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Analyzing Façade Scenarios and Daylight Levels in the Reid Building: A Reflective Case Study on the Designed Daylight under Overcast Sky

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***Abstract*—**This study presents the use of daylight in the case study of the Reid building at the Glasgow School of Art in the city of Glasgow, UK. In Nordic countries, daylight is one of the main considerations within building design, especially in the face of long, lightless winters. A shortage of daylight, contributing to dark and gloomy conditions, necessitates that designs incorporate strong daylight performance. As such, the building in question is designed to capture natural light for varying needs, where studios are located on the North and South façades. The study's approach presents an analysis of different façade scenarios, where daylight from the North is observed, analyzed and compared with the daylight from the South façade for various design studios in the building. The findings then are correlated with the results of daylight levels from the daylight simulation program (Autodesk Ecotect Analysis) for the investigated studios. The study finds there to be a dramatic difference in daylight nature and levels between the North and South façades, where orientation, obstructions and designed façade fenestrations have major effects on the findings. The study concludes that some of the studios positioned on the North façade do not have a desirable quality of diffused northern light, due to the outside building's obstructions, area and volume of the studio and the shadow effect of the designed mezzanine floor in the studios.

***Keywords*—**Daylight levels, educational building, façade fenestration, overcast weather.

I. Introduction

DAYLIGHT plays a vital role in the design of the interior environment; materials, colors, people and objects are each affected by how light interacts with them. As such, daylight has always been encouraged to be effectively used within the built environment, especially given that our bodies and minds respond well to sunlight [1], with it being directly linked to health and energy savings. Therefore, in overcast locations, such as in Scotland, the lack of daylight makes it critical to design a building that can accommodate a certain amount of daylight for a satisfactory dynamic nature and to meet functional demands. As such, the implementation of daylight into gloomy interiors without taking consideration of its impact on the users, would lead to passive consequences. Accordingly, the design of façade buildings is considered a crucial element in an architectural building. Its material embodiment has greatest control over its performance, as opposed to its superficial ornamentation, and its fenestration arrangement and sizes determine the quality and quantity of penetrated daylight inside. Moreover, it has been argued that the aesthetic value and performance of the façade has to be "re-attached" to the political, economic, cultural and technological forces that would affect the construction process of the contemporary image of the façade [2].

After changing the architectural modes and pedagogy in the design of the educational building, ideas for air quality, hygiene and light levels began to materialise retaining to the creation of an environmentally-controlled space that shifted from teacher-centred space to a student-centred space in the mid-twentieth century. As a result, architects initiated new designs to reflect the social shift that happened between the late nineteenth century and the twentieth century. The concepts of a healthy environment for educational buildings altered, with the façade's windows enlarging, along with the introduction of a passive ventilation system which causes changes in the physical appearance of educational building and how it is placed [3].

According to the design and architecture educational building, where innovation and learning are engaged, the discipline is experienced through researching, sharing, listening, and understanding, drawing and processing [4]. As such, the SLL code for lighting has mentioned the recommended maintained illuminance E_m on the reference surface to be 300 lux for classrooms, 750 lux for art rooms in art schools, 750 lux for the technical drawing room, and 500 lux for the teaching workshop [5]. The rule of thumb, as proposed by the architect ER Robson, was that the window area to floor area ratio should be around 20% [6]. The first systematic methodology on environmental appraisal in Charles Mackintosh building was done by Raid Hanna (2002), where sound, heat, and light levels were analyzed in studios. The investigated parameters are comparable in scale with the Reid building [7].

II. Case of Investigation

'The soul has more need for the ideal than the real' [8].

The Reid Building is located on Renfrew Street in Glasgow, Scotland and was designed by the American architect Steven Holl for the Glasgow School of Art. It has been lauded as providing the functional requirements of educational and research purposes through an intensive design process. Its contemporary form with its innovative lighting design and distinctive materials has made for an inspiring environment for both students and visitors. The secret of Steven Holl's design touch is to use light as a building material, and to

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merge his architecture with their surroundings to achieve a neutral integration [6], taking inspiration from The Glasgow School of Art masterpiece building, designed by Charles Rennie Mackintosh in 1900, which has been referred to as the foundation of modern architecture.

'The old and the new are said to "sing" and "dance" together' [9].

The architect worked from the inside out, merging the psychological desires of the programme with the functional needs. Accordingly, the rhythms and melody of interior spaces reflect surprises, where each floor is a new experience to stimulate the mind through time [9].

'It's all about sequence, like a piece of music, you keep going in a sequence' [8].

The Raid Building has rich properties of light that created unexpected spatial phenomena with intense sensibilities of atmosphere. It is indeed the light factor that has produced new experiences in space and is responsible for drawing the eye through the building. The power to impose lighting on a space is manifested by a striking technique that has been used to capture the natural light and reflect it inside; the resulting vaulted voids with light coming down were hailed: 'a celebratory for the institution'. The main aim behind the innovative design of the 'driven voids of light' and the integration between concrete and glass is to: 'forge 'a symbiotic relation' with Charles Rennie Mackintosh's masterpiece across the road [9].

The architect explains the intelligent scheme of creating three cylindrical shafts of light to reflect responses to the weather conditions and to realize space with strong phenomenal properties: 'the procession of spaces, and how one's space open up and the other reveals itself, your drawn through spaces and the quality of light come through'[8]. So, the spaces have been coordinated with respect to the lighting requirements. Accordingly, the studios and workshops, which are the basic building blocks of the building, are located along the northern façade in order to receive the highest quality of diffused northern light [10]. However, some other studios are located alongside the south façade.

Based on the researcher's observations and notes from a previous research, it seems that the general atmosphere adds spacious and light-filled experience precisely because of the high-level amount of consistent daylight that competes with other light sources. Moreover, the designed wall catches the bluish northern light and mixes it with the warm yellowish southern light, resulting in an impressive overall effect of sensory qualities that condition the interior experience. The integration of a variety of daylight sources has created a sequence, almost like a piece of music, which you cannot predict from the outside of the building. Steven Holl explains this as: 'the silence is on the outside and our interior is our symphony' [11].

III. Methodology

The study is based on a linear - analytical type of case study research, in which a general set of observations have also been conducted in a real-life context for the investigated building. The formal analysis of façade scenarios and interior layout covered ten studios, with four of them located on the south façade, and the rest on the northern one. Moreover, the study also used simulation research, whereby physical reality has been represented using a substitute medium by Ecotect simulation software. This paper presents four studios, two along the north elevation and two along the south one.

Fig. 1 The south elevation of the Reid building [12]

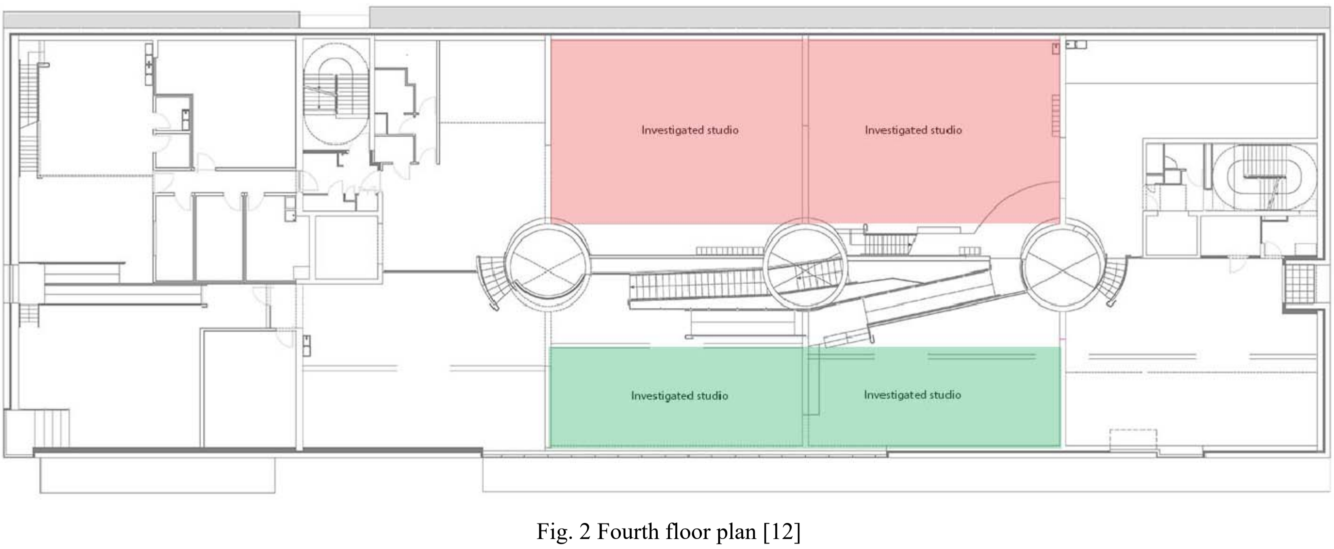

Fig. 2 Fourth floor plan [12]

