ISSN 2729-7640

sciendo

ALFA
ARCHITECTURE PAPERS
OF THE FACULTY OF ARCHITECTURE AND DESIGN STU
www.alfa.stuba.sk

2/2024 (Vol. 29)
DOI: 10.2478/alfa-2024-0010

Enhancing visual comfort in staircases: A comprehensive analysis and design recommendations

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Article information
Sent: Apr 17, 2024
Accepted: Jun 14, 2024

Abstract: People should be walking towards the inside of the dwelling through an appropriate visual environment in transitional space; this environment is the staircase in the collective housing. The proper understanding of visual adaptation parameters in the staircase helps architects provide a suitable environment for inhabitants. This paper aims to specify design elements of the staircase in collective housing, to achieve a visual comfort in this transitional space. The work involved two approaches: field measurements and a visual comfort survey using a questionnaire; 144 questionnaires are collected, in four residential buildings with different staircases treatment in the city of Arris, Algeria, to examine the illuminance levels in different staircase positions along the path from outside the building to inside, in summer and winter where illuminance ratios were calculated and compared with CIBSE Code. The discomfort sensations ranged from "subtle" to "dramatic". The results show that a staircase with the percentage of opening of 88% indicated "strong" and "dramatic" visual shock in many points and as this staircase is open, it is exposed to light conditions and so it does not ensure the necessary transition. This leads to advising against the open staircase. In the case of a staircase treated with transoms of clear glass with the percentage of opening of 11%, these transoms direct the light to specific areas creating "strong" visual shock in many points of the stair landings and hence it leads to advise against that. The staircases treated with vertical bays throughout the façade presenting a percentage of opening between 19% and 22%, these treatments allow the penetration of daylight in a diffused way which ensures a balanced distribution of daylight inside the staircases. The existence of a solid overhang at the entrance; the façade treated with vertical bays, where the percentage of opening of the façade is about 19% and 22%, provided adequate transition leading to reasonable visual comfort.

Keywords: visual comfort, transitional space, adaptation, staircase, design, illuminance, changes, occupants, performance

INTRODUCTION

Sustainable building design is a dynamic field that continuously evolves to incorporate new approaches that minimize a building's environmental impact. A crucial aspect of this approach is creating a healthy and comfortable indoor environment. This, in turn, significantly influences the well-being, comfort, and productivity of the building's occupants. Sustainable structures make the most of natural light and use the right ventilation and moisture control techniques. Additionally, it is crucial to maximize the building's acoustic performance and provide residents control over the lighting and climate systems. Natural light affects not only our biological mechanisms but also our ability to see (Gronfier et al., 2004). It has practical, aesthetic, and emotional effects on the design of the built environment (Belakehal, et al. 2009). It is crucial to consider how the user will feel in the light conditions. By including issues for aesthetics, amenity, comfort, energy efficiency, and cost efficiency, a more suitable approach must balance the needs of owners, tenants, and society (Gregg, Saddler, 1995). Transitional spaces are defined as spaces located in-between outdoor and indoor environments (Pitts, Bin Saleh, 2007), so they are neither interior nor exterior spaces. People should approach the interior of a house through a suitable visual environment in a transitional space; in a collective housing, this last visual environment is the staircase.

When designing a building's interior or transitional space, light is a crucial component. Designing well-lit spaces with daylight presents complexities in achieving optimal lighting conditions. It is not a new concept to use natural light to illuminate indoor spaces. In the 1990s, the well-being of building residents received increasing attention. This interest is driven in part by long-term and broader issues covered by the "green buildings and sustainable design movements" (Gregg, Saddler, 1995). In these spaces, the occupants are able to experience the dynamic effects of the external climatic changes (Taleghani, et al., 2014). The ability of users to adapt to changing dynamic conditions of the environment around them is very important. Luminous conditions can change drastically as users transit from indoor to outdoor spaces or vice versa. The human eye has physical, neural and photochemical mechanisms for adapting to changing light conditions (Rea, 2000). While the human eye can adjust to a wide range of light levels (luminance), rapid changes in brightness, luminance, and contrast can cause temporary discomfort for many; especially for the elderly, for whom such visual shock may be detrimental, painful (Steffy, 2002). Bright light changes cause vision problems. Glare, from excessive or uneven light, disrupts how we see. Scotomatic, a type of glare, reduces our ability to see briefly after bright light exposure. This happens because light receptors in our eyes take time to recover after being overwhelmed. (Wooten, Hammond, 2002)

A study by Araji et al. (2007) identified changes in lighting conditions in architectural transition spaces as one of the main factors in altering human eye adaptation and identified this problem as a possible cause of "visual shock" (Araji et al., 2007). Therefore, in these transitional spaces, subjects might not have enough time to reach a stable state of visual adaptation to ensure the best response needed to perform a task. At the same time, the subjects could suffer some kind of visual discomfort (Owsley, et al., 1983). Most studies were related to thermal comfort in transitional spaces (Li, et al., 2018; Tse, Jones, 2019; Du, et al., 2020; Lu, Li, 2020). A few discussed the problem of visual comfort in transitional spaces, and examined eye adaptation and how users perform in these spaces.

The study effected by Araji et al. (2007), explores the issue of light adaptation and visual discomfort due to drastic variations in light intensity near building entryways. Also López et al. (2012) deals with features of light closer to user perception. To evaluate the visual reaction in a transitional space, four parameters were used. Lasagno et al. (2014) aim to perform a field experiment to quantify the effect of an abrupt change of the illuminance at a transitional space on the task performance under transient adaptation. The limited availability of recent research on the transitional space stems from two factors: a scarcity of studies conducted in this environment and the inadequacy of existing standards for such spaces. This lack of prior research, however, fuelled our interest in investigating the visual conditions within the transitional space, and highlights this neglected space.

Transitional spaces can provide different functions, including seating areas, circulation passage as staircase, entrance lobby, cafeteria, and meeting places (Ilham, 2016). Lighting is an important aspect regarding stair safety design (Van de Perre, et al., 2019). Poor lighting has been associated with an increased risk of falls on stairs (Jacobs, 2016). Staircases shall be provided with adequate natural lighting. Many elements, such as the kind of glass used, the quantity, size and placement of windows, and the layout of the staircase, affect how well natural lighting illuminates staircases (Marco, 2003). This paper studies the effect of staircase design on the visual comfort of users and how they perform and adapt in this transitional space.

MATERIALS AND METHODS

This research employs a two-pronged approach: field measurements and a visual comfort survey conducted using a questionnaire. A questionnaire was employed to assess participant responses to luminous environment within staircases in four buildings in Arris, Batna city, Algeria. The survey investigates the subjective appreciation of daylight conditions in typical staircases with varying design and different percentage area of windows opening. The research design is represented in Fig. 1.

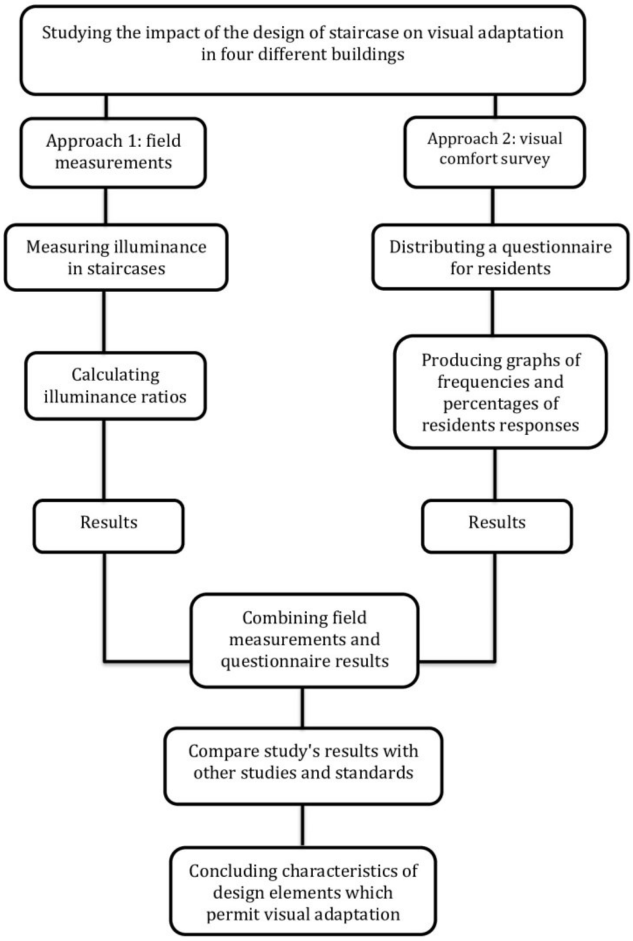


Fig. 1. Research design. (Source: Authors, 2024)

Case study description

Arris is a Daira in the Wilaya of Batna in eastern Algeria. It is located in the South East of the Wilaya, about sixty km (Fig. 2). The coordinates of the city are: 35° 15′ 30″ north, 6° 20′ 40″ east. The region is generally presented as a region of moderate relief and slopes steep. This mountainous region has altitudes between 1100 and 2000 m. The summers are mostly clear; winters are partly cloudy. The climate of Arris is a semi-arid.

