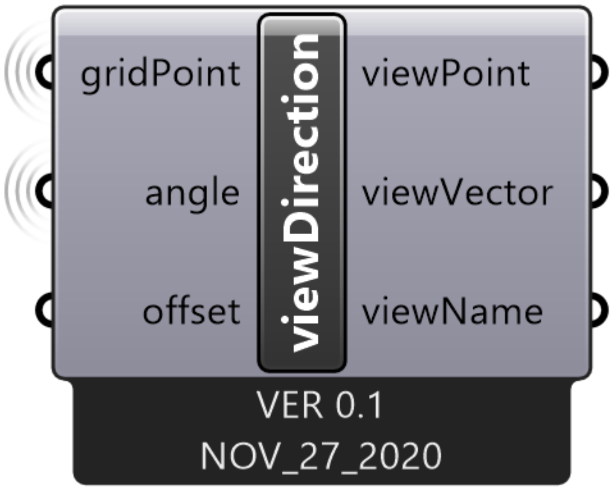


Figure 7: The component `viewDirection` contains Python code that displace the *gridPoint* to *viewPoint* in z-direction, an *angle* that rotatet a south-facing vector to *viewVector*, and the creation or setting of the existing Rhino view 'Perspective'.

2.5 View orientations and grid point

The number of views centered around each point is defined by typing in the number of angles in a panel as shown in Fig. 8. The number of angles are connected to `angle` which will output an *angle* based on the slider value. The *angleStep* is only used to show the user the rotation (degrees) of each consecutive simulation. Exemplified by Fig. 8 the *angleStep* will be 40 with 9 angles ($360/9 = 40$).

The grid point group is a passive group, i.e. the user does not have to input any values. It will take the points generated by `calculationGrid` or `analysisPoints` as input (*gridPoints)* in `gridPoint`. The output will be a single *gridPoint* based on the slider value.

The orientation and grid point will be joined to create the *imageName* by `namingImage`. As an example - for the first orientation (0) and the first point (0), the *imageName* will be image_0_0.

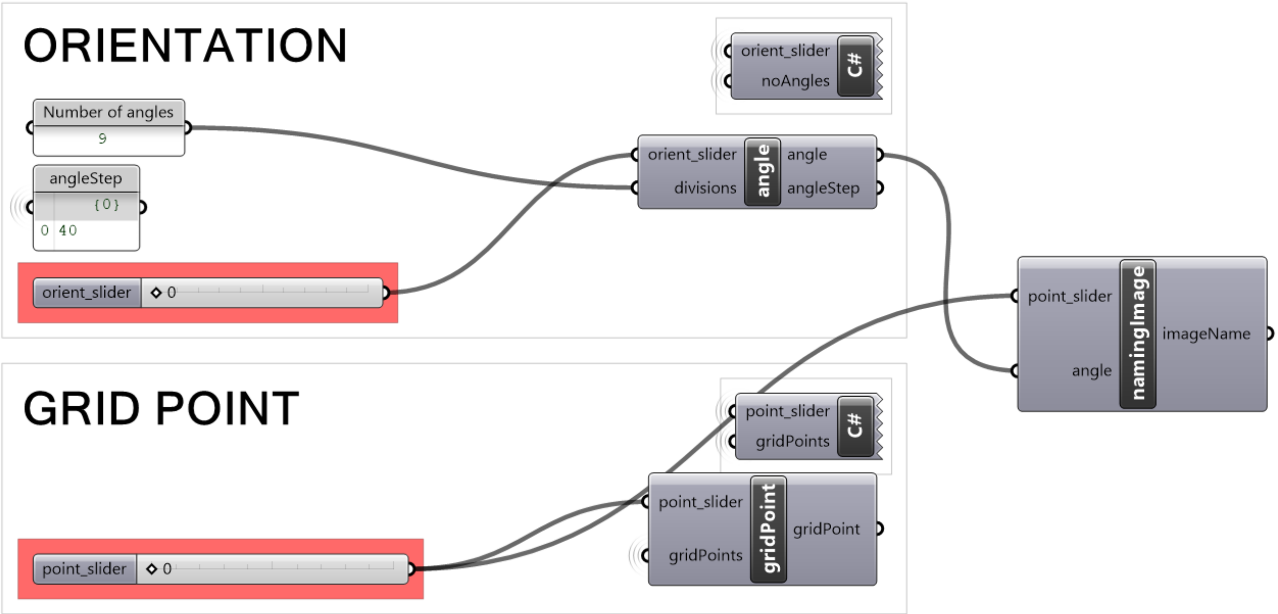


Figure 8: Selection of number of angles for each point. If the number of angles is 9, there will be 9 simulations for each point, each with a rotation of 40 degrees.

2.6 Point-in-time and sky

The simulation must be given a set of months, days, and hours - essentially the point-in-time. The point-in-time selection is seen in Fig. 9. The user will input months (1-12), days (1-31), and hours (0-23) in `pointInTime`. This component is using `DOY/HOY` and `Day_Month_Hour_Calculator` from Ladybug. The selection of sky types is typed in a panel. The example in Fig. 9 is set up to use two sky types (0, 4). The months, days, hours, and sky types are used to generate a description of the sky. For the valid sky types please refer to the Radiance program gensky. In Honeybee terms this means the user input is passed on to `genStandardCIESky`. The sliders are used to iterate over all the user defined input. The C# scripts in Fig. 9 are automatically updating the maximum value of the sliders based on the length of the input.

The month, day, hour, and sky type is joined to create the simulation *subfolder* by `namingSubfolder`. As an example - for the 21st of March at 12:00 with a sunny sky, the *subfolder* will be 3_21_12h_sunny.

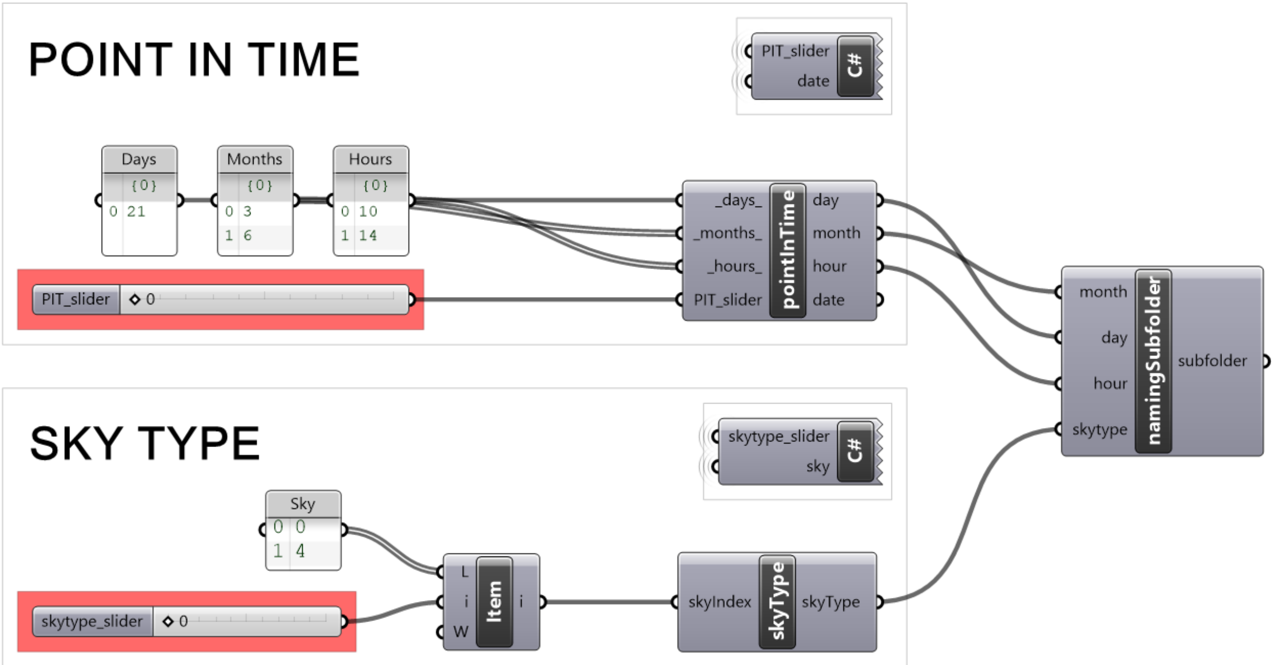


Figure 9: Selection of months, days, hours, and sky types for the analysis. The user selection creates the *subfolder* by `namingSubfolder`.

2.7 Iteration of input

In order to make Grasshopper iterate over the sliders in sections 2.5 and 2.6, the sliders must be connected to `BatchRun`, which is a C# component. To start the iteration process, the input *startme* must be set to True. Before executing the iteration process, the user will be given a warning message with a list of the connected sliders, and the total number of combinations that will be run. This message can be excluded by setting *ignoreMessage* to True.

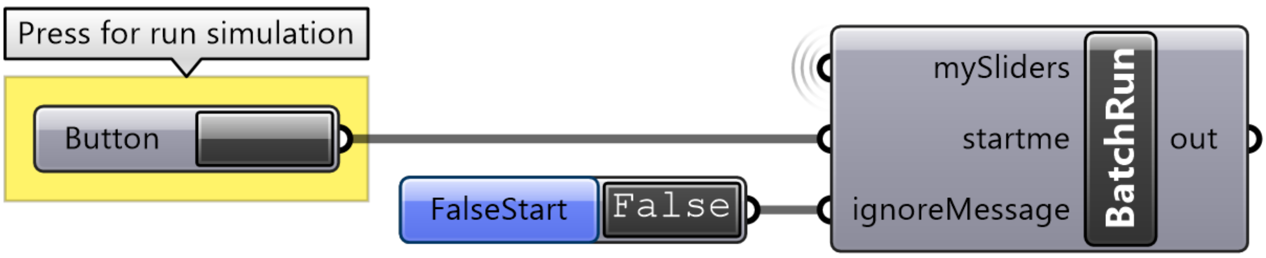


Figure 10: The component `BatchRun` will iterate over all connected sliders.

3 Gaze

3.1 Image generation

The base of the image generation is `imageBasedSimulation` which is a Honeybee recipe for light and daylight simulation. The first step to create the images is to define the sky. The component `genStandardCIESky` makes a description of the sky based on the month, day, hour, and sky type that the user selected in 2.6. These are connected to `genStandardCIESky` along with the epw file. If needed the sky can be rotated by entering an angle in *north_*. The sky is then connected to *_skyFile* in `imageBasedSimulation`. The next step is to connect to Rhino view name that the user wants to simulate. This is view created by `imageDirection` which will be connected to *_rhinoViewsName_*. The camera type must be 1 to generate a fisheye image. The simulation type must be 2 to generate a image in luminance. Both *_imageWidth_* and *_imageHeight_* are set to 800 px - ideally not lower than that, and they must be the same value. The quality of the simulation can be chosen by the user with *_radParameters_* and the component `RADParameters`. If the parameters are not connected, the default quality will be 0, i.e. the lowest quality out a three predetermined set of parameters in `RADParameters`.

Once the recipe is made, the simulation will be run by `runDaylightAnalysis`. It takes the geometry as input in *_HBObjects*. The recipe form `imageBasedSimulation` is connected to *_analysisRecipe*. The input *_workingDir_* is *GazeSubfolder* from `folderStructure`, and *_radFileName_* is *imageName* from `namingImage`. Finally, to run the simulation both *_writeRad* and *runRad_* must be set to true.

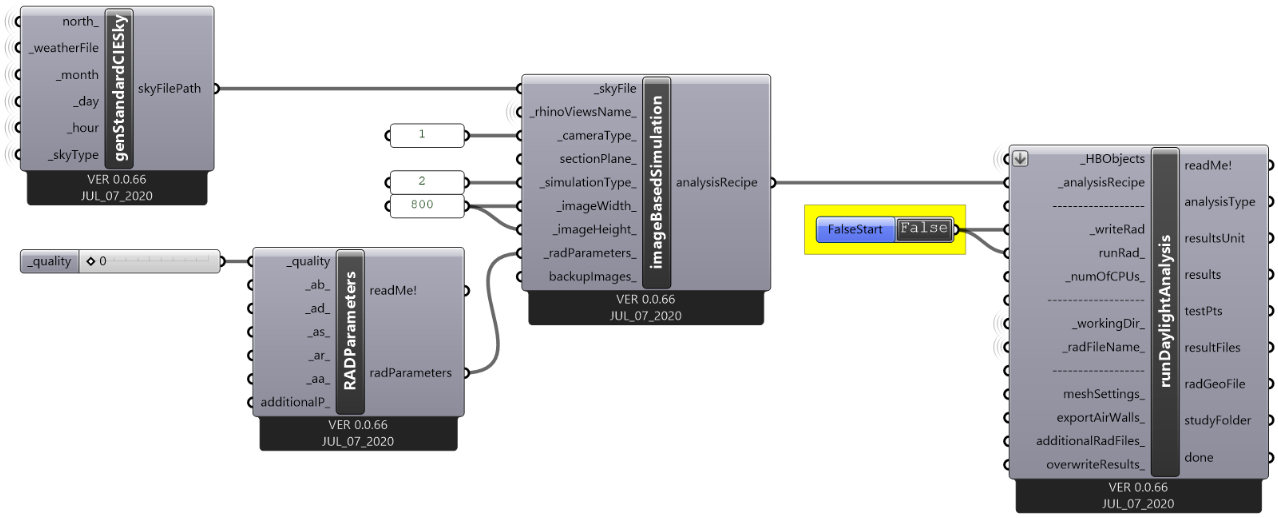


Figure 11: Image generation for Gaze analysis.

3.2 Gaze Tool

The core of the gaze analysis is `GazeShift`. It analyses the data from all images, and if there is a glare source for an image it will calculate the gaze shift vector. But first we must gather the data.

The component `runEvalglare` uses the Radiance program evalglare to extract photometric data of all image. The input is a path, *imageDir*, which in the context of this tool must be the path of a *subfolder* that you wish to analyse (see Fig. 12 for an example). To start the process *runIt* must be set to true. The output of `runEvalglare` is a list called *photometricData* with seven values for each image. These are average luminance of image (1), luminance of glare source (2), solid angle of glare source (3), position index (4), x-direction of glare source (5), y-direction of glare source (6), z-direction of glare source (7).

Along with the data from `runEvalglare`, we must also include the intersection points between the initial view direction and the geometry. For that purpose `initialViewDirections` is used. It needs the *gridPoints* from either `calculationGrid` or `analysisPoints`. The number of angles, *noAngles*, should be connected. The *context* geometry must be connected as well to find the intersection. The core of this component is `forwardRaytracing` from Ladybug. It will find the ray from each view point to the intersecting geometry in the view direction.

The *photometricData* and *rays* are combined in `gazeData`. This component simply extracts the end points of the *rays*, and merge the x, y, and z coordinates of the end points with the *photometricData* - so that the list continues as follows: x-coordinate of intersection (8), y-coordinate of intersection (9), z-coordinate of intersection (10).

The gaze shift vectors can now be calculated using `GazeShift`. The input *gazeData* is the list that has just been merged. We will again use the number of angles, *noAngles*, and the *gridPoints* from either `calculationGrid` or `analysisPoints`. Based on the data from the images, a gaze shift vector will be calculated and converted to a line. The output *linesGazeShift* contains all the lines for each point. It is important to note, that it will show certain lines as invalid curves. This is not an error or concern - it means that for that view direction there was not found any glare source.

The count of gaze shifts within each gaze zone is counted with `gazeCount`. It takes *linesGazeShift*, *gridPoints*, *circleRadius*, and *gazeZones*. The component finds the intersection point between the lines and the circle for each point, and counts the number of points within each gaze zone.

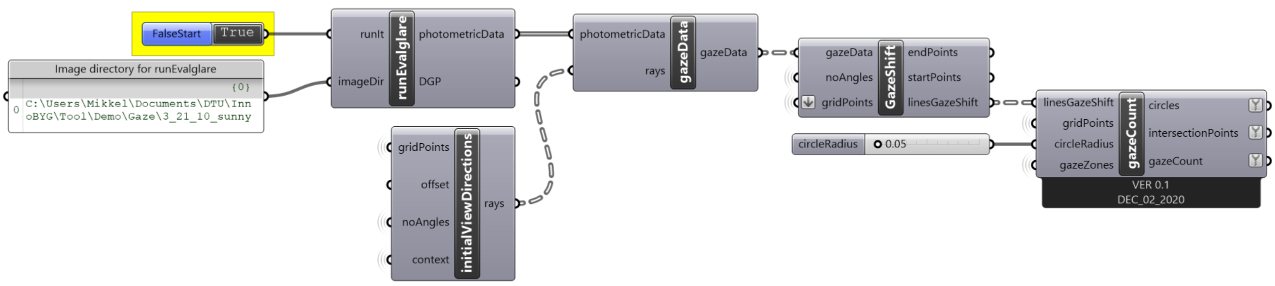


Figure 12: Gaze Tool analysis.

3.3 Gaze Visualization

The visualization of the gaze analysis is performed by `GazeVisualizer`. It creates a radial grid with 8 grid cells in polar direction. It needs the *gazeCount* and *gridPoints*. The size of the radial grid can be selected by entering a number in *gridSize*, and the number of cells in radial direction can be defined by *gridCells*. The input *scaled* will scale the results according to the domain, i.e. if the largest gaze count of all gaze zones is 3, then the radial grid will be filled to the maximum in that direction. In other words, the results will be remapped to a target domain being 0 to *gridCells*. It is also possible to add the gaze count as numbers by *showCount*. An example of the visualization is shown in Fig. 15a. Each red colored cell means that `GazeShift` calculated a gaze shift vector in that direction.

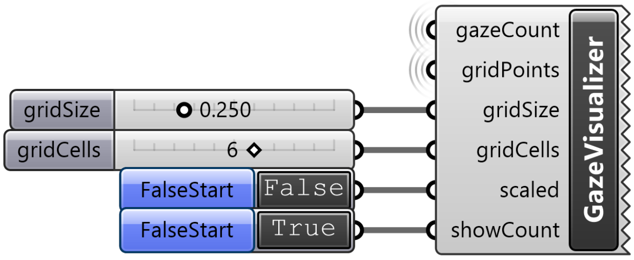


Figure 13: Visualization of gaze shifts by creation of radial grids. The size and cell count can be adjusted. It is possible to scale according to the domain of the results, and to show the gaze count with number.

The gaze shifts can also be visualized as colored surface using gradient to map colors with the gaze zones based on the gaze count. This workflow is shown in Fig. 14. The colored mesh is given a smooth appearance by using `Weld`. An example of the visualization is shown in Fig. 15b. Alternatively, a more visual pleasing smooth appearance can be created by using `wbCatmullClark`, which requires the Weaverbird package.

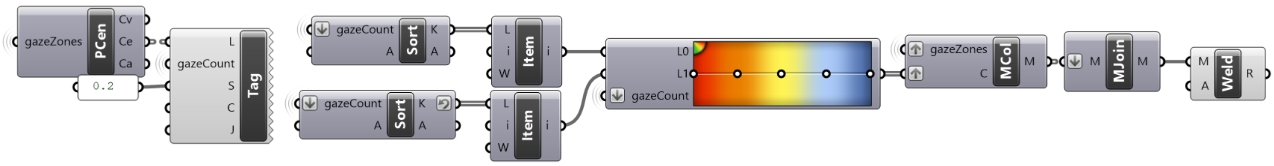
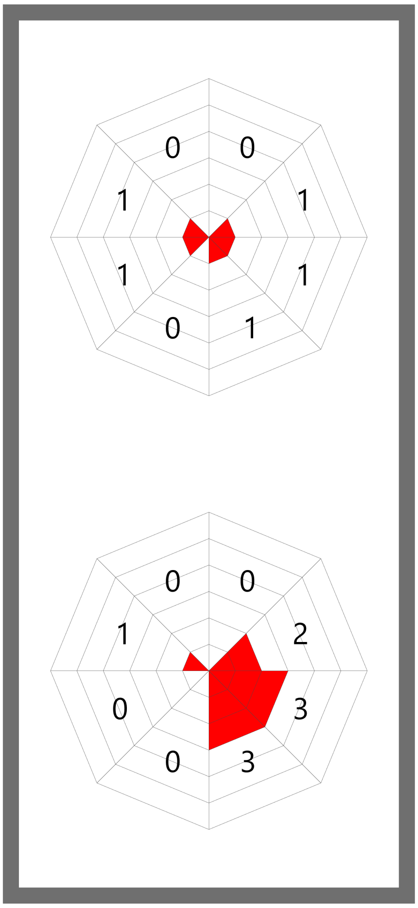
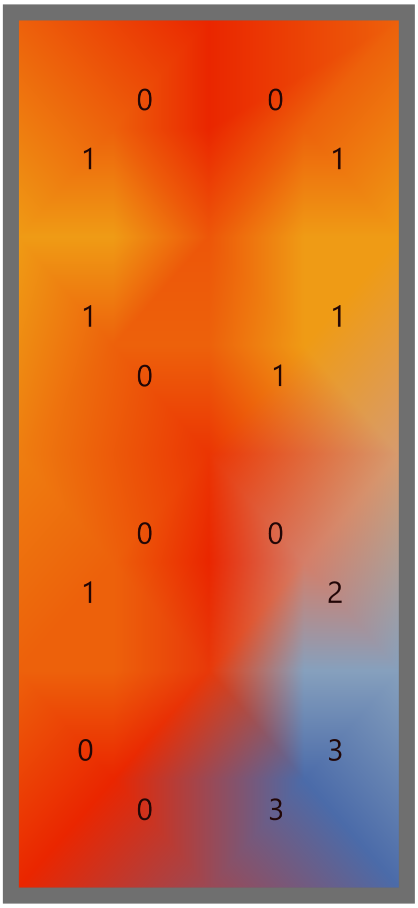


Figure 14: Visualization of gaze shifts by coloring the gaze zones based on the gaze count.