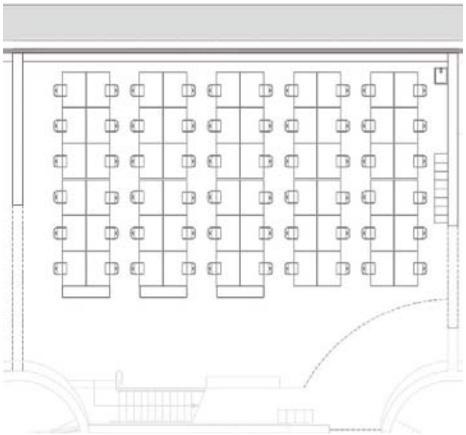

Fig. 3 Studio A floor plan

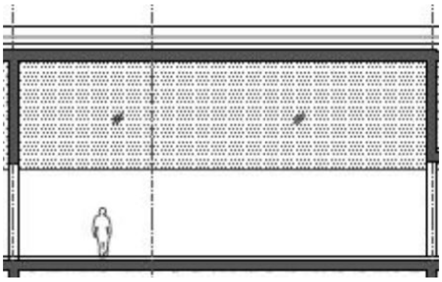

Fig. 4 Interior section for the studio A

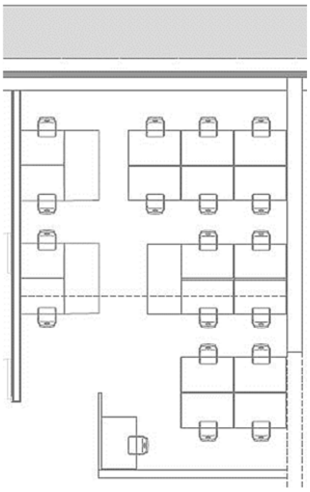

Fig. 5 Floor plan for studio B

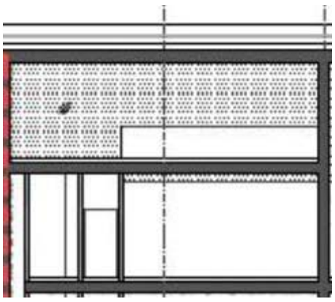

Fig. 6 Interior section for studio B with the mezzanine floor

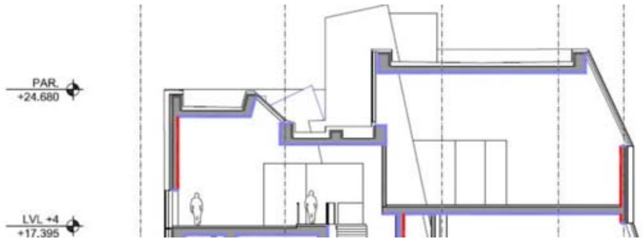

Fig 7 Interior section for studio A and C

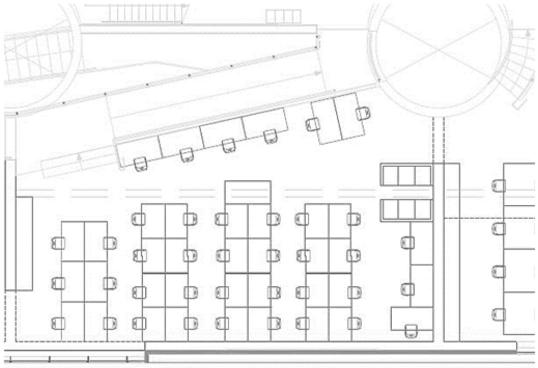

Fig. 8 Floor plan for studio C

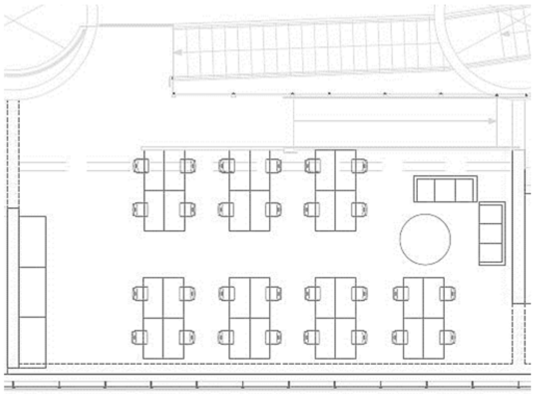

Fig. 9 Floor plan for studio D

TABLE I
STUDIO SURVEY DATA

Studio	Orientation	Dimension (m)	Area (m^2)	Design type	Window orientation
A	North	14.65*11*7	161	Double- volume	North
B	North	6*7*3	42	Double- volume with mezzanine	North
C	South	14.65*8*4	117	Normal	South
D	South	14.65*6*4	88	Normal	South

TABLE II
STUDIO SURVEY DATA

Studio	Window dimension (m)	window sill height (m)	Window/ Floor ratio	Window/ Wall ratio	No. of windows
A	14.65*3.5	4	32%	50%	1
B	6*3.5	4	50%	50%	1
C	4*1	0	3.4%	6.8%	1
D	14.65*2	0	33.3%	50%	1

IV. Daylight Analysis and Findings

Glasgow is located on the north temperate zone where, despite its northern latitude, the weather tends to be oceanic and very changeable. Its solar altitude in the northern hemisphere would be described as follows:

The shortest day and the winter solstice fall on the 22st of December with a total of 6:58:52 hours of daylight, in which the sun rises and sets at its lowest in the sky (Fig. 10). However, the longest day and summer solstice is on the 21st of June with a total of 17:35:01 hours of daylight, during which time the sun rises and sets at its highest in the sky (Fig. 11).

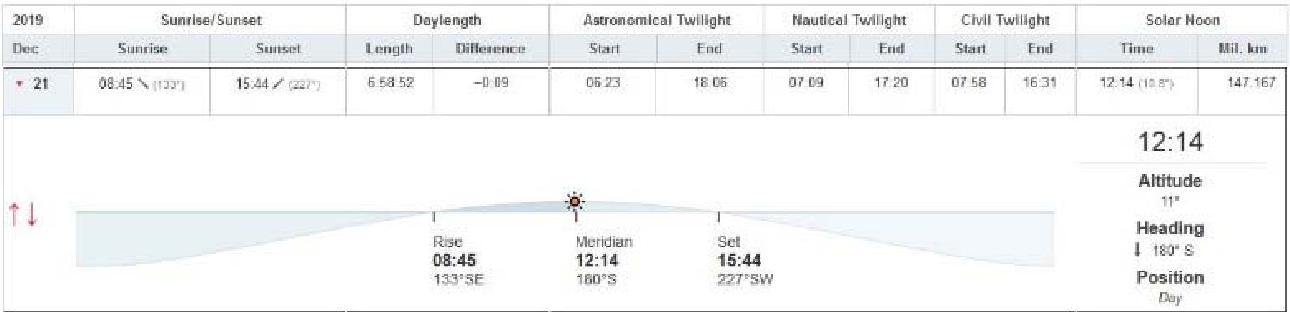

Fig. 10 Daytime for the winter solstice [13]

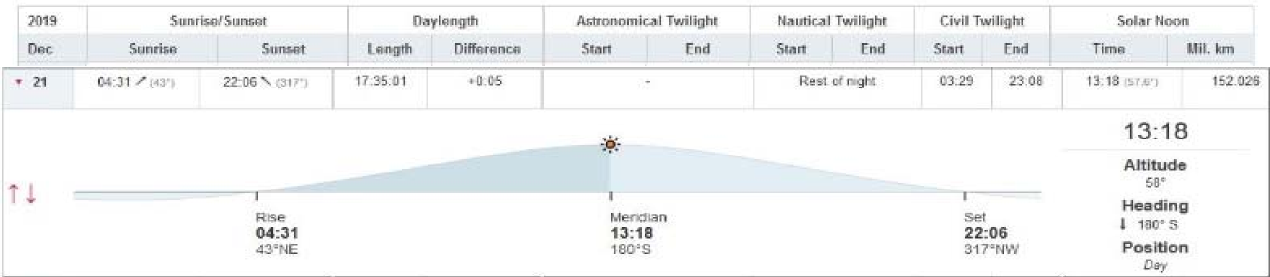

Fig. 11 Daytime for the summer solstice [13]

