

**Measuring Real Daylight Exposure Afforded by Various Architectural Environments
and the Implications for our Health and Wellbeing**

9-month Progress Report for Jean Heap Research Bursary
Society of Light and Lighting

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Outline of Report

This document constitutes the 9-month progress report for the Society of Light and Lighting (SLL) and the Jean Heap Research Bursary programme.

The *Introduction* summarises the project stages and procedures that have been completed to date.

The *Methodology* describes the various types of data that have been collected together with the strategy that has been undertaken to manage this extensive body of material. Examples of the raw data recorded with the LYS wearable sensors and the spectrophotometer will be included. The statistical computing package chosen to manage, display and analyse the data will be described .

The *Results* section presents examples of the graphs generated for the four offices studied.

The *Next three months* section describes the final stages of this project that will include statistical analysis of the data and presentation of preliminary results.

Introduction - summary of research project

Aims of study

The stated aim of this research project is to understand the actual daylight exposure experienced by populations in a wide range of typical working environments found in our current urban context. This study set out to measure the intensity, spectral composition, duration, timing and distribution of light in four offices in central London, during the winter months. The objective is to define a scale of daylight exposure potentials afforded by different architectural forms typically found in our working environments. A secondary aim is to establish the reliability of the wearable sensors used, for research purposes.

Measuring methods

Two methods of measuring were used. A commercially available wearable Button sensor manufactured by LYS Technologies Ltd was worn continuously for the duration of the study. These devices were chosen in order to be able to record illuminance received as close as possible to the eye, in the vertical plane over 24-hours, throughout the 7-day study period.

The second measuring method used was a calibrated spectrophotometer which recorded both the spectral composition of the lit scene being viewed by the participant when seated in their normal working position and the vertical illuminance received at the eye. Spectrophotometer measurements were taken throughout the day for each participant, in 6 orientations at eye height, providing a photometrically accurate 'snapshot' of the participant' lighting experiences.

Sites

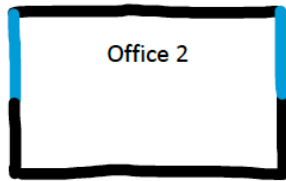
The first stage of the project identified potential offices for conducting the study. The four offices chosen are architecturally diverse with varying methods of daylight ingress, as follows:

1. Office 1 - individual skylights and east facing vertical windows
2. Office 2 - continuous vertical windows along the full length of the office, facing south
3. Office 3 - no daylight available in the main working space
4. Office 4 - large continuous rooflights facing east and west



Office 1

First floor in converted Victorian warehouse with majority of individual skylights and windows facing east



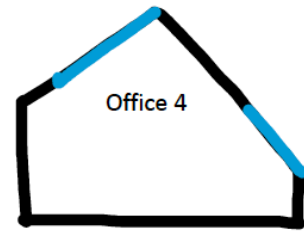
Office 2

7th floor in 1960's office tower with continuous windows in main space facing south



Office 3

Ground floor in converted Victorian warehouse with no daylight ingress in main space



Office 4

First floor mezzanine level in converted Victorian train shed with two large, continuous rooflights facing east and west

Architectural spaces - daylight typology



Office 1



Office 2



Office 3



Office 4

Participants

My aim was to enlist five participants per office and this was achieved in all but one office. Those who expressed interest in taking part were given detailed information sheets explaining the context, aims and structure of my study including the responsibilities and obligations for participants. All participants completed formal consent forms and complied wholeheartedly and enthusiastically with the research process.

Throughout the week, each participant completed a series of questionnaires including

1. MCTQ Core Munich Chrono Type Questionnaire. This identifies typical sleep behavior during the preceding 4 weeks, to ascertain if any participants were extreme early or late chronotypes.
2. Karolinska Sleepiness Scale (KSS) measures subjective alertness. Questionnaires were completed in the morning, after lunch and in the later afternoon, every day for 7 days.
3. Questionnaire every day about participants' journeys to and from work and whether or not they spent any time outdoors.