(a) Each red cell indicates a gaze shift in the given direction. The number of gaze shifts in each direction (each gaze responsive zone) is shown with numbers.



(b) The gaze zones are colored according to the gaze count for the zone. The mesh is 'smoothened' by `Weld`.

Figure 15: Two ways of visualizing gaze shifts.

4 Lark

4.1 Global horizontal illuminance

The first step of the Lark workflow is to find the illuminance of a unobstructed point looking up. For this we will use `gridBasedSimulation` with only one point in *_testPoints*, and its vector should be a vector with 0 in both x- and y-direction - for this we use the native Grasshopper object to create a unit vector in z-direction (0, 0, 1) and connect it to *ptsVectors_*. The gridbased recipe needs a sky description, which is created by `genStandardCIESky`. The input to this component is the month, day, hour, and skytype from section 2.6. The sky is connected to *_skyFile*. The quality of the simulation does not matter, hence why the component `RADParameters` is excluded from this part. However, it is important to note that the point should be unobstructed.

The simulation is run by `runDaylightAnalysis`. To make sure the point is unobstructed, the geometry connected to *_HBObjects* should not cover the point. You cannot leave it empty since Honeybee needs at least one object to run the simulation - in this example only the ground surface is connected. For this simulation *_workingDir_* and *_radFileName_* does not matter much. In Fig. 16 *_radFileName_* is left empty and *_workingDir_* is set to C:\lark\materials\sky.

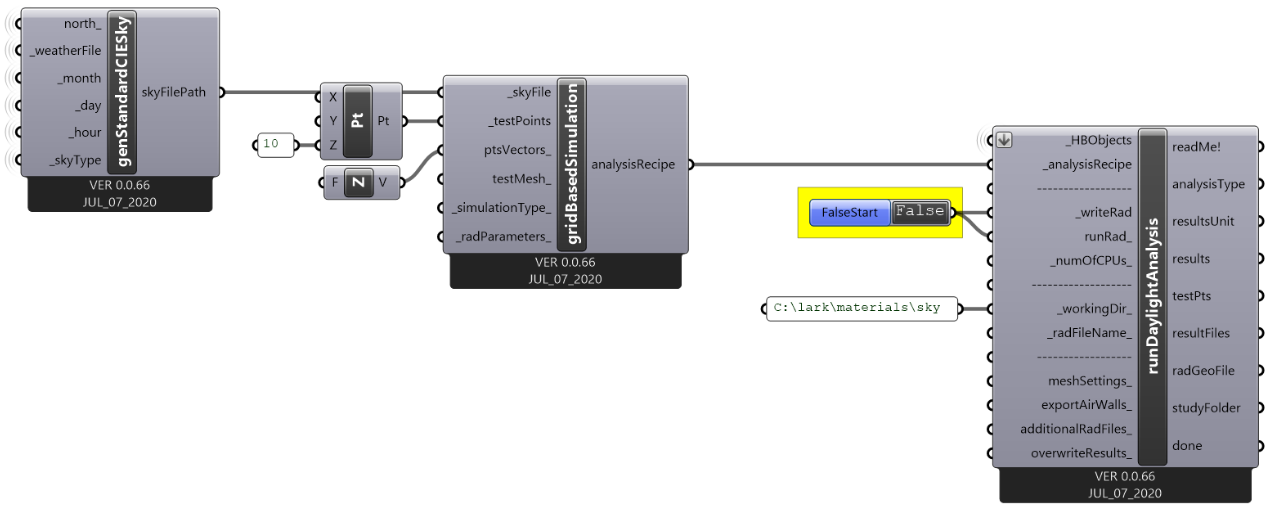


Figure 16: Simulation to find the illuminance of an unobstructed point looking up. The quality of the simulation is not important - it can be left to the default.

4.2 Spectral sky

To run simulations with spectral data, the sky should also be a spectral sky. The first step is to write the spectral channels. The Lark component `Spectral Materials` will do that based on the spectral power distribution file that must be connected to *spd_input*. The user must specify the wavelength increment of the file in *source_interval*. The input *excel_daylight_series_cal* is a boolean - it must be True if the data from the SPD file is derived from the Rochester Institute of Technology Excel Daylight Series Calculator. The *material_type* must be set to 2 indicating that we are dealing with sky material. The *channel_type* must be either 0 (3 channel) or 1 (9 channel). In this tool we want 9 channels - the *channel_type* must then be 1.

To create the sky material in Radiance format the component `Spectral Sky` from Lark is used. The *channel_output* from `Spectral Materials` must be connected as well as the *channel_type* which once again is 1 for 9 channels. The output from `explodeLocation` is connected to *latitude*, *longitude*, and *UTC*. The specifications of *sky_type*, *month*, *day*, and *hour* is those defined in section 2.6. The input for *global_illuminance* is the illuminance value from the simulation in section 4.1. To create the Radiance sky materials *run_reindl* is set to True. In this case we will have three materials (9a, 9b, 9c) because we specified that we want 9 channels.

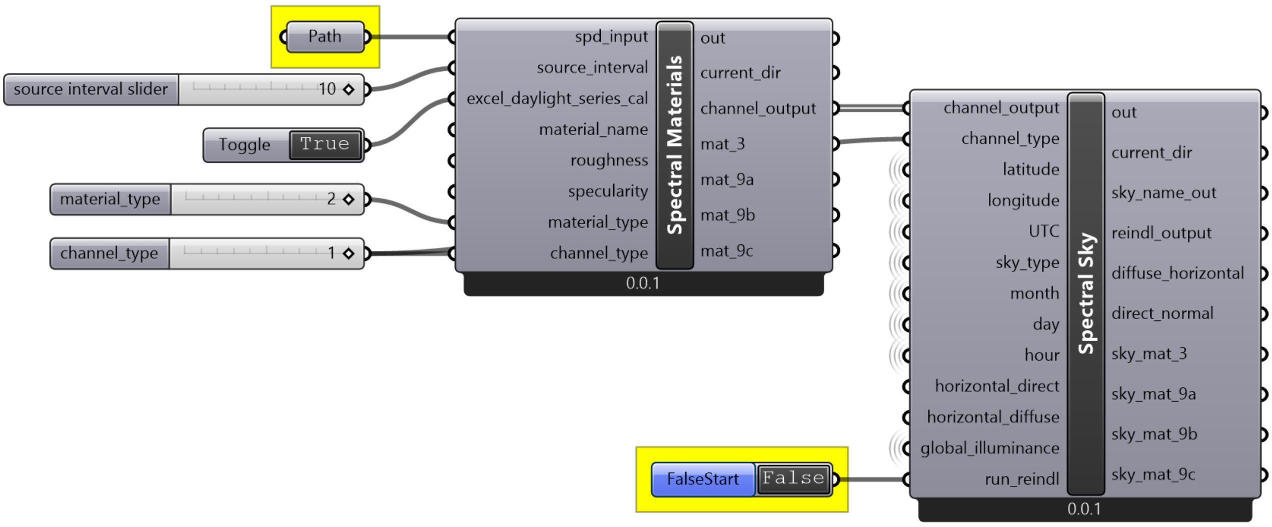


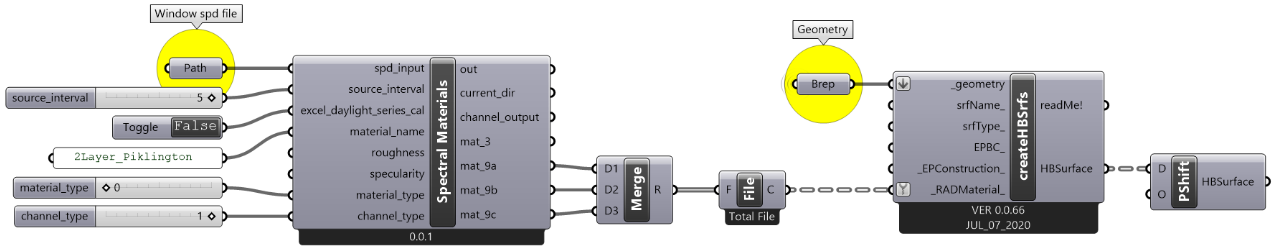
Figure 17: Creation of the spectral sky by `Spectral Sky`. It needs the *channel_output* from `Spectral Materials`.

4.3 Geometry and spectral data

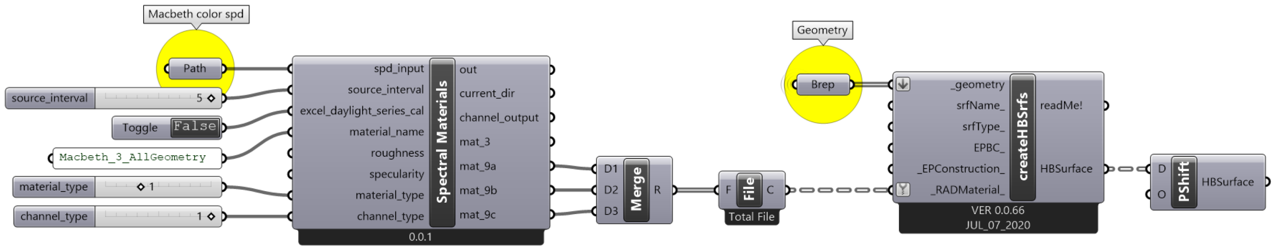
The geometry for the simulations need spectral data and materials created by `Spectral Materials`. The user must input a SPD file in *spd_input* and connect the wavelength increment in *source_interval*. We will set *excel_daylight_series_cal* to False. Contrary to section 4.2 we must connect a *material_name* - otherwise the Radiance materials will not be written. The *channel_type* is set to 1 for 9 channels. The *material_type* is set to 0 for glass or 1 for plastic. Optional values can be connected to *roughness* and *specularity*. Once everything has been connected `Spectral Materials` will create three Radiance materials - *mat_9a*, *mat_9b*, and *mat_9c*. These are merged and read by the file reader (`File`) - here it must be set to Total File, which can be done by right clicking and unchecking Per Line.

The materials will be applied to geometry by `createHBSrfs`. The geometry connected to *_geometry* must be flattened. For this case we do not care about *srfName_*, *srfType_*, *EPBC_*, and *_EPConstruction_* since we are only simulating daylight. The materials read by the file reader is connected to *_RADMaterial* and we want to simplify the input. Since we are adding three materials `createHBSrfs` will apply each material to all of the flattened geometry. By using `PShift` with the default offset of -1 we will get three branches of Honeybee surfaces, each branch with a different material.

The workflows in Fig. 18 show only the creation of geometry with two SPD files - one for glass and one for plastic. In a real case there are different surface materials, i.e. floor, walls, ceiling etc., and the steps to create Honeybee surfaces with spectral materials should be copied for each material/SPD file.



(a) Creation of glass surfaces with spectral data.



(b) Creation of plastic surfaces with spectral data

Figure 18: The workflow in (a) creates Honeybee surfaces with spectral glass materials. The workflow in (b) creates Honeybee surfaces with spectral plastic materials. The main difference between the is the *material_type* which is set to 0 for glass in (a) and 1 for plastic in (b).

4.4 Lark simulation

To get meaningful results using Lark, we must run two types of simulations - the first being `imageBasedSimulation` and the second being `gridBasedSimulation`.

The Radiance sky descriptions (from section 4.2) are merged and connected to *_skyFile* in both recipes. For `imageBasedSimulation` the Rhino view name must be connected - this is the view name created by `viewDirection`. To create a fisheye image *_cameraType_* is set to 1. The *_simulationType_* is set to 2 to get a luminance image. The image size is set by *_imageWidth_* and *_imageHeight_*. For `gridBasedSimulation` the view point is connected to *_testPoints* - this is the view point coming from `viewDirection`. We will also use the view vector from `viewDirection` and connect it to *ptsVectors_*. The *_simulationType_* is set to 0 to get the result in illuminance. For both recipes it possible to define simulation quality by connecting `RADParameters` to *_radParameters_*.

The simulations are run by `runDaylightAnalysis`. We are creating one for each type of recipe. The Honeybee surfaces are merged - these are the Honeybee surfaces from section 4.3. In Fig. 19 there is only two inputs *D1* and *D2* matching the two groups of Honeybee surface creation with spectral data from section 4.3. When merging the Honeybee surfaces we get three branches of *_HBObjects* - one for each material (9a, 9b, 9c) - with all the geometry from section 4.3 combined. The three branches are connected to *_HBObjects*. Since we are inserting three Radiance sky descriptions in each recipe, we will also get three recipes from each component. There are connect to *_analysisRecipe*. It is important to note that its input is grafted and simplified. In both cases the *_workingDir_* is the *LarkSubfolder* from `folderStructure`. We create the *_radFileName_* by concatenating the *imageName* from `namingImage`, a list roots (a, b, c), and the channel type (9). To run the simulations both *_writeRad* and *runRad_* is set to True.

For every instance (view) there will be a total of six simulations - three for each recipe. To split the results for each recipe type, we use the native Grasshopper component `Item` and add more outputs (three in total).

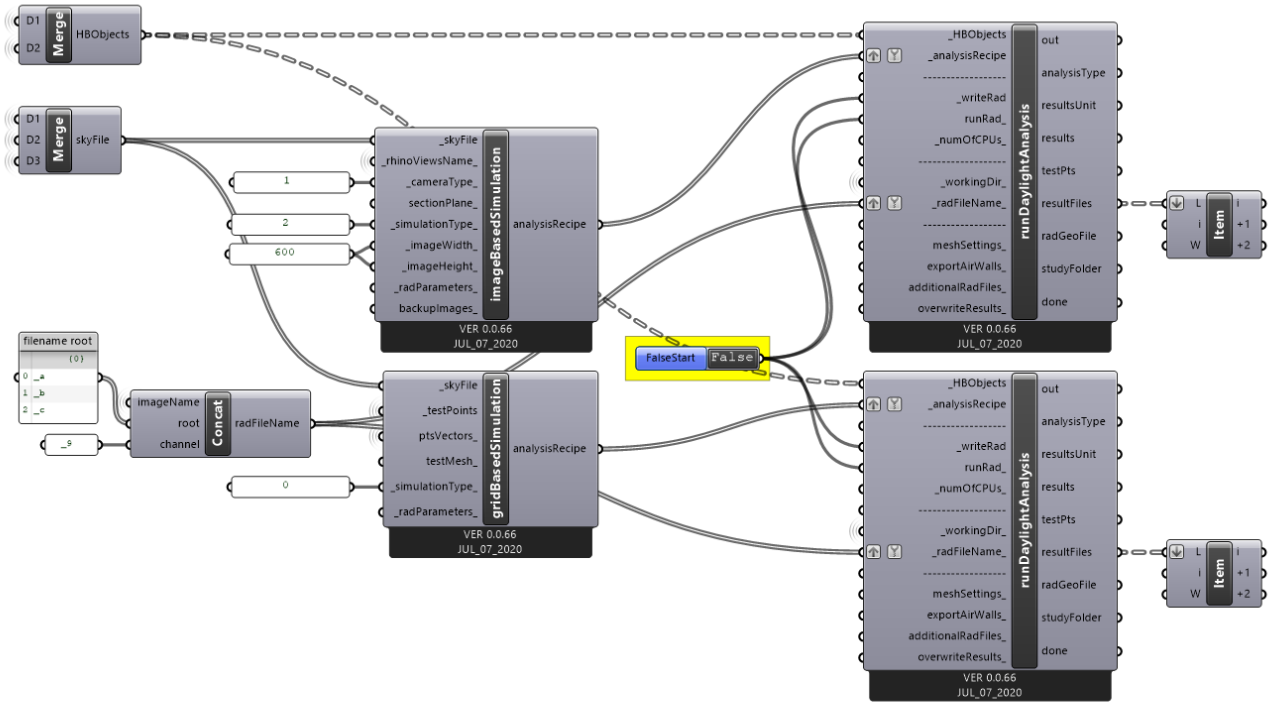


Figure 19: Simulation with two recipe types. For each recipe there will be three simulations - red, green, and blue.

4.5 Lark result

The result files from section 4.4 are connected to `9-channel luminance`. The three images are connected to *picture1*, *picture2*, and *picture3*. The three files for the single view point are connected to *irradiance1*, *irradiance2*, and *irradiance3*. The *Directory* is *LarkSubfolderFinal* from `folderStructure`. To compute the results *RunPcomb* is set to True.

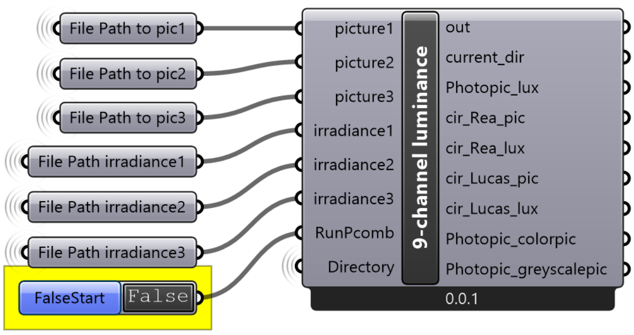


Figure 20: The result files from the two recipe types are combined by `9-channel luminance`.

Since this workflow is set up to iterate over the sliders defined in section 2, we want to record the results for each iteration. For this purpose to Python components has been created as seen in Fig. 21. The first one, `combineLarkData`, needs the *subfolder* from `namingSubfolder`, the *imageName* from `namingImage`, the *viewPoint* and *viewVector* from `viewDirection`. It also needs the results (*Photopic_lux*, *cir_Rea_lux*, and *cir_Lucas_lux* from `9-channel luminance` in section 4.5. The output of `combineLarkData` is simply a list of the input data with an addition of the Equivalent Melanopic Lux, which is calculated in the component.

To write the results, *dataToWrite* must be connected to `writeLark`. The *LarkFinalSubfolder* is taken from `folderStructure`. To write the results to a txt file *runIt* is set to True. The component checks if there are any Null items in *dataToWrite* - it will only write if there are none.

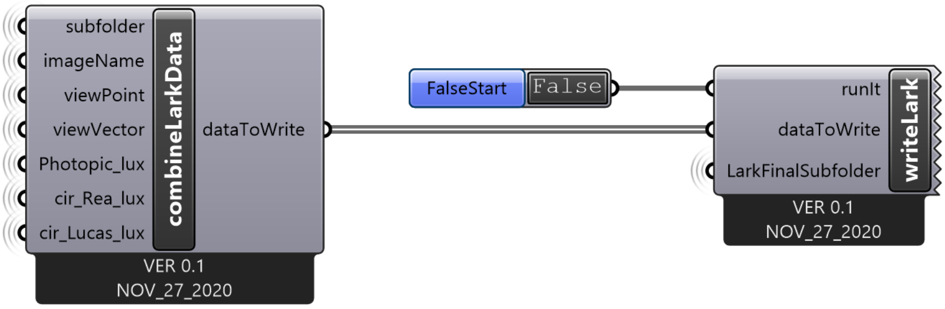


Figure 21: The Lark results are combined by `combinedLarkData` - including calculating Equivalent Melanopic Lux (EML). The data is written by `writeLark`.

4.6 Lark visualization

Once all iterations have been simulated we need to read the result files (txt files). A Python component, `readLarkFilter`, will read all the results found in the *LarkDirection* from `folderStructure`. Based on the input of *month*, *day*, *hour*, and *sky*, it will match the results with the input specifications and output the filtered results.

To visualize the results we use the Python component `viewThreshold`. It takess *viewPoint*, *viewVector*, *photopicLux*, and *EML* as input. The component will assign colors to each view direction for EML and photopic lux if it meets the threshold. The threshold for EML is 250 lux, and for photopic lux it is 500 lux. If it meets the threshold it will be green, and red if it does not meet the threshold. The colors are passed on gives as *RGB_EML* and *RGB_Photopic*. The visualization of the vectors are done with `VDisEx` by connecting the *viewPoint*, *viewVector*, and *RGB_EML* or *RGB_Photopic*. An example of the visualization is seen in Fig. 23.