The study focuses on four buildings located in three districts: Building 1 in the district of 32 housing units, Building 2 in the district of Zarouali Ahmed Belahcen, Buildings 3 and 4 in the district of 1st November. The details of the selected buildings are listed in Tab. 1. To ensure a controlled investigation of the effect of the transitional space design and daylighting's influence on visual adaptation in different designs, the study employed similar building characteristics throughout. The four buildings selected for this study have a different staircase design with a different percentage of openness. This selection aligns with the study's objective: to investigate the influence of staircase design on visual adaptation. Additionally, the buildings share similar characteristics such as orientation and colour, minimizing the effects of these variables and allowing for a more focused analysis of design impact.

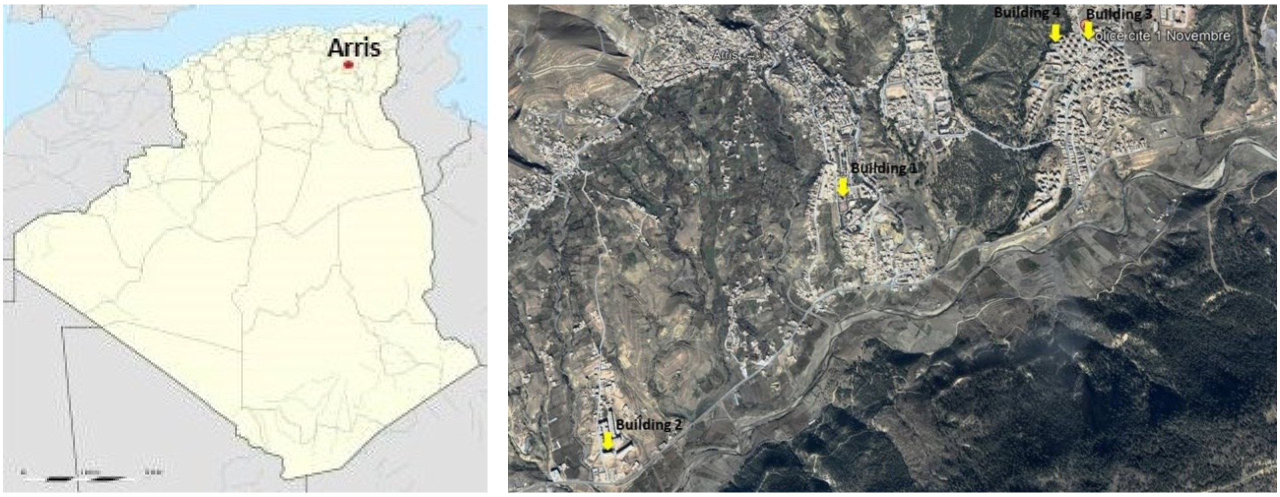
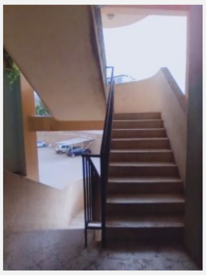
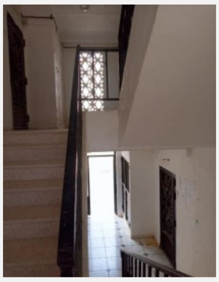
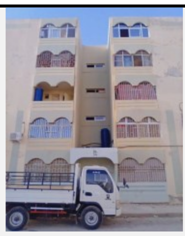
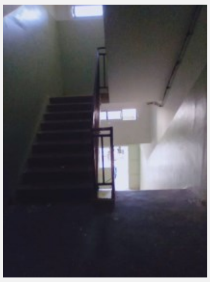
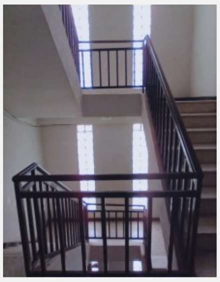
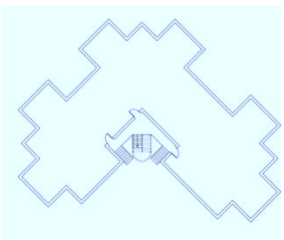
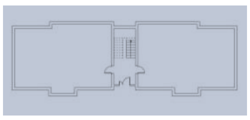
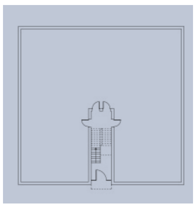
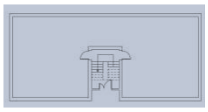


Fig. 2. (a) Geographical location of Arris city (Google), (b) Location of the Buildings in the Arris city. (Source: Google Earth, 2023)

Tab. 1. Case study description. (Source: Authors, 2023)

Information	Building 1	Building 2	Building 3	Building 4
Staircase	 	 	 	 
Plan				
Staircase dimensions	5.60 m * 5.60 m	2.60 m * 6.75 m	2.35 m * 8.0 m	2.70 m * 4.0 m
Percentage of the area which enters the light in the staircase	88%	19%	11%	22%
Staircase treatment	Opened	Vertical bays (10 * 60 cm/120 cm)	Transom of clear glass (4 * 40 cm/140 cm)	Vertical bays (8 * 40 cm/220 cm)
Floors number	4	6	5	5
Orientation	Northeast	North		
Climate	Semi-arid			

Sky conditions	Overcast	
Soil colour	Shades of grey	
Façade colour	Between light brown and off-white	
Colour inside staircase	Between light brown and off-white	
Entrance door dimensions	300 * 250 cm	90 * 210 cm
Distance between each two points of measurements	250 cm	
Measurements day	20, 21, 22 January	
Measurements time	8 a.m., 12 a.m., 2 p.m., 4 p.m.	

Field measurement

Field measurements were conducted in winter 2021 (20th, 21st and 22nd January) and in summer 2021 (20th, 21st and 22nd July), in four staircases of collective housing buildings in the Arris city. Measurements were taken during daytime hours at 8 a.m., 12 a.m., 2 p.m., 4 p.m. as these are the hours when residents go and return from school and work. The quality of day lighting was evaluated by measuring horizontal illuminance levels at the height of 1.5 m from the ground. The measurements were taken at that level to simulate the average human height. Horizontal illuminance is a standard metric for assessing daylight quality in buildings, including on horizontal surfaces like stairs, which are crucial for safe navigation. 172 measurements were taken from the exterior of the buildings to the interior of the houses passing through each landing in the staircase (Fig. 3 left). A distance of 2.5 m is maintained between each measuring point. Illuminances were measured by Delta OHM LP 471 PHOTO (Fig. 3 right) (Photometric probe for measuring the illuminance, spectral response according to the photopic curve, class B according to CIE N° 69, cosine correction diffuser. Measuring range: 0.10 lx…200·10^3 lx).

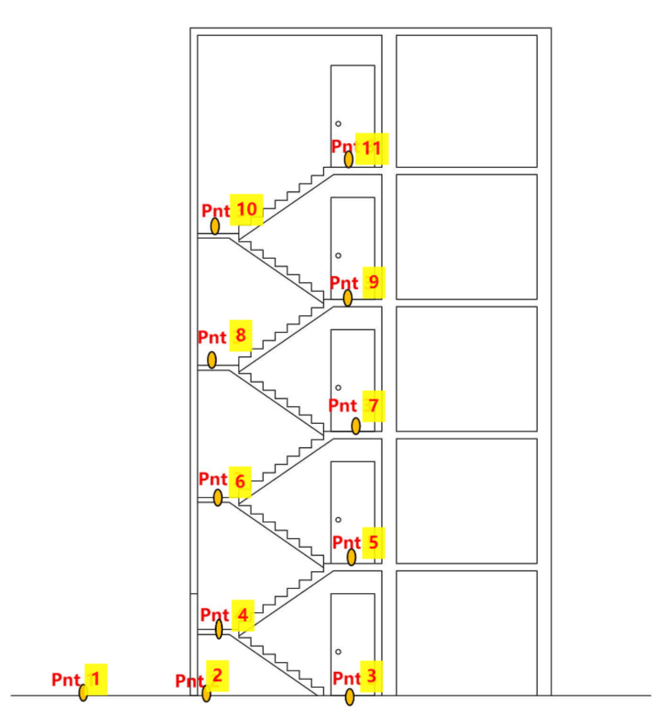


Fig. 3. Top: Measurements points. (Source: Authors, 2023). **Below:** Measurement with Delta OHM LP 471 PHOT. (Source: left – TESTOON, 2022; right – INDOMULTIMETER, 2024)

The illuminance at a point *P* on a particular surface is a physical quantity measured in lx and defined as the ratio of the luminous flux incident on a small surface near *P* to the area of that surface (*Arec*).