Data collection

Participants wore their Button sensors at all times for the 7 days of the study. I collected their light exposure data by synchronising the sensors via Bluetooth with the LYS Collect App installed on my phone. Data was collected every morning and afternoon during the weekdays. The raw data was downloaded directly from the LYS Collect app via e-mail. The downloaded file was saved onto my laptop in both CSV and Excel format and anonymised.

The spectrophotometer was connected to a Windows laptop onto which I had installed Konica Minolta software. This allowed for the exact recording of a number of photometric quantities such as Lux, CCT, dominant wavelength. All measurements were saved as Excel files on laptop and anonymised.

Ethical and data protection approval

As this study collected and analyses non-sensitive data that is gathered via sensors worn by non-vulnerable adults, it fell within the UCL BSEER category of low-risk. A full ethical and data protection application was submitted to University College London (UCL) detailing every aspect of this research study and formal approval was received prior to beginning my field work.

Methodology

Limitations of data collection methods

At the end of the first week's study in Office 1, it became evident that participants' weekend light exposure data could not be collected as intended. My original proposal was to use the *LYS Insight* app rather than the *LYS Collect* for this purpose. This alternative app allows for data to be uploaded to the LYS server directly (and then emailed to me), without the need to synchronise the individual sensors with the app on my mobile phone. I proposed this method of data collection because it was impractical to meet with participants outside of the offices, each day over the weekend.

However, it transpired that switching between the two different LYS apps resulted in significant and unpredictable loss of weekend data. In order to overcome this limitation, I attempted to collect the weekend data from Office 2 participants using the *Collect* app, on the Monday morning following the week's

study. Unfortunately, the data storage limitations of the LYS sensors meant that the data collected was again, inconsistent. My third attempt to gather weekend data was to meet with participants at agreed locations close to their homes on the Sunday afternoon following the third week's study in Office 3, to synchronise the sensors with the *Collect* app. Once again, I discovered inconsistent data loss. Having exhausted all options, I decided reluctantly that it was unfeasible to collect reliable weekend light data with the LYS system, within the methodological design of this project.

Nonetheless, as the focus of this study is to understand the actual daylight exposure experienced in a range of typical working environments, I concluded that the lack of consistent weekend data would not impact the fundamental aims of this project, i.e. the light exposure experienced by participants in their diverse office environments.

Management of data

The field study element of this project is complete and the past two months have been spent collating and reviewing the vast amount of raw data collected. For each office, the raw data from the LYS sensors have been checked and processed to remove any redundant information, ensuing workable files covering only the five days under investigation. The relevant spectrophotometer measurements have been extricated from the Excel files and saved separately.

Site	Data	Format	Participants	Description
Office 1	LYS raw data	csv file	5	All data since sensors synchronised with Collect app, data recorded every 15 seconds
	LYS tidy data	csv file	5	Monday to Friday of study week from 00:00:00 on 28/10/19 - 23:59:00 on 01/11/19
	LYS tidy data for further analysis in this study	csv file	4	Sensor 1 faulty, hence data only available for 3 days. Sensor 1 excluded from further analysis
	Spectrophotometer files	Excel file	5	2/3 times per day of study week 28/10/19 - 01/11/19
Office 2	LYS raw data	csv file	5	All data since sensors synchronised with Collect app, data recorded every 15 seconds
	LYS tidy data	csv file	5	Monday to Friday of study week from 00:00:00 on 11/11/19 - 23:59:00 on 15/11/19
	LYS tidy data for further analysis in this study	csv file	4	Participant 2 unwell and off work, hence data only available for 3.5 days. Sensor 2 excluded from further analysis
	Spectrophotometer files	Excel file	5	2/3 times per day of study week /11/19 - /11/319