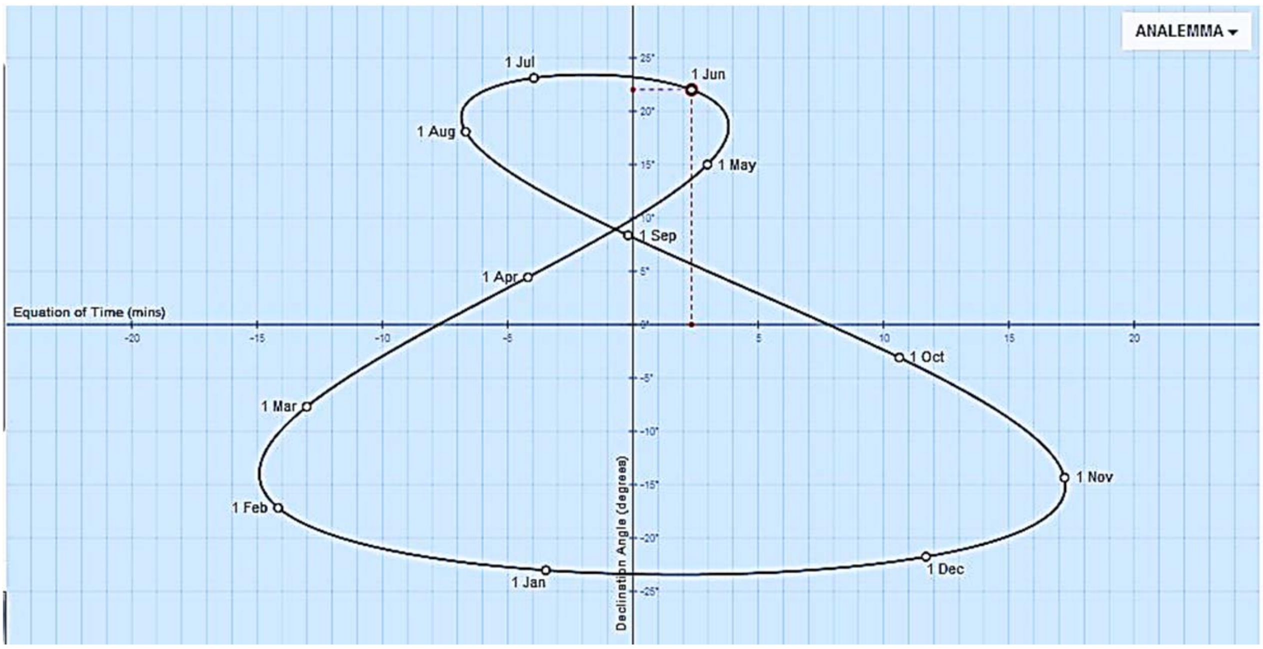

Fig. 12 Position of the sun in the sky of Glasgow [14]

In Fig. 12, analemma diagram shows the position of the sun in the sky at 12:00 noon in Glasgow city, Scotland (latitude 55.860916°N, longitude 4.251433°W) during the year 2019.

Table I shows the solar data for the first day of every month during the year 2019 at 12:00 noon. The data are measured by NOAA Solar Calculator, NOAA's Earth System Research Laboratory (ESRL), Global Monitoring Division.

The relationship between the geographic location and solar position is highly linked. During the winter season (Dec, Jan, Feb) in the city of Glasgow, the sun tends to be closer to the southern horizon with an average of about 7:30 hours of daylight. During the winter solstice (21st Dec), the sun will rise in the southeast at 09:35 and set in the southwest at 4:45; by noon it will have reached an angle of 9 degrees above the horizon. During the summer season (Jun, Jul, Aug), the sun tends to be closer to the northern horizon with an average of about 17 hours of daylight. During the summer solstice (21st Jun), the sun will rise in the northeast at 04:31 and set in the northwest at 10:06; by noon it will have reached an angle of 55 degrees above the horizon.

Using Dr. Andrew J. Marsh's launched software, the CIE sky model has been generated, using hourly weather data from the weather station in Scotland (Oban weather station) and represents overcast sky conditions. Fig. 18 shows the cumulative sky for the winter solstice with a 24-hour time range. Fig. 19 shows the cumulative sky for the summer solstice with a 24-hour time range. Fig. 20 shows the cumulative sky for all year with a 24-hour time range.

TABLE III
SUN'S DATA FOR THE 1ST DAY OF EVERY MONTH THROUGHOUT THE YEAR 2019 AT 12:00 NOON [15]

Month	Solar Declination Angle (in°)	Daylength	Azimuth	Elevation (Altitude)
December	-21.78	7:26:04	150.7	8.04
January	-23.01	7:06:28	147.87	5.87
February	-17.12	8:38:07	143.61	10.54
March	-7.62	10:41:31	140.39	19.49
April	4.5	13:05:38	137.59	31.52
May	15.05	15:20:36	134.28	41.85
June	22.04	17:09:39	129.73	48.06
July	23.11	17:28:45	127.13	48.34
August	18.03	16:03:23	129.81	43.58
September	8.31	13:51:10	136.89	35.39
October	-3.15	11:34:05	144.44	25.61
November	-14.39	9:14:52	149.72	15.42

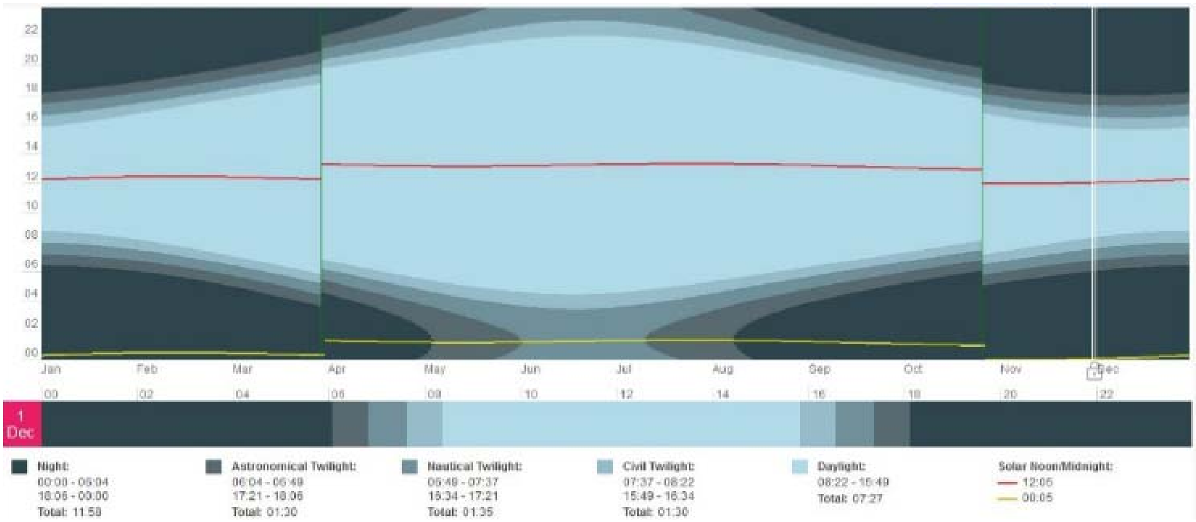

Fig. 13 Sun graph for daylight, December 2019 [13]