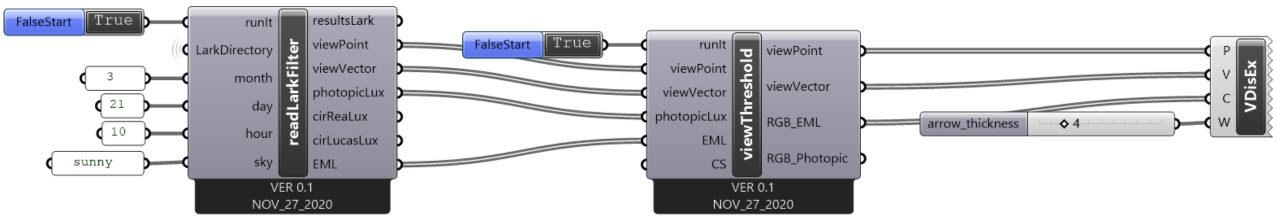


Figure 22: Reading of Lark results by `readLarkFilter`, and calculation of whether or not the results meet the threshold by `viewThreshold`.

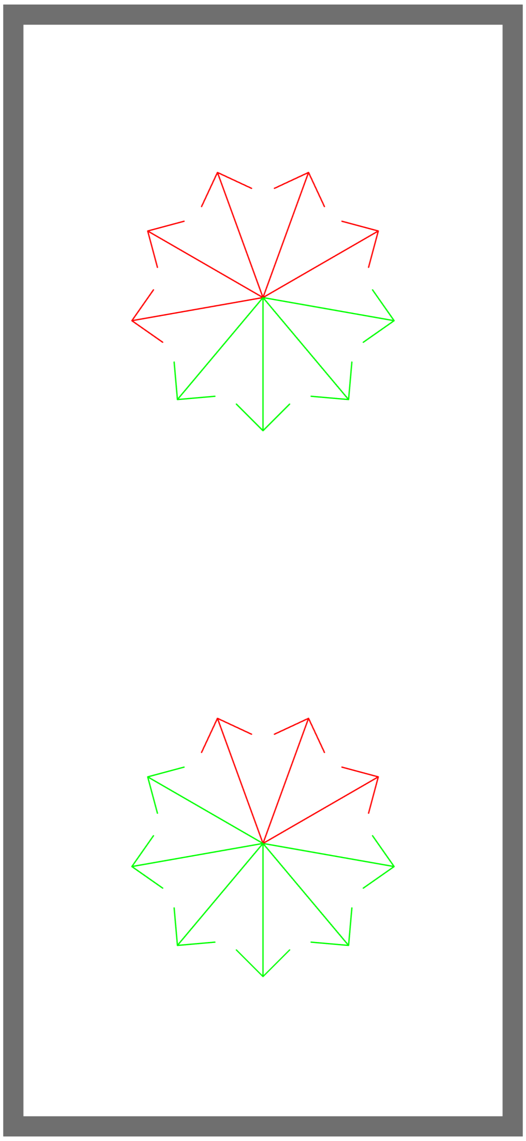


Figure 23: Visualization of view directions and if they meet the threshold. Each arrow/vector represents a view direction.

A Appendix

A.1 viewDirection

```python
"""Sets the view point, view direction and outputs a view name. This component modifies or creates a Rhino view. The default view name is 'Perspective'. If the view name already exists, it will be modified. If it does not exists, it will be created.
-
This component is heavily inspired by the components 'setTheView' and 'viewFromSun' provided by Ladybug.
    Inputs:
        gridPoint: Grid point.
        angle: Angle (degrees) of the view direction relative to a south facing view direction (0, -1, 0). Counter-clockwise rotation.
        offsetDistance: An optional offset distance in the z-direction of the grid points. The default value is 1.168405.
    Output:
        viewPoint: View point.
        viewVector: View vector.
        viewName: Name of the modified view or created view."""

__author__ = 'Mikkel Pedersen'
__version__ = '2020.11.27'

ghenv.Component.Name = 'DTU_viewDirection'
ghenv.Component.NickName = 'viewDirection'
ghenv.Component.Message = 'VER 0.1\nNOV_27_2020'
ghenv.Component.Category = "DTU"
ghenv.Component.SubCategory = '03 :: Misc'

import scriptcontext as as sc
import Rhino as rc
import rhinoscriptsyntax as rs
import Grasshopper.Kernel as gh

if not offset:
    offset = 1.168405
else:
    try:
        offset = float(offset)
    except:
        offset = 1.168405
        w = gh.GH_RuntimeMessageLevel.Warning
        ghenv.Component.AddRuntimeMessage(w, 'Failed to convert to float. Using default value: 1.168405.')

viewPoint = rc.Geometry.Point3d(gridPoint.X, gridPoint.Y, gridPoint.Z + offset)

startVec = rc.Geometry.Vector3d(0, -1 , 0)
rotAxis = rc.Geometry.Vector3d(0, 0, 1)

rotAngle = angle

viewVector = rs.VectorRotate(startVec, rotAngle, rotAxis)

_cameraLocation = viewPoint
_cameraDirection = viewVector
viewName_ = 'Perspective'

```

```python
def main(cameraLocation, cameraDirection, viewName):
    if viewName == None:
        viewName = 'Perspective'

    isView = rc.RhinoDoc.ActiveDoc.Views.Find(viewName, False)

    if isView == None:
        w = sc.doc.Views.ActiveView.ActiveViewport.Size.Width
        h = sc.doc.Views.ActiveView.ActiveViewport.Size.Height

        x = round((System.Windows.Forms.Screen.PrimaryScreen.Bounds.Width - w) / 2)
        y = round((System.Windows.Forms.Screen.PrimaryScreen.Bounds.Height - h) / 2)

        rectangle = System.Drawing.Rectangle(System.Drawing.Point(x, y), System.Drawing.Size(w, h))

        newRhinoView = rc.RhinoDoc.ActiveDoc.Views.Add(viewName, rc.Display.DefinedViewportProjection.Perspective, rectangle, False)

        isView = rc.RhinoDoc.ActiveDoc.Views.Find(viewName, False)

    rc.RhinoDoc.ActiveDoc.Views.ActiveView = isView

    dispModeStr = 'Shaded'

    try:
        dispMode = rc.Display.DisplayModeDescription.FindByName(dispModeStr)
        sc.doc.Views.ActiveView.ActiveViewport.DisplayMode = dispMode
    except: pass

    distance = 100
    target = rc.Geometry.Point3d.Add(cameraLocation, distance * cameraDirection)

    # modify the view
    sc.doc.Views.ActiveView.ActiveViewport.SetCameraLocation(cameraLocation, True)
    sc.doc.Views.ActiveView.ActiveViewport.SetCameraDirection(cameraDirection, False)
    sc.doc.Views.ActiveView.ActiveViewport.SetCameraTarget(target, False)

    return viewName

if _cameraLocation and _cameraDirection:
    viewName = main(_cameraLocation, _cameraDirection, viewName_)
```

A.2 runEvalglare

```python
"""
Connects images to be analyzed in evalglare.exe. Calculates the needed photometric values for further analysis by the 'GazeViz' component
-----
Please notice that only HDR images can be analyzed
-----

    Args:
        runIt: Set to 'True' to run analysis
        imageDir: Input directory for HDR images as string
    Returns:
        output: Output is given as string
"""
import os
import glob
import math
import Grasshopper as gh

#Running process in Dos
from subprocess import *

def runCmd(args):
    process= Popen(['cmd']+list(args), stdout=PIPE, stderr=PIPE)
    out= []
    while process.poll() is None:
        line= process.stdout.readline()
        if line!= '' and line.endswith('\n'):
            out.append(line[:-1])
        stdout, stderr= process.communicate()
        out+= stdout.split('\n')
        return out

#Directory to evalglare.exe
evalglare = 'C:\\Radiance\\bin\\'

#simulationName = []
DGP = []
photometricData = []

if runIt:
    #Get paths of all folders in image directory
    imagePaths = glob.glob(os.path.join(imageDir, 'image_*'))

    #Get folder names only
    imageFolders = [os.path.split(path)[-1] for path in imagePaths]

    #Sort by grid point, then orientation
    maps = sorted(imageFolders, key= lambda x: (int(x.split('_')[1]), int(x.split('_')[2])))

    hdrFiles = []

    #Get hdr image file path
    for folder in maps:
        fileName = os.path.join(imageDir, folder, 'imageBasedSimulation', folder + '_IMG_Perspective.hdr')
        hdrFiles.append(fileName)

```

```python
    #Running evalglare.exe on hdrfiles with parameters and collecting results
    for hdrFile in hdrFiles:
        print(hdrFile)
        data = runCmd(['/c', evalglare + 'evalglare.exe','-d','-vth', '-vv', '180', '-vh', '↩
    180', hdrFile, '&&exit'])
        Ldata = (data[1].split(' '))
        value = (data[0].split(' ')[0])
        valueInt = int(value)
        DGP_Value = ((data[-2].split(' '))[1])

        if valueInt != 0: #if there is glare sources
            myList = data[1]
        for x in range(1, valueInt+1):
            aStr = data[x].split(' ')[4]
            bStr = myList.split(' ')[4]
            aFloat = float(aStr)
            bFloat = float(bStr)

            if aFloat > bFloat:
                myList = data[x]
        myArray = myList.split(' ')

        if valueInt == 0: #if there is no glare sources
            myArray  = data[valueInt+1].split(' ')
            M_La     = data[valueInt+2].split(' ')[2]
            M_Ls     = myArray[5]
            M_Omega  = myArray[6]
            M_pIndex = myArray[7]
            M_Ev     = myArray[10]
            M_x      = str(0)
            M_y      = str(0)
            M_z      = str(0)

        elif valueInt != 0:
            M_La     = data[valueInt+1].split(' ')[2]
            M_Ls     = myArray[4]
            M_Omega  = myArray[5]
            M_pIndex = myArray[6]
            M_Ev     = myArray[10]
            M_x      = myArray[13]
            M_y      = myArray[14]
            M_z      = myArray[15]

        photometricData.append([M_La, M_Ls, M_Omega, M_pIndex, M_x, M_y, M_z])
        DGP.append(DGP_Value)
```

A.3 GazeShift

```
"""
Calculates the gaze shift based on the Gaze Responsive Light Driven Model
    Args:
        gazeData: Insert list of photometric data from "runEvalglare" and intersection ↩
    points between the view directions and building
        noAngles: Number of angle divisions
        gridPoints: Insert list of grid points from "calculationGrid"
    Returns:
        endPoints: Endpoints for gaze shift vector
        startPoints: Startpoints for gaze shift vector
        linesGazeShift: Line representation of gaze shift vectors
"""

import math
import rhinoscriptsyntax as rs
import Rhino as rh
import Grasshopper as gh

x = []
y = []
z = []
Ls = []
La = []
Omega = []
pIndex = []
x_gla = []
y_gla = []
z_gla = []
x_cam = []
y_cam = []
z_cam = []

for i in range(gazeData.BranchCount):
    branchList = gazeData.Branch(i)
    La.append(float(branchList[0]))
    Ls.append(float(branchList[1]))
    Omega.append(float(branchList[2]))
    pIndex.append(float(branchList[3]))
    x_gla.append(float(branchList[4]))
    y_gla.append(float(branchList[5]))
    z_gla.append(float(branchList[6]))
    x_cam.append(float(branchList[7]))
    y_cam.append(float(branchList[8]))
    z_cam.append(float(branchList[9]))

    if Ls[i] > 0:
        x_gla1 = x_gla[i]/math.sqrt(x_gla[i]**2+y_gla[i]**2+z_gla[i]**2)
        y_gla1 = y_gla[i]/math.sqrt(x_gla[i]**2+y_gla[i]**2+z_gla[i]**2)
        z_gla1 = z_gla[i]/math.sqrt(x_gla[i]**2+y_gla[i]**2+z_gla[i]**2)
        x_cam1 = x_cam[i]/math.sqrt(x_cam[i]**2+y_cam[i]**2+z_cam[i]**2)
        y_cam1 = y_cam[i]/math.sqrt(x_cam[i]**2+y_cam[i]**2+z_cam[i]**2)
        z_cam1 = z_cam[i]/math.sqrt(x_cam[i]**2+y_cam[i]**2+z_cam[i]**2)

        glareImpact = Ls[i]*Omega[i]/pIndex[i]
        DistAngle = math.acos(x_gla1 * x_cam1 + y_gla1 * y_cam1 + z_gla1 * z_cam1)
        Shift = 1.92-0.56*math.log10(glareImpact)/(math.log10(La[i])*DistAngle)
        Iphi = math.atan2(y_cam1,x_cam1)
```

```
        Itheta = math.atan2(z_cam1,math.sqrt(x_cam1**2+y_cam1**2))

        Gphi = math.atan2(y_gla1,x_gla1)
        Gtheta = math.atan2(z_gla1,math.sqrt(x_gla1**2+y_gla1**2))

        GIphi = Iphi - Gphi


        if GIphi > math.pi:
            kGIphi = GIphi - (math.pi*2)
        else:
            kGIphi = GIphi

        sign = lambda a: 1 if a>0 else -1 if a<0 else 0
        gamma = sign(kGIphi) * Shift
        alpha = sign(kGIphi) * Shift

        vdd = [[x_cam1],[y_cam1],[z_cam1]]
        Rz = [[math.cos(alpha),-math.sin(alpha), 0],[math.sin(alpha),math.cos(alpha)↩
    ,0],[0,0,1]]

        result2 = [[0],[0],[0]]
        for i in range(len(Rz)):
           for j in range(len(vdd[0])):
              for k in range(len(vdd)):
                  result2[i][j] += Rz[i][k] * vdd[k][j]
        R2 = []
        for r in result2:
           R2.append(r)

        VDf=R2
        xnew=VDf[0][0]
        ynew=VDf[1][0]
        znew=VDf[2][0]

        x.append(xnew)
        y.append(ynew)
        z.append(znew)

    else:
        x.append(0)
        y.append(0)
        z.append(0)


Atrix = [x, y, z]

matrix = map(list, zip(*Atrix))

noOfCoordinates = 3
noOfVectors = noAngles
noOfPoints = len(gridPoints)

tripple = [[[0.0 for i in range(noOfCoordinates)] for j in range(noOfVectors)] for k in ↩
    range(noOfPoints)]

for k in range (noOfPoints):
    for j in range(noOfVectors):
        for i in range(noOfCoordinates):
```

```
            tripple[k][j][i] = matrix[k*noOfVectors+j][i]

linesGazeShiftList = []
endPoints = []
startPoints = []

#Curves from vectors
for i in range(noOfPoints):
    lines = []
    for j in range(noOfVectors):
        xx= gridPoints[i][0]+tripple[i][j][0]
        yy= gridPoints[i][1]+tripple[i][j][1]
        zz= gridPoints[i][2]
        xyz = (xx,yy,zz)
        end = rs.AddPoint(xyz)
        endPoints.append(end)
        start = rs.AddPoint(gridPoints[i][0], gridPoints[i][1], gridPoints[i][2])
        startPoints.append(start)
        line = rs.AddLine(start, end)
        lines.append(line)
    linesGazeShiftList.append(lines)

linesGazeShift = gh.DataTree[object]()
for i, l in enumerate(linesGazeShiftList):
    linesGazeShift.AddRange(l, gh.Kernel.Data.GH_Path(i))
```

A.4 gazeCount

```python
"""This component find the number of gaze shifts within each gaze zone. It finds the intersection points between the gaze shift lines and circles created by the grid points and circle radius. If the intersection point is within a gaze zone, it means that there is a gaze shift in the direction of that gaze zone.
    Inputs:
        linesGazeShift: Gaze shift lines calculated by 'GazeShift'
        gridPoints: Grid points
        circleRadius: Radius of circle to intersect with gaze shift lines
        gazeZones: Gaze zone centered around each grid point
    Output:
        circles: The circles created by the grid points and circle radius
        intersectionPoints: The intersection points between gaze shift lines and circles
        gazeCount: The number of gaze shifts within each gaze zone"""

__author__ = "Mikkel Pedersen"
__version__ = "2020.12.02"

ghenv.Component.Name = "DTU_gazeCount"
ghenv.Component.NickName = 'gazeCount'
ghenv.Component.Message = 'VER 0.1\nDEC_02_2020'
ghenv.Component.Category = "DTU"
ghenv.Component.SubCategory = '03 :: Misc'

import rhinoscriptsyntax as rs

intersectionPoints = []
circles = []

#Set circle radius if no input.
if not circleRadius:
    circleRadius = 0.05

#Add circles at every grid point.
for point in gridPoints:
    circles.append(rs.AddCircle(point, circleRadius))

#Find intersection points between gaze shift lines and circles.
for line in linesGazeShift:
    for circle in circles:
        ccx = rs.CurveCurveIntersection(line, circle)

        if ccx != None:
            intersectionPoints.append(ccx[0][1])

gazeCount = []

#Count the gaze shifts per gaze zone.
for zone in gazeZones:
    containment = []

    for point in intersectionPoints:
        #Find if point is outside of the curve (0), inside of the curve (1), on the curve (2).
        #Tolerance is set low reduce errors, i.e. that some points are found to be within two curves.
        containment.append(rs.PointInPlanarClosedCurve(point, zone, tolerance=0.000001))

```

```
    #Count all elements larger than 0 in 'containment'
    zoneCount = sum(map(lambda x: x > 0, containment))

    #Append the count per zone.
    gazeCount.append(zoneCount)
```

A.5 projectFolder

```python
"""Creates project folder.
    Inputs:
        workingDir: Name of working directory. Default: C:\
        projectFolder: Name of project folder. Default: Tool_Project
        createFolder: Boolean value. Set to True to create project folder
    Output:
        directory: Path of project folder"""

__author__ = "Mikkel Pedersen"
__version__ = "2020.11.16"

import rhinoscriptsyntax as rs
import Grasshopper.Kernel as gh
import os

if not workingDir:
    workingDir = 'C:\\'

if not projectFolder:
    projectFolder = 'Tool_Project'

#Path of the project folder
dirPath = os.path.join(workingDir, projectFolder)

#Creates folder if createFolder = True, otherwise checks if folder exists
if createFolder == True:
    if not os.path.isdir(dirPath):
        os.mkdir(dirPath)
        print('The directory does not exist. Creating directory at {}.'.format(dirPath))
    else:
        print('The directory {} already exists.'.format(dirPath))
    projectPath = dirPath
else:
    if os.path.isdir(dirPath):
        projectPath = dirPath
        print('The directory {} already exists'.format(dirPath))
    else:
        print('The directory {} does not exists. You must first create the directory!'.
    format(dirPath))
        w = gh.GH_RuntimeMessageLevel.Warning
        ghenv.Component.AddRuntimeMessage(w, 'The directory {} does not exists. You must 
    first create the directory!'.format(dirPath))
```

A.6 folderStructure

```
"""Creates folder structure for analysis with Lark and Gaze.
    Inputs:
        projectPath: Path of project folder
        LarkFolder: Name of Lark folder. Default: "Lark"
        GazeFolder: Name of Gaze folder. Default: "Gaze"
        subfolder: Name of subfolder
        createFolder: Boolean value. Set to True to create folder structure.
    Output:
        LarkSubfolder: Lark subfolder
        LarkFinalSubfolder: Lark subfolder (combined image)
        GazeSubfolder: Gaze subfolder"""

__author__ = "Mikkel Pedersen"
__version__ = "2020.11.16"

import rhinoscriptsyntax as rs
import Grasshopper.Kernel as gh
import os

#Default gaze folder if no input
if not GazeFolder:
    GazeFolder = 'Gaze'

#Default Lark folder if no input
if not LarkFolder:
    LarkFolder = 'Lark'

#Lark and Gaze paths
LarkDirectory = os.path.join(projectPath, LarkFolder)
GazeDirectory = os.path.join(projectPath, GazeFolder)

#Subfolder paths
LarkTempSubfolder = os.path.join(LarkDirectory, subfolder)
LarkTempFinalSubfolder = os.path.join(LarkTempSubfolder, '_'.join([imageName, "LarkFinal"]))
GazeTempSubfolder = os.path.join(GazeDirectory, subfolder)

folderList = []
tempList = [LarkDirectory, GazeDirectory, LarkTempSubfolder, LarkTempFinalSubfolder, ↩
    GazeTempSubfolder]

for path in tempList:
    folderList.append(path)

LarkDirectoy, GazeDirectory, LarkSubfolder, LarkFinalSubfolder, GazeSubfolder = folderList
```