Office 3	LYS raw data	csv file	4	All data since sensors synchronised with Collect app, data recorded every 15 seconds
	LYS tidy data	csv file	4	Monday to Friday of study week from 00:00:00 on 18/11/19 - 23:59:00 on 22/11/19
	LYS data for further analysis in this study	csv file	4	All 4 participants completed the week's study
	Spectrophotometer files	Excel file	4	2/3 times per day of study week 18/11/19 - 23/11/19
Office 4	LYS raw data	csv file	5	All data since sensors synchronised with Collect app, data recorded every 15 seconds
	LYS tidy data	csv file	5	Monday to Friday of study week from 00:00:00 on 06/01/20 - 23:59:00 on 10/01/20
	LYS data for further analysis in this study	csv file	5	All 5 participants completed the week's study
	Spectrophotometer files	Excel file	5	2/3 times per day of study week 06/01/20 - 10/01/20

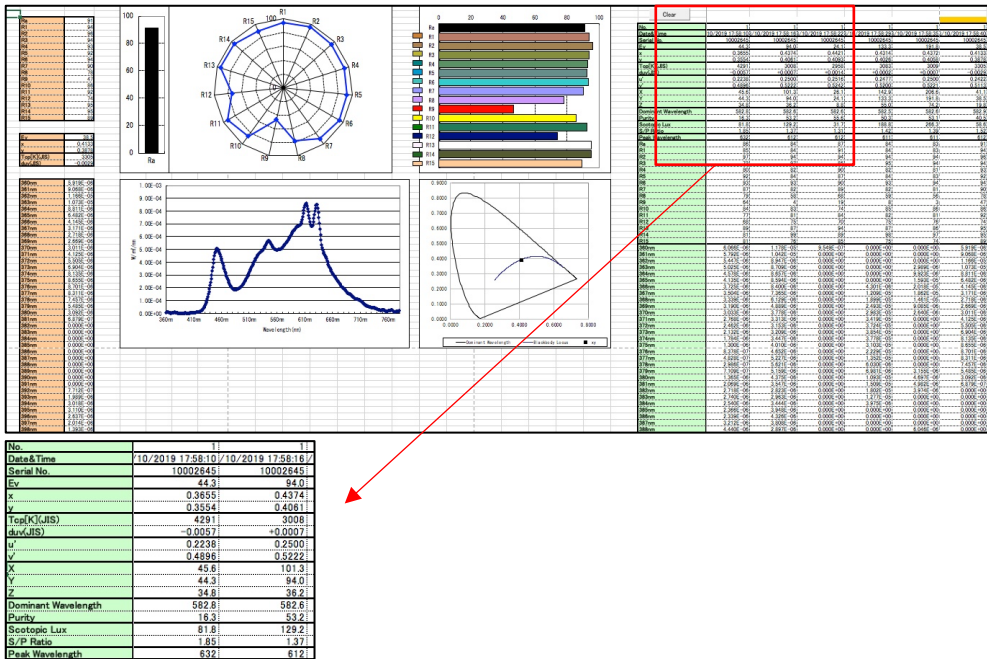
Summary of LYS data refinement process

Examples of data collected

The examples below show the format in which information is displayed in the two types of data files. The quantities that will be investigated further are the vertical illuminance measurements - *lux* column in LYS data file and *Ev* in spectrophotometer file. Note, both measurement files include exact timestamps for future comparison and evaluation.