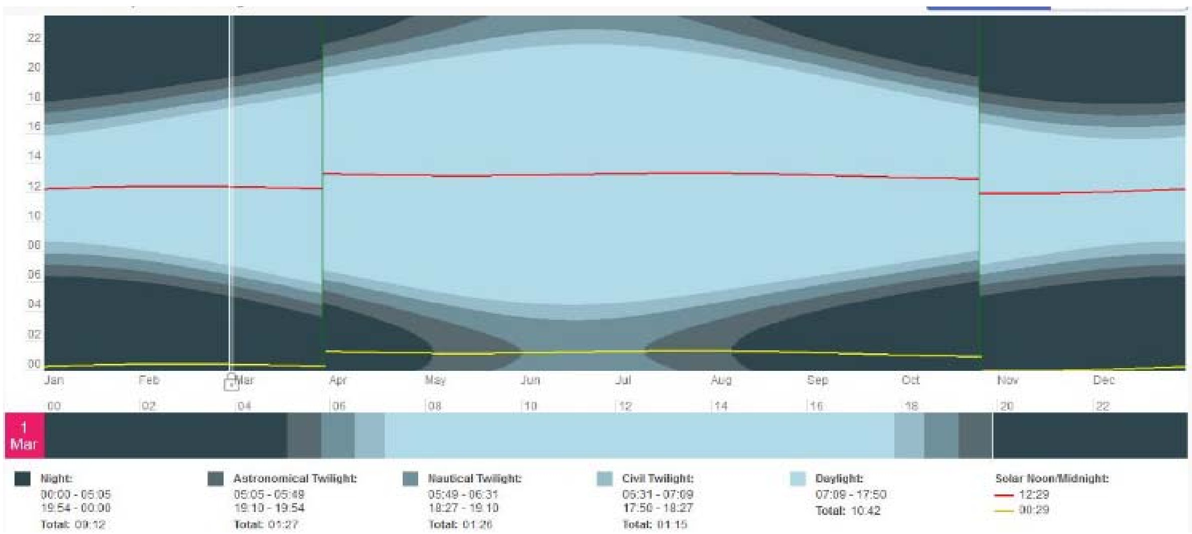

Fig. 14 Sun graph for daylight, March 2019 [13]

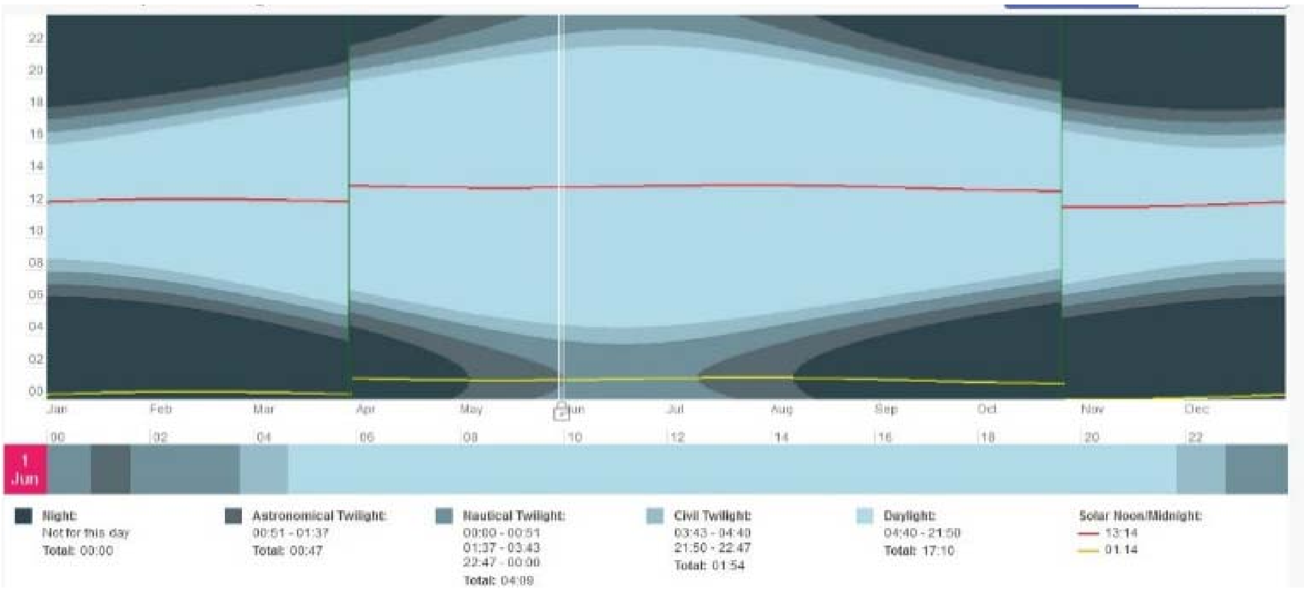

Fig. 15 Sun graph for daylight, June 2019 [13]

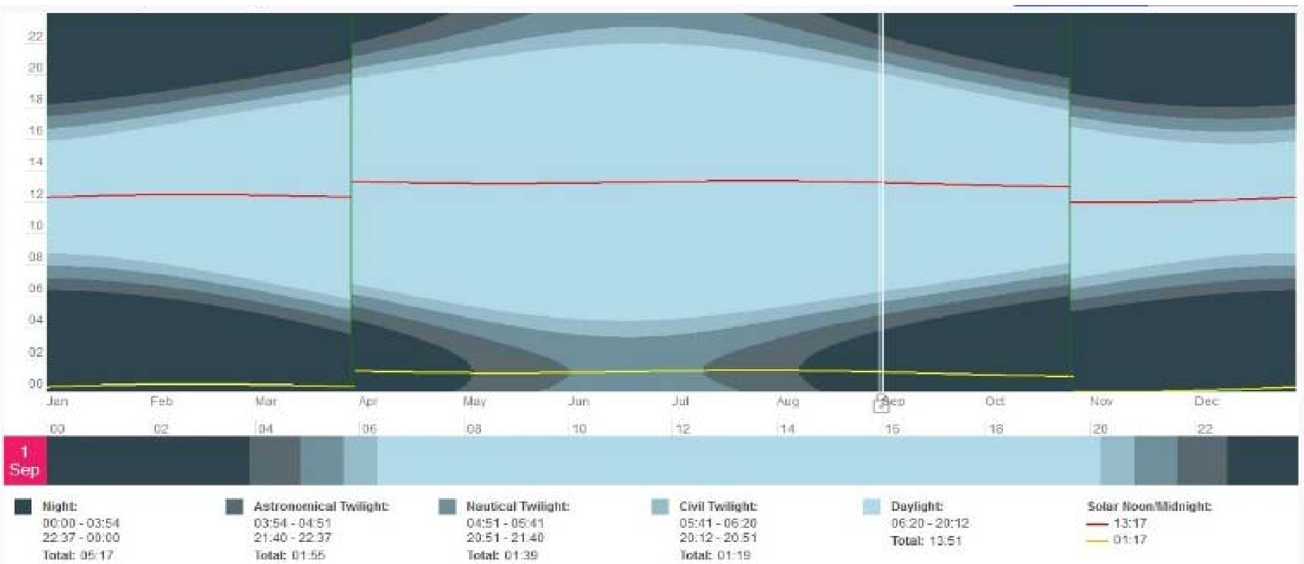

Fig. 16 Sun graph for daylight, September 2019 [13]

Using the Ecotect simulation programme, the natural light levels and daylight factor have been measured, based on the CIE overcast condition recommendations and model latitude, in which the chosen sky illuminance value is 3000 lux, and window cleanliness average (x 0.090). The illumination grid is measured in the workplane level of 0.75 m (value taken from the field survey).

Based on the Ecotect analysis, the average daylight levels for studio (A) registered at 379.16 lux with a contour range of 120-620 lux, in which 300, 500, 400, 300, 170 lux registered from 1 m, 2 m, 5 m, 9 m and 14 m respectively from the north elevation. Meanwhile, the average daylight factor registered at 12.64% with a contour range of 4-24%, in which 17%, 18%, 14%, 12%, 5% registered from 1 m, 2 m, 5 m, 9 m and 14 m, respectively from the north elevation.

From the analysis, the daylight levels are higher the closer they are to the north elevation, decreasing towards the south.

In terms of studio (B), the average daylight levels registered at 776.6 lux with a contour range of 64-1764 lux.1650, 1750, 1000, 200, 64 lux registered from 1 m, 2 m, 5 m, 9 m and 14 m respectively from the north elevation. Meanwhile, the average daylight factor registered at 25.89% with a contour range of 2.1-62.1%, in which 57%, 59%, 38%, 8%, 4% registered from 1 m, 2 m, 5 m, 9 m and 14 m, respectively from the north elevation. The clear contrast in this studio stems from the fact that a mezzanine floor is designed above half of studio (B), which results in the daylight difference between the double-volume area close to the north elevation and the area far from the north elevation covered by the mezzanine floor.