A.7 combineLarkData

```
"""Combine data. Connect the output to 'writeLark' to write the data to a txt file.
    Inputs:
        subfolder: Subfolder
        imageName: Image name
        viewPoint: View point
        viewVector: View vector
        Photopic_lux: Photopic lux
        cir_Rea_lux: Rea lux
        cir_Lucas_lux: Lucas lux
    Output:
        dataToWrite: Data to write. Connect to 'writeLark'. Data is in the following order:
            -
            index data
            0 subfolder
            1 imageName
            2 point
            3 view vector
            4 photopic Lux
            5 Rea lux
            6 Lucas lux
            7 Equivalent Melanopic Lux"""

__author__ = "Mikkel Pedersen"
__version__ = "2020.11.27"

ghenv.Component.Name = "DTU_combineLarkData"
ghenv.Component.NickName = 'combineLarkData'
ghenv.Component.Message = 'VER 0.1\nNOV_27_2020'
ghenv.Component.Category = "DTU"
ghenv.Component.SubCategory = '03 :: Misc'

import rhinoscriptsyntax as rs
import Grasshopper as gh

data = []

#Convert Lucas lux to Equivalent Melanopic Lux
if cir_Lucas_lux >= 0:
    EML = (179/149) * cir_Lucas_lux
else:
    EML = None

data.append([subfolder, imageName, viewPoint, viewVector, Photopic_lux, cir_Rea_lux, ↩
    cir_Lucas_lux, EML])

dataToWrite = gh.DataTree[object]()

for i, l in enumerate(data):
    dataToWrite.AddRange(l, gh.Kernel.Data.GH_Path(i))
```

A.8 writeLark

```python
"""Write data from Lark analysis.
    Inputs:
        runIt: Set to True to write data.
        dataToWrite: Data to write. Input must be a list in following order:
            index data
            0 subfolder
            1 imageName
            2 point
            3 view vector
            4 photopic Lux
            5 Rea lux
            6 Lucas lux
            7 Equivalent Melanopic Lux
            -
            The correct data input can be created by using the components/user objects from Gaze/Lark/something???.
        LarkFinalSubfolder: Path of the final subfolder for Lark.
    Output:
"""

__author__ = "Mikkel Pedersen"
__version__ = "2020.11.26"

ghenv.Component.Name = "DTU_writeLark"
ghenv.Component.NickName = 'writeLark'
ghenv.Component.Message = 'VER 0.1\nNOV_27_2020'
ghenv.Component.Category = "DTU"
ghenv.Component.SubCategory = '03 :: Misc'

import rhinoscriptsyntax as rs
import os

if None in dataToWrite:
    pass
else:
    if runIt == True and len(dataToWrite) == 8 and LarkFinalSubfolder:
        filename = os.path.join(LarkFinalSubfolder, 'lark_results.txt')

        f = open(filename, 'w')

        #Join data by newline. This method is alright since dataToWrite is only seven item.
        data = '\n'.join(dataToWrite)
        f.write(data)

        f.close()
```

A.9 readLarkFilter

```
"""Provides a scripting component.
    Inputs:
        runIt: Set to True to read results.
        LarkDirectory: Path of Lark folder.
        month: Month to include.
        day: Day to include.
        hour: Hour to include.
        sky: Sky type to include.
    Output:
        resultsLark: Results from Lark analysis. Each branch represents the results fron one↩
     simulation.
        viewPoint: View point.
        viewVector: View vector.
        photopicLux: Photopic lux.
        cirReaLux: Rea lux.
        EML: Equivalent Melanopic Lux."""

__author__ = "Mikkel Pedersen"
__version__ = "2020.11.26"

ghenv.Component.Name = "DTU_readLarkFilter"
ghenv.Component.NickName = 'readLarkFilter'
ghenv.Component.Message = 'VER 0.1\nNOV_27_2020'
ghenv.Component.Category = "DTU"
ghenv.Component.SubCategory = '03 :: Misc'

import rhinoscriptsyntax as rs
import os
import glob
import math
import Grasshopper as gh
import Rhino as rc

subfolder = []
imageName = []
viewPoint = []
viewVector = []
photopicLux = []
cirReaLux = []
cirLucasLux = []
EML = []

#Change this later
month = month
day = day
hour = hour
sky = sky

if runIt == True:
    #Get paths of all folders in directory
    folderPaths = glob.glob(os.path.join(LarkDirectory, '*_*_*_*'))

    filter = '_'.join([month, day, hour + 'h', sky])

    for path in folderPaths:
        if os.path.relpath(path, LarkDirectory) == filter:
            pr = path
```

```
            break
        else:
            pr = []

    #Get paths of all folders in image directory
    l = glob.glob(os.path.join(pr, 'image_*_*_LarkFinal'))

    #Get folder names only
    imageFolders = [os.path.relpath(path, pr) for path in l]

    #Sort by grid point, then orientation
    maps = sorted(imageFolders, key= lambda x: (int(x.split('_')[1]), int(x.split('_')[2])))

    txtFiles = []

    #Get txt file path
    for folder in maps:
        fileName = os.path.join(pr, folder, 'lark_results.txt')
        txtFiles.append(fileName)

    txtRead = []

    for file in txtFiles:
        txtRead.append([line.rstrip('\n') for line in open(file)])

    resultsLarkTemp = []

    for list in txtRead:
        vec = ([float(i) for i in list[3].split(',')])
        subfolder.append(list[0])
        imageName.append(list[1])
        viewPoint.append(rs.AddPoint(list[2]))
        viewVector.append(rc.Geometry.Vector3d(vec[0], vec[1], vec[2]))
        photopicLux.append(float(list[4]))
        cirReaLux.append(float(list[5]))
        cirLucasLux.append(float(list[6]))
        EML.append(float(list[7]))

    resultsLark = gh.DataTree[object]()

    for i, l in enumerate(txtRead):
        resultsLark.AddRange(l, gh.Kernel.Data.GH_Path(i))
```

A.10 viewThreshold

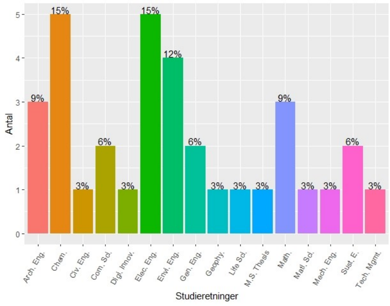
```
"""This component calculates if the threshold for Equivalent Melanopic Lux (EML) and photopic lux is met. If the threshold is met, the view direction (view vector) will be assigned green (RGB: 0, 255, 0). If the threshold is not met, the view direction (view vector) will be assigned red (RGB: 255, 0, 0). The colors can be used to visualize the vectors.
-
Connect inputs with outputs from 'readLarkFilter'.
    Inputs:
        runIt: Set to True to run.
        viewPoint: View point.
        viewVector: View vector.
        photopicLux: Photopic lux.
        EML: Equivalent Melanopic Lux.
    Output:
        viewPoint: View point.
        viewVector: View vector.
        RGB_EML: RGB color for each view direction.
        RGB_PhotopicLux: RGB color for each view direction."""

ghenv.Component.Name = 'DTU_viewThreshold'
ghenv.Component.NickName = 'viewThreshold'
ghenv.Component.Message = 'VER 0.1\nNOV_27_2020'
ghenv.Component.Category = "DTU"
ghenv.Component.SubCategory = '03 :: Misc'

import rhinoscriptsyntax as rs

if runIt == True:
    if EML != 0:
        if float(EML) >= 250:
            R = 0
            G = 255
            B = 0
        elif float(EML) < 250:
            R = 255
            G = 0
            B = 0
        RGB_EML = '{},{},{}'.format(R, G, B)

    if photopicLux != 0:
        if photopicLux >= 500:
            R1 = 0
            G1 = 255
            B1 = 0
        elif photopicLux < 500:
            R1 = 255
            G1 = 0
            B1 = 0
        RGB_Photopic = '{},{},{}'.format(R1, G1, B1)
```

Attachment C Overview of the participants

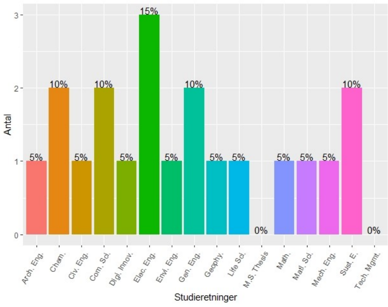
Zone 5					Zone 30				
Person	Position	View	Sky type	Date and Hour	Person	Position	View	Sky type	Date and Hour
Person 9	4	7	Sunny	31-10-2019 16:49	Person 1	3	1	Overcast	30-10-2019 14:16
Person 14	1	3	Overcast	05-11-2019 10:17	Person 2	3	1	Overcast	30-10-2019 14:23
Person 16	2	3	Overcast	05-11-2019 11:33	Person 3	3	1	Overcast	30-10-2019 16:18
Person 17	4	6	Overcast	05-11-2019 13:00	Person 7	6	7	Overcast	31-10-2019 15:25
Person 21	2	3	Overcast	05-11-2019 16:40	Person 11	3	6	Overcast	04-11-2019 11:14
Person 22	4	7	Overcast	05-11-2019 17:47	Person 13	2	5	Overcast	04-11-2019 11:20
Person 23	3	3	Overcast	07-11-2019 10:54	Person 19	3	6	Overcast	05-11-2019 15:11
Person 24	6	7	Overcast	07-11-2019 10:54	Person 20	6	6	Overcast	05-11-2019 15:11
Person 25	2	3	Overcast	07-11-2019 12:47	Person 32	3	1	Overcast	07-11-2019 14:06
Person 26	2	3	Overcast	07-11-2019 14:02	Person 34	3	5	Overcast	07-11-2019 14:08
Person 27	2	3	Overcast	07-11-2019 14:02	Person 36	6	8	Sunny	12-11-2019 13:58
Person 29	1	3	Overcast	07-11-2019 14:03					
Person 30	4	7	Overcast	07-11-2019 14:03					
Person 31	5	7	Overcast	07-11-2019 14:04					

Attachment D Further explorative results from the questionnaire

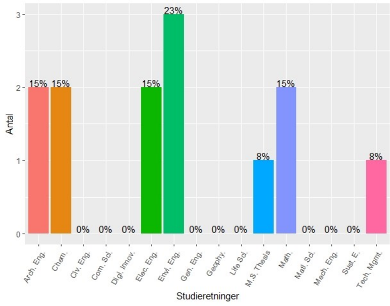
Indledende analyse - Spørgeskemaundersøgelse



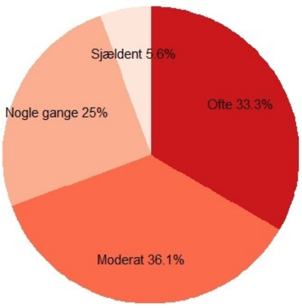
Spm. 4, Samlet



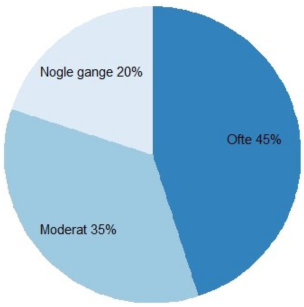
Spm. 4, Zone 5



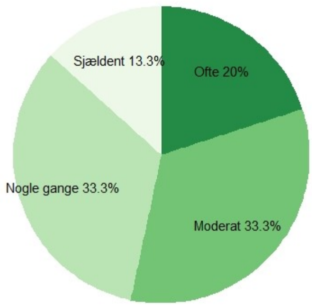
Spm. 4, Zone 30



Spm. 5, Samlet



Spm. 5, Zone 5



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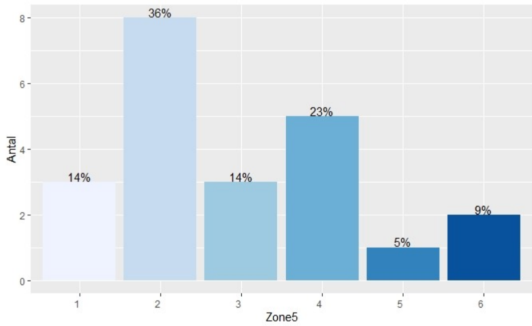

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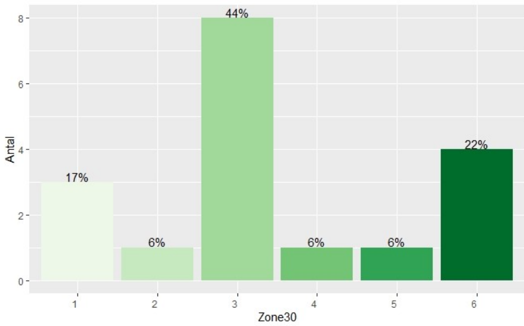

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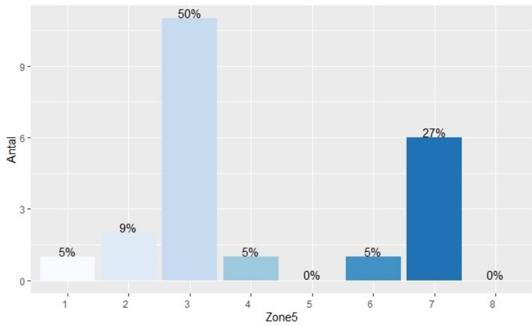

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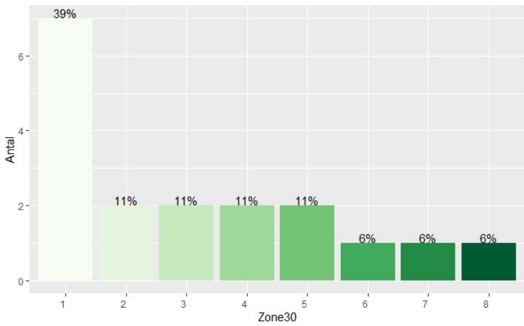

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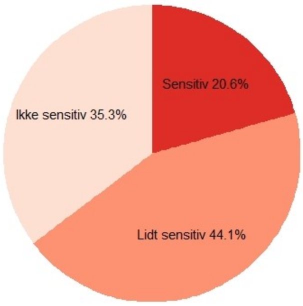

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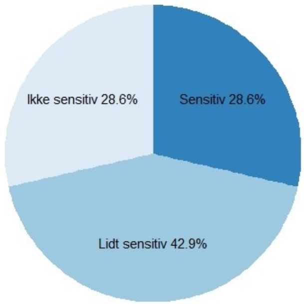

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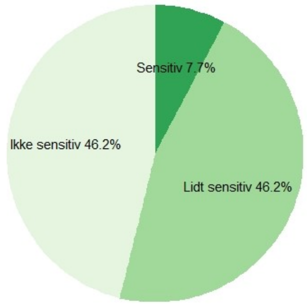

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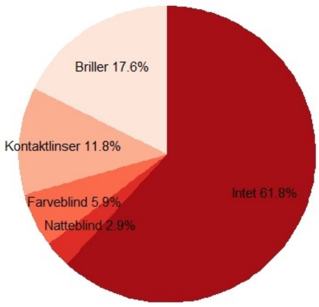

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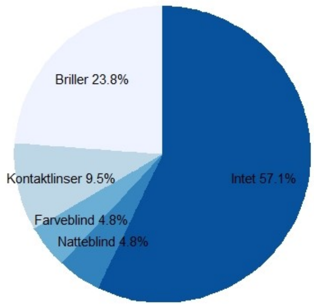

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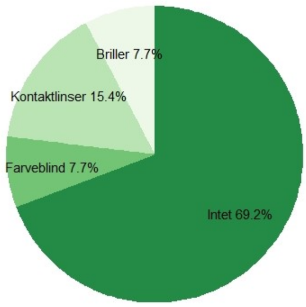
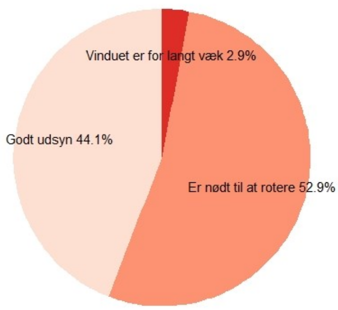


Spm. 10, Zone 30



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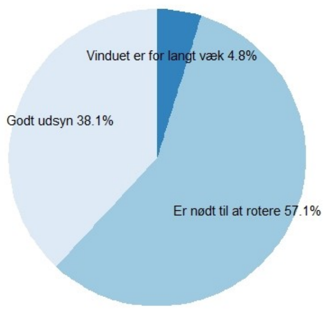

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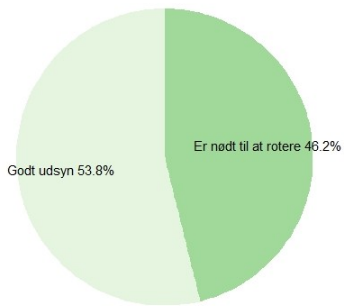

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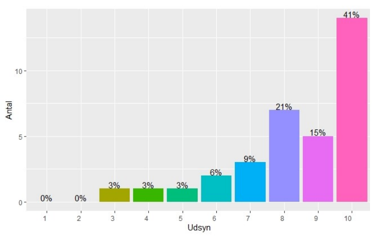

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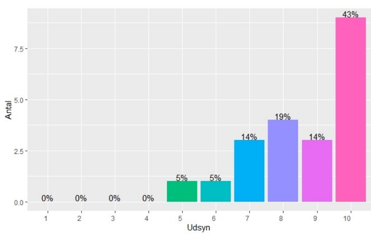

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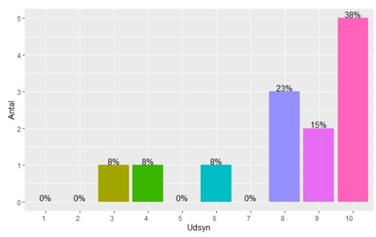

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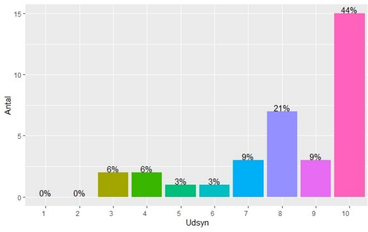

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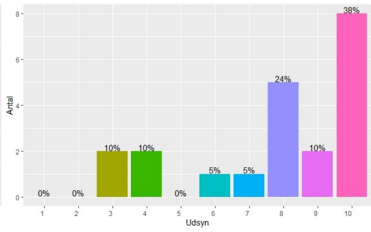

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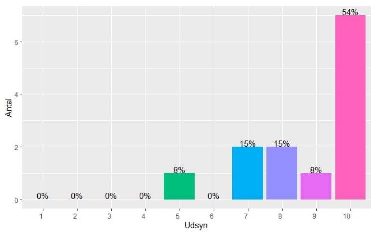

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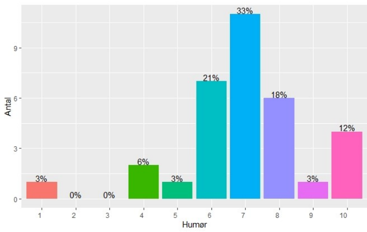

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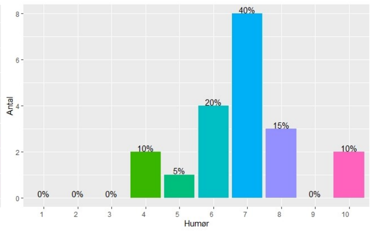

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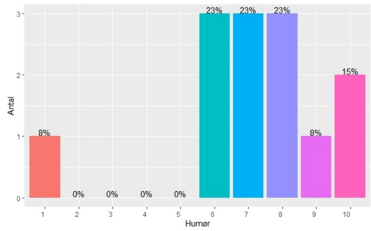

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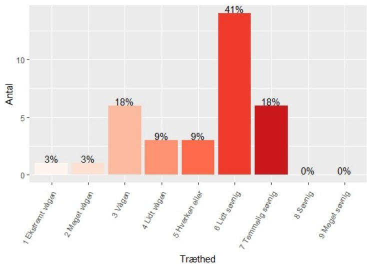

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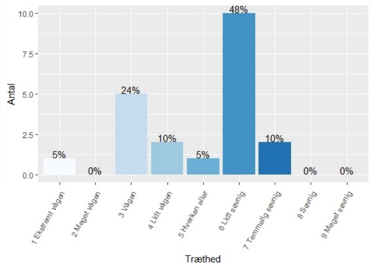

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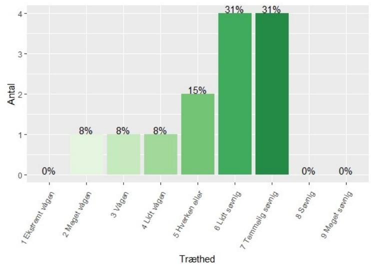