timestamp	sensor	lux	kelvin	rgbR	rgbG	rgbB	rgbIR	movement
28-10-2019 10.15.10	sensor 2 o	246	3581	214	178	123	47	0
28-10-2019 10.15.25	sensor 2 o	166	3465	158	120	86	35	0
28-10-2019 10.15.40	sensor 2 o	129	3311	129	91	65	29	0
28-10-2019 10.15.56	sensor 2 o	116	3346	115	83	59	27	0
28-10-2019 10.16.11	sensor 2 o	115	3212	113	80	54	33	0
28-10-2019 10.16.26	sensor 2 o	249	3592	225	181	130	42	0
28-10-2019 10.16.41	sensor 2 o	249	3592	225	181	130	42	0
28-10-2019 10.16.56	sensor 2 o	243	3288	225	169	112	52	0
28-10-2019 10.17.11	sensor 2 o	244	3612	223	178	130	43	0
28-10-2019 10.17.26	sensor 2 o	262	3497	237	188	131	52	0
28-10-2019 10.17.41	sensor 2 o	262	3585	231	190	133	48	0
28-10-2019 10.17.56	sensor 2 o	254	3585	231	185	133	43	0
28-10-2019 10.18.11	sensor 2 o	249	3563	228	181	130	44	0
28-10-2019 10.18.26	sensor 2 o	228	3777	198	169	124	43	1
28-10-2019 10.18.42	sensor 2 o	184	3612	163	134	95	43	0
28-10-2019 10.18.57	sensor 2 o	184	3612	163	134	95	43	0
28-10-2019 10.19.12	sensor 2 o	199	3655	175	145	104	41	0
28-10-2019 10.19.27	sensor 2 o	187	3655	170	138	101	42	0
28-10-2019 10.19.42	sensor 2 o	76	3321	75	54	38	27	0
28-10-2019 10.19.57	sensor 2 o	181	3612	163	132	95	44	1
28-10-2019 10.20.12	sensor 2 o	69	3405	70	50	37	20	0

Example of LYS data file for Office 1, day 1, sensor 2 - tidy data



Example of Konica-Minolta spectrophotometer file for Office 1, day 1, sensor 2

Focus for analysis

In order to investigate how much daylight was experienced by participants in the four offices, I have decided to focus on the following criteria:

1. Vertical illuminance (lux) received by the participant over the working day
2. Variability of illuminance received by the participant over the working day.

The current guidance regarding suitable illuminance levels within working environments recommends a maintained illuminance on a horizontal working plane of between 300 and 500 lux for primary offices (*ref SLL Handbook, 2018, p168*). From the measurements taken, it appears that the artificial lighting in all of the four offices studied provides light levels that at best, meet these recommendations. It is unlikely that the artificial lighting systems in any of the offices would have provided light levels above 500 lux on the horizontal working plane. Consequently, illuminance measurements over and above 500 lux will be attributed to *daylight* entering the space. This assumption and the *actual threshold* for daylight contribution will be confirmed in each office by examining the highest illuminance recorded after sunset when all lighting would have been provided by electric sources alone.

