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An international survey on residential lighting: Analysis of winter-term results

Rengin Aslanoğlu [a,*], Jan K. Kazak [a], Sepideh Yekanialibeiglou [b], Piotr Pracki [c], Begüm Ulusoy [d]

[a] Institute of Spatial Management, Wrocław University of Environmental and Life Sciences, Grunwaldzka 55, 50-357, Wrocław, Poland
[b] Department of Interior Architecture and Environmental Design, Faculty of Art, Design and Architecture, Bilkent University, Ankara, Bilkent, Çankaya, 06800, Turkey
[c] Institute of Electrical Power Engineering, Division of Lighting Technology, Warsaw University of Technology, 00-661, Warsaw, Poland
[d] Interior Architecture and Design, School of Design, University of Lincoln, Lincoln, Brayford Pool, LN6 7TS, UK

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ABSTRACT

By conducting an international survey on residential lighting, a great variety of data showing the differences and similarities in lighting conditions among Poland, Turkey, Sweden and the U.K. were collected which provided an overall perspective for raising the standards of luminous environments. A total of 500 participants (125 respondents from each country- 47.6% females, 51.2% males, and 1.2% who did not wish to specify gender) provided detailed self-assessments of the lighting conditions in their living areas. The study identified interrelated factors associated with residential lighting using descriptive statistics, correlation coefficient functions and thematic analysis. As the survey results showed, the satisfaction with daylighting quality depends on daylighting sufficiency, daylighting uniformity, and number of sunlight hours (i.e., sunlight exposure), view-out and ratio of windows in the living area. Moreover satisfaction with artificial lighting quality depends on artificial lighting sufficiency, artificial lighting uniformity, artificial lighting brightness, and artificial lighting color rendering index. Overall, the findings of the study showed the potential factors that can be used to effectively change the day- and artificial lighting in residential areas, leading to a sustainable and better lighting environment.

1. Introduction

Balancing the quantity and quality of lighting is fundamental solution for satisfactory lighting applications [1,2]. Academics, practitioners, and research funders are increasingly seeking to understand and evaluate [3] (p. 258) both day and artificial lighting in built environments, yet most research on lighting has been conducted for public interiors, leaving a gap in knowledge regarding residential lighting. By conducting an international survey on residential lighting, we collected data showing the differences and similarities in lighting conditions from Poland, Turkey, Sweden, and the U.K. This provided an overall perspective for raising the standards of luminous environments. As previous research [4–7] and related statistics [8] show, residential lighting is responsible for a significant share in energy consumption. It also causes environmental pollution and light pollution, defined by the International Commission on Illumination (CIE) [9] as the "sum total of all adverse effects of artificial light", and thus has an impact on humans and ecosystems [10,11]. Accordingly, it is critical that decisions related to residential lighting adopt The 2030 Agenda for Sustainable Development which has been accepted and applied by all United Nations Member States starting from 2015 [12]. However, goal-setting and policymaking demonstrates a one-way flow of knowledge from experts to policy-makers. All decided goals and policies regarding residential lighting, which affects communities and the publics' way of life, are then announced under a "decide-announce-defend model" [13,14] p. 2; [15]. This expert-driven process can sometimes appear too complex for the public to understand. Importantly, as highlighted by Riegler, Vogler, Neumueller and Komendantova [14]; the human factor of public support and willingness to participate are vital factors for the successful implementation of new goals and policies and lack of end-user support mitigates attempts to implement such changes. Thus, it is important to raise public participation in and awareness for new residential lighting policy in order to achieve such goals.

Lighting's environmental impact must be decreased, but it is also a key tool to achieve sustainability and it influences other human behaviors and activities. Sustainability in lighting cannot only be obtained with the developments in lighting design (such as improvements to energy efficiency, decreasing waste and emission, and lowering the use

* Corresponding author.
E-mail address: rengin.kocaoglu@bilkent.edu.tr (R. Aslanoğlu).

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of raw materials), but also with permanent changes in human behaviors such as attachment to land and tradition, cultural preservation, health and well-being, higher productivity and homogenous production and consumption [16] (p.5). In this manner, it is noteworthy to analyze end-users' self-assessments about residential and sustainable lighting. First, a luminous environment supports visual performance, comfort, productivity, well-being, and health of people [17–20]. It is widely accepted that all indoor environments, including residential areas, have a significant impact on people's lives and health. The relationship between the building conditions of residential areas and human well-being became more significant with the outbreak of the recent coronavirus pandemic. COVID-19 had a significant impact on people's routines and thus on their behaviors and priorities. Besides its numerous negative influences on people's lives, COVID-19 raised more awareness about how people spent time in residential buildings. Such areas are now not only shelters, but also offices, schools, and recreational areas. This will affect the future design and construction of residential areas.