E*p* = df / d*Arec* (Lx) .... (Eq. 1)

To evaluate the amount of light with a one-sided criterion, illuminance is used to construct a local and short-term metric. Visual comfort is not only related to the amount of light, but also to how it is distributed. The illuminance uniformity (U_0) of a given plane is defined as the ratio, at a given time, between the minimum value of illuminance on the plane (E_{min}) and the average illuminance on that plane ($E_{average}$). It is also possible to use the ratio between the minimum and maximum (E_{max}) values of illuminance on the given plane, but this must be specified (Carlucci, et al. 2015). Illuminance and its distribution across the task area and its surroundings have a major impact on how quickly, safely and comfortably a person perceives and performs a visual task. Excessive variations of horizontal illuminance across an interior must be avoided; the diversity of illuminance expressed as the ratio of the maximum illuminance to the minimum illuminance. In many lighting applications, performing tasks does not require high-precision visual focus. This releases lighting designers from the strict adherence to uniform illuminance levels, allowing them to introduce more variation (CIBSE, 2002).

The established standards, such as Leadership in Energy and Environmental Design (LEED), are primarily focused on optimizing interior spaces. These frameworks may not be directly applicable to transitional spaces, as the activity, behaviour, and needs within these spaces differ significantly from those within traditional interiors; our study highlights a potential discomfort factor due to significant lighting level changes between the house interior and exterior space (as shown in Tabs. 3, 5 and 9 in the result section). Since staircases connect these areas, we examined the visual conditions there. Given the substantial illuminance difference (e.g. 8705 lx and 21.5 lx) and the limited time it takes to traverse a staircase (less than 1 min) compared to human eye adaptation time (up to 30 min in the case of dark adaptation (Rea, 2000)), we are concerned about the ability of occupants to comfortably navigate this transitional space.

Questionnaire survey

To determine how the residents felt and performed inside the staircases, a visual comfort questionnaire was designed. The questionnaire consisted of three sections: physiological symptoms, visual task performance and user preferences. The questionnaire responses were processed using Microsoft Excel, which produced graphs and charts to illustrate the survey results. *Part 1* of the survey asks about the physiological indications that may occur to the residents. The intention for this section was to determine how many people experienced at least one physiological symptom. *Part 2* of the survey asks about how users perform and what kind of disturbances they may feel inside the staircases. *Part 3* of the survey asks about how the user feels about the light in the staircases. The results will show how the users actually perceived the space.

Part 1: Physiological symptoms

Please, choose an answer according to how you feel

When leaving the building:

I feel that it is dark

My vision becomes blurred

Yes / No

When entering the building:

I feel pain in my eyes

My eyes tear up

I have a headache

I blink

My vision becomes blurred

I feel that it is too bright

Yes / No

Part 2: Visual task performance

1. It is difficult to see the first stairs

2. It is difficult to see the handrails

3. It is difficult to find something that I dropped

4. It is difficult to identify people

Very difficult / difficult / neutral / easy / very easy

5. I bump into someone because I did not see them

Yes / no

Part 3: Preferences

1. How do you find the light in the staircase?

Very low / low / neutral / strong / very strong

2. Do you find that the distribution of light is similar along the course of the staircase? Yes / no

3. Which place causes you visual discomfort?

The entrance to the building

The entrance to the house

Moving from one level to another

There is not such a place

RESULTS

Field measurements

According to CIBSE (2002), "Objective Display Illuminance Ratios", can be described on a scale ranging from subtle to dramatic as indicated in Tab. 2.

Tab. 2. Visual comfort sensation according to the CIBSE. (Source: CIBSE, 2002; modified by Authors, 2023)

Display effect	Objective display illuminance ratio	
Subtle	5 : 1	
Moderate	15 : 1	
Strong	30 : 1	
Dramatic	50 : 1	

The current method compares measured data to the CIBSE recommendations. Illuminance ratios were computed and then matched on a four-point scale of "Objective Display Illuminance Ratios" ranging from "subtle" to "dramatic", expressing the variations in illuminance ratios between various points of measurements. It is very important to note that although the CIBSE guidelines were not initially intended to be used for assessing visual comfort in transitional spaces, they measure visual comfort based on objective display illuminance ratios and thus the authors feel that there is no reason not to use them in transitional spaces.

Our field study revealed significant illuminance variations within the staircase. To assess the impact on visual adaptation, we chose the CIBSE Code: Objective Display Illuminance Ratios (2002). CIBSE's illuminance ratio method helps identify zones within the staircase where occupants are more likely to experience discomfort due to significant changes in illuminance levels. It aligns with visual adaptation principles and offers a flexible approach applicable in various contexts, unlike fixed illuminance values in some standards, which can be challenging to maintain with daylight variations in lx.

The sensitivity lag of the cone system adapts in about 5–7 minutes (Miller, Tredici, 1992) or 10–12 minutes (Rea, M.S., 2000) with high levels of luminance. The rod system will take 30–45 minutes or longer to adapt to fully dark situations to attain maximum sensitivity after exposure to bright light (adaptation is about 80% complete within 30 minutes) (Rea, 2000). The equation provides the amount of time (T) required for a walking person to travel within the given transitional space.

T= D/V ……………………………………….(.Eq2)

Where:

T: is the time (sec)

D: is the distance between two consecutive station points (m),

V: is the average walking speed (m/sec)

On average, a speed of 0.77 m/sec for normal walking speed in stairs for all age groups was used. Therefore, the time required to travel from point to point equals 3.2 sec (3.2 sec = 2.5m / 0.77m/sec).

Building 1:

Tab. 3 indicates big differences in illuminance levels in winter period at 8 a.m. between points three and four (10 lx, 284 lx), five and six (17.2 lx, 420 lx), and between points seven, eight, nine and ten (36.8 lx, 828 lx, 30.7 lx, 1.07 lx), leading to illuminance ratios of 28.4:1, 24.4:1, 22.5:1, 26.9:1, 28.7:1 respectively (Tab. 4). As this staircase is open, it is exposed to light conditions, so it does not ensure the necessary transition. According to the CIBSE, illuminance ratio of more than 15:1 is considered strong and has the potential to provoke a visual shock to residents when they walk through the staircase and when they enter to the house. At the entrance of Building 1, the stair landings protrusion served as an overhang and permitted "subtle" and "moderate" visual shock in summer, providing adequate transition leading to reasonable visual comfort. The staircase presenting the percentage of opening of 88%, indicated "strong" visual shock in most points of the staircase at 8 a.m., and "moderate" visual shock at 12 a.m., 2 p.m. and 4 p.m., while in winter, a strong visual shock was indicated at several points.