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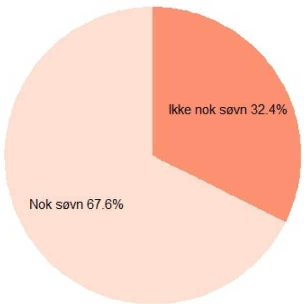

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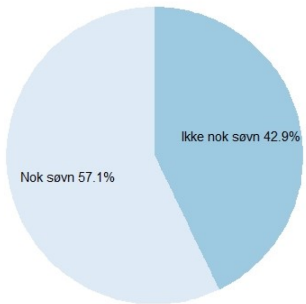

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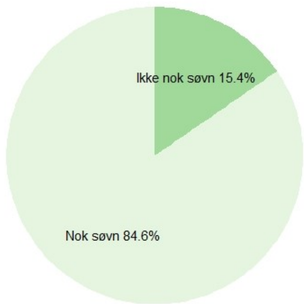

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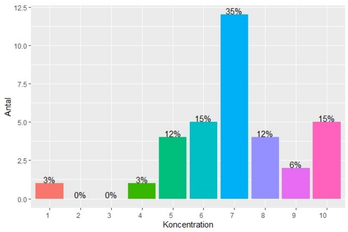

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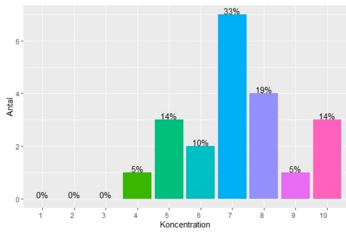

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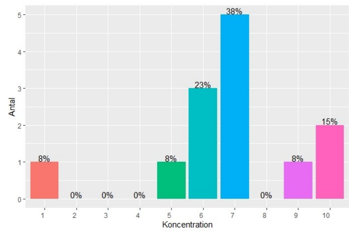

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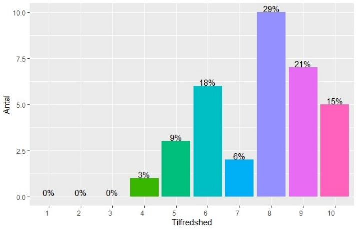

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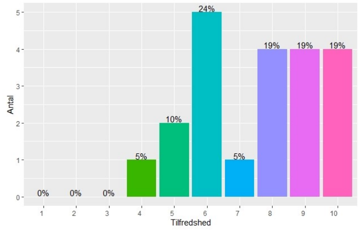

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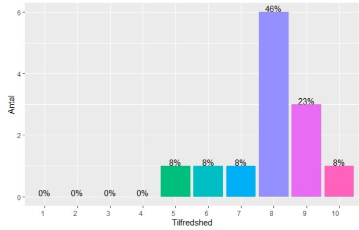

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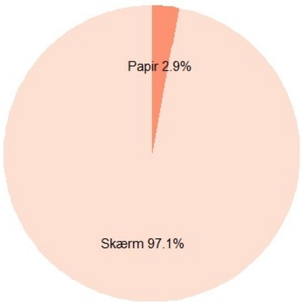
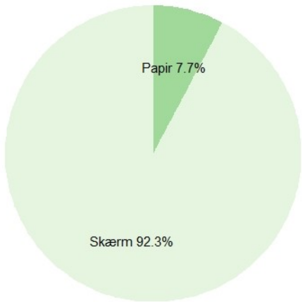
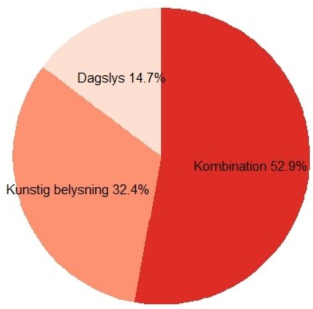


Spm. 20, Samlet

Spm. 20, Zone 5



Spm. 20, Zone 30



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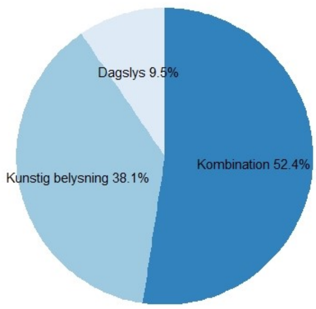

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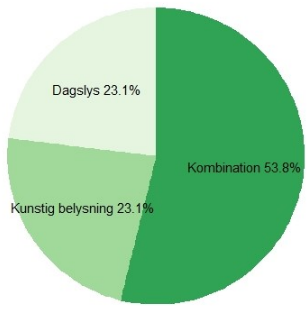

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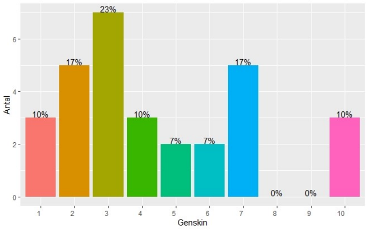

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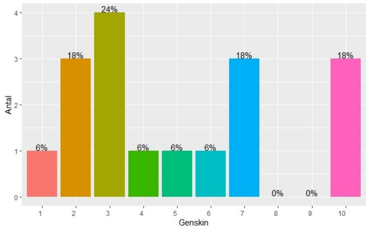

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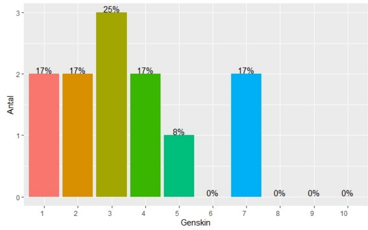

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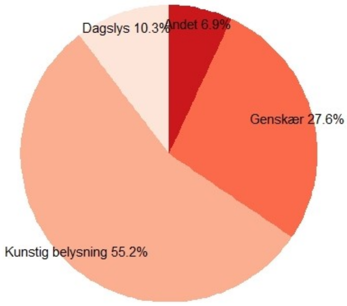

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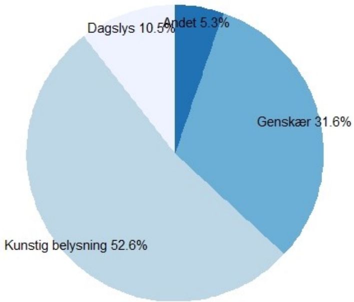

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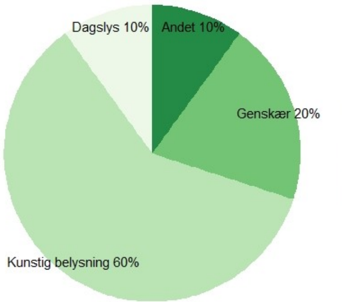

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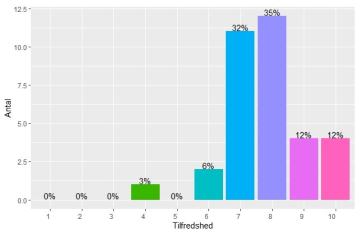
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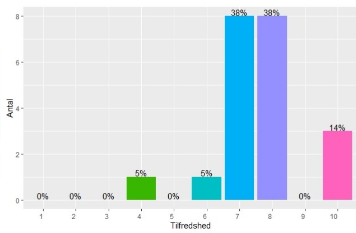
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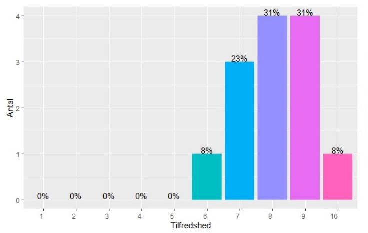
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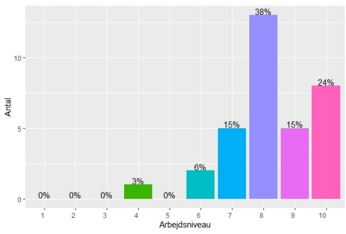
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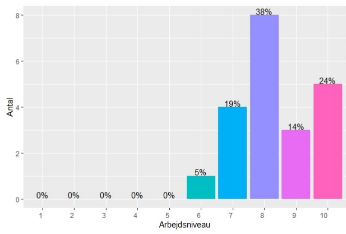
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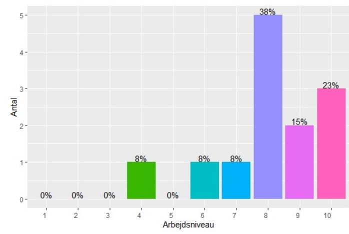
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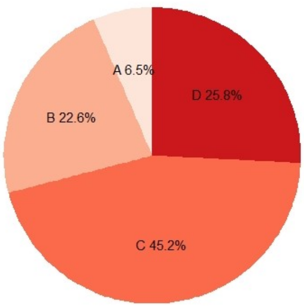
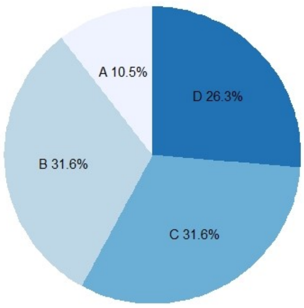
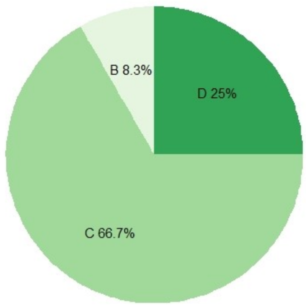


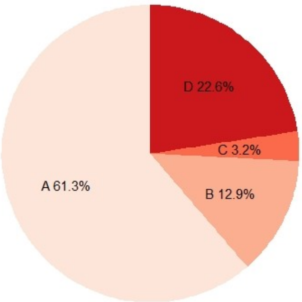
LT 1, Samlet



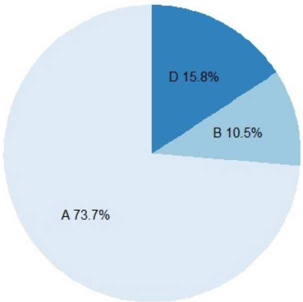
LT 1, Zone 5



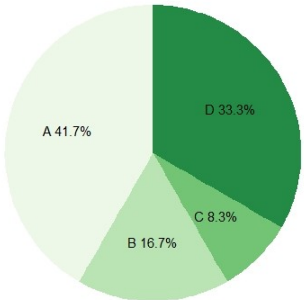
LT 1, Zone 30



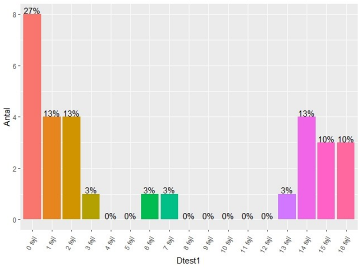
LT 2, Samlet



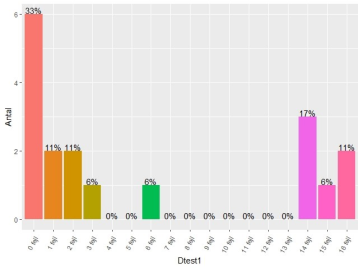
LT 2, Zone 5



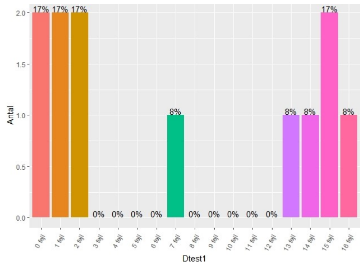
LT 2, Zone 30



D2-test 1, Samlet



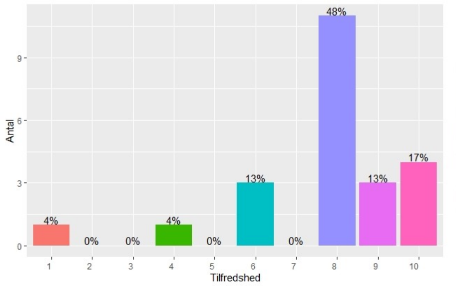
D2-test 1, Zone 5



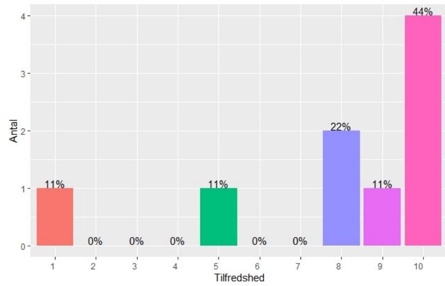
D2-test 1, Zone 30

Indledende analyse - Spørgeskemaundersøgelse med gruppering af data

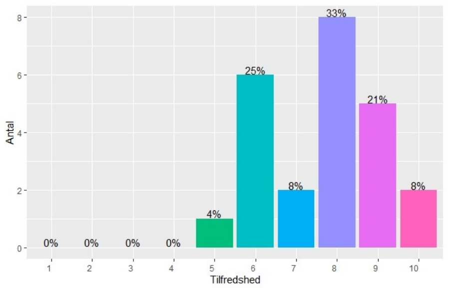
Køn



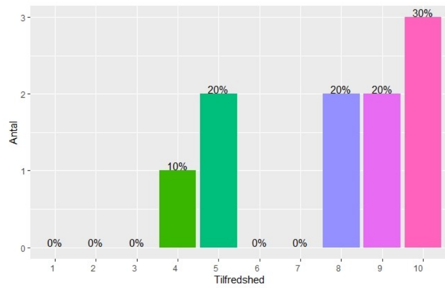
Spm. 8, Mænd



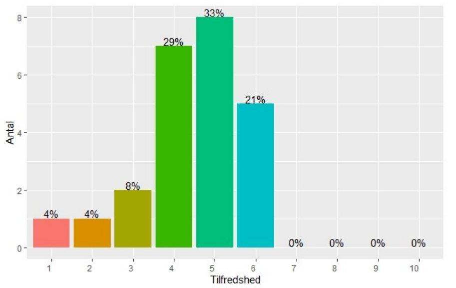
Spm. 8, Kvinder



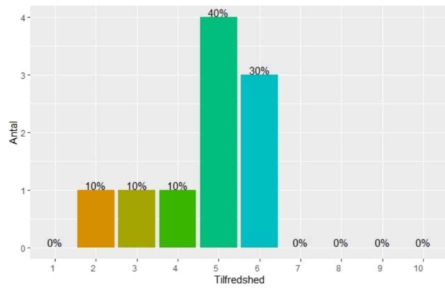
Spm. 19, Mænd



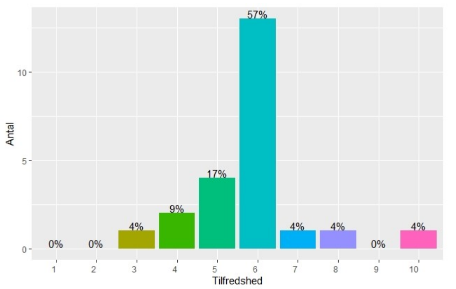
Spm. 19, Kvinder



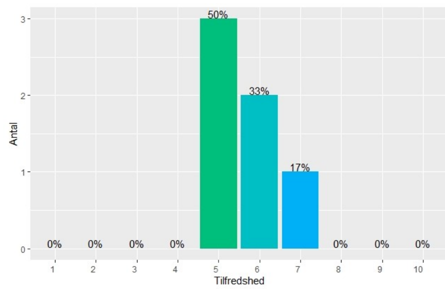
Spm. 22, Mænd



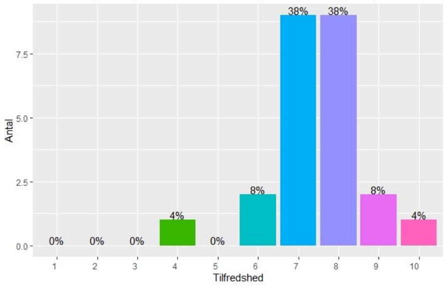
Spm. 22, Kvinder



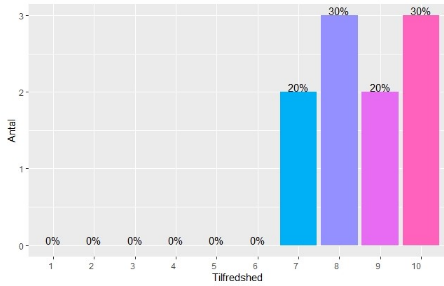
Spm. 23, Mænd



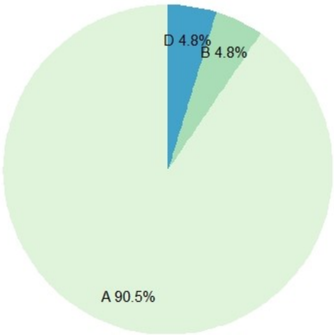
Spm. 23, Kvinder



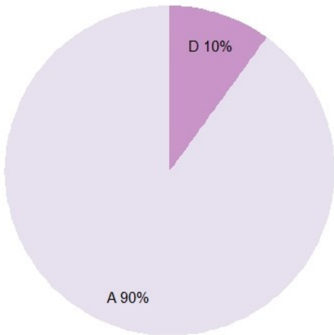
Spm. 26, Mænd



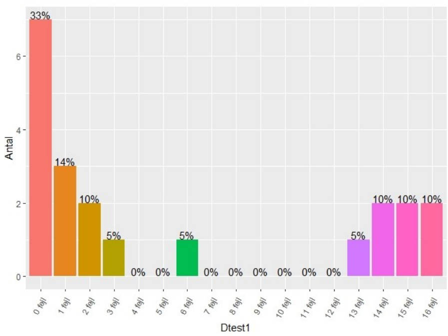
Spm. 26, Kvinder



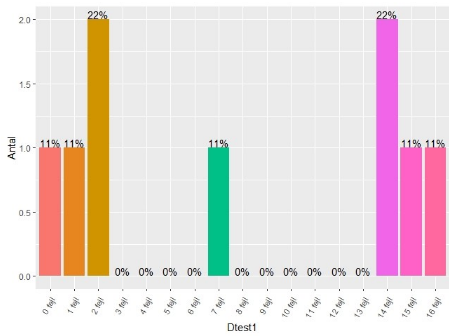
LT 3, Mænd



LT 3, Kvinder

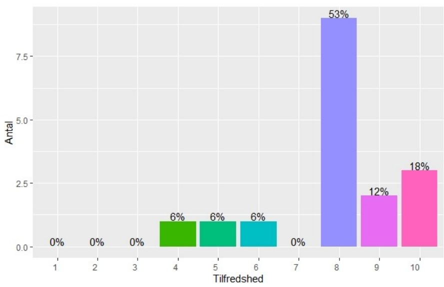


D2-test 1, Mænd

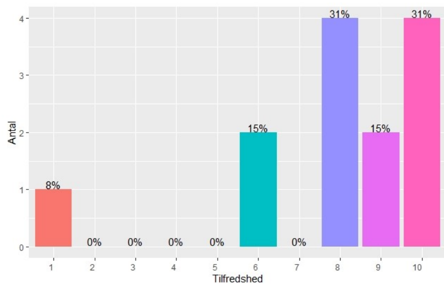


D2-test 1, Kvinder

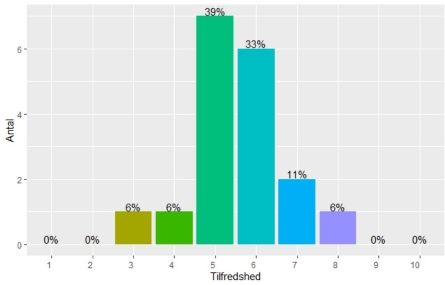
Alder



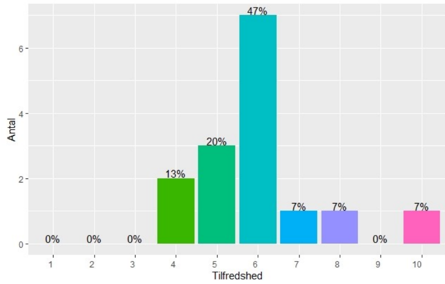
Spm. 8, < 24 år



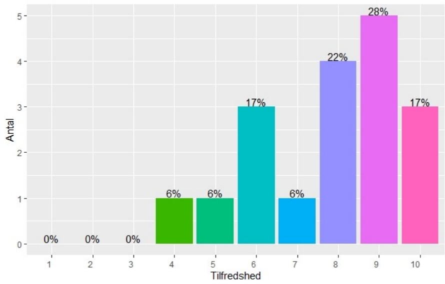
Spm. 8, > 23 år



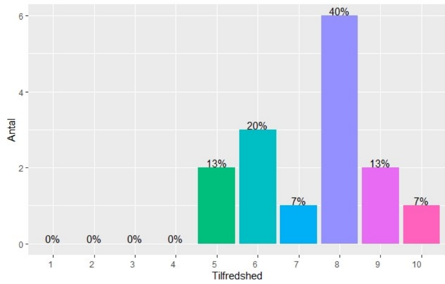
Spm. 14, < 24 år



Spm. 14, > 23 år



Spm. 19, < 24 år



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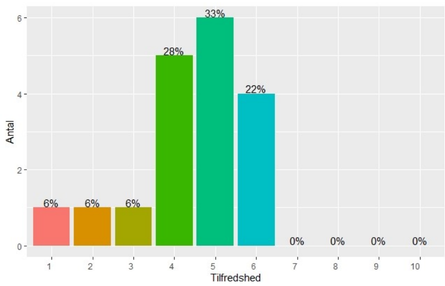
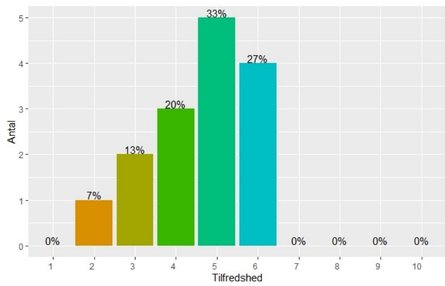
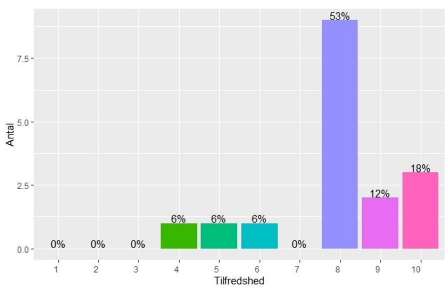