As Altomonte et. al. [21] highlighted, "the visual scene needs to be considered holistically, accounting for the dynamic contribution of all sources of direct and reflected light, and where people are most likely to be looking" (p. 4). Thus, this study focuses on the overall lighting conditions of the living areas in which people spend most of their time while occupying their residential buildings [22]. It should also be noted that the visual scene includes both day and artificial lighting, as well as the surfaces onto which lighting falls and reflects and their characteristics such as color and transparency. All surfaces and the absolute levels of illumination determines the visual field. However, the relative brightness is more important than the absolute levels of illumination [21]. Taking into account the previously mentioned aspects, this study captures respondents' subjective assessments of the lighting conditions in their living areas (such as their user behaviors, satisfaction levels, personal attempts in increasing their well-being, perspectives about sustainability and lighting policies) to identify their particular needs and potential lighting solutions. This study also focuses on winter-term evaluations with more challenging lighting conditions compared to the summer-term since, human circadian rhythms are not only diurnal but also seasonal [23,24]. As humans are evolved according to lighting patterns that are closest to the Earth's natural cycle of bright days, dark nights [21] (p.4), and seasons, having access to indoor daylight is key to support the circadian well-being of occupants. In addition, daylight exposure influences sleep cycles, memory formation, immune response, growth, development, mental functioning, and metabolic health [25, 26].

In brief, we examine the existing luminous environments of residences in Poland, Turkey, Sweden and the U.K. with the aim of identifying how to improve visual comfort and sustainability. In order to investigate geographical, seasonal, and subjective differences, an international survey was formed and distributed in four countries to obtain a crosscutting perspective. This survey collected a great variety of data addressing the needs and perspectives of end-users about residential lighting and related policies. Since luminous environments support visual performance, comfort, productivity, well-being, and the health of occupants, it is important to gather self-assessments. This was especially important given the dramatic changes to people's routines occasioned by the coronavirus pandemic. The new multipurpose nature of residential areas necessitated a re-analysis of needs while producing new opportunities for research, one of which is the study of day and artificial lighting as it affects the provision of high-quality living areas. Overall, the gap in the literature can be filled through future investigations that address the issues highlighted in this study. This paper compares and contrasts winter-term residential lighting conditions in four different countries while emphasizing end-users' perspectives about sustainable lighting and lighting policies, since overall success in sustainability and balancing quantity and quality of lighting can only be achieved with their support.

2. Method

Day and artificial lighting is an intricate and broad concept that needs to be examined from various perspectives using more than one scientific methodology. Thus, a mixed methods perspective was used in this study for gathering valuable knowledge about day and artificial lighting which cannot be obtained by a single methodology. Qualitative studies are used for understanding the "why" and "how" whereas quantitative studies are focusing on cause and effect, how much, and numerical correlations [27]. In order to converge the strengths of multiple methodologies (quantitative methods' large sample size, trends, generalization; qualitative methods' small sample size, detail, in-depth answers [28]) we used one of the most common and well-known approaches to mixing methods, "Triangulation Design: Validating Quantitative Data Model" [29]. With this design, it is possible to gather "different but complementary data on the same topic" [30] (p. 122) and build a broad understanding about the concept. Hence, this study used mixed methods to obtain new and valuable insights about day and artificial lighting by conducting an international survey that expanded quantitative results with qualitative data.

Before the international residential lighting survey was distributed, the authors conducted a pilot study between July–August 2020 with a sample size of 60 participants to check the clarity and understandability of the survey questions [22]. The pilot study gathered respondents' comments on the entire survey, which suggested modifications concerning the wording of questions and survey structure. We provided some additional explanations and/or photographs for questions based on the pilot study's evaluations before it was distributed to 500 participants in winter-term to be used for the current study. The pilot study depicted the most impactful results on the topic of day and artificial lighting in residential areas and showed their possible causes. Thus, for obtaining and examining more about residential lighting and other related issues such as sustainable lighting, the revised survey was distributed in Sweden from Northern Europe, Poland from Central Europe, the U.K. from Northwestern Europe, and Turkey from Western Asia (See Fig. 1). The survey was distributed online via e-mail invitations and/or cross-platform messages (through a web-based survey tool offered by Google) in the native languages of these four countries between November 2020 and January 2021. As it was in the pilot study, the respondents of the study were the users of residential buildings who reside in Poland, Turkey, Sweden and the U.K. and could provide comprehensive insight into lighting conditions [22]. A total of 500 participants (125 respondents from each country), aged between 18 and 66 years provided detailed self-assessments of the lighting conditions in their living areas. Respondent data indicates that 85.8% had a university degree or higher, 47.6% were females, 51.2% males, and 1.2% did not wish to specify gender; 43.2% were aged between 25 and 34 years, 26.2% aged between 35 and 44 years and 18.4% aged between 18 and 24 years; and 44.6% had a monthly income above the national averages