Tab. 3. Illuminance value (lx) in Building 1. (Source: Authors, 2023)

Position	Illuminance value (Lux) Building 1							
Time	8 a.m.		12 a.m.		2 p.m.		4 p.m.	
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
Outdoor (Pnt 1)	291	19720	8947	18940	11037	13340	6368	7440
Door (Pnt 2)	62	4141	2363	4924	1446	1734	1369	1562
Entrance Hall (Pnt 3)	10	763	568	366	411	341	332	303
Stair landing 01 (Pnt 4)	284	13990	6478	5040	5300	4680	2857	4130
Stair landing 02 (Pnt 5)	17.2	677	570	454	396	449	328	345
Stair landing 03 (Pnt 6)	420	10900	8560	5270	6098	4660	2610	3740
Stair landing 04 (Pnt 7)	36.8	960	986	535	552	495	278	433
Stair landing 05 (Pnt 8)	828	18720	11320	6990	7780	6610	4260	6030
Stair landing 06 (Pnt 9)	30.7	904	487	798	450	766	341	719
House (Pnt 10)	1.07	46	15.27	62	17	70	11.3	78

Tab. 4. Illuminance ratio Building 1 (in summer and winter period). (Source: Authors, 2023)

Transition position	Illuminance ratios Building 1								
Winter period	Pnt 1-2	Pnt 2-3	Pnt 3-4	Pnt 4-5	Pnt 5-6	Pnt 6-7	Pnt 7-8	Pnt 8-9	Pnt 9-10
8 a.m.	4.7:1	6.2:1	28.4 :1	10.7:1	24.4 :1	11.4 :1	22.5 :1	26.9 :1	28.7 :1
12 a.m.	3.8 :1	4.2:1	11.4 :1	11.4:1	15 :1	8.7 :1	11.5 :1	23.2 :1	31.9 :1
2 p.m.	7.6 :1	3.5 :1	12.9 :1	13.4 :1	15.4 :1	11 :1	14.1 :1	17.3 :1	26.5 :1
4 p.m.	4.7 :1	4.1 :1	8.6 :1	8.7 :1	7.9 :1	9.4 :1	15.3 :1	12.5 :1	30.1 :1
Summer period									
8 a.m.	4.7 :1	5.4 :1	18.3 :1	20.6 :1	16.1 :1	11.3 :1	19.5 :1	20.7 :1	19.6 :1

12 a.m.	3.8 :1	13.4 :1	13.7 :1	11.1 :1	11.6 :1	9.8 :1	13:1	8.7 :1	12.8 :1
2 p.m.	7.6 :1	5:1	13.7 :1	10.4 :1	10.3 :1	9.4 :1	13.3 :1	8.6 :1	10.9 :1
4 p.m.	4.7 :1	5.1 :1	13.6 :1	11.9 :1	10.8 :1	8.6 :1	13.9 :1	8.3 :1	9.2 :1

Building 2 and 4:

Tab. 4 and 5 show big differences in illuminance levels between points two and three (at the entrance of the buildings), with value of 990 lx, 57 lx and 380 lx, 21 lx respectively, leading to illuminance ratios of 17.4:1 and 18.1:1 and between points thirteen and fourteen 48.8 lx, 1.2 lx with ratio of 40.3:1. (Tab. 7, 8) which according to the CIBSE code (Tab. 2) are considered strong and dramatic and as such cause a visual shock, at the entrance of these buildings and when entering to the houses. As found in the study of Araji (2007), the absence of transition element in the entrance of the building can cause a visual shock. Tab. 5 between points from three to thirteen and from point three to eleven (in stair landings), show little difference in illuminance levels. The values reach 57 lx, 66 lx, 17.9 lx, 58 lx, 26.6 lx, 76.6 lx, 35 lx, 98.9 lx, 45.7 lx, 190 lx, 48.8 lx and 21.5 lx, 26.8 lx, 108 lx, 33.1 lx, 94.1 lx, 35 lx, 115 lx, 28.9 lx respectively, leading to illuminance ratios of 1.2:1, 3.7:1, 3.2:1, 2.2:1, 2.9:1, 2.2:1, 2.8:1, 2.2:1, 4.2:1, 3.9:1 (Table VI) and 1.02:1, 1.2:1, 4.02:1, 3.3:1, 2.8:1, 2.7:1, 3.3:1, 3.9:1. (Tab. 7), which according to the CIBSE code (Tab. 2) are considered subtle. Clearly, these values indicate a better transition as opposed to the previous results. The treatment of the staircases represented in vertical bays throughout the façade allows the penetration of daylight in a diffused way which ensures a balanced distribution of daylight inside the staircases. This design leads to better visual comfort transition between indoors and outdoors. However, there is a rating of "moderate" discomfort as the user transits between point three and point four. The overall results are acceptable and encounter no strong or dramatic visual shock in the transitional space.

Tab. 5. Illuminance value (lx) in Building 2 and Building 4. (Source: Authors, 2023)

Position	Illuminance value (Lux) Building 2							
Time	8 a.m.		12 a.m.		2 p.m.		4 p.m.	
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
Outdoor (Pnt 1)	1900	7970	13905	12150	11907	13080	5108	14490
Door (Pnt 2)	990	4144	6608	5710	4850	5232	2378	6665
Entrance Hall (Pnt 3)	57	170	291	833	333	704	210	510
Stair landing 01 (Pnt 4)	66	343	274	1001	565	733	292	332
Stair landing 02 (Pnt 5)	17,9	133	115	303	272	399	86	392
Stair landing 03 (Pnt 6)	58	344	583	966	714	774	325	486
Stair landing 04 (Pnt 7)	26,6	163	301,5	354	306	466	103	634
Stair landing 05 (Pnt 8)	76,7	368	1052	849	752	706	233	592
Stair landing 06 (Pnt 9)	35	153	481	354	300	466	109	633
Stair landing 07 (Pnt 10)	98,9	350	1738	871	746	755	261	580
Stair landing 08 (Pnt 11)	45,7	88	587	225	284	223	81	230
Stair landing 09 (Pnt 12)	190	340	1722	1112	1178	841	304	463
Stair landing 10 (Pnt 13)	48.4	134	1527	326	901	444	321	620
House (Pnt 14)	1.2	46	13.2	62	11	69	9.4	73

Position	Illuminance value (Lux) Building 4							
Time	8 a.m.		12 a.m.		2 p.m.		4 p.m.	
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
Outdoor (Pnt 1)	3300	5580	8705	10220	7362	8680	8169	6360
Door (Pnt 2)	380	613	3240	3781	1928	2256	1777	1335
Entrance Hall (Pnt 3)	21	23	698	211	207	142	57	38
Stair landing 01 (Pnt 4)	21.5	20	470	249	224	198	68	122
Stair landing 02 (Pnt 5)	26.8	22	808	149	191	103	58	35
Stair landing 03 (Pnt 6)	108	96	1592	1057	1178	746	251	279
Stair landing 04 (Pnt 7)	33.1	26	842	134	182	96	62	40

Stair landing 05 (Pnt 8)	94.1	88	1552	1057	832	685	206	128
Stair landing 06 (Pnt 9)	35	27	715	139	148	98	24.3	37
Stair landing 07 (Pnt 10)	115	144	1590	1202	760	796	75	168
Stair landing 08 (Pnt 11)	28.9	390	282	1404	176	1076	20.2	585
House (Pnt 12)	2.19	11	21.5	15	5.9	12	1.4	7

Tab. 6. Illuminance ratio Building 2 (in summer and winter period). (Source: Authors, 2023)

Transition position	Illuminance ratios Building 2												
Winter period	Pnt 1-2	Pnt 2-3	Pnt 3-4	Pnt 4-5	Pnt 5-6	Pnt 6-7	Pnt 7-8	Pnt 8-9	Pnt 9-10	Pnt 10-11	Pnt 11-12	Pnt 12-13	Pnt 13-14
8 a.m.	1.9:1	17.4:1	1.2:1	3.7:1	3.2:1	2.2:1	2.9:1	2.2:1	2.8:1	2.2:1	4.2:1	3.9:1	40.3:1
12 a.m.	2.1:1	22.7:1	1.1:1	2.4:1	5.1:1	1.9:1	3.5:1	2.2:1	3.6:1	2.9:1	2.9:1	1.1:1	115.7:1
2 p.m.	2.5:1	14.6:1	1.7:1	2.1:1	2.6:1	2.3:1	2.5:1	2.5:1	2.5:1	2.6:1	4.1:1	1.3:1	81.9:1
4 p.m.	2.1:1	11.3:1	1.4:1	3.4:1	3.8:1	3.2:1	2.3:1	2.1:1	2.4:1	3.2:1	3.7:1	1.1:1	34.1:1
Summer period													
8 a.m.	1.9:1	24.3:1	2:1	2.5:1	2.5:1	2.1:1	2.2:1	2.4:1	2.2:1	3.9:1	3.8:1	2.5:1	2.9:1
12 a.m.	2.1:1	6.8:1	1.2:1	3.3:1	3.1:1	2.7:1	2.3:1	2.3:1	2.4:1	3.8:1	4.9:1	3.4:1	5.2:1
2 p.m.	2.5:1	7.4:1	1:1	1.8:1	1.9:1	1.6:1	1.5:1	1.5:1	1.6:1	3.3:1	3.7:1	1.8:1	6.4:1
4 p.m.	2.1:1	13.0:1	1.5:1	1.1:1	1.2:1	1.3:1	1.0:1	1.0:1	1.0:1	2.5:1	2.0:1	1.3:1	8.4:1

Tab. 7. Illuminance ratio Building 4 (in summer and winter period). (Source: Authors, 2023)