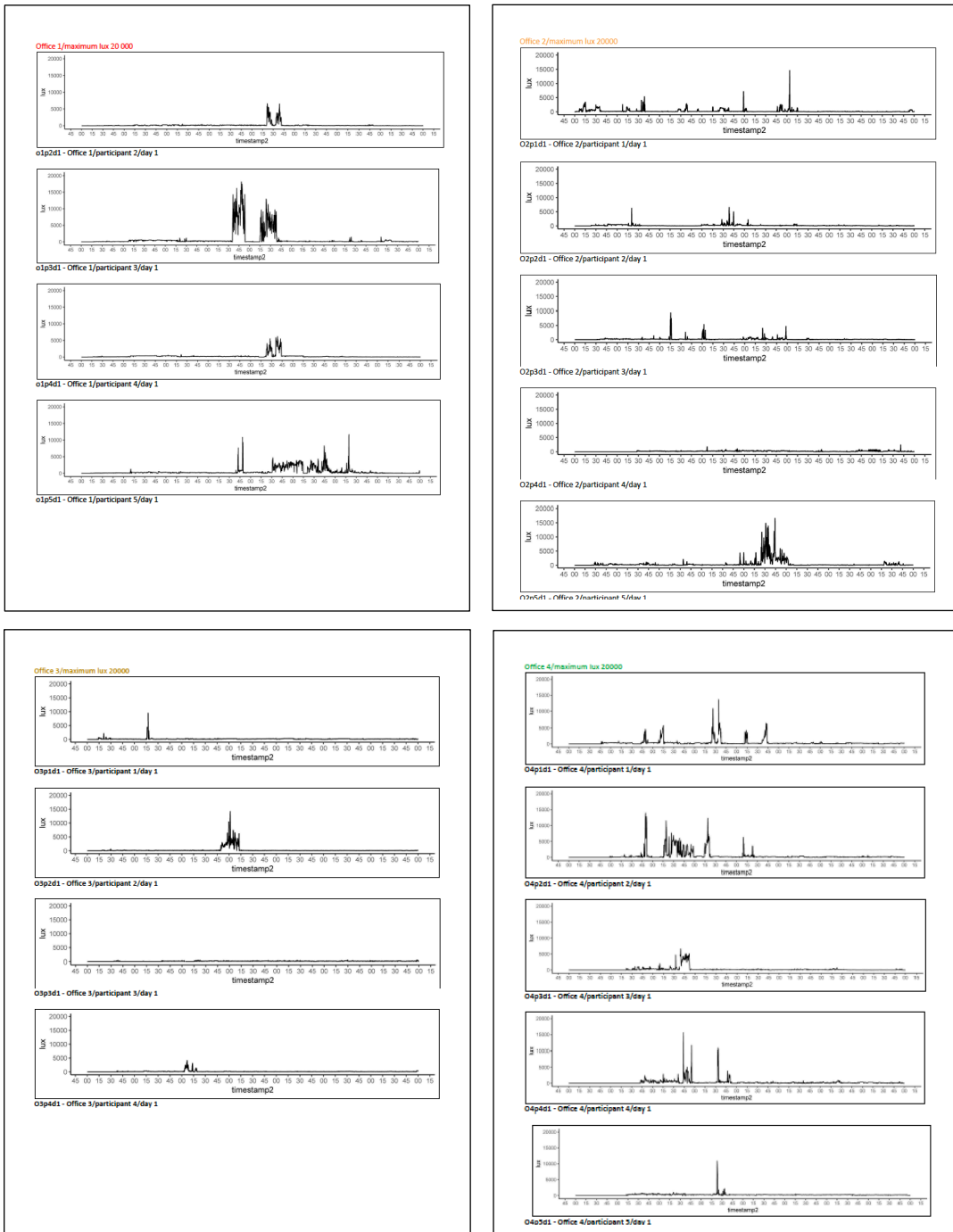
Statistical tools

In order to further manage, display and analyse the data, I have elected to use the statistical computing package R. For the purposes of this study, the main benefits of using R is that it allows for large datasets to be used without the need for separate data management software as well as allowing data correlations to be clearly displayed in graphical form. Individual components of datasets can be easily selected and plotted for rapid inspection of the data. Additionally, because R uses coding language, all instructions given to manipulate the data files are easily retrievable and reproducible. Using R, I have formulated suitable code to plot participants' daily light exposure in each office as recorded with the LYS Button sensors. The resultant graphs will be used to identify patterns between individual participants in the same office as well as between the four separate offices.