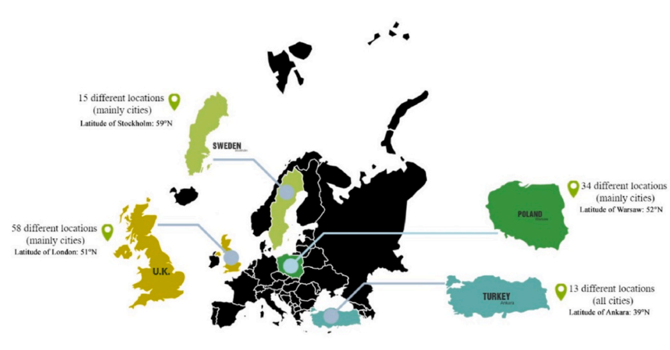

Fig. 1. Participant countries, number of locations, and latitudes of each capital city.

of each country.

2.1. Survey

The survey questions asked respondents to rate the physical characteristics of their living areas and lighting systems, as well as lighting conditions and their satisfactions in the winter-term. There were open-ended, single, and multiple-choice questions (mostly four-point and five-point scales answers such as “very satisfied; satisfied; neither satisfied nor dissatisfied; dissatisfied; very dissatisfied”) in the survey. The respondents were asked to give their age, gender, education level, and approximate monthly household income. Residential buildings’ location, type, construction year, number of rooms, and exact floor area were asked to gather data about the characteristics of residential buildings. Respondents were also asked to answer questions about the area which they spend their most time in a day in their residential buildings. Thus, relevant information about this specific area (which can be a separate working room, living room or any kind of room) such as exact floor area and room height were gathered. Besides, the information about the number of hours spent and the type of activities that respondents mostly did in that living area were collected (options provided for respondents were: “working with computer”; “reading or writing but without a computer”; “mostly resting and watching TV”; or “mostly resting but without TV”). They were asked to provide further information about surface colors, color saturation, orientation, number of windows and their locations, window areas’ ratio to the whole floor area, and views out from the windows which may affect daylighting. Respondents were asked to give information about the daylight conditions in their living areas by answering questions about daylight quantity and its distribution, their satisfaction level about daylight, number of hours of direct sunlight penetration and shading device’s type, and its position and purpose. The next questions gathered data about the artificial lighting conditions in the living areas. Artificial lighting usage time, its type, system, quantity, uniformity, lamp brightness, perceived color of light, and color rendering quality were asked with explanations and photographs to guide respondents. Also, the survey asked questions about satisfaction levels of respondents with artificial lighting in their living areas, their artificial lighting selection methods, and priorities. In order to gather self-assessments about the adoption of sustainable lighting solutions and to understand the impact of current lighting policies, some questions were asked including smart lighting control systems, sustainable solutions, and national policies. The survey concluded with two open-ended questions about light-related adjustments that respondents enacted in their living areas, with the latter question about light-related changes that occupants were planning to improve their lighting conditions [22]. The collected data was analyzed using IBM SPSS 27.0 (descriptive statistics and correlation coefficient functions indicating the direction of association with statistical significance) [31,32] and NVivo 12- QSR International for qualitative analysis.

3. Results

In addition to identifying interrelated factors associated with residential lighting, the survey questions also provided information about the characteristics of respondents’ residential areas. 70.4% of participants live in an apartment flat mostly built between 1990 and 2019 (50.8%) or between 1960 and 1989 (22.6%). The average floor area of the houses and living areas were 132 m^2 and 34 m^2 respectively. The height of the living areas was mostly less than 3 m (55.4%), with white painted ceilings (92.0%) and walls (64.8%). Flooring on living areas were mostly brown (60.4%), as was furniture on the vertical (34.4%) and horizontal (35.0%) surfaces. 20.2% of the living areas were south-facing, 18.2% were east-facing, 16.0% were north-facing and 15.8% were west-facing. The remainder of the living areas were bi- or tri-directional in orientation. More than half of the participants spent 3–8 h in their living area and spent this time using their computers (See Fig. 2 and Fig. 3). Spending a great amount of time in the same place for long periods, given the type of activity done there, emphasizes the importance of residential lighting. According to existing information obtained from studies into the effect of lighting on visual performance in office space, where mostly screen-related tasks are being conducted, we concluded that illuminance, luminance ratio, and correlated color temperature were found to affect performance [33]. Strong conclusions regarding visual performance in office environments can be reached from the countless number of studies conducted in this field. However, we lack studies about the visual tasks done in residential areas and the relationship to residential lighting. Thus, the data collected by this study can guide future research in this area, even though a significant relationship among the type of the visual activity and day and artificial lighting could not be detected since more than half (53%) of our participants were conducting a single type of activity (See Fig. 3).