Transition position	Illuminance ratios Building 4										
Winter period	Pnt 1-2	Pnt 2-3	Pnt 3-4	Pnt 4-5	Pnt 5-6	Pnt 6-7	Pnt 7-8	Pnt 8-9	Pnt 9-10	Pnt 10-11	Pnt 11-12
8 a.m.	8.7:1	18.1:1	1.02:1	1.2:1	4.02:1	3.3:1	2.8:1	2.7:1	3.3:1	3.9:1	13.2:1
12 a.m.	2.7:1	4.6:1	1.5:1	1.7:1	1.9:1	1.9:1	1.8:1	2.2:1	2.2:1	5.6 :1	13.1:1
2 p.m.	3.8:1	9.3:1	1.1:1	1.2:1	6.2:1	6.5:1	4.6:1	5.6:1	5.1:1	4.3:1	29.8:1
4 p.m.	4.5:1	31.2:1	1.2:1	1.2:1	4.3:1	4:1	3.3:1	8.5:1	3.1:1	3.7:1	14.1:1
Summer period											
8 a.m.	9.1:1	26.6:1	1.1:1	1.1:1	4.3:1	3.6:1	3.3:1	3.2:1	5.3:1	2.7:1	35.4:1
12 a.m.	2.7:1	17.9:1	1.1:1	1.6:1	7.0:1	7.8:1	7.8:1	7.6:1	8.6:1	1.1:1	93.6:1
2 p.m.	3.8:1	15.8:1	1.3:1	1.9:1	7.2:1	7.7:1	7.1:1	6.9:1	8.1:1	1.3:1	89.6:1
4 p.m.	4.7:1	35.1:1	3.2:1	3.4:1	7.9:1	6.9:1	3.2:1	3.4:1	4.5:1	3.4:1	83.5:1

Building 3:

Tab. 7 indicates little difference in illuminance levels between points one, two and three: 1115 lx, 186 lx, 42 lx and 4680 lx, 1440 lx, 313 lx and 4519 lx, 860 lx, 276 lx and 5004 lx, 1115 lx, 186 lx, respectively, leading to illuminance ratios of 5.9:1, 4.4:1 and 3.3:1, 4.6:1 and 5.3:1, 3.1:1 and 4.5:1, 5.9:1. However, there is a rating of “moderate” discomfort, when the overall results are acceptable and encounter no strong or dramatic visual shock in the transitional space. As mentioned in the study of Araji (2007), the presence of solid overhang at the entrance of the building leads to smaller or moderate visual shock in the transitional space. Illuminance ratios between points four, five, six, seven, eight, nine and ten change from subtle to dramatic discomfort (Tab. 8). The transoms pierced along the façade allow the penetration of daylight in a directional way which creates areas less illuminated and then some big differences in illuminance levels between stair landings which cause visual discomfort inside the staircase. The little difference in illuminance levels between points ten and eleven (Tab. 9) leads to illuminance ratios of 10.7:1, 1.8:1, 5.7:1, 4.9:1 (Tab. 10) indicating subtle and moderate discomfort. Reducing the illuminance levels near the doors of houses can guarantee entering the house without suffering from visual discomfort.

Tab. 8. Illuminance value (lx) in Building 3. (Source: Authors, 2023)

Position	Illuminance value (Lux) **Building 3**							
Time	8 a.m.		12 a.m.		2 p.m.		4 p.m.	
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
Outdoor (Pnt 1)	1115	4370	4680	8990	4519	10730	5004	13360
Door (Pnt 2)	186	699	1440	2697	860	2038	1115	2939
Entrance Hall (Pnt 3)	42	65	313	588	276	526	186	432
Stair landing 01 (Pnt 4)	3.6	8	12.53	21	13.5	19	13.7	17
Stair landing 02 (Pnt 5)	33.4	65	104	134	112	117	129	92
Stair landing 03 (Pnt 6)	1.55	7	8.8	18	8.8	16	9	14
Stair landing 04 (Pnt 7)	67	65	97	106	125	109	142	113
Stair landing 05 (Pnt 8)	3.8	8	14.6	19	13.1	17	10	14
Stair landing 06 (Pnt 9)	74	89	103	145	165	144	215	143
Stair landing 07 (Pnt 10)	4.9	13	24.9	45	23.1	35	18.9	20
House (Pnt 11)	0.46	6	13.55	7	4	4	3.8	7

Tab. 9. Illuminance ratio Building 3 (in summer and winter period). (Source: Authors, 2023)

Transition position	Illuminance ratios Building 3									
Winter period	Pnt 1-2	Pnt 2-3	Pnt 3-4	Pnt 4-5	Pnt 5-6	Pnt 6-7	Pnt 7-8	Pnt 8-9	Pnt 9-10	Pnt 10-11
8 a.m.	5.9:1	4.4:1	11.6:1	9.3:1	21.5:1	43.2:1	17.6:1	19.5:1	15.1:1	10.7:1
12 a.m.	3.3:1	4.6:1	24.9:1	8.3 :1	11.8:1	11:1	6.6:1	7.1:1	4.1:1	1.8:1
2 p.m.	5.3:1	3.1:1	20.4:1	8.3:1	12.7:1	14.2:1	9.5:1	12.6:1	7.1:1	5.7:1
4 p.m.	4.5:1	5.9:1	13.6:1	9.4:1	14.3:1	15.7:1	14.2:1	21.5:1	11.4:1	4.9:1
Summer period										
8 a.m.	6.2:1	10.7:1	8.1:1	8.1:1	9.2:1	9.2:1	8.1:1	11.1:1	6.8:1	2.1:1
12 a.m.	3.3:1	4.5:1	28:1	6.3:1	7.4 :1	5.8:1	5.5:1	7.6:1	3.2:1	6.4:1
2 p.m.	5.2:1	3.8:1	27.6:1	6.1:1	7.3:1	6.8:1	6.4:1	8.4:1	4.1:1	8.7:1
4 p.m.	4.5:1	6.8:1	25.4:1	5.4:1	6.5:1	8.0:1	8.0:1	10.2:1	7.1:1	2.8:1

Tab. 10. Comparison of Illuminance ratios in different building. (Source: Authors, 2023)

Transition position Pnt 1-3	Illuminance ratios (Summer period) Building 1	Building 2	Building 3	Building 4
8 a.m.	25.8	46.8	67.2	242.6
12 a.m.	51.7	14.5	15.2	48.4

2 p.m.	39.1	18.5	20.3	61.1
4 p.m.	24.5	28.4	30.9	167.3
Illuminance ratios (Winter period)				
8 a.m.	29.1	33.3	26.5	157.1
12 a.m.	15.7	47.7	14.9	12.4
2 p.m.	26.8	35.7	16.3	35.5
4 p.m.	19.1	24.3	26.9	143.3

QUESTIONNAIRE RESULTS

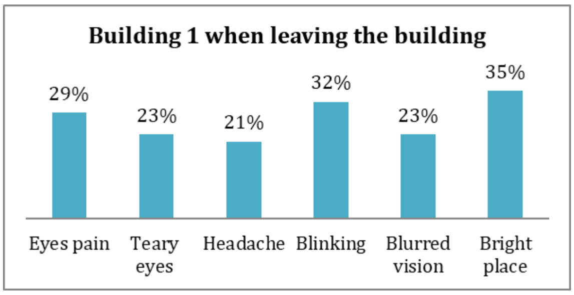
In the four buildings, 144 questionnaires were collected. The number of male respondents is 46%, and the number of female respondents is 54%. In order to produce graphs and charts for further comparisons, the data from each section of the questionnaire was processed in Microsoft Excel. This study employs a self-administered questionnaire for data collection. Questionnaires were distributed in paper format to residents of the four surveyed buildings. A brief explanation of the study's purpose accompanied the questionnaires. Residents completed the questionnaires at their convenience within their homes. Following completion, the questionnaires were retrieved. We conducted a pilot test with 14 participants from our target population (residents of the four surveyed buildings) of the visual comfort questionnaire to assess its clarity and effectiveness. The pilot test results were positive, and the questionnaire did not require any significant changes.