Studio (C) is located along the south elevation, with windows designed in the edge and a skylight along the roof with dimensions of 4*1m. The average daylight levels for studio (C) have registered at 1919.52 lux with a contour range of 1500-2100 lux, in which 1700, 1800, 2000, 1800, 1740 lux registered from 1 m, 2 m, 5 m, 9 m, and 14 m respectively from the south elevation. Meanwhile, the average daylight factor registered at 63.98% with a contour range of 54-74%%, in which 56%, 60%, 72%, 63%, 60% registered from 1 m, 2 m, 5 m, 9 m and 14 m respectively from the north elevation. The designed skylight allows a certain level of daylight to penetrate inside and produce a positive effect, especially in the middle of studio just where the skylight is designed above.

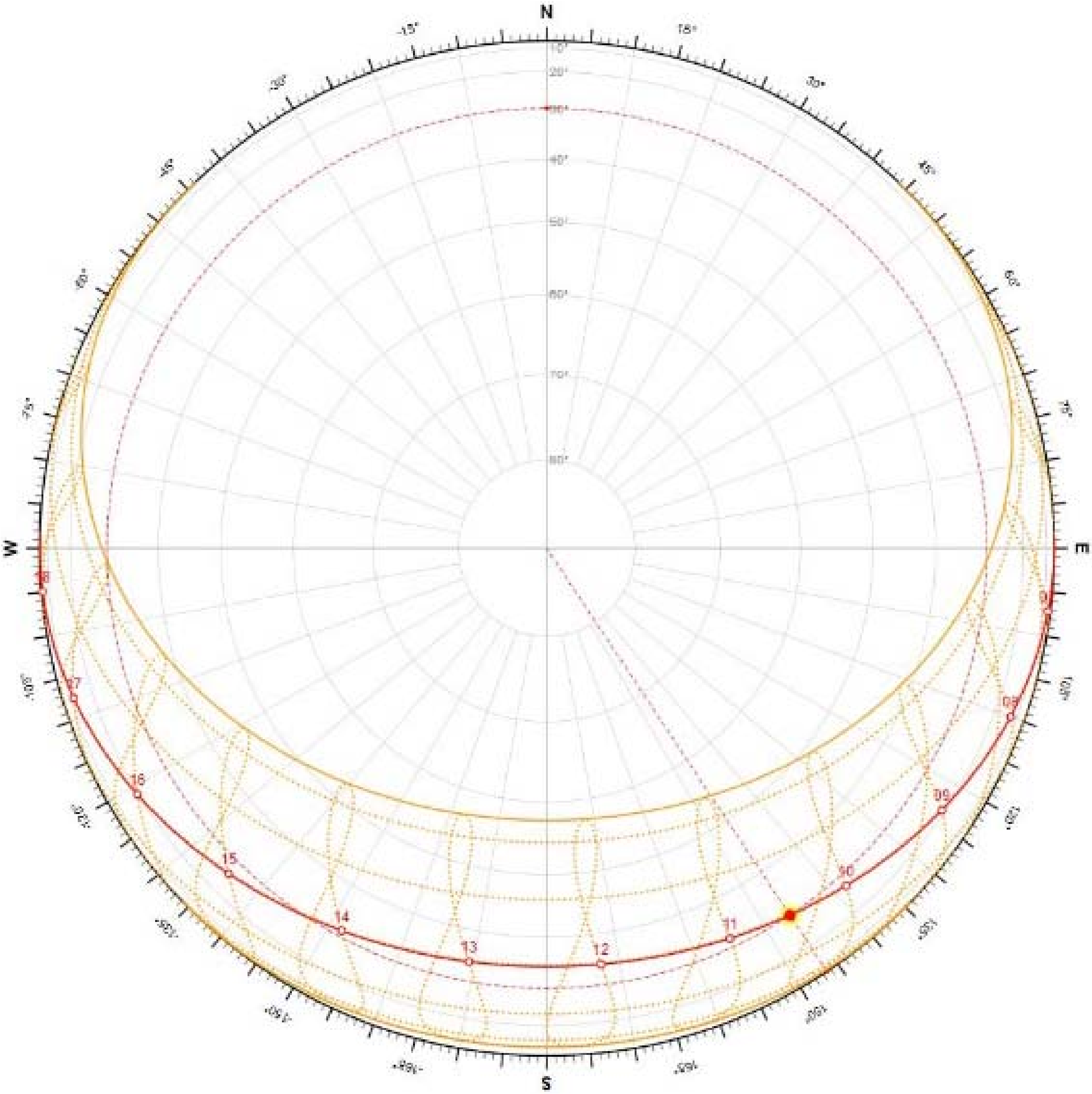

Fig. 17 Sun path diagram for Glasgow [16]

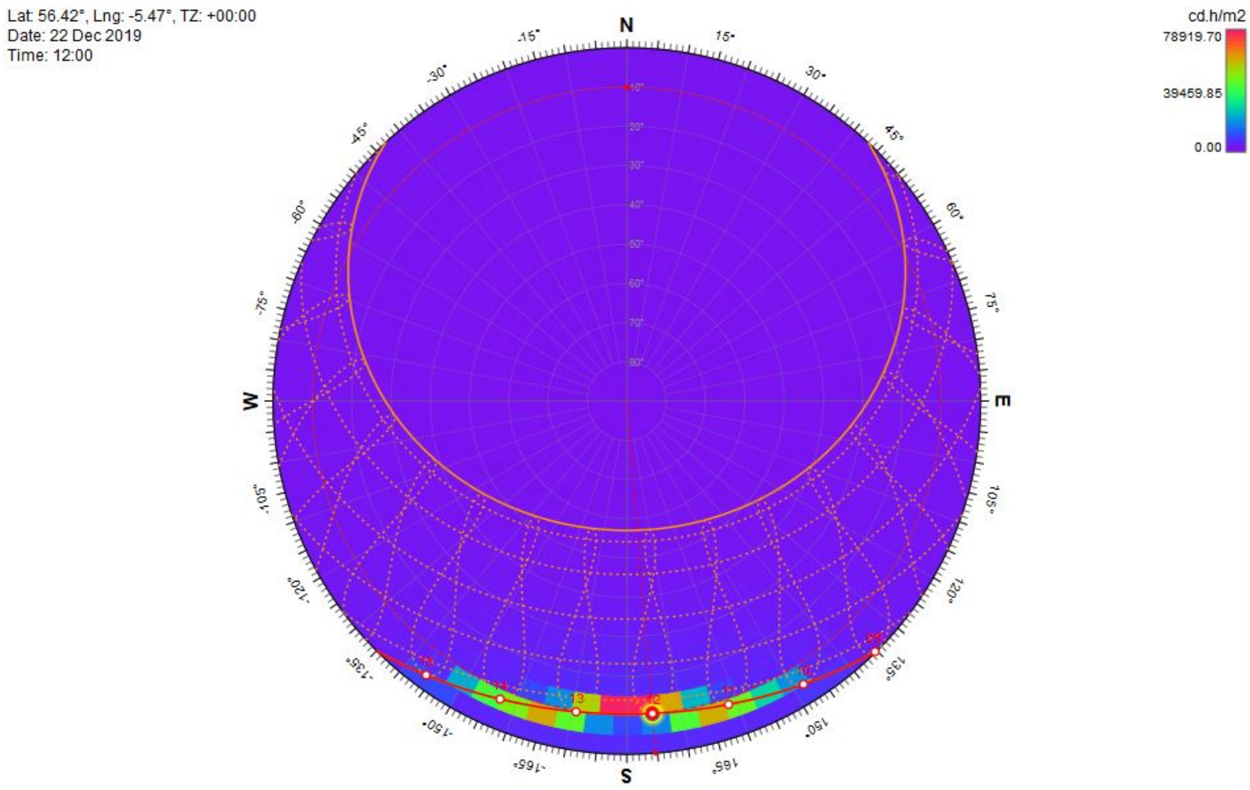

Fig. 18 The cumulative sky for the winter solstice with a 24-hour time range [14]