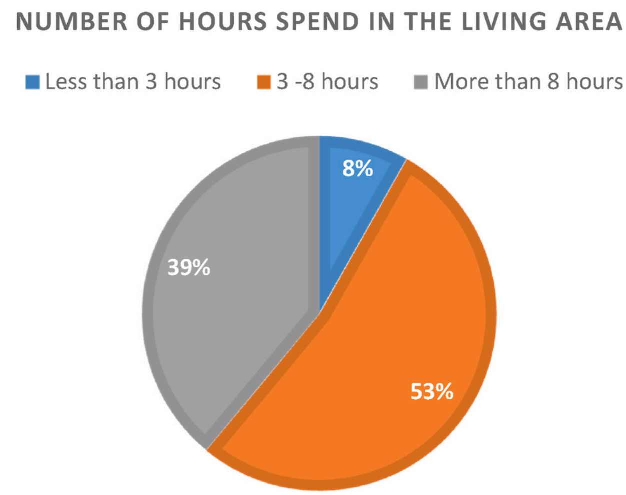

Fig. 2. Number of hours spend in the living area.

3.1. Residential lighting conditions

The pilot study findings revealed the fundamentals of residential lighting conditions and provided basis for the current lighting study. This study was aware of the many aspects that the pilot study could not reveal, and thus investigated these aspects in-depth to confirm some suppositions and present fully reliable recommendations on residential lighting conditions [22]. Being aware of the various aspects of residential lighting, the understanding and explanation of residential lighting from multiple perspective, is of importance. Hence, as professionals from various disciplines, this study was taken jointly to

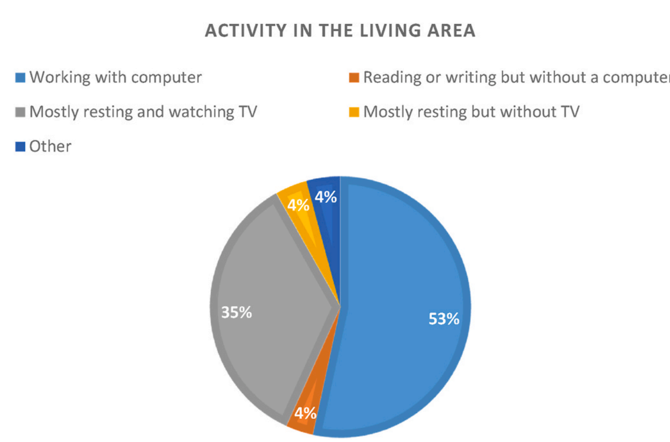

Fig. 3. The type of activity done in the living area.

develop a holistic perspective on residential lighting conditions. We highlighted the interrelated factors related to residential lighting by gathering the results of our pilot study and the current study.

Both day and artificial lighting provides an improved and more sustainable luminous environment, and therefore should be examined holistically from all perspectives. Since daylighting is the primary source of light, it plays an important role in human health, energy saving, and environmental protection [34] (p.1). The visual connection to daylight and the view-out from interior environments are provided by the transparent surfaces of building envelopes. Views to the outdoors and exposure to sun and daylight from windows can be beneficial for reducing stress [35,36], and improving overall health and well-being [37]. 32.4% of living areas under this study have two windows. 57.0% of living areas have only side windows on one wall and the approximate ratio of window area to total floor area of the living area was 20–40% (35.4% of windows). 40.4% of the windows have some obstructions in the front, but mostly skylight can be seen through the windows (See Appendix A for details). According to the respondents' answers, on a winter day, direct sun penetrates the living areas between four to 6 h in Poland (40.0%), Turkey (34.4%) and Sweden (36.0%) (the U.K. was a notable exception- 34.4% of respondents get 1–3 h of daylight exposure). Blinds and curtains were most commonly used in Poland (69.6%) whereas the most commonly selected shading device for the living areas in Turkey (35.2%) and the U.K. (34.4%) was curtains. In Sweden, louvres were the most commonly used shading device (40.8%). Shading devices are used to reduce glare and overheating [38–40], however, in all countries, 45.0% of shading devices were not drawn and were used to obtain privacy during the winter-time. According to our pilot study findings, participants use their shading devices to obtain privacy and prevent direct sunlight regardless of country of residence. However, in summer-term most of the respondents from Poland and Turkey stated that they did not draw their shading devices. Most of the respondents from Sweden drew their shading devices half, whereas the shading devices in the U.K. were all drawn in most cases [22] (p. 4). There are notable differences between summer and winter-terms according to our studies, despite previous studies highlighting that occupants mostly forget to show adaptive-behaviors in shading device usage [41–44]. A study conducted in an office environment showed that occupants rarely adjusted their shading devices, and once they changed, they left them in that position for a long time (potentially up to two weeks, [41]; p. 750). As our survey results pointed out, participants do not draw their shading devices during winter, possibly to secure the most daylight, but in summer some of the participants (from Poland and Turkey where average sunshine durations are considerably high) left them totally open which may hinder sustainability and increase energy demand because of overheating in the living area. Thus, further studies are needed focusing on occupant's adaptive-behavior and shading device usage in residential areas.