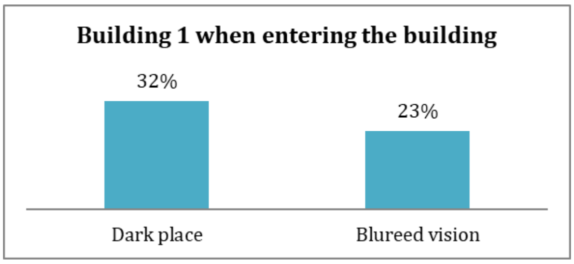
The statistical analysis of the visual comfort questionnaire data will help us understand how residents perceive the transitional space, represented by staircases, and their experiences within them. Since the questionnaire uses a combination of yes/no and Likert scale questions, we will employ appropriate statistical methods for each type of data. For yes/no questions, we calculate frequencies and percentages of 'yes' and 'no' responses. This will help us understand the prevalence of specific visual discomfort issues. For Likert scale questions, we calculate descriptive statistics like means and medians to identify the most common visual discomfort factors. This will provide a more nuanced understanding of how residents perceive different aspects of visual comfort within the staircases. To ensure validity, we conducted a pilot test with a small group of participants. The pilot test helped us assess whether the questions accurately captured residents' experiences and identify any areas for improvement in the questionnaire's clarity or comprehensiveness. The pilot test we conducted played a valuable role in assessing the questionnaire's potential reliability. By administering the questionnaire to the same participants twice, their responses remained consistent, which would be an indicator of reliability.

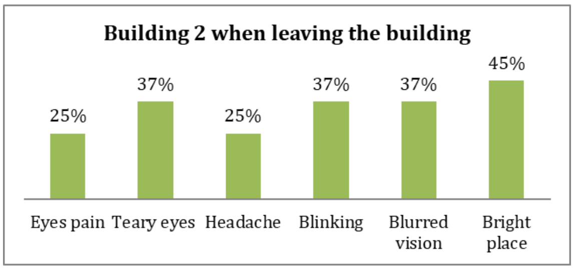
Participants were provided with a form that clearly explained the purpose of the study, the type of questions involved, and how their data would be used. They were assured of their anonymity and right to withdraw from the study at any point. All data will be anonymized and stored securely. Only authorized researchers will have access to the data. We are committed to conducting research ethically and respectfully of all participants.

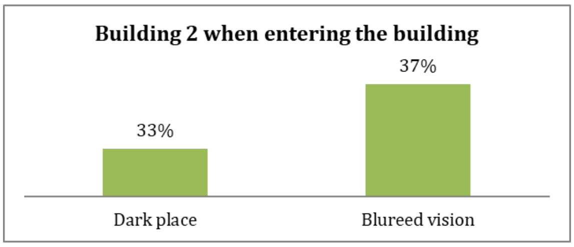
Part 1: Physiological symptoms

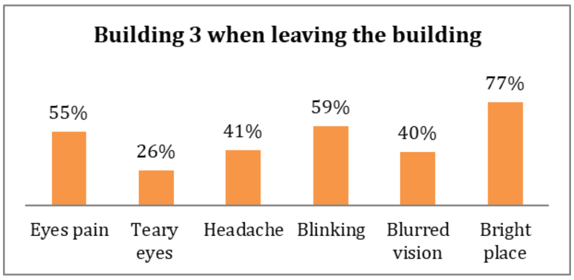
The results show that residents from the four buildings experience physiological symptoms of visual discomfort when leaving and entering the building, which signifies that the staircases do not represent the transitional space which offers the necessary conditions of adaptation. The highest percentages (Fig. 4) were found when residents were asked if they found the place too bright when they leave the building 35%, 45%, 77%, 83% respectively, which means that the illuminance is not gradual as needed in the path from the house to the outside of the building to make the necessary adaptation and to avoid visual shock.











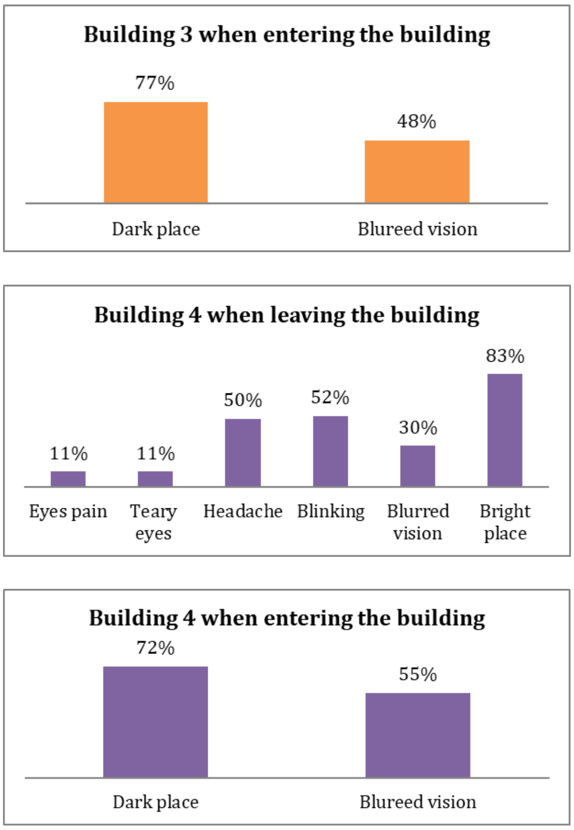
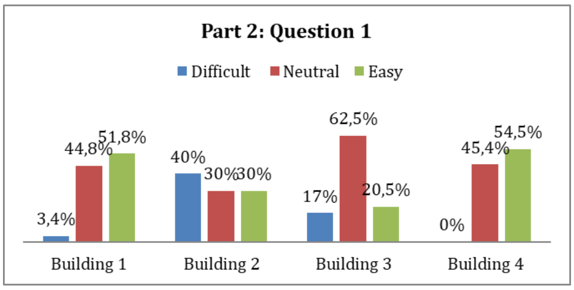


Fig. 4. Answers to Part 1 of the questionnaire. (Source: Authors, 2023)

Part 2: Visual task performance

Part 2 of the questionnaire will be assessed in the next discussion. Values range from -2 to 2, where -2 represents the most negative result (very difficult), while 2 represents the most positive result (very easy). In the four buildings, there are residents who have difficulties in performing visual tasks like difficulties to see the first stair, see the handrail, to find something that they dropped or identify people, which indicates problems in light distribution. In Building 2 negative values were more frequent than positive values, in buildings 1, 3 and 4 there were more positive values than negative ones, indicating that some residents adapt to the conditions in the staircases and used to them and perform normally (Fig. 5). For question 5 the highest percentage was in Building 3 because of the poor light in the staircase (Fig. 6).



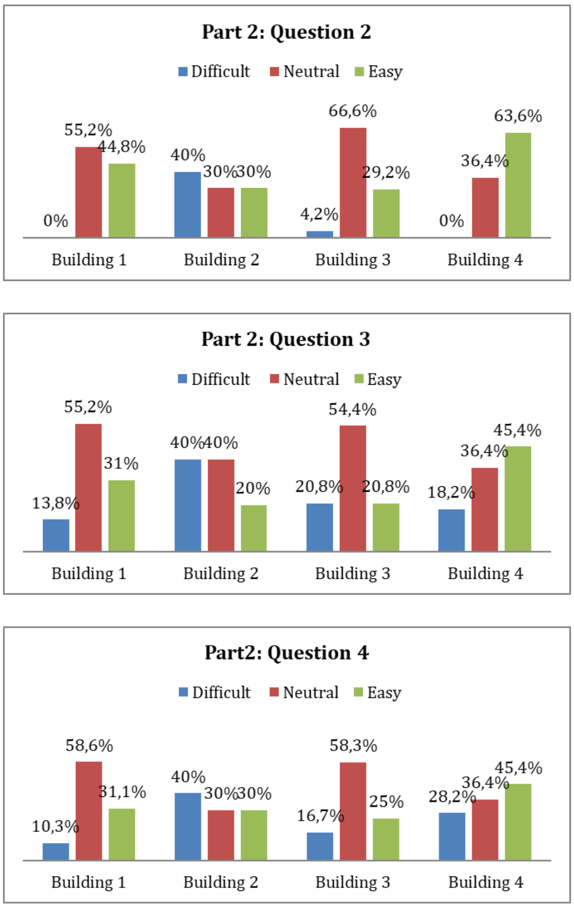


Fig. 5. Answers to Part 2 of the questionnaire. (Source: Authors, 2023)

Question 5: I bump into someone because I didn't see them

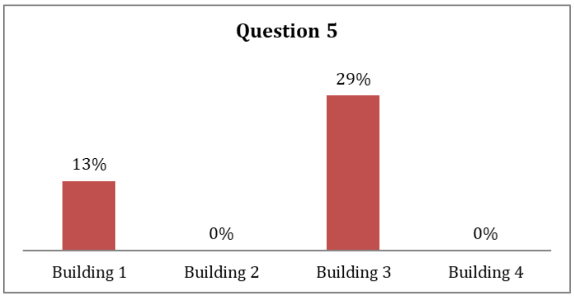


Fig. 6. Answers to Part 2, question 5 of the questionnaire. (Source: Authors, 2023)

Part 3: Preferences

In the four buildings, most respondents were neutral (Fig. 7). In Building 1, the second highest percentage of answers stated that the lighting is strong or very strong, and this is confirmed by the measurements, which is due to the fact that the staircase is open and exposed to direct lighting conditions. In Building 2, the second highest percentage of answers stated that the lighting is strong. In Building 3, the second highest percentage of responses stated that the lighting is weak and very weak, and this is confirmed by the measurements, which is due to the fact that the staircase openings are small and direct the lighting to specific areas. In Building 4, the second highest percentage of responses stated that the lighting is weak because there is no element at the entrance of the building ensuring the diminution of light with a comfortable gradation. In all buildings, there were residents who saw that the distribution of light is unbalanced while passing the staircases; the high percentage was in Building 3 confirming that treating the staircase with transoms introduce bad light distribution (Fig. 8).