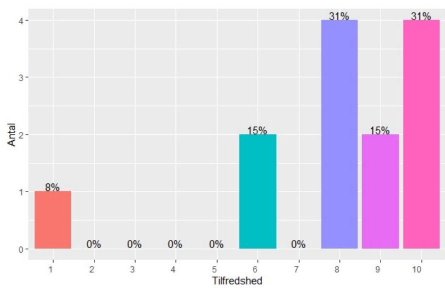
Spm. 19, < 24 år



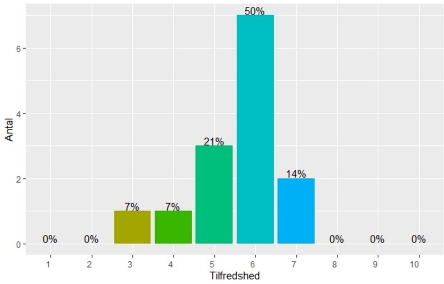
Spm. 19, > 23 år



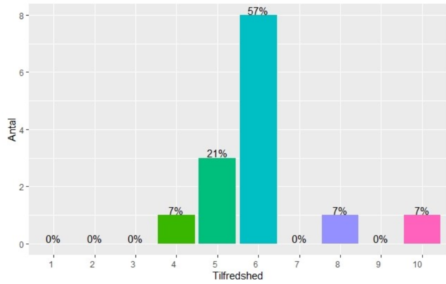
Spm. 22, < 24 år



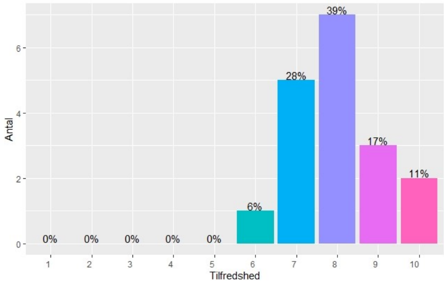
Spm. 22, > 23 år



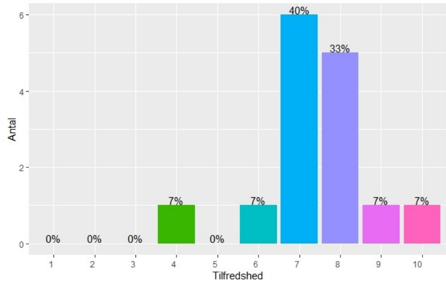
Spm. 23, < 24 år



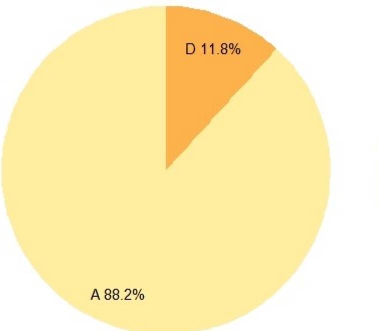
Spm. 23, > 23 år



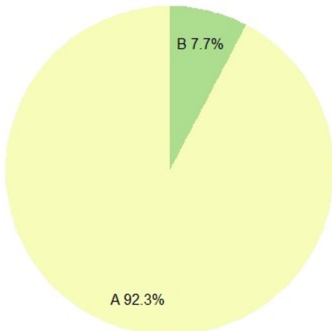
Spm. 26, < 24 år



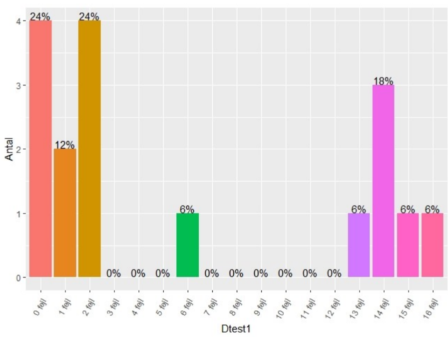
Spm. 26, > 23 år



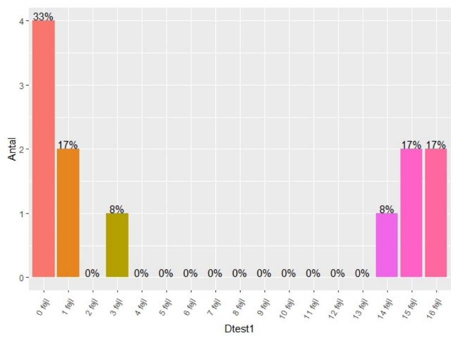
LT 3, < 24 år



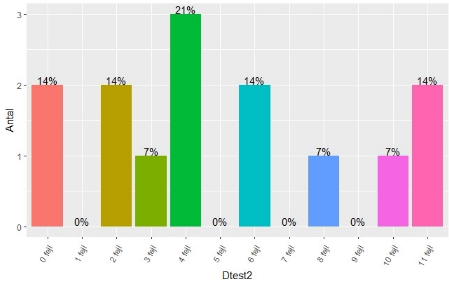
LT 3, > 23 år



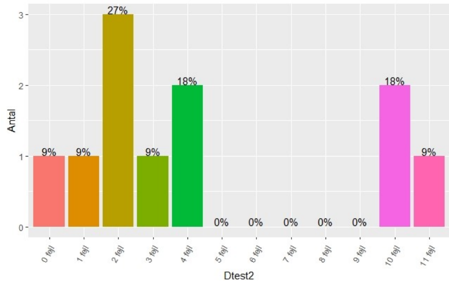
D2-test 1, < 24 år



D2-test 1, > 23 år

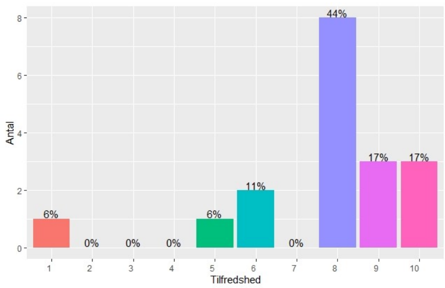


D2-test 2, < 24 år

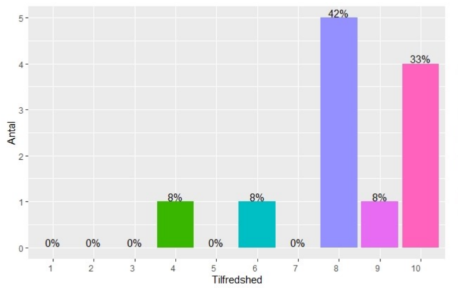


D2-test 2, > 23 år

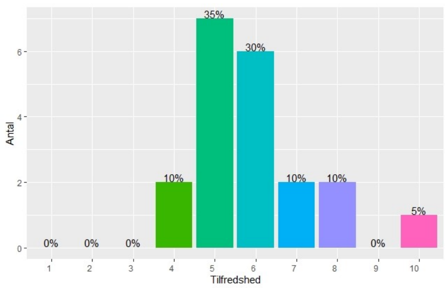
Nationalitet



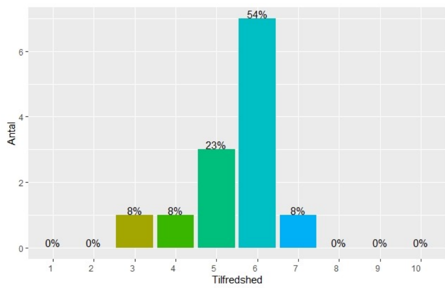
Spm. 8, Danskere



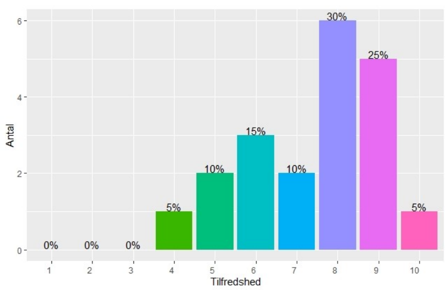
Spm. 8, Udlændinge



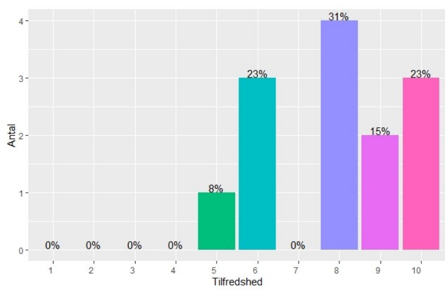
Spm. 14, Danskere



Spm. 14, Udlændinge



Spm. 19, Danskere



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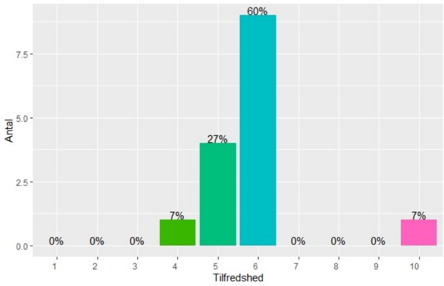
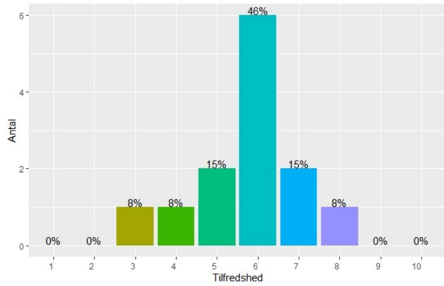
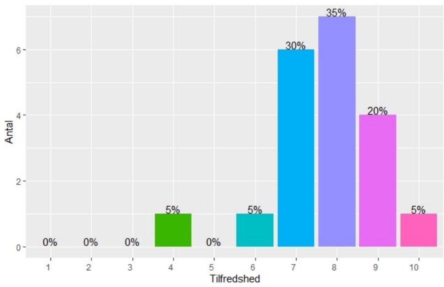


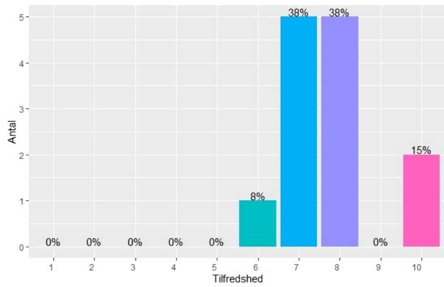
Spm. 23, Danskere



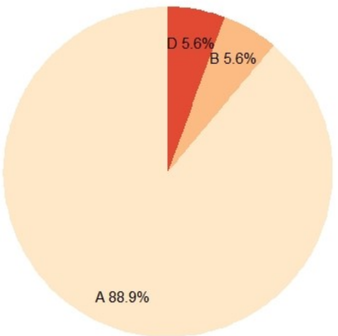
Spm. 23, Udlændinge



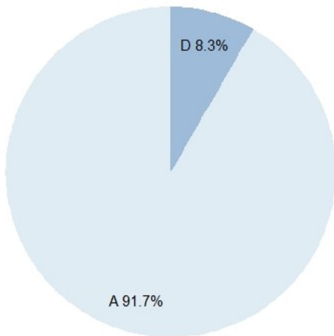
Spm. 26, Danskere



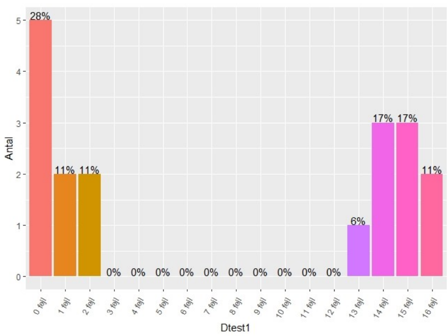
Spm. 26, Udlændinge



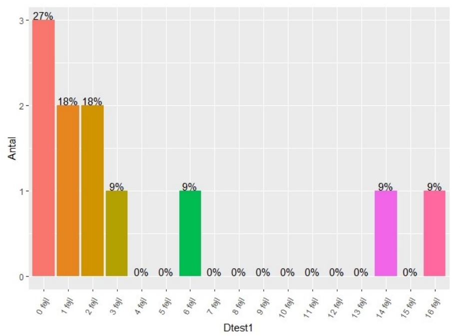
LT 3, Danskere



LT 3, Udlændinge



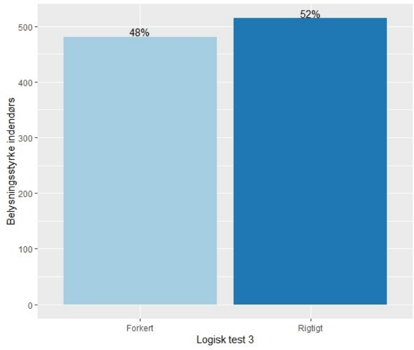
D2-test 1, Danskere



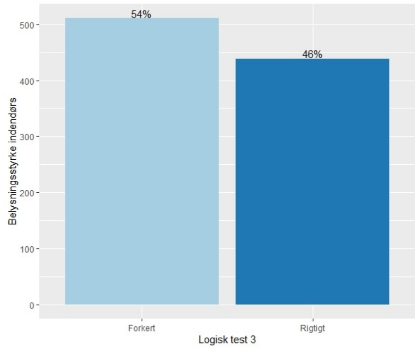
D2-test 1, Udlændinge

Statistisk analyse

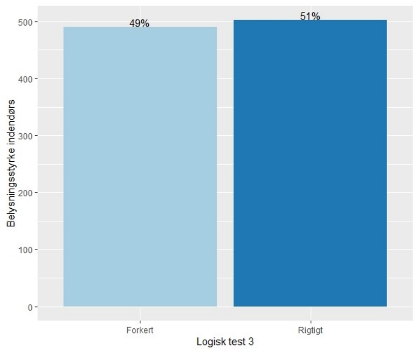
Indendørs belysning



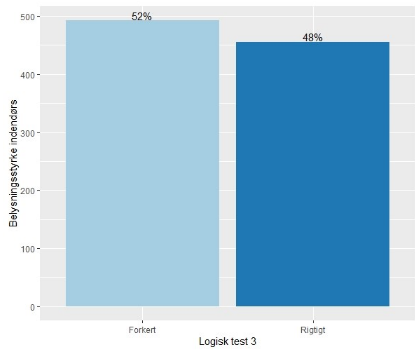
LT 3, Danskere
Effektstr.: 0,008



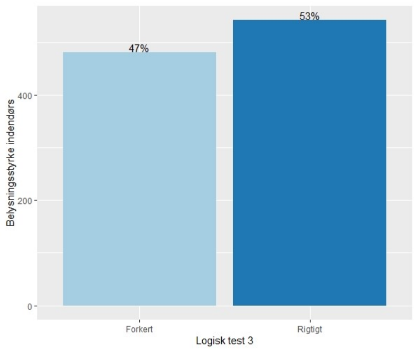
LT 3, Udlændinge
Effektstr.: 0,050



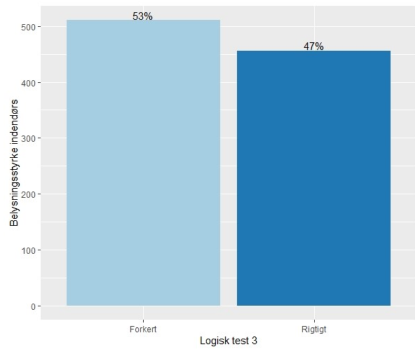
LT 3, < 24 år
Effektstr.: 0,001



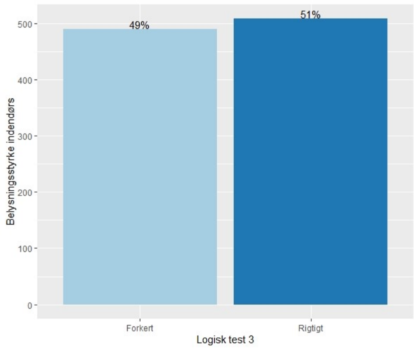
LT 3, > 23 år
Effektstr.: 0,020



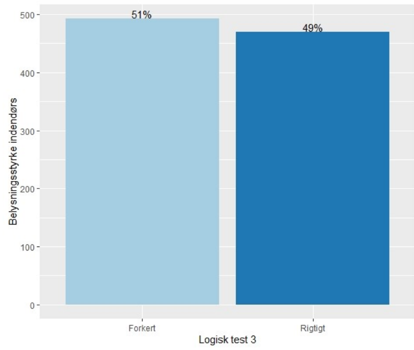
LT 3, Udsyn
Effektstr.: 0,025



LT 3, Intet udsyn
Effektstr.: 0,027

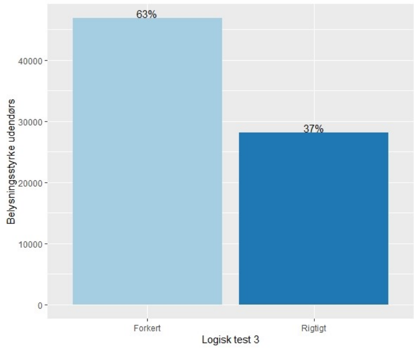


LT 3, God koncentration
Effektstr.: 0,004

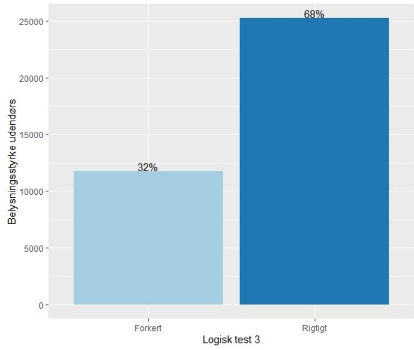


LT 3, Ingen koncentration
Effektstr.: 0,002

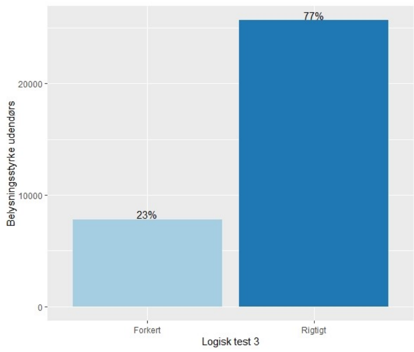
Udendørs belysning



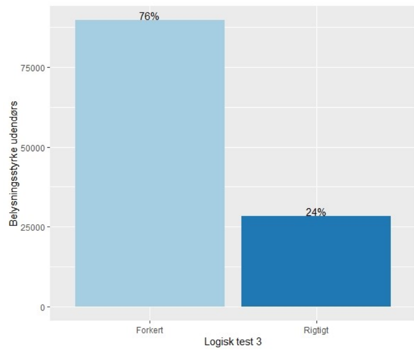
LT 3, Danskere



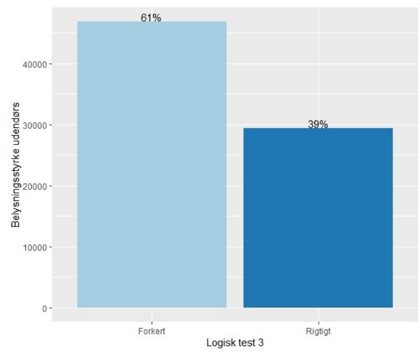
LT 3, Udlændinge



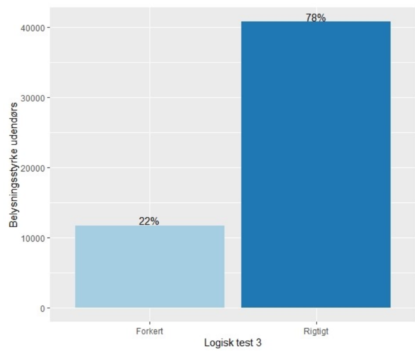
LT 3, < 24 år



LT 3, > 23 år



LT 3, Udsyn



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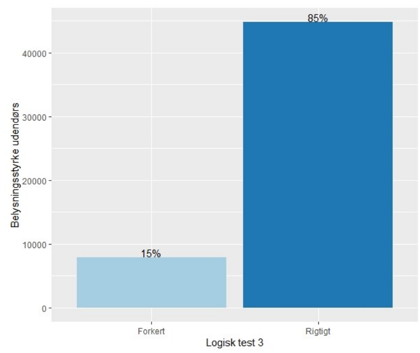
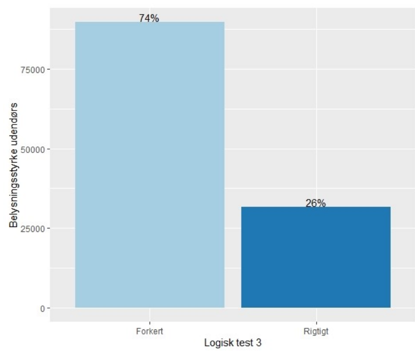
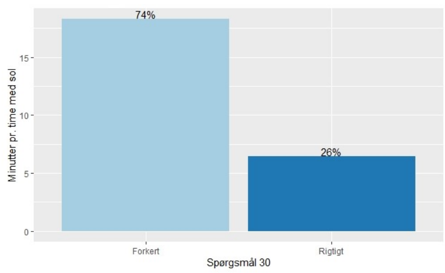