Most participants in the four countries (Turkey has the lowest rate of sufficiency in the amount of daylight among all countries with 69.6%) indicated that the amount of daylight in their living area is sufficient, and at least half of the participants (Sweden has the lowest rate of daylight uniformity among all countries with 51.2%) indicated that the daylight in their living area is uniformly distributed (See Fig. 4). As seen in Fig. 4, there were no major differences between countries in terms of sufficiency and uniformity of daylight, despite differences in geographic locations (See Fig. 1) and hence day length and sunshine durations (Average day length in Warsaw 8.3 h; Ankara 9.7 h; Gothenburg 7.4 h and London 8.4 h; sunshine duration in Warsaw 1.3 h; Ankara 3.1 h; Gothenburg 1.3 h and London 4.1 h https://www.weather-atlas.com/). However, there were differences between countries and seasons in terms of satisfaction with daylight. In our pilot study, 51.7% of the participants indicated that they were very satisfied with daylight quality in their living areas during summer [22]. This percentage decreased to 19.0% in winter in our current study. Differences among countries were also detected. For instance, 32.0% of respondents from Turkey stated that

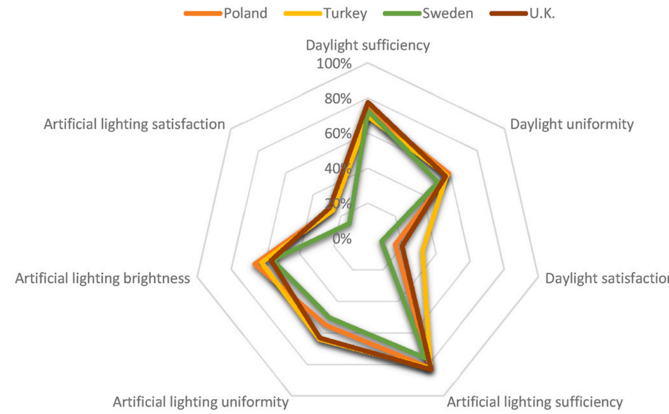

Fig. 4. Evaluations for daylighting and artificial lighting.

they were very satisfied with daylight in the winter-term, whereas in Poland this rate was 16.0%. Only 8% of respondents from Sweden and 20% of respondents from the U.K. rated that they were very satisfied with daylight in their living area in winter-term, owing to day length and sunshine duration differences. Similarly for artificial lighting, smaller percentage of respondents were very satisfied with their artificial lighting (Poland; 26.4%, Turkey; 25.6%, Sweden; 13.6%, U.K.; 28.0%, 23.4% at total) (See Fig. 4), even if the hours of usage of artificial lighting were high (participants spent 3 to 8 h in their living areas where all of the areas were conditioned to artificial lighting use). Similar results were reached in our pilot study. 26.7% of participants indicated that they were very satisfied with their artificial lighting in summer [22]. Hence, satisfaction with artificial lighting showed no difference between seasons. No difference was found between countries in the sufficiency of artificial lighting. The ratings of brightness and uniformity of artificial lighting in Sweden were the lowest (56.0% and 50.4%, respectively) among the countries in this study (See Fig. 4).