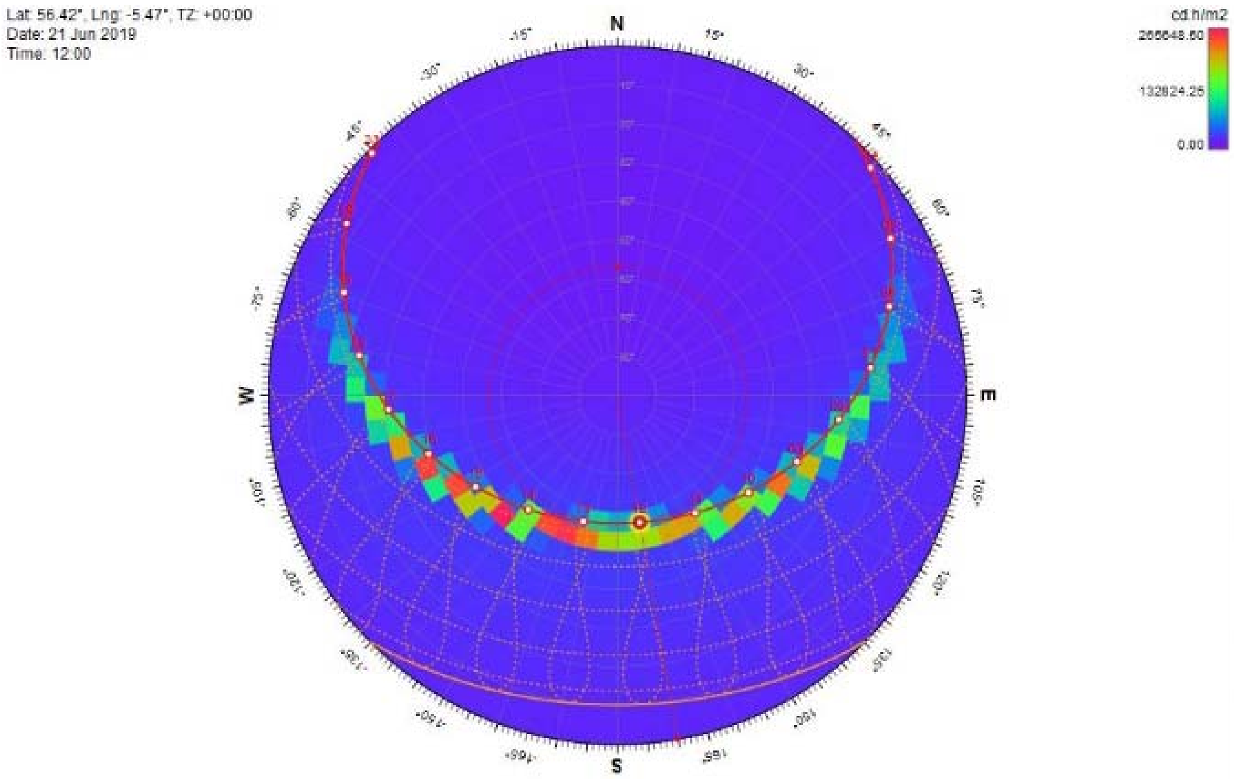

Fig. 19 The cumulative sky for the summer solstice with a 24-hour time range [14]

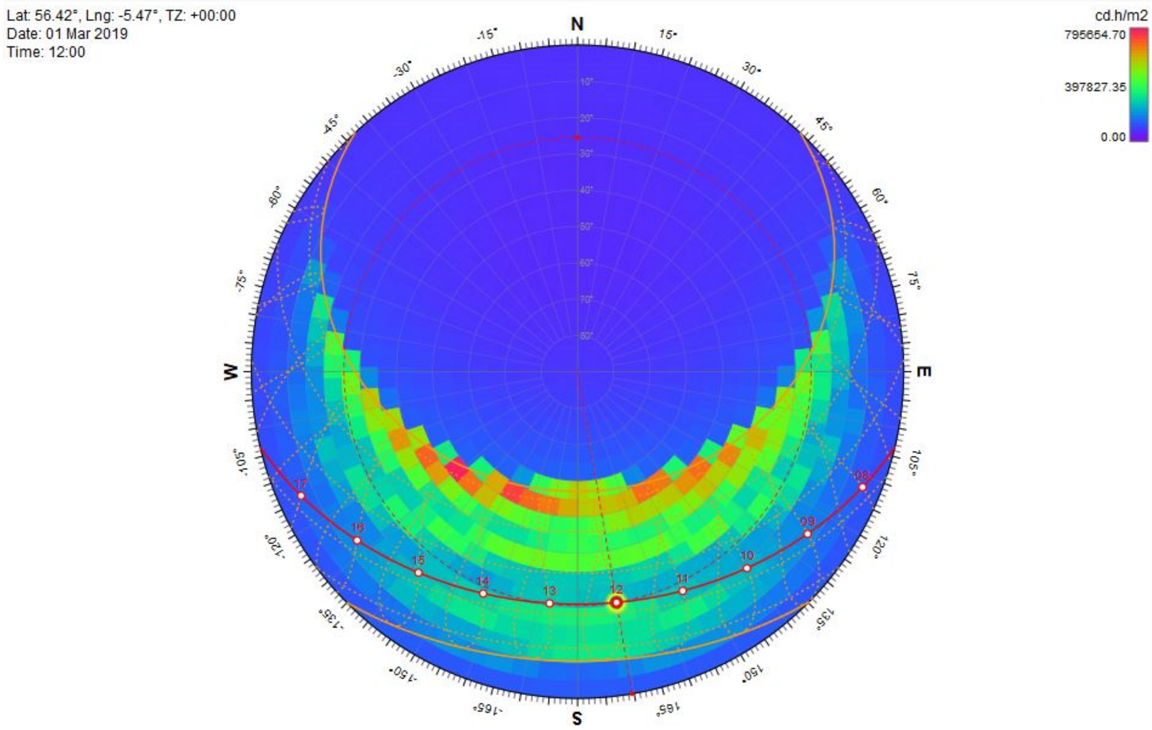

Fig. 20 The cumulative sky for all year with a 24-hour time range [14]