LT 3, God koncentration

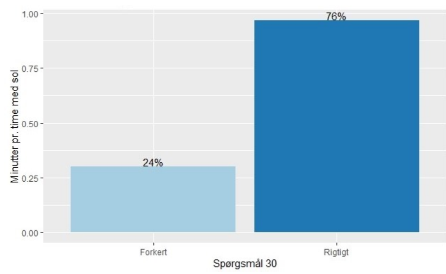


LT 3, Dårlig koncentration

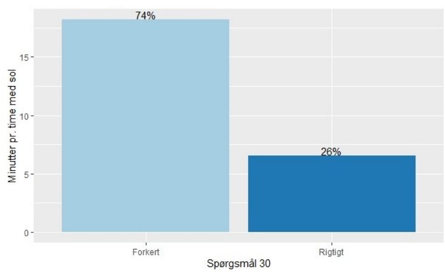
Minutter med sol pr. time pr. dag



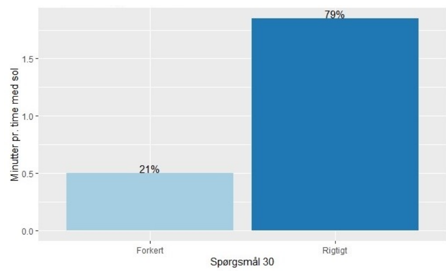
LT 3, Danskere



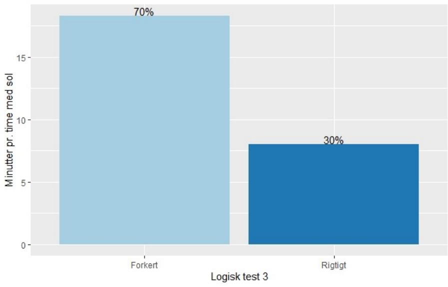
LT 3, Udlændinge



LT 3, < 24 år



LT 3, > 23 år



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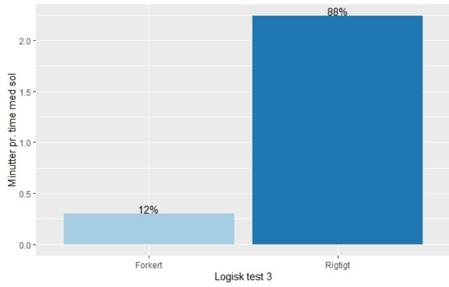
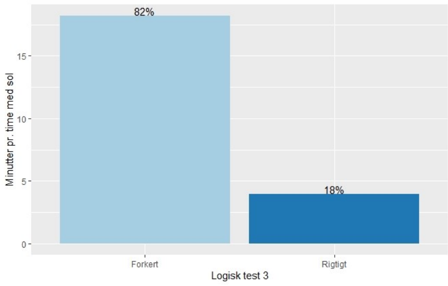


LT 3, Intet udsyn



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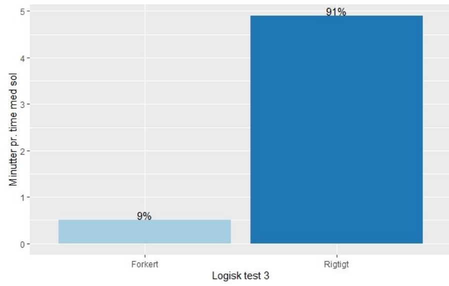
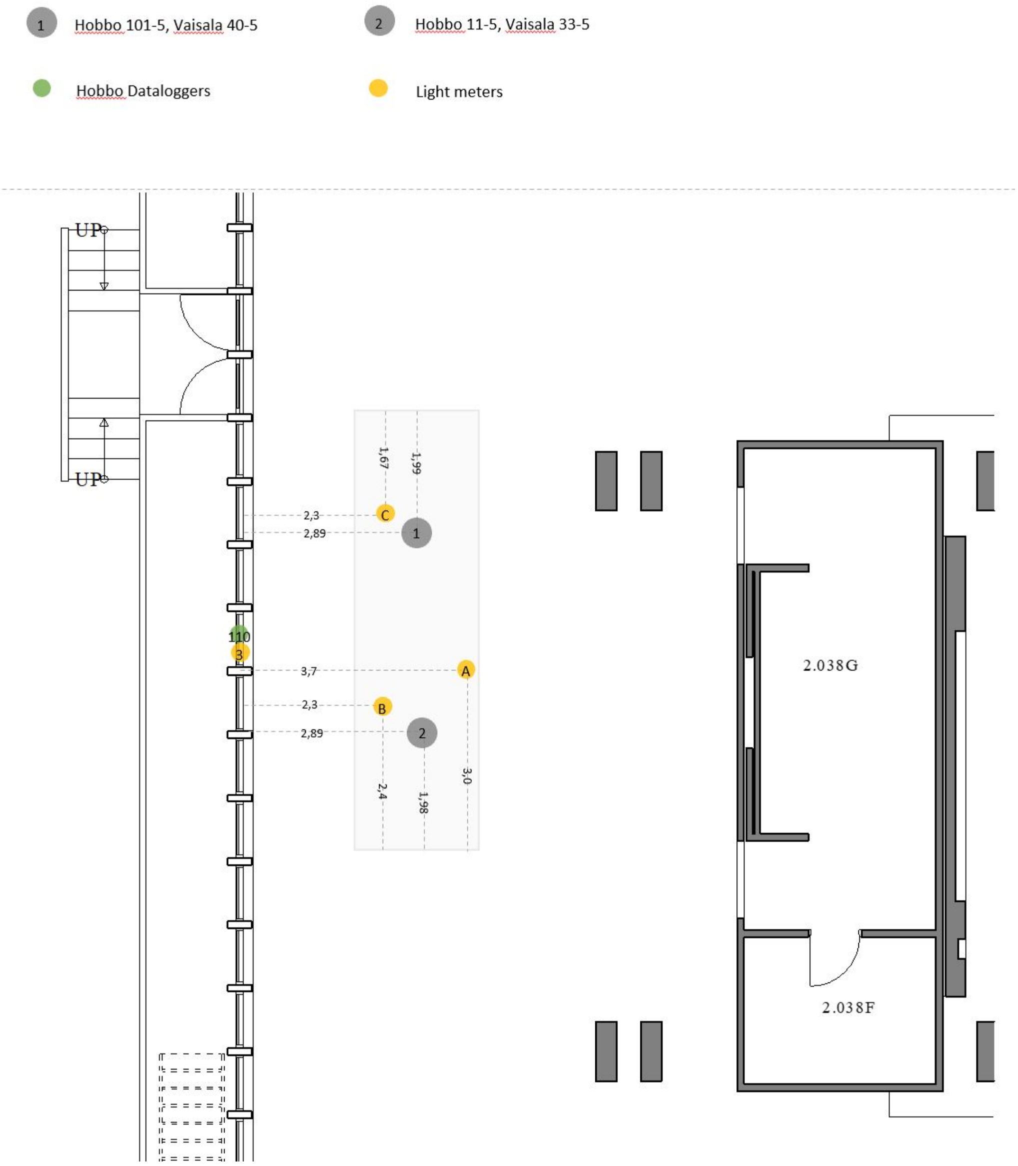


LT 3, Dårlig koncentration

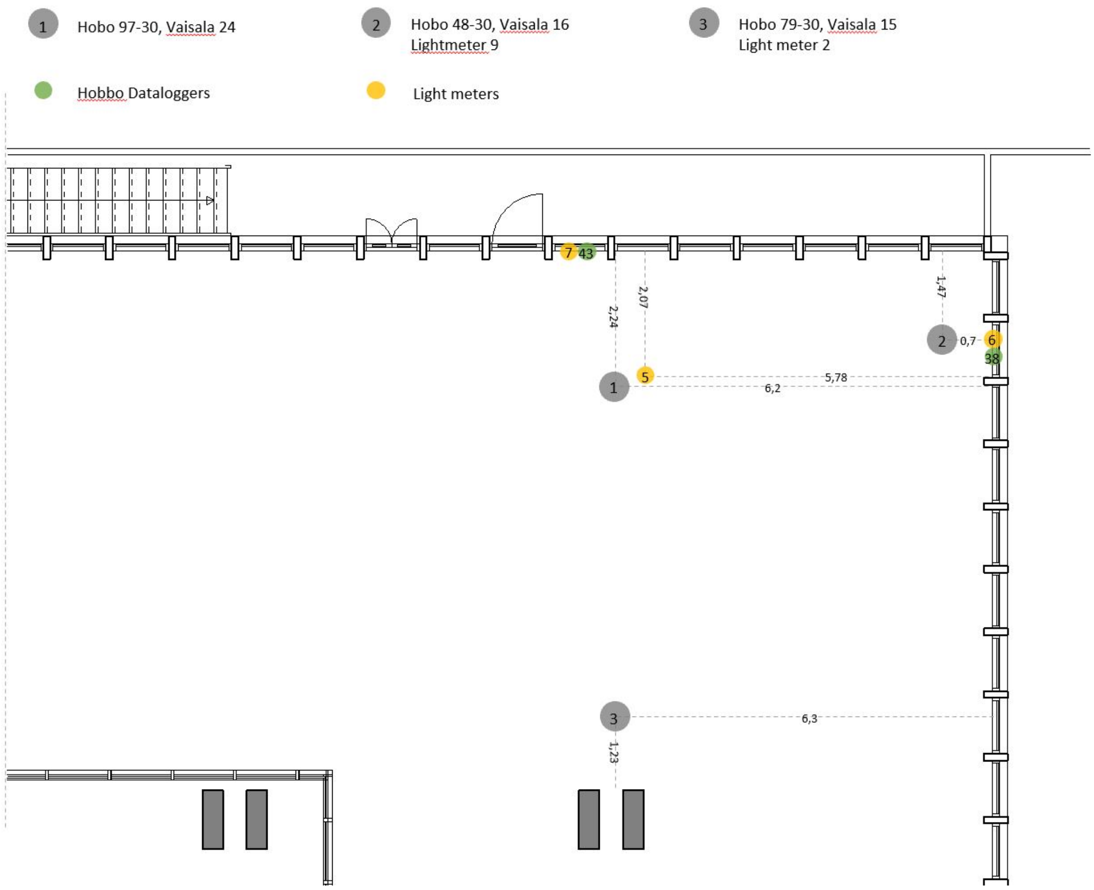
Attachment E Measurement points on site

Placering af udstyr

Placering af målere i zone 5



Placering af målere i zone 30



Attachment F A short summary in Danish

'Karakterisering af spektral eksponering afhængigt af beboeres position og blik adfærd i bygninger for en højere præstationsevne: Et bevis på metodologi

Gennem omfattende undersøgelser af menneskers daglige adfærd har det vist sig, at vi i gennemsnit opholder os indenfor 90% af tiden. Ved at studere effekten af indendørs miljøforhold på børn og unge voksne [1–4] har det vist en fælles tendens, hvor indeklima parametre påvirker kognitive funktioner [5]. Ved indeklima parametre menes temperatur, fugtighed, ventilationshastighed, luftkvalitet, lydniveauer, dagslys og belysning. Det er derfor vigtigt, at de indendørs miljøer vi opholder os i skaber et sundt og komfortabelt miljø.

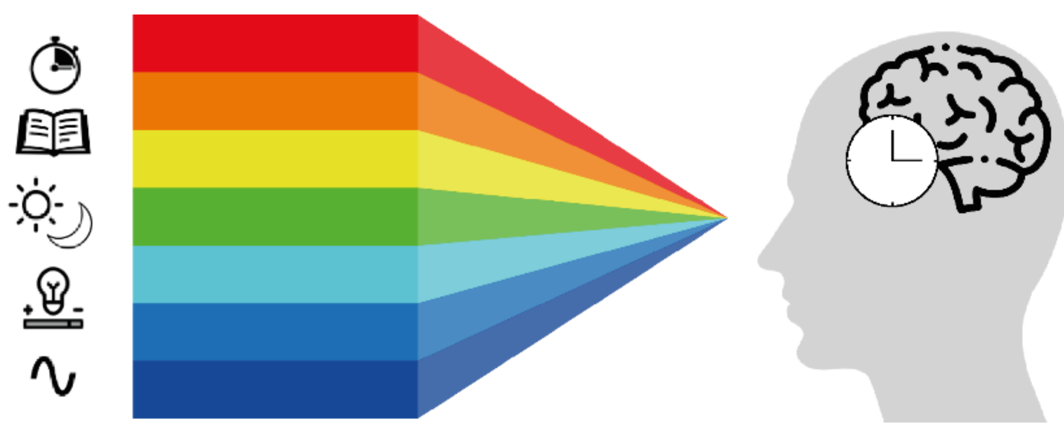
Dagslys og belysningen har stor betydning for vores oplevelse af rummet [6,7], samt en indvirken på vores psykiske og fysiske helbred, hvor særligt belysningsstyrken og lysintensiteten påvirker vores døgnrytme. De bør derfor reguleres efter, det arbejde vi udfører samt tidspunktet for det udførte arbejde for at fremme vores præstationsevne.

Boyce, Hunter og Howlet har, baseret på en tidlig litteraturgennemgang, opdelt de veje, hvor lys kan påvirke vores præstationsevne, og indsnævret det til tre hovedkanaler for dagsbelyste forhold. De præsenterer en konceptuel ramme om, hvordan disse kanaler er relateret til menneskelig ydeevne: det visuelle system samt det døgnrytme genererende og perceptuelle system [8]. Ifølge disse forfattere er det visuelle system kanalen til visuel ydeevne, der påvirkes af parametre som visuel størrelse, luminanskontrasten, farveforskellen, nethindens billedkvalitet og nethinde belysning. Efter opdagelsen af en ny fotoreceptor i menneskets nethinde vedrører nyere forskning indenfor dagslys i stigende grad såkaldte 'ikke-visuelle effekter'. Det er menneskets sundhed der sættes i fokus, og nærmere bestemt døgnrytmen der styrer hormoner og funktioner i kroppen på daglig basis. Disse lysfølsomme celler har ikke-visuelle effekter, der påvirker vores humør [9,10] og søvn [11–13] med konsekvenser som f.eks. tab af produktivitet [14–16] på grund af manglende dagslys og overdreven eksponering for kunstigt lys. Denne anden vej, vores cirkulære døgnrytme, er forbundet med vores visuelle ydeevne, og definerer vores generelle præstation. Den tredje kanal er gennem vores perceptuelle system, hvilket er, hvordan vi opfatter og forstår det afhængigt af personlige dispositioner.

Adskillige studier gennem tiden har peget på, at der er en direkte sammenhæng mellem mængden af dagslys og præstation. Studier har bl.a. vist, at en øget mængde dagslys øger menneskets præstation og produktivitet samt reducerer menneskets træthed. Grunden til at dette emne er så interessant, er at forsøg har vist, at en yderligere dæmpning af melatonin med lys kan hænge sammen med øget ydeevne og mere vedvarende opmærksomhed [17]. På trods af forskellige eksisterende bølgelængdeafhængige modeller til forudsigelse af lysets spektraleffektivitet [18], [19], kan disse metoder kun forudsige sundhedspotentialerne i et rum med antagelse af statiske beboere på faste foruddefinerede punkter [20]. Med store fordele for vores velbefindende [21], [22] er en eksponeringskarakterisering af et belyst rum baseret på dynamisk beboeradfærd et skridt fremad. Dette trin giver mulighed for bedre forståelse af beboeres trivsel indendørs baseret på den faktiske beboers position og orientering.

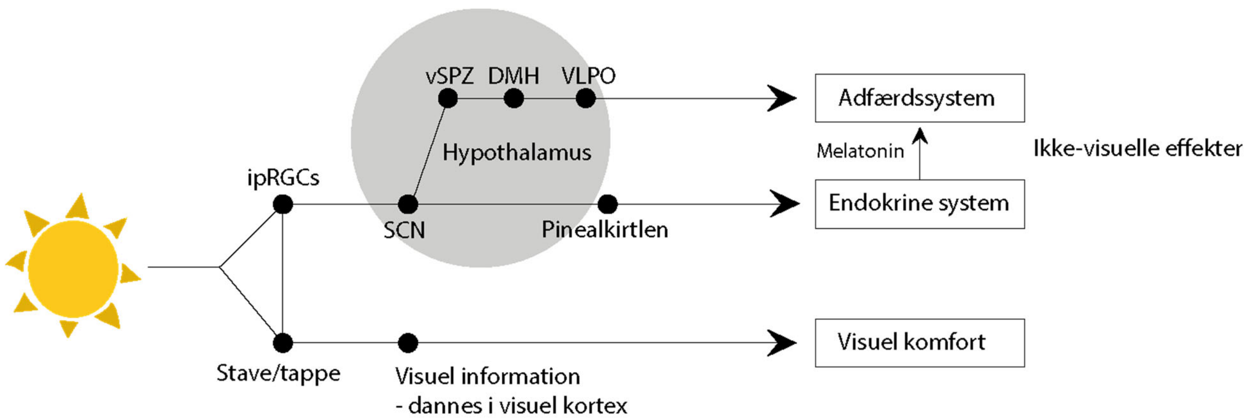
Den dynamiske menneskelige adfærd over for lyseksponering er blevet behandlet i færre studier, hvor fotometriske målinger og øjensporingsmetoder er blevet koblet til observationer af blik eller øjets respons på lys [23], [24]. Baseret på disse metoder vil dette projekt introducere et bevis på metodoloi til vurdering af dagslysets præstationer i bygninger ved at karakterisere niveauet af eksponering for lys baseret på menneskelig adfærd. Beboernes lysdrevne opførsel bruges til at forudsige eksponeringen for spektral belysning og belysningsniveauer i rummet og konkludere den resulterende effekt på deres produktivitet og ydeevne.

6 studerende fra DTU, der er entusiastiske inden for dagslys og belysning, arbejdede med forskellige aspekter af den faktiske lyseksponering på menneskelig præstationsevne. For at nå dette mål har de studerende udviklet et værktøj til karakterisering af eksponering for lys niveauer med hensyn til visuel komfort og ikke-visuelle effekter. Der blev desuden foretaget en pilot feltundersøgelse, hvor beboernes positioner og orienteringsadfærd i rummet blev overvåget såvel som deres præstationsniveau ved hjælp af spørgeskemaer. Værktøjet og metoderne introduceret i dette projekt kan hjælpe designere og ingeniører med at forbedre indendørsmiljøet, så det går fra designidéer til en række løsninger, der maksimerer beboernes sundhed og komfort. Det udviklede værktøj og behandlingsmetode kan bruges i designfaser til at indføre interventioner, f.eks. ændring af indvendigt layout for optimale belysningsløsninger. Det ultimative mål for denne undersøgelse er netop at undersøge sammenhængen mellem belysningen, særligt dagslysniveauet, og menneskers præstationsevne. Her præsenterer vi separat det udviklede værktøj og resultaterne fra pilotundersøgelsen.



Figur 1: Lysfaktorer der påvirker døgnrytmesystemet: Afhængigt af beboeres position og blik adfærd i bygninger.

Visuelle og ikke-visuelle stier i hjernen



Figur 2: Visuelle og ikke-visuelle stier aktiveret af lys.