As our previous study has shown [22], satisfaction with daylight quality depends on daylight sufficiency, daylight uniformity, number of sunlight hours (i.e., sunlight exposure), and views from and ratio of windows in the living area. The current study shows the related correlations between satisfaction with daylight and these aspects (See Fig. 5 and Appendix B). Among all the correlations, daylight satisfaction had a moderately positive correlation with daylight sufficiency ($r = 0.548$, $p = 0.000$). As daylight sufficiency increased, so did daylight satisfaction. A low, but positive, correlation was found between daylight satisfaction and daylight uniformity ($r = 0.473$, $p = 0.000$) [45]. Daylight satisfaction also had a low and positive correlation with the views out through the windows ($r = 0.316$, $p = 0.000$) [46]. Both views from the windows and daylight uniformity had an effect on daylight satisfaction, but the influence on daylight satisfaction was not as strong as daylight sufficiency. In addition, there were very low and negative correlations between daylight satisfaction and sunlight exposure ($r = -0.280$, $p =$

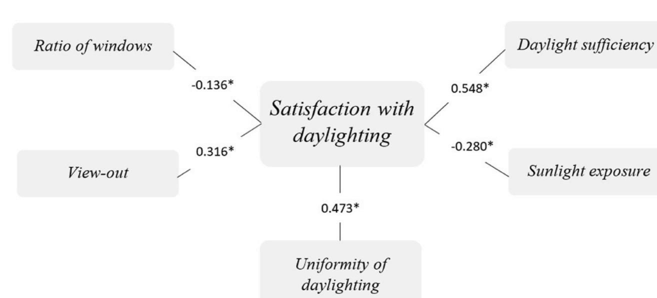

Fig. 5. Diagram showing the correlations about satisfaction with daylight regardless of country *(all of the correlation coefficient values shown in the figure are statistically significant* for* $p < 0.01$; [31,32].

0.000) and the ratio of windows in the living area (r = −0.136, p = 0.002). Although the correlations found in this study were limited, strong consensus has yet to be obtained in existing literature. Previous studies focused on office environments, and can point out noteworthy interconnections. Boubekri, Hull, and Boyer [47] investigated the effects of window size and amount of direct sunlight on occupants' satisfaction, but could not find a significant relation. Another study conducted by Leather, Pyrgas, Beale, and Lawrence [48] showed a significant direct effect for sunlight penetration on job satisfaction. As An, Colarelli, O'Brien, and Boyajian [49] found, direct sunlight was a dominant predictor of anxiety, and indirect sunlight was a dominant predictor of depressed mood, job satisfaction, and organizational commitment. As our findings showed, daylight satisfaction became slightly higher when the ratio of windows decreased, which was connected to decreased sunlight exposure, reduced glare, and less overheating [50].

Daylight uniformity and daylight sufficiency also had a low positive correlation with each other (r = 0.422, p = 0.000) (See Fig. 6 and Appendix B). Views out through windows had a very low, but nevertheless positive correlation with daylight uniformity (r = 0.271, p = 0.000). The lower the barriers to window visibility became, the more uniform daylight became in an occupant's living area. As the amount of sunlight exposure in a living area increased, so the uniformity of daylight decreased (r = −0.220, p = 0.000). Thus, the ratio of windows also had a very low effect on the decrease in daylight uniformity (r = −0.097, p = 0.000). In brief, for the comfortable accomplishment of visual tasks, sufficient and well-distributed daylight is required to avoid the glare produced by direct sunlight [51].

Daylight sufficiency had very low correlations with views through windows (r = 0.261, p = 0.000), ratio of the windows (r = −0.117, p = 0.009), and number of sunlight hours (r = −0.188, p = 0.000). Daylight sufficiency increases with unobstructed views through windows. However, a decrease in daylight sufficiency can be detected when the proportion of windows increases and, subsequently, as the amount of sunlight in the living area increases [52]. Some more expected correlations can be seen from the survey results. The number of sunlight exposure hours increases as the ratio of windows increases (r = 0.115, p = 0.010), because the transparency of living areas' surfaces increases with larger window ratios. With the unobstructed views through windows, sunlight exposure in living areas increases (r = −0.111, p = 0.000) (See Fig. 7 and Appendix B).

The basic features of artificial lighting such as the amount, uniformity, brightness, and color rendering have the potential to improve lighting quality according to users' needs [22] (p. 6). As the survey results showed, satisfaction with artificial lighting quality depends on artificial lighting sufficiency (r = 0.463, p = 0.000), artificial lighting uniformity (r = 0.366, p = 0.000), artificial lighting brightness (r = 0.124, p = 0.006), and artificial lighting color rendering index (r = 0.279, p = 0.000) (See Fig. 8 and Appendix C). Of all the correlations on satisfaction with artificial lighting, sufficiency of artificial lighting was the highest. However, this correlation showed a low but positive relationship between satisfaction with artificial lighting and sufficiency of artificial lighting. Another similar correlation can be found between satisfaction with artificial lighting and uniformity of artificial lighting. Satisfaction with artificial lighting quality increases as sufficiency and

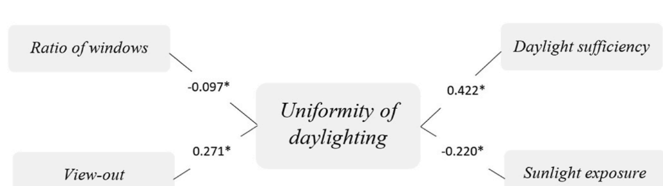

Fig. 6. Diagram showing the correlations from uniformity of daylight regardless of country *(all of the correlation coefficient values shown in the figure are statistically significant* for p < 0.01;* [31,32].