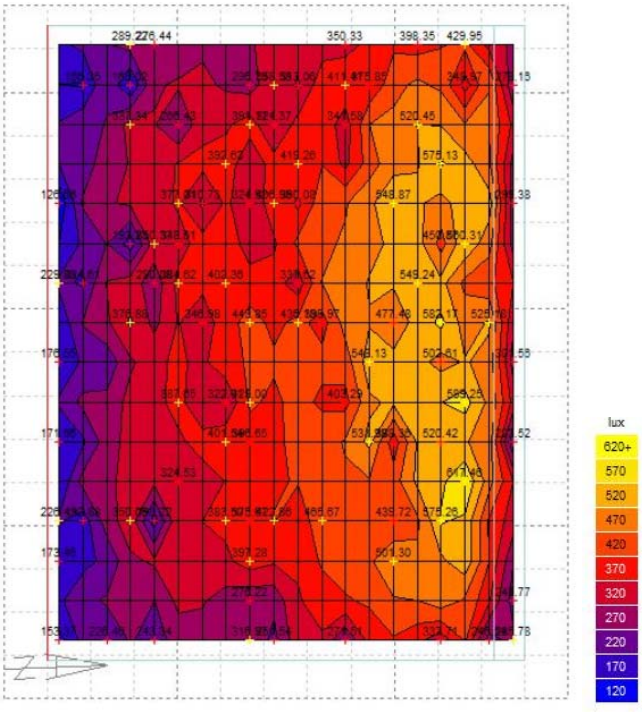

Fig. 21 Daylight levels analysis for studio A

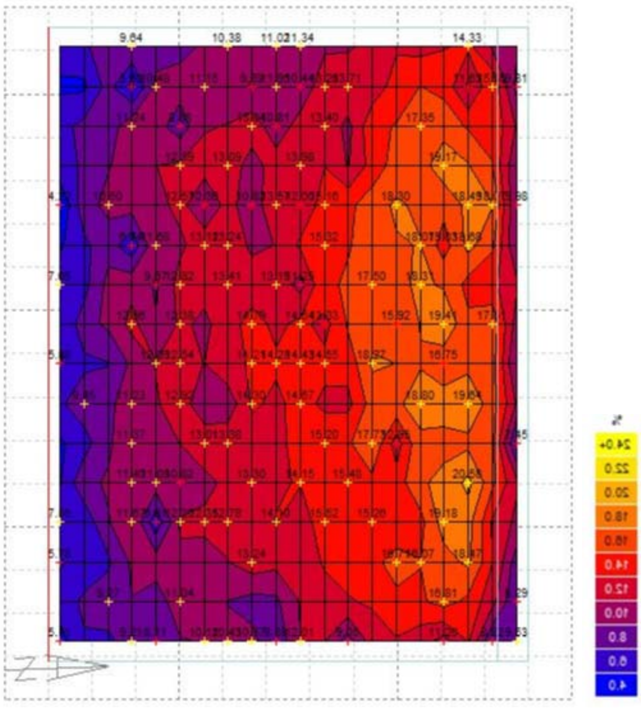

Fig. 22 Daylight factor analysis for studio A

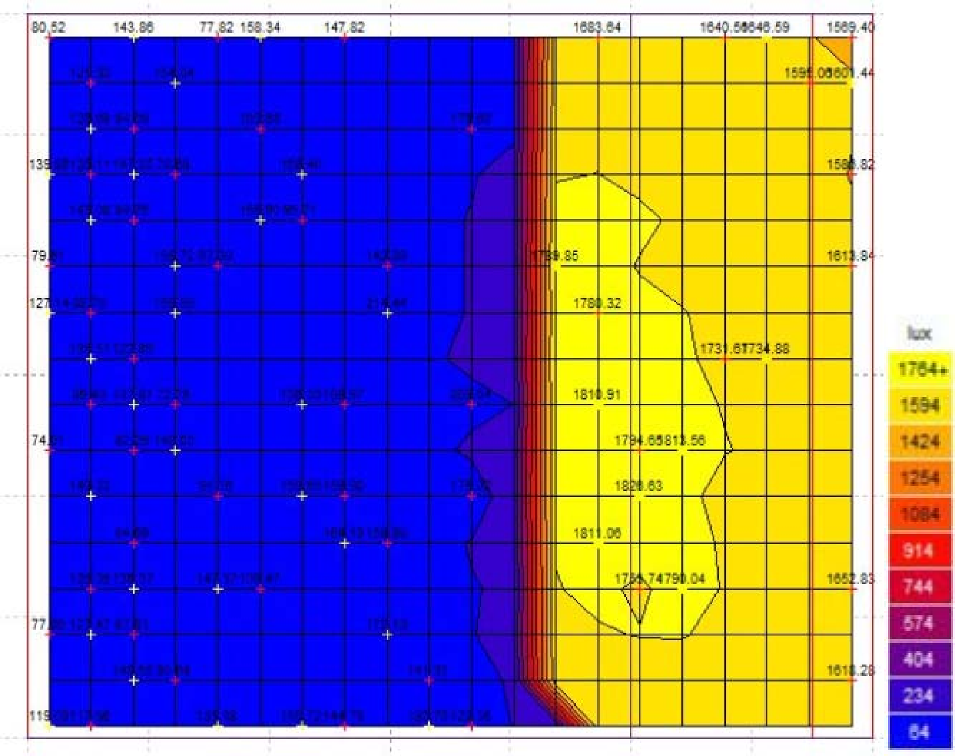

Fig. 23 Daylight levels analysis for studio B

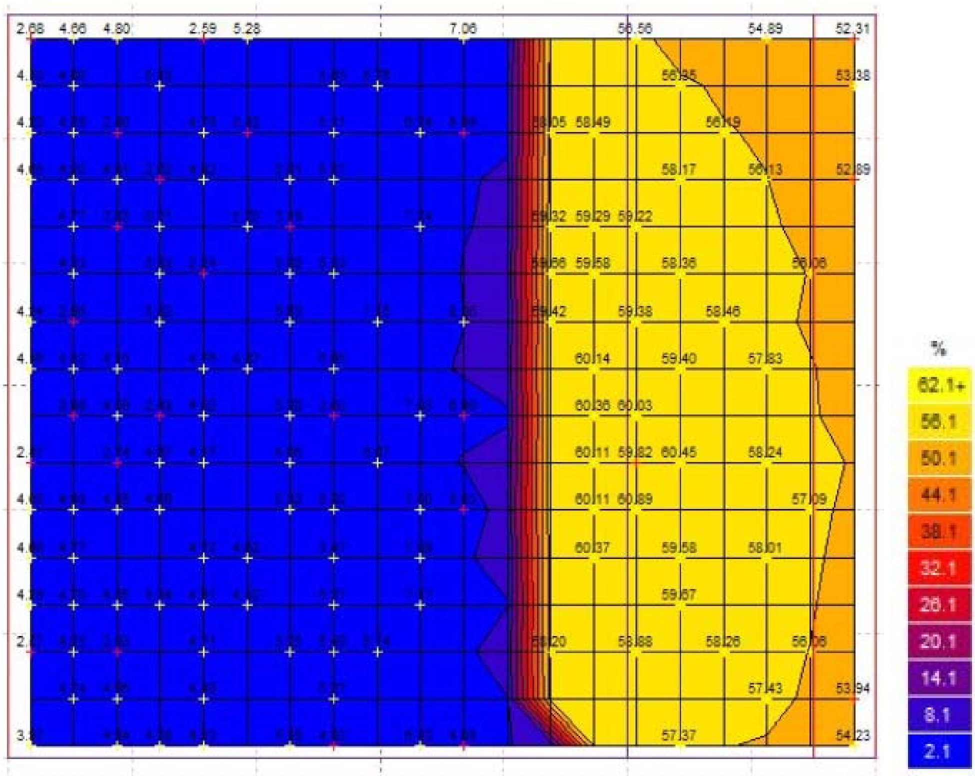

Fig. 24 Daylight factor analysis for studio B

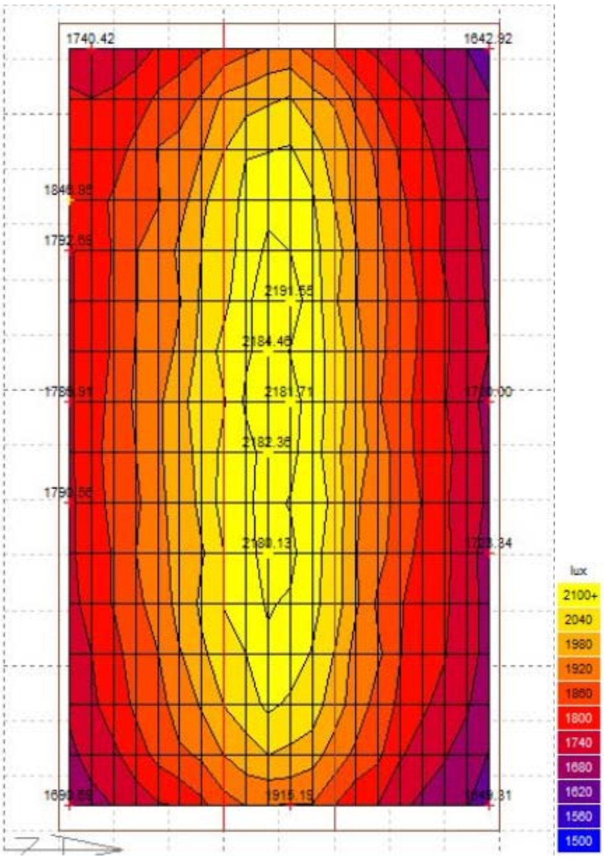

Fig. 25 Daylight levels analysis for studio C

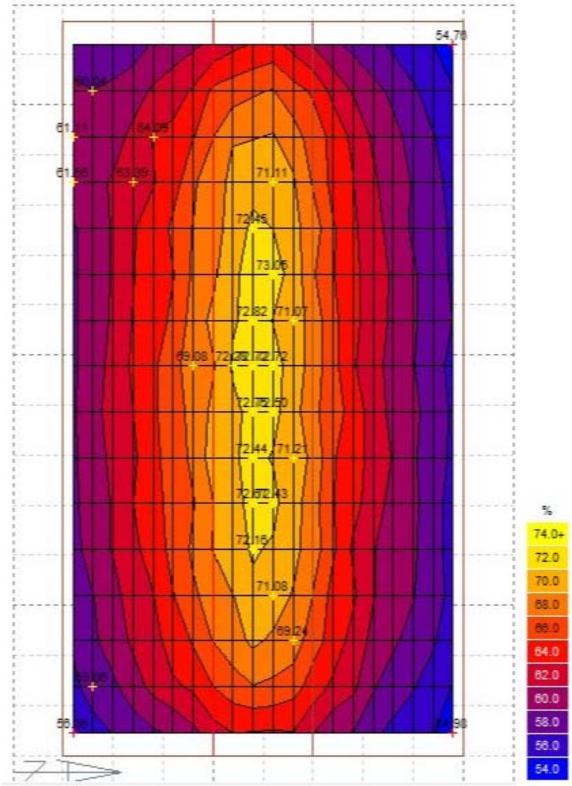

Fig. 26 Daylight Factor analysis for studio C

Studio (D) is adjusted to studio (C) along the south elevation, however, the window design is different in that it is extended along the elevation with 2m height. The average daylight levels for studio (C) registered at1935 lux with a contour range of 1500-2100 lux, in which 1700, 1900, 2192, 1920, 1800 lux registered from 1 m, 2 m, 5 m, 9 m and 14 m respectively from the north elevation. Meanwhile, the average daylight factor registered at 64.51% with a contour range of 54-74%%, in which 54%, 60%, 73%, 64%, 62% registered from 1 m, 2 m, 5 m, 9 m and 14 m respectively from the north elevation. Although the studio has a wider window than in studio (C), the way this affects daylight levels is minimal.