Results

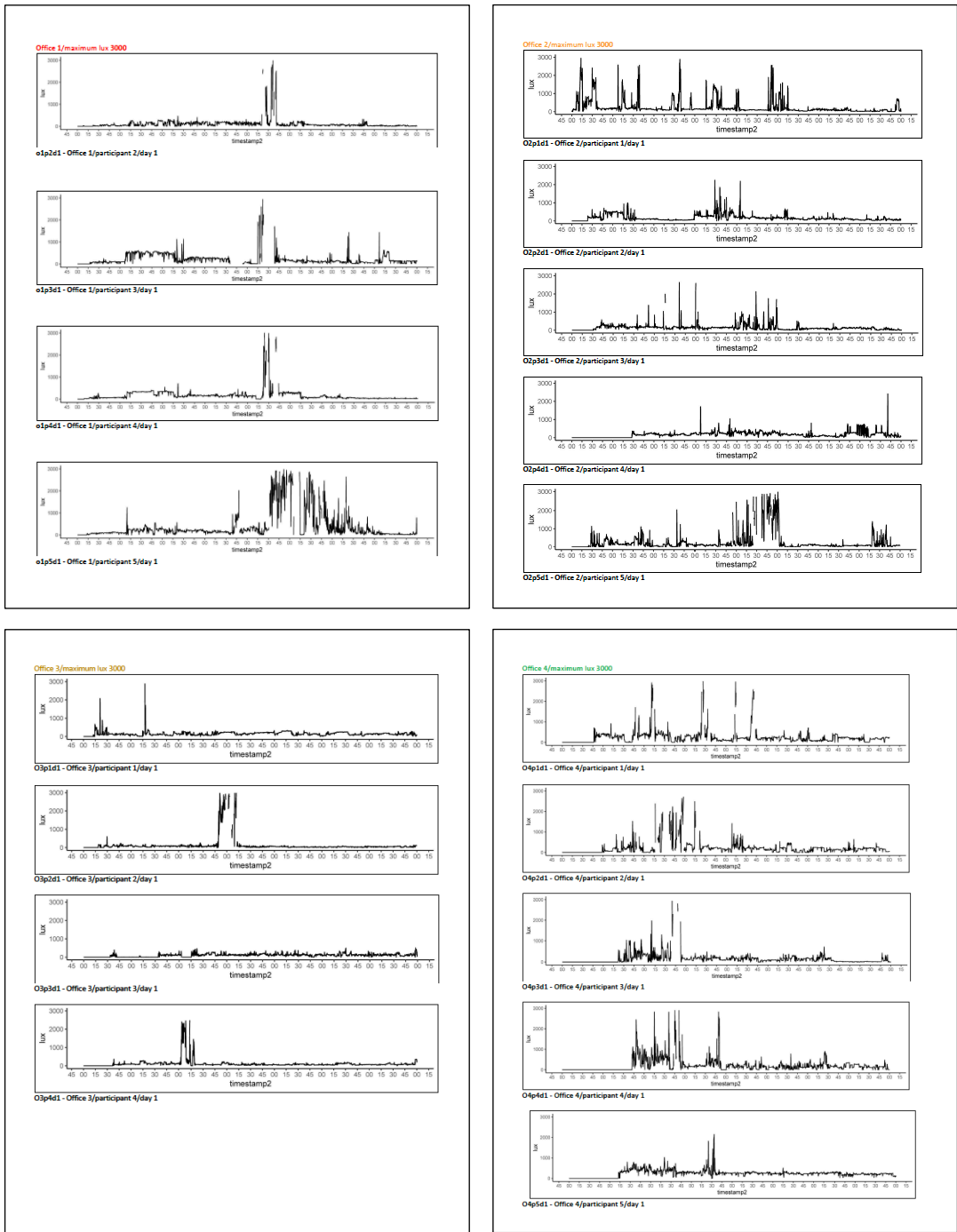
Graphical display of data

The graphs below represent participants' light exposure during a day in the office. The y-axis displays *lux* values which in this case, are set to a maximum of 20 000 lux. The x-axis displays *time* which in this case has been set from 9:00 until 17:00 on day 1 of the study in each office.



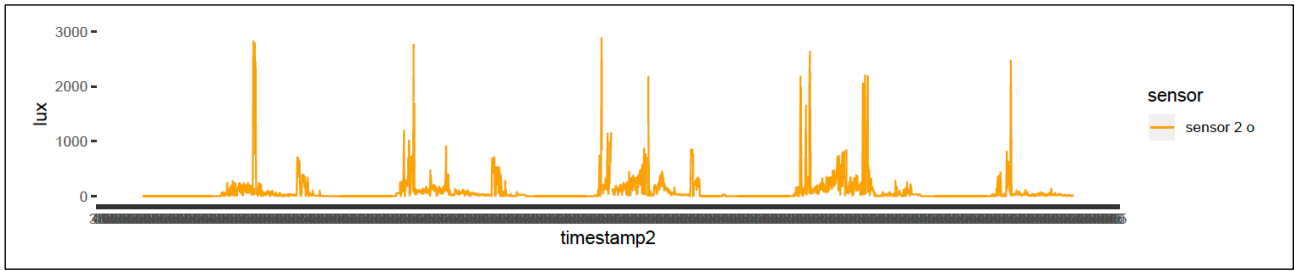
Example of initial graphs showing data from four offices on day 1 of each week with y-axis set to 20 000 lux