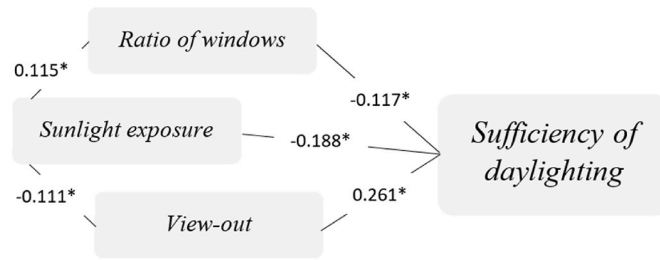

Fig. 7. Diagram showing the correlations about sufficiency of daylight regardless of country *(all of the correlation coefficient values shown in the figure are statistically significant* for p < 0.01;* [31,32].

uniformity of artificial lighting in a living area increase [45]. Very low and positive correlations can be found between satisfaction with artificial lighting, brightness of artificial lighting [53], and the color rendering index of artificial lighting [54].

Artificial lighting uniformity (r = 0.309, p = 0.000), artificial lighting brightness (r = 0.300, p = 0.000), and artificial lighting color rendering index (r = 0.280, p = 0.000) were related to artificial lighting sufficiency. However, the correlation between them was low for uniformity and brightness and very low for color rendering index. Artificial lighting brightness also had a very low positive correlation with artificial lighting uniformity (r = 0.292, p = 0.000) and artificial lighting color rendering index (r = 0.137, p = 0.002). Another low but positive correlation is found between artificial lighting uniformity and artificial lighting color rendering index (r = 0.269, p = 0.002) (See Fig. 9 and Appendix C). All the previously mentioned correlations about the basic features of artificial lighting specified potential solutions that could increase users' needs. For instance, 60.0% of the participants indicated that the colors of their furnishings, paintings, etc. were properly rendered when only exposed to artificial lighting. Since the color rendering of the artificial lighting was correlated with artificial lighting satisfaction (r = 0.279, p = 0.000) (See Fig. 8 and Appendix C), it may be possible to meet users' needs by increasing the color rendering ability of artificial lighting used in living areas [54]. Although no correlation was found surrounding the correlated color temperature of artificial lighting in this study, low correlated color temperature (70.6%) was found to be the most preferred in living areas in all countries. 80.8% of respondents in Sweden, 71.2% in Poland, 65.6% in Turkey, and 64.8% in the U.K. had warm white as the most dominant color of artificial lighting. The reason people (70.6% of study participants) use warmer lights (with reduced blue short wavelengths) in their living areas might be for obtaining privacy and relaxation. The circadian photoreceptors of the eye are most sensitive to blue wavelengths, which is notably dominant in the sky [55], and being exposed to the blue portion of the visible spectrum at nighttime is known to cause sleep disturbance via suppression of the hormone melatonin [19,56–58].

Although the results of the pilot study were insufficient to show statistically interrelated light-related factors, we were aware of the importance of those aspects (See Figs. 5–9 and Appendices C) in determining lighting evaluations. With the increase in sample size, we were able to identify statistically-significant correlations among most aspects. Among all correlations, lighting sufficiency was the most important factor in determining day and artificial lighting satisfaction, which should be the focus of further study. Additionally, this study highlighted other factors influencing lighting sufficiency that can be used in the design of better luminous residential areas.

3.2. Raising participatory awareness and information

Lighting is essential for living [59] (p.16) and most light sources depend on electricity. Electric lighting became increasingly used in the last decades of the 19th century and has since transformed from the incandescent lamp (which had a lifetime of 45 h and a luminous efficacy

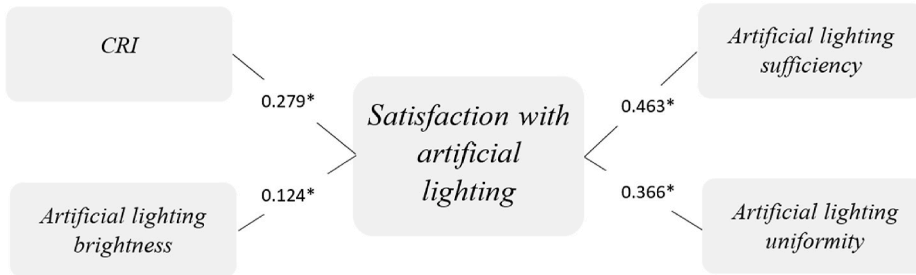

Fig. 8. Diagram showing the correlations for satisfaction with artificial lighting regardless of country *(all of the correlation coefficient values shown in the figure are statistically significant* for p < 0.01;* [31,32].