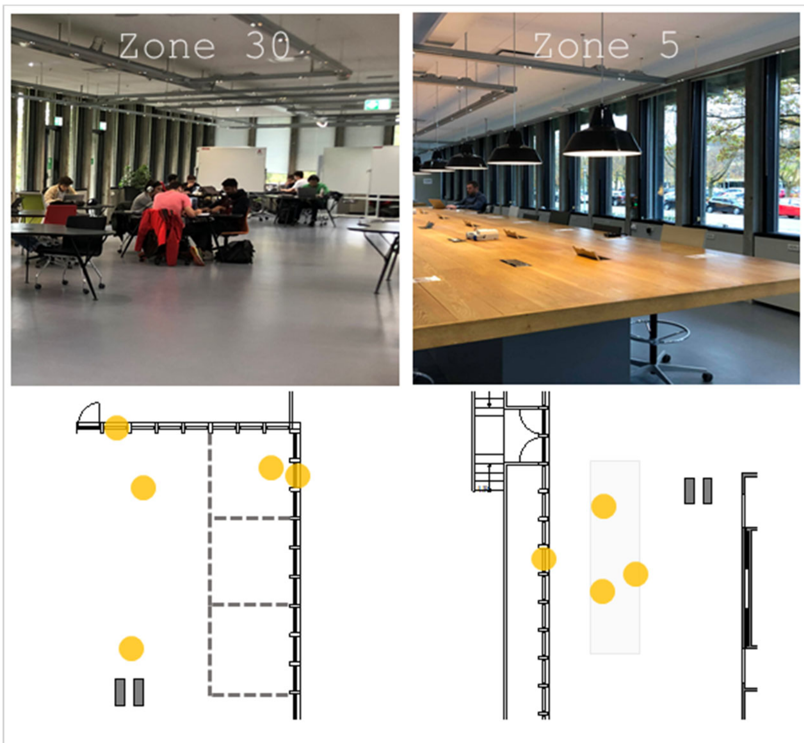
På Figur 1 kan en skematisk opbygning af det døgnrytmegenererende system observeres. Foruden den visuelle fornemmelse, som starter ved detektion af lys i de velkendte fotoreceptorer stave og tappe, aktiveres også et andet lysdetekteringssystem. Ikke-visuelle effekter starter ved detektion af lys i 'ipRGCs' som er betegnelsen for ganglieceller. Den vigtigste komponent i systemet er 'hjernens ur', der er beliggende i den suprakiasmatiske kerne (SCN). 'Hjernens ur' regulerer vores døgnrytmer og fortæller dermed kroppen at gøre det rigtige på det rigtige tidspunkt. Dagslys er en vigtig stimulus af 'hjernens ur' og kan gennem komplicerede flertrinsbaner indirekte influere vores adfærd og hormonsystem [25]. Der er fem lysfaktorer, der påvirker stimuleringen af døgnsystemet, som er dets timing, intensitet, varighed, bølgelængde og foregående lyseksponering.

Lysets påvirkning på menneskers præstationsevne

Der findes forskellige måder hvorpå, lysets påvirkning på menneskets præstationsevne kan måles. Adskillige studier har bl.a. evalueret hastigheden for at afslutte en arbejdsopgave, symptomer på Sick Building Syndrome og fravær.
Disse studier gør derudover ofte brug af supplerende spørgeskemaundersøgelser som et vigtigt led til at indsamle oplysninger om deltagerne og dermed opnå en repræsentativ viden inden for problemstillingen. Til undersøgelse af præstation har flere studier benyttet D2-test af Opmærksomhed, som er et neuropsykologisk mål af selektiv og vedvarende opmærksomhed samt visuel scanningshastighed.

Feltstudiet

For at undersøge de studerendes præstationer i henhold til mængden af dagslyset og belysningsstyrken blev et feltstudie udført på Danmarks tekniske universitet, DTU Smart Libary. Pilotundersøgelsen blev udført over en periode på 2 måneder i to udvalgte lyszoner, hvor beboernes orientering blev sporet ved hjælp af en billedbaseret sensor, der optog omgivelserne og bevægelser af testpersonerne. I stueetagens zone 5, med vest og nordvendte vinduespartier, blev der observeret længerevarende ophold for de studerende, hvorfor zone 5 blev udvalgt som den ene af de to zoner. I bibliotekets nordøstlige hjørne på 2. sal, zone 30, blev der observeret gener ved dagslys, da flere gardiner var trukket for, hvorfor zone 30 også var interessant at undersøge. De to lyszoner ses på Figur 3.



Figur 3: Lyszone 30 og 5 på DTU's bibliotek, samt lyssensorenes placering

Kvantificering af lysforhold og præstationsevne

For at undersøge den eventuelle sammenhæng mellem belysning og præstationsevne blev der opsat lysmålere i de to udvalgte zoner. Der blev yderligere opsat måleudstyr til at måle CO2-koncentrationen, temperaturen og luftfugtigheden, da disse faktorer kan indvirke præstationsevnen og forsøgspersonernes oplevelse af indeklimaet. Der blev udarbejdet en brugervurderingsundersøgelse af lysforholdene, der indeholdt en præstationstest til kvantificering af de studerendes præstationsevner. Brugervurderingsundersøgelsen blev opdelt i fem sektioner; demografisk data, lys, humør, formål og præstationstest. Den demografiske data blev indsamlet, da menneskers påvirkning af og forventning til belysning kan variere efter køn, nationalitet og alder. Sektionerne; lys, humør og formål, var de studerendes subjektive vurderinger af DTU's bibliotek som et studiemiljø med særligt fokus på belysningen. Præstationstesten indeholdt to forskellige testformer; logisk test og D2-test. Den logiske test forudsatte, at de studerende var i stand til at tænke logisk, hvilken blev forventet af de ingeniørstuderende, der deltog i forsøget. Den logiske test bestod af tre spørgsmål, der testede de studerendes koncentrationsevne. De var alle tre forskellige, og testede de studerendes koncentration og omstillingsparathed. Den anden del af præstationstesten var en D2-test. En D2-test er udarbejdet til at måle folks koncentrationsevne og præstation uafhængig af intelligensevne. Testen har almindeligvis to parametre; tid og antal rigtige besvarelser. Da det ikke var muligt at indsamle gennemførelsestiderne, blev de studerende i dette forsøg udelukkende vurderet på antal rigtige besvarelser.

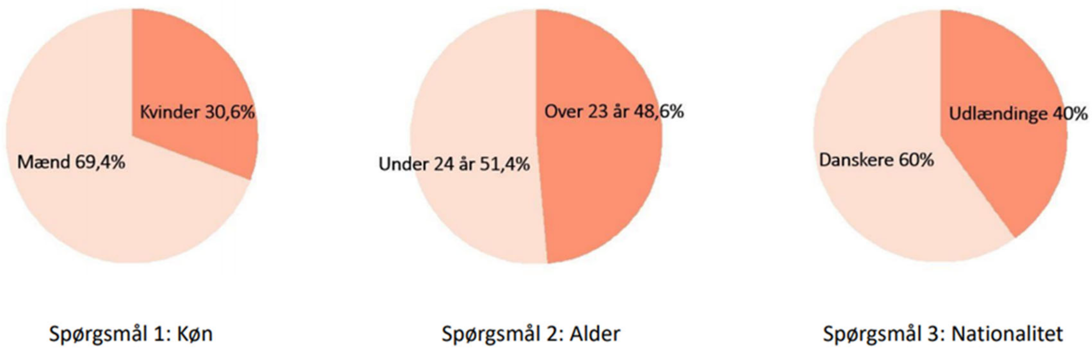
Karakterisering af spektral eksponering

Et Grasshopper3D-værktøj udviklet til at demonstrere blikadfærd [23], [27], eksponering for belysningsniveauer og spektral belysning, hvilket muliggør karakterisering af eksponering af rummet i øjenhøjde ved hver given position. Sidstnævnte blev behandlet ved hjælp af Lark Spectral Lighting, et plug-in til Grasshopper3D, [28] for at tage højde for fotopisk samt Rea [29] og Lucas [30] cirkadisk lysstyrke. Figur 4 beskriver den metode, der blev fulgt for at implementere dynamiske blik ændringer og ikke-visuelle effekter af dagslys i Grasshopper 3D. Selve opsætningen er opdelt i tre dele, hvor der indledningsvist er blevet opbygget en geometri i Rhino. Herefter tilføjes materialeegenskaber til de respektive overflader gennem Ladybug og HoneyBee komponenter. Dynamiske blik ændringer tilføjes gennem komponenter fra Gaze-Tool, der bl.a. kan forudsige blikskifte på en placering gennem en implementeret formel i Python. Metrics blev derudover brugt til at beregne ikke-visuelle effekter af dagslys tilføjet gennem Lark Spectral Lighting, hvor dagslyssimuleringer blev beregnet gennem 9-kanaler frem for konventionelle 3-kanals simuleringer.

Figur 4: Skematisk beskrivelse af værktøj.

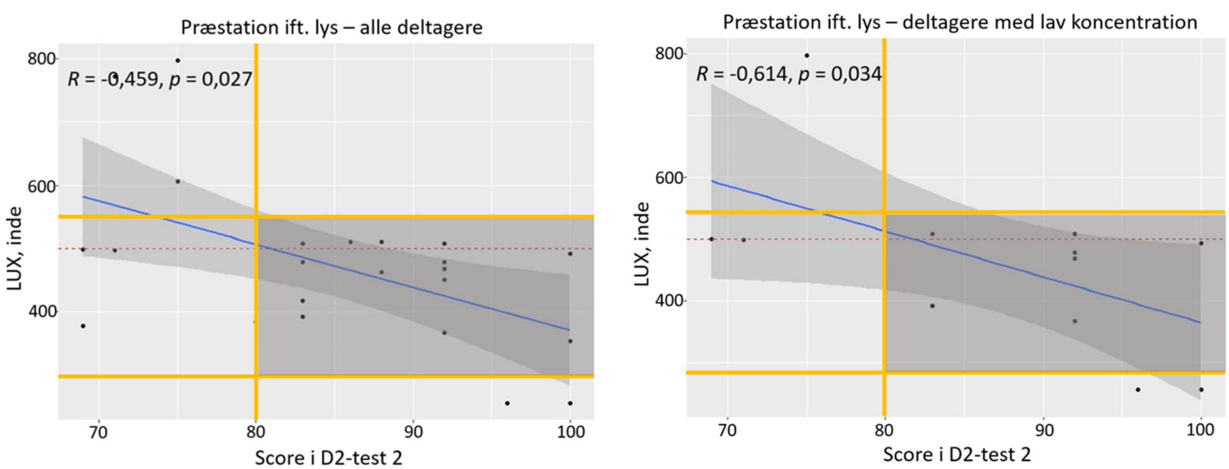
Resultater

36 studerende besvarede spørgeskemaet i løbet af forsøgsperioden. Fordelingen mellem køn, alder og nationalitet kan ses på Figur 5.



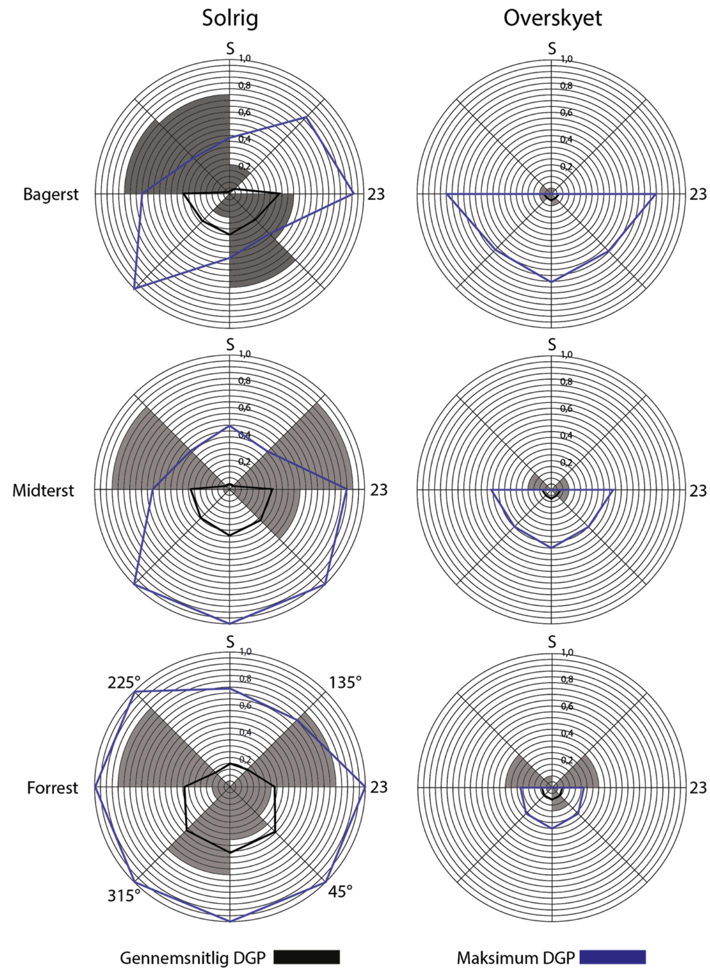
Figur 5: En oversigt over demografien for den indsamlede dataprøve

I løbet af forsøgsperioden var belysningsstyrken i zone 30 blevet målt højere end den i zone 5. De indledende analyser viste bl.a. at deltagerne i brugerundersøgelsen udviste størst tilfredshed med lys niveauet i zone 30 fremfor i zone 5. Deltagerne i zone 5 præsterede dog generelt lidt bedre i D2-test ift. dem i zone 30. På Figur 6 ses det på punktdiagrammet, at der kunne findes en negativ sammenhæng. Det der kunne observeres var, at flertallet af forsøgspersoner, der scorede over 80% korrekt vurderet på deres præstationsrate, faldt inden for visse tærskler. Højeste præstation var mellem 300 og 550 lux, og i få tilfælde gjorde mænd det bedre i endnu lavere lys niveauer. Den statistiske analyse igennem en envejs ANOVA viser imidlertid, at de observerede forskelle ikke er signifikante for en ydeevne over og under 500 lux. Det kunne også observeres, at folk, der vurderede sig selv som havende en lav koncentration, klarede sig bedre i lys niveauer mellem 400 og 550 lux.



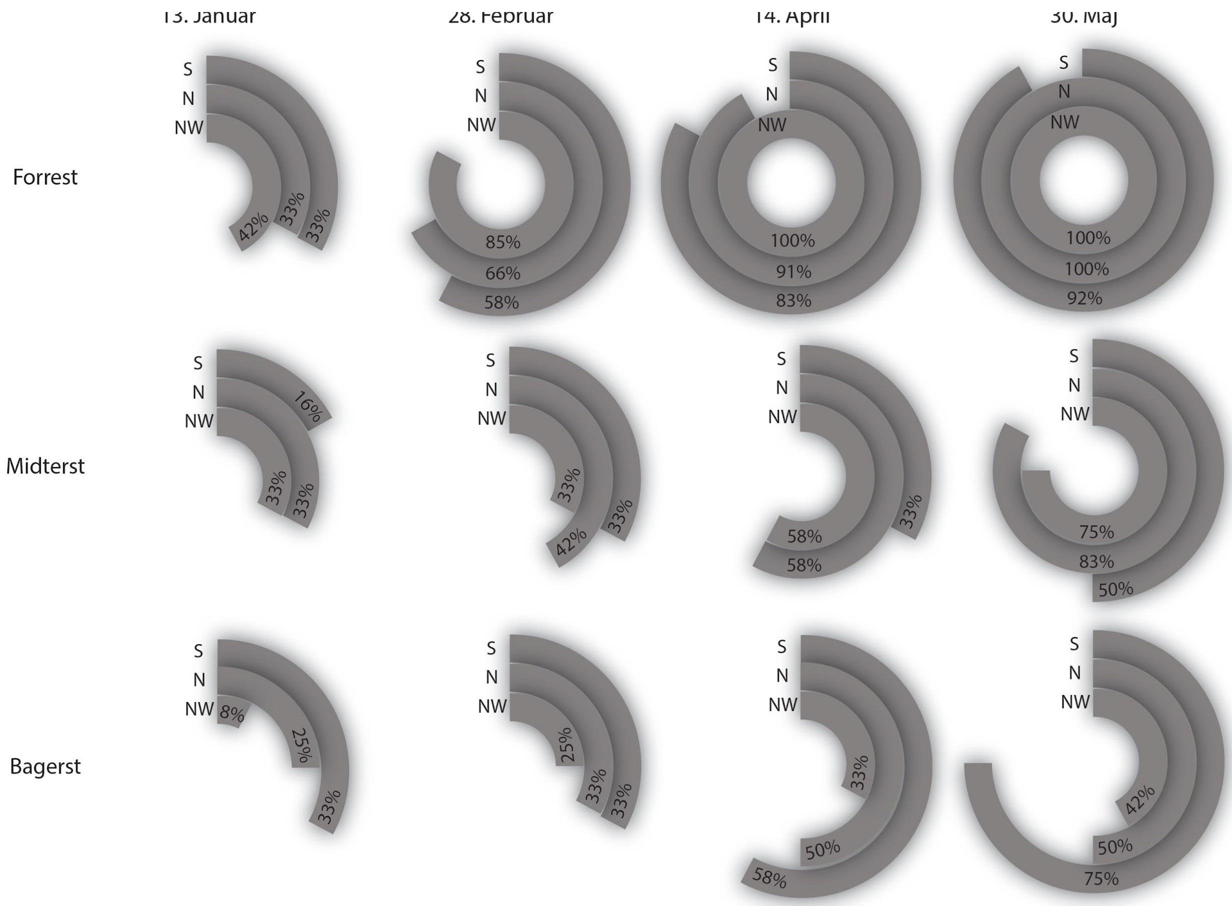
Figur 6: Resultater for indendørs belysning og præstation

Simuleringsundersøgelsen gav en klar demonstration af visuelle mønstre og eksponeringsmønstre på forskellige steder i rummet baseret på den dynamiske beboers adfærd. Igennem værktøjet Gaze-Tool blev dominerende synsvinkler udvalgt baseret på beboerens synsmønster over et symmetrisk halvår. Det sås i resultaterne, på Figur 5, at blikskiftene forekom ligeligt fordelt på alle placeringer i zonen, hvilket betyder, at der er lige så meget kontrast induceret blænding forrest såvel som bagerst i zonen.



Figur 7: Blikskifte for den sydlige orientering med 23 inddelinger. Hvert plot viser synsmønsteret i en position 360° omkring. Facaden er placeret i bunden af hvert plot. Udover blikskifte optælling gennem rød markering kan gennemsnitligt og maksimale DGP-værdier aflæses.

I anden del af simuleringsundersøgelsen blev sundhedspotentialet evalueret i de valgte dominerende blikorienteringer for hver position. Fra Lark-værktøjet [6] skulle værdierne konverteres, da de valgte tærskelværdier anvendte enhederne Circadian Stimulus (CS) og Equivalent Melanopic Lux (EML). Tærskelværdien CS forklarede den optimale stimulus gennem hele arbejdsdagen, hvor der gives specifikke værdier for hver time, mens tærskelværdien EML gav en fast værdi over alle timer. Mens de fleste positioner i zonen viste en tilfredsstillende overholdelse af tærskelværdierne om sommeren og under solrige forhold, ville resultaterne under overskyet himmel kun i få situationer opnå tærskelværdierne. Det har derfor vist sig, at klimatiske regioner er afgørende for en optimeret overholdelse af sundhedspotentialerne. På nordfacaden blev der fundet minimalt visuelt ubehag, hvilket muliggør orienteringer mod vinduet, som resulterede i et højere sundhedspotentiale. Det kan derfor konkluderes, at orienteringen i rummet er afgørende for den lodrette illuminans målt ved øjet, dog skal den visuelle komfort stadig opretholdes.



Figur 8: Resultater af procentvis overholdelse af tærskelværdien CS for de tre positioner i zonen (y-akse) over et symmetrisk halvår (x-akse). Der er yderligere opdelt efter tre forskellige facade orienteringer.

Konklusion

I et udforskende projekt satte studerende ved DTU sig for at undersøge mulighederne for at relatere lys eksponeringsniveauer til menneskelig ydeevne i sammenhæng med et InnoBYG-spireprojekt. Projektet stammer fra en pilotundersøgelse og en værktøjsudvikling, der har skabt rygraden til denne indsats.

Det udviklede værktøj giver mulighed for at identificere eksponeringen for lys niveauer såvel som cirkadiske udløsere i rummet afhængigt af beboerens position og orientering (synsretning) i rummet. Feltpilotundersøgelsen blev udført på DTU Smart Libary i en periode på 2 efterårsmåneder. Feltpilotundersøgelsen resulterede i en lille dataprøve til støtte for beviset for metodologi i projektet. De opnåede resultater vedrørende belysningens effekt på ydeevnen er dog ikke afgørende. Disse resultater viste, at flertallet af forsøgspersonerne klarede sig bedre i visse lys tærskler.

Det umiddelbare fremtidige trin for projekterne er at initiere og integrere løsninger i det udviklede værktøj til bedre forudsigelse af beboerorientering i rummet i forhold til lys og udsigt. For at estimere beboernes præstationsniveauer baseret på eksponering karakteriseringen af lys skal der foretages en mere omfattende undersøgelse.

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