The graphs below represent the same information but with the y-axis amended so that the maximum lux value is 3000. This allows for closer inspection of the illuminance data.

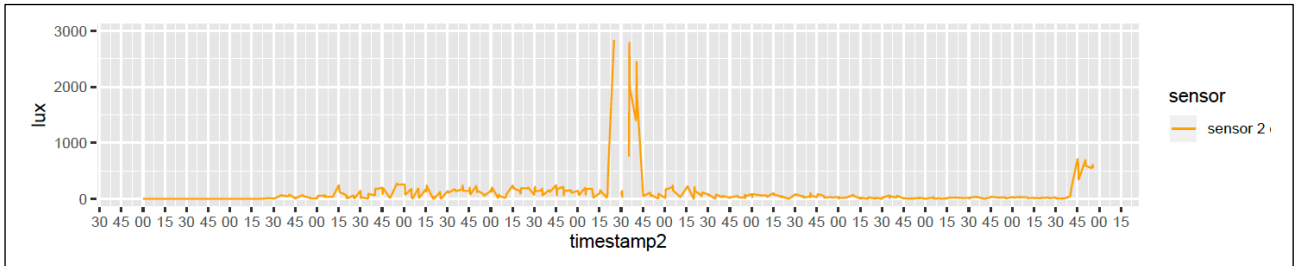


Example of initial graphs showing data from four offices on day 1 of each week with y-axis set to 3000 lux

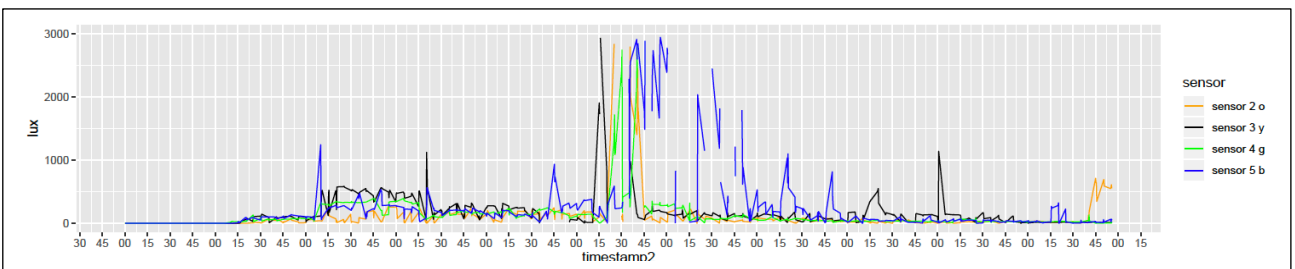
Progressing to more advanced use of R allows for enhanced graphical representations of the data. The selection of graphs below demonstrates the scope of this tool and the way in which the data is displayed for Office 1, Participant 2. The same graphical display of data has been produced for all participants in the four offices.