Question 1: How do you find the light in the staircase?

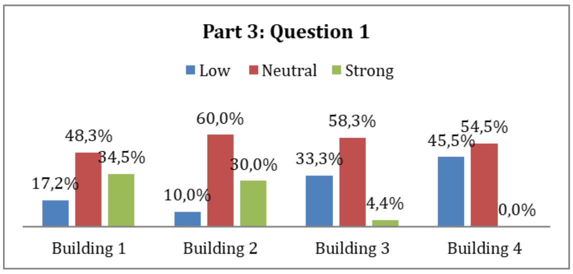


Fig. 7. Answers to Part 3, question 1 of the questionnaire. (Source: Authors, 2023)

Question 2: Do you find that the distribution of light is similar along the course of the staircase?

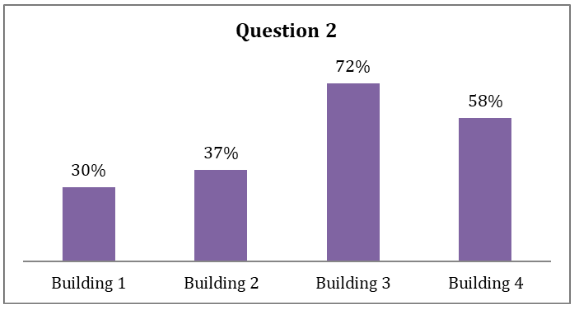
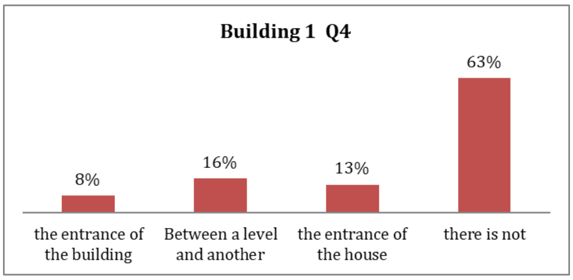
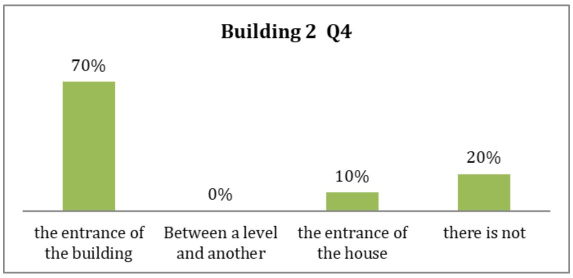


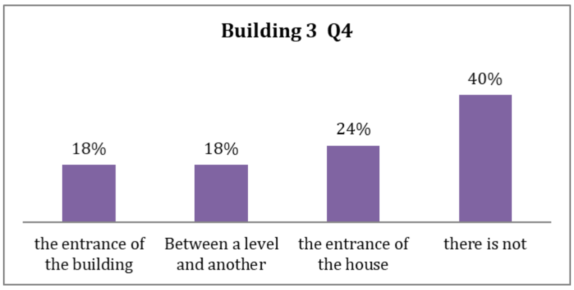
Fig. 8. Answers to Part 3, question 2 of the questionnaire. (Source: Authors, 2023)

Question 3: Which place causes you visual discomfort?

In this question, for buildings 1, 3 and 4, the highest percentages were for the inexistence of a place causing visual discomfort, showing that residents are used to the light conditions in staircases so they do not feel discomfort (Fig. 9). In Building 1, for the residents who expressed the presence of a place that causes them visual discomfort, the percentages were close, and the highest percentage was between one level and another, which confirms the results reached in the field measurements.







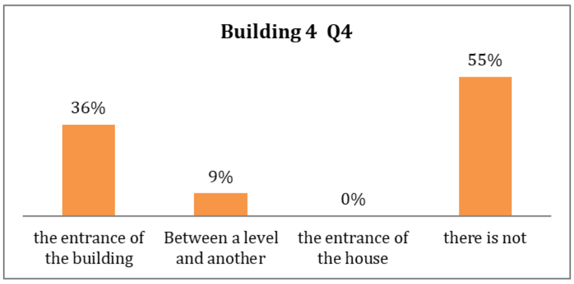


Fig. 9. Answers to Part 3, question 3 of the questionnaire. (Source: Authors, 2023)

DISCUSSION

Winter season

For the entrances:

At the entrance of Building 3, the solid overhang (with a depth of 2 m) permit "subtle" and "moderate" visual shock providing adequate transition leading to reasonable visual comfort and prepare the eye for the changes in illuminance (Fig. 10). As mentioned in the study of Araji (2007), the presence of solid overhead element at the entrance of the building leads to smaller or moderate visual shock in the transitional space. The absence of solid overhang at the entrances to Buildings 2 and 4 means that there is no area that allows for the gradation of illuminance values, making the eye experience a sudden change between the outside and inside of the building, which makes entering and exiting the building visually uncomfortable. In addition to that, in part 3, question 4 of the questionnaire, when residents were asked what place caused them visual discomfort, most of those who answered: the entrance to the building, were from Buildings 2 and 4.

Inside the staircases:

In Building 1 with percentage of the area entered by light of 88% indicated "strong" and "dramatic" visual shock in many points and as this staircase is open, it is exposed to light conditions so it does not ensure the necessary transition, which leads to advising against the open staircase. In Building 3 the staircase treated with transoms of clear glass with percentage of the area entered by light of 11%, these transoms direct the light to specific areas creating "strong" visual shock in many points of the stair landings which leads to advising against that. Buildings 2 and 4: the staircases treated with vertical bays throughout the façade presenting a percentage of opening of 19% and 22%, these treatments allow the penetration of daylight in a diffused way which ensures a balanced distribution of daylight inside the staircases, indicating "subtle" in most points and "moderate" in some points provides adequate transition leading to reasonable visual comfort in the stair landings, according to CIBSE (2002). In part 3, question 4 of the questionnaire, when residents were asked what place caused them visual discomfort, for who answered: between level and another, low percentages (0%, 9%) were from buildings 2 and 4.