From the above analysis, it is clear that there is a considerable difference between the daylight levels in studios along the north elevation and the studios located along the south elevation, especially when the sun position is close to the northern or southern horizon, or as a result of wind coverage, the height of the building from the ground level, and fenestration characteristics. Moreover, special additions, such as the skylight and light shafts design, are beneficial in overcast locations, although thermal comfort should also be considered.

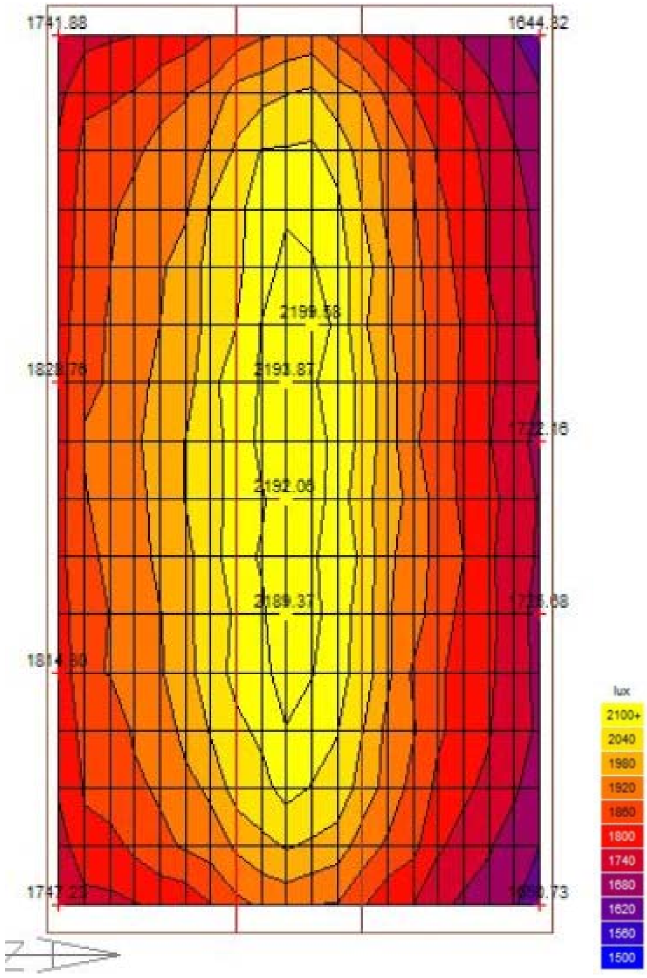

Fig. 27 Daylight levels analysis for studio D

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V. Conclusion

Daylight design is critical in overcast locations, where sun positions and movement should be considered in façade design. The analysis demonstrates that the studio dimensions and orientation play a major role in daylight levels inside. For the investigated studio along the north elevation, where average daylight levels on 0.79 working plan registered less than 500-700 lux, then artificial lights are needed to provide the required daylight levels for functional needs, as mentioned in the SLL code for light and lighting. According to the studios along the south elevation, the average daylight levels registered higher than the recommended value because of the use of skylight. However, based on the researcher's observations, artificial lights were on during the winter as the cloud coverage was 100%.

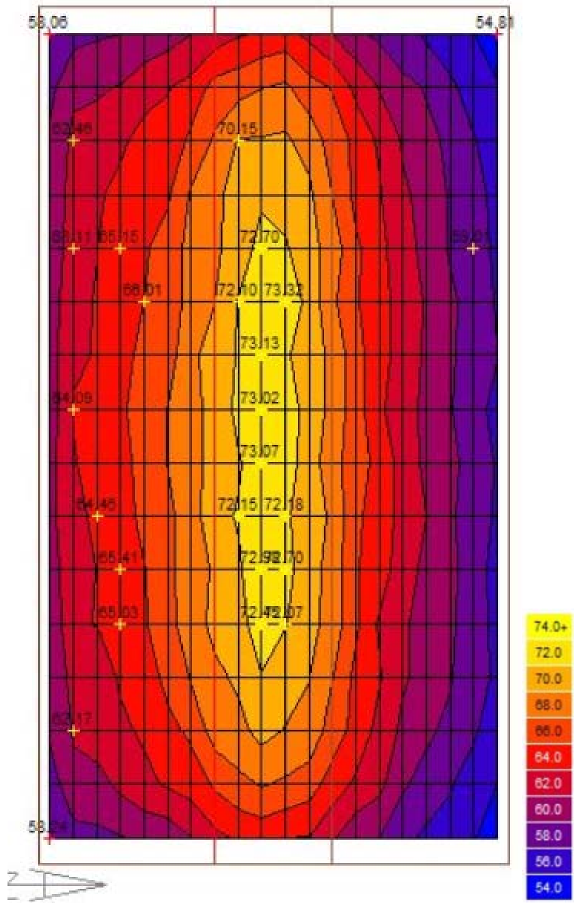

Fig. 28 Daylight factor analysis for studio D

References

[1] Hobday, R., 2006. The light revolution. Forres: Findhorn.
[2] Rem Koolhaas, A. Z.-P. S. T. V. B. o. A. (. I. B., 2014. Facade. Venice: Marsilio.
[3] K Darian-Smith, J. W., 2017. Designing Schools. London: Routledge.
[4] Eskandari, M., 2019. redesign school. (Online) Available at: http://redesign.school/ (Accessed 9 5 2019).
[5] Peter Raynham, S. o. L. a. L., 2012. The SLL code for lighting. London: CIBSE.
[6] Wei Wu, E. N., 2003. A review of daylighting in schools. Lighting Res.Technol., 2(35), p. 111–125.
[7] Hanna, R., 2002. Environmental appraisal of historic buildings in Scotland: the case study of the Glasgow School of Art. Building and Environment, Volume 37, pp. 1-10.
[8] Holl, S., 2007. Charlie rose (Interview) (23 7 2007).
[9] Moore, R., 2014. The Guardian. (Online) Available at: https://www.theguardian.com/artanddesign/2014/mar/02/reid-building-review-mackintosh-glasgow-school-art-steven-holl (Accessed 13 7 2017).
[10] Frearson, A., 2014. Dezeen. (Online) Available at: https://www.dezeen.com/2014/03/06/glasgow-school-of-art-reid-building-steven-holl/ (Accessed 9 11 2019).
[11] Platt, C. J., 2013. Uneasy balance. Glasgow: MSA Publications.
[12] Archdaily, 2014. archdaily. (Online) Available at: https://www.archdaily.com/483381/seona-reid-building-steven-holl-architects (Accessed 9 5 2019).
[13] Thorsen, S., 2019. timeanddate.com. (Online) Available at: https://www.timeanddate.com/information/copyright.html (Accessed 9 5 2019).
[14] Marsh, D. A. J., 2018. ANDREWMARSH.COM. (Online) Available at: http://andrewmarsh.com/software/ (Accessed 9 5 2019).
[15] NOAA's Earth System Research Laboratory (ESRL), 2019. (Online) Available at: https://www.esrl.noaa.gov/gmd/grad/solcalc/ (Accessed 9 5 2019).
[16] SunEarthTools, 2019. SunEarthTools.com. (Online) Available at: https://www.sunearthtools.com/dp/tools/pos_sun.php#contents (Accessed 4 5 2019).