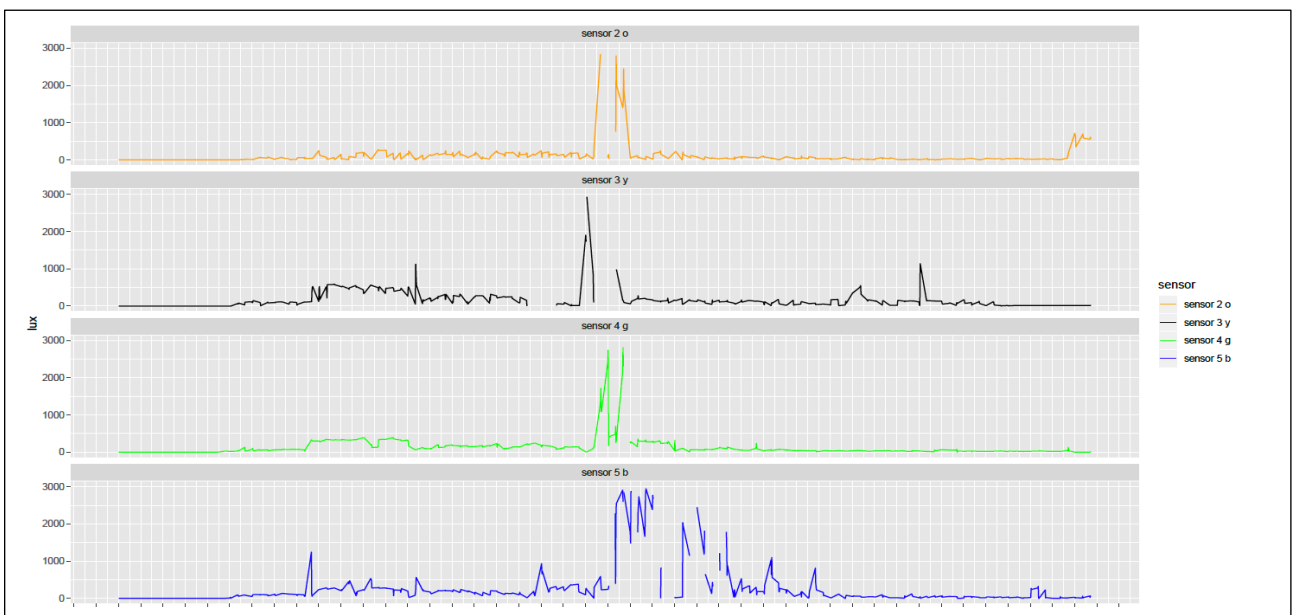
Time plot showing light exposure for participant 2 in Office 1 on days 1 to 5.



Time plot showing light exposure for participant 2 in Office 1 on day 1, from 08:00 until 18:00.



Time plot showing light exposure for participants 2, 3, 4 & 5 in Office 1 on day 1, from 08:00 until 18:00.



Separated graphs of time plots showing light exposure for participants 2, 3, 4 & 5 in Office 1 on day 1, from 08:00 until 18:00.

Comparison of the data collection methods

The next stage in displaying the data will be to plot the spectrophotometer spot measurements onto the graphs showing the LYS sensor data. Work on this is underway. This exercise will identify whether there is any overlap between the two forms of measurement or whether any discernible pattern is evident. Both the LYS and spectrophotometer data have exact timestamps for every lux measurement taken. This will allow for direct comparison of the data at two or three times per day, thereby acting as a means to 'calibrate' the LYS sensor measurements.

Next three months

Analysis of data collection methods

Statistical mapping of the LYS sensors and spectrophotometer data will be undertaken to establish whether there is a correlation between the two measuring systems. We know that the data from the properly calibrated spectrophotometer will deliver accurate measurements. By comparing these two sets of results I will be able to determine the accuracy and reliability of the wearable device for future research purposes.

Analysis of daylight availability

Data from the field study will be analysed to understand the daylight exposure experienced by participants in the four different offices. The criteria to be used includes vertical illuminance (recorded as close as possible to participants' eyes) together with the degree to which this illuminance varies throughout the day.

The impact of architectural typology on the results will be examined including the impact of building orientation, type of windows and presence of roof lights. Statistical analysis of the data will help establish a hierarchy of daylight availability within the different architectural spaces. Furthermore, the data will be analysed in terms of some of the known impacts of light on our non-image forming processes, using a range of both traditional and circadian metrics.