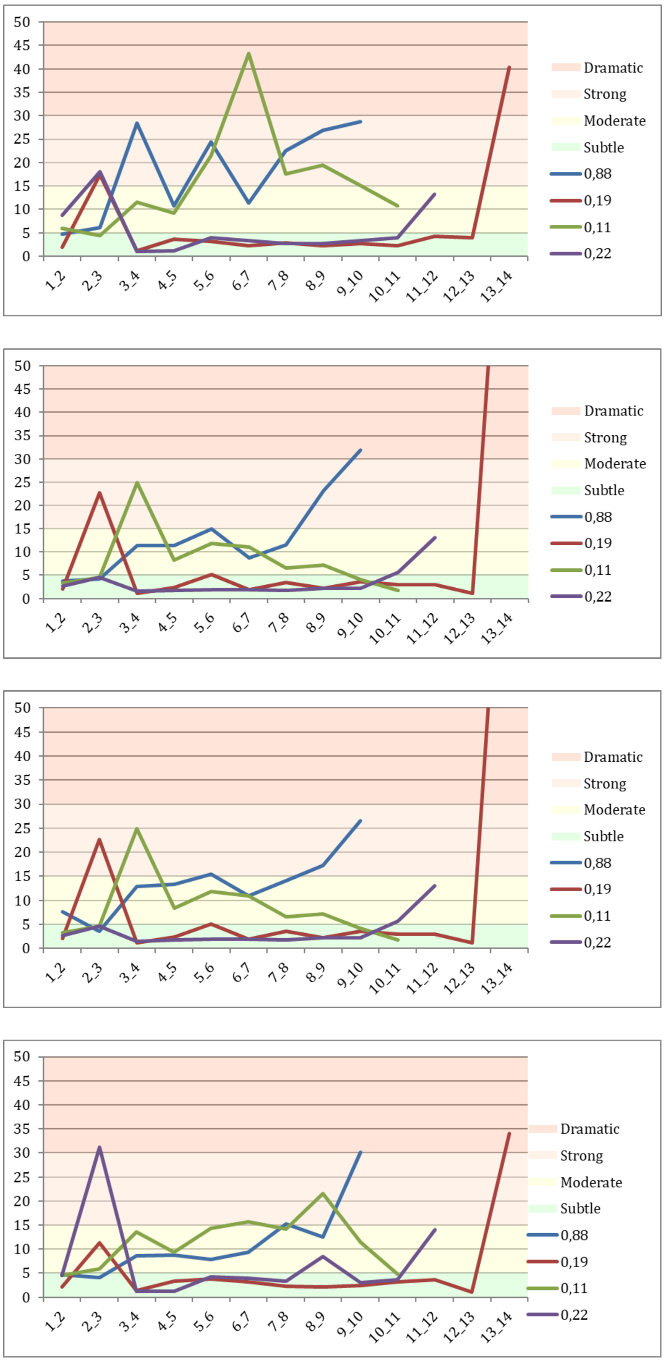


Fig. 10. Relation between percentage of opening of the staircase and visual shock in winter at 8 a.m., 12 a.m., 2 p.m. and 4 p.m. (Source: Authors, 2023)

Summer season

At the entrance of Building 1, the stair landings protrusion served as an overhang and permitted "subtle" and "moderate" visual shock providing adequate transition leading to reasonable visual comfort. At the entrance of Building 2, "strong" and "moderate" visual shock (Fig. 11) was indicated. As mentioned in the study of Araji (2007). At the entrance of Building 3, the solid overhang (with a depth of 2 m) permits "subtle" and "moderate" visual shock providing adequate transition. At the entrance of Building 4, "strong" and "dramatic" visual shock was indicated. The strong visual shock in summer was higher than in winter. The staircase presenting percentage of opening of 88%, indicated "strong" visual shock in most points of the staircase at 8 a.m., and "moderate" visual shock at 12 a.m., 2 p.m. and 4 p.m., while in winter, a strong visual shock was indicated at several points.

The staircase treated with vertical bays throughout the façade presenting a percentage of opening of 19% indicated "subtle" visual shock in all points of the staircase. "Subtle" and "moderate" visual shock was indicated at the entrance of houses, while in winter, it was strong. The staircase treated with transoms of clear glass presenting a percentage of opening of 11% indicated "moderate" visual shock in most points of the staircase and "strong" and "subtle" visual shock in some points; the "strong" visual shock in summer is less strong than in winter. The staircase treated with vertical bays throughout the façade presenting a percentage of opening of 22% indicated "subtle" and "moderate" visual shock. "Dramatic" visual shock was indicated at the entrance of houses, while in winter, it was mostly "moderate", according to CIBSE (2002).

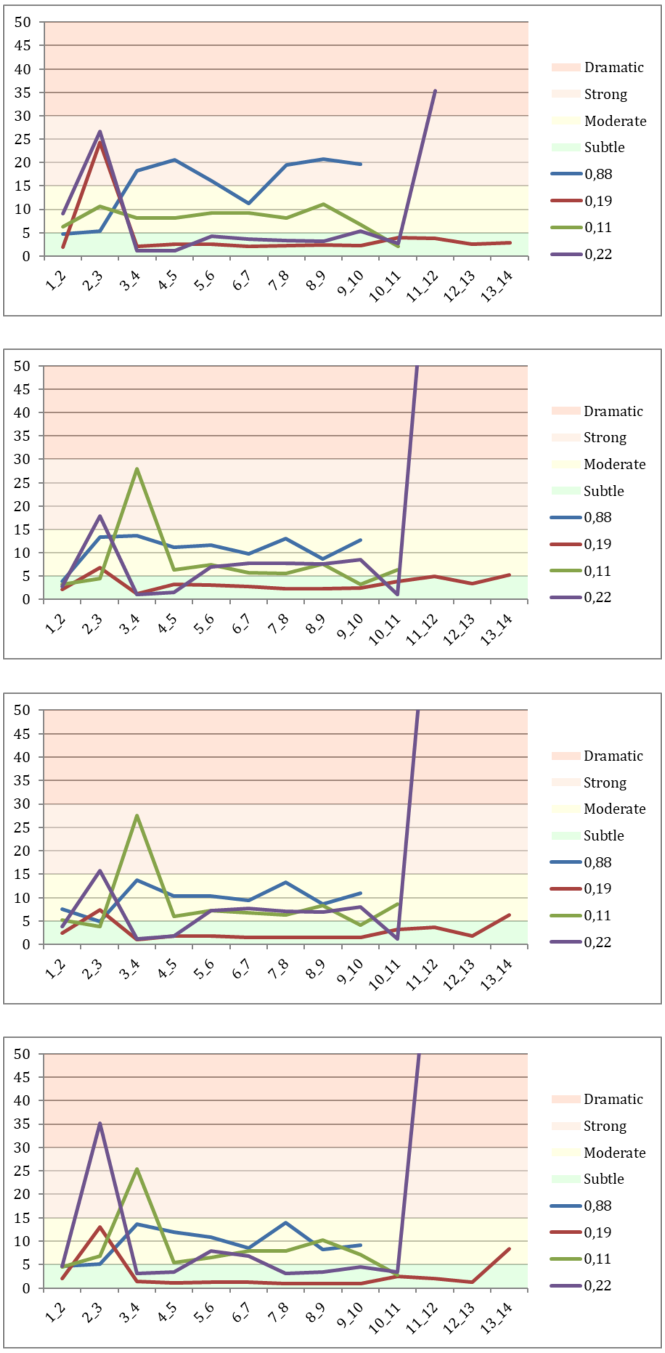


Fig. 11. Relation between percentage of opening of the staircase and visual shock in summer, at 8 a.m., 12 a.m., 2 p.m. and 4 p.m. (Source: Authors, 2023)

CONCLUSION

Accessing and walking in a building through comfortable transitional spaces is a necessity. These spaces ought to permit the user's visual system more time to make the necessary changes in adaptation. While relating physical measurements and questionnaire results with perceptions of visual comfort, this study indicated that: An open staircase, with the percentage of opening of 88%, exposed to light conditions, indicated "strong" and "dramatic" visual shock at many points in the staircase, which leads to advice against the open staircase. This was the staircase where the highest percentage of residents expressed that the light in the staircase is strong. Staircases treated with vertical bays throughout the façade, with percentages of opening ranging between 19% and 22%, allow the penetration of daylight in a diffused way which ensures a balanced distribution of light inside the staircases, indicating "subtle" in most points and "moderate" in some points providing adequate transition leading to reasonable visual comfort in the stair landings. These vertical bays reduced the percentage of residents expressing visual discomfort inside the staircase to 0%, while it was 18% inside the staircase with transoms, and 16% inside the open staircase.

The staircase treated with transoms of clear glass, with percentage of opening of 11%, directed the light to specific areas creating a "strong" visual shock in many points of the stair landings, hence it leads to advice against that. The highest percentage of residents (72%) expressed that the light distribution in the staircase is imbalanced. The existence of a solid overhang (2 m deep) above the entrance of a building, permits "subtle" and "moderate" visual shock providing adequate transition leading to reasonable visual comfort in the entrance of the building. Moreover, its inexistence caused visual discomfort, where the percentage of residents who expressed their visual discomfort at the entrance of a building without an overhang, reached 70%.

Residents from the different buildings experience physiological symptoms of visual discomfort when leaving and entering the building through the staircases, and there are residents who have difficulties in some visual tasks like difficulties to see the first stair, to see the handrail, finding something that they dropped or identifying people. However, significant percentages of them (55%, 63%) expressed that there was no place in the staircase causing them visual discomfort, even if they experienced it, showing that they are used to the light conditions in staircases that they do not feel disturbed or upset. Hence living in the same conditions for a long time makes them adapted to these conditions which makes it unnecessary to set very precise visual environment and allows wider visual comfort ranges in this transitional space.

Limitations and future studies

The study has limitations. Including a larger and more diverse sample of buildings with varying staircase designs and openness percentage would strengthen the findings and provide valuable insights to inform future building design. Future studies can build upon this research by expanding the diversity of staircases studied. This could involve including a wider range of architectural styles and locations.

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