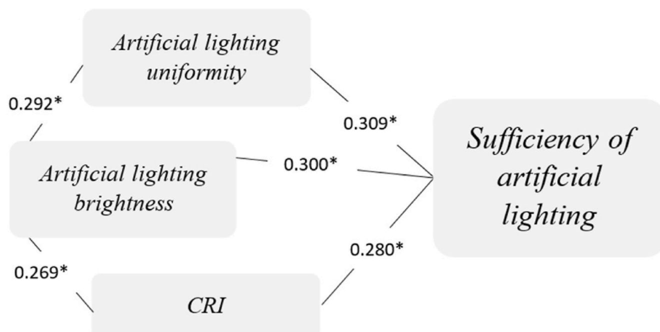

Fig. 9. Diagram showing the correlations for sufficiency of artificial lighting regardless of country *(all of the correlation coefficient values shown in the figure are statistically significant* for p < 0.01;* [31,32].

of 2 lm/W) to today's long-lasting, energy efficient LEDs (minimum lifetime of 10.000 h and an average luminous efficacy of 200 lm/W) [59, 60] p.17; [61]. However, energy consumption of electric lighting contributes to irreversible environmental pollution and global climate change. In 2018, households accounted for 26.1% of final energy consumption, or 16.6% of the gross inland energy consumption within the EU [8]. The level of household energy consumption usually depends on outdoor temperatures (or climate conditions), energy performance of buildings, the use and efficiency of electrical appliances, and the behavior and economic status of inhabitants (e.g. the desired or affordable level of thermal comfort, frequency of clothes washing, use of TV-sets, gaming and lighting preferences, etc.). Electricity accounted for 26.1% of final household energy consumption in the EU, followed by renewable energy at 19.5% [8]. According to 2017 statistics [62], the shares of fuels in final energy consumption in households are 13.0% electricity and 13.9% renewables in Poland, 51.7% electricity and 10.9% renewables in Sweden, 23.8% electricity and 5.3% renewables in the U.K., 22.8% electricity and 16.8% renewables in Turkey. Most energy use in households, including renewables, is related to occupants' thermal comfort [63,64]. Nevertheless, lighting in residential buildings is mainly dependent on electricity (57.2% of the 26.1% of final household energy consumption) [65].

Changes to residential lighting can drastically improve energy efficiency and sustainability. For instance, "smart lighting can help to decrease massive migrations from rural zones to big cities, contribute to a fair distribution of goods, preserve traditional ways of life, improve the health and well-being of people, and many other effects directly impacting on the environment and allowing development in accordance with the Sustainable Development Goals" [16] p.2; [12]. Reconsidering daylight use is as valuable as supporting the use of smart lighting. A Europe-wide standard, EN 17037 [66], addresses daylight exposure in residential buildings to reduce the need for artificial lighting demand, which will produce energy savings. Another recent standard, EN 16798–1 [67] specifies energy-efficient criteria to be used in standard energy calculations for indoor environments meant for human consumption, such as heating, cooling, ventilation, and lighting systems. It does not intervene directly in the design process but specifies parameters that must be taken into account when planning these systems in order to make indoor environments more energy efficient [68]. Also, countries set bold and solid lighting strategies for more sustainable lighting. In 2007, the U.K. announced a phase-out strategy for incandescent lamps by 2011. This solid strategy was then applied by all EU member states [69]. A further step was taken in 2018, as the final phase of EU energy regulations to switch to LEDs banned halogen lamps that do not fulfil EU eco-design requirements in residential areas [70]. This recent step was the progressive phase of the commitment to rein in CO2 emissions and reduce carbon footprints [71].

There are numerous informative policies and standards for residential lighting, but raising participatory awareness and information among the general public is just as important. Most strategies focus on sustainable lighting solutions at the design stage, with associated technical calculations (e.g. EN 17037 and EN 16798–1). This can be complex for people who have not received any education in lighting. Thus, the majority of respondents (81.2%) in our study from all countries were not aware of national policies about day and artificial lighting. Only a small percentage of respondents (17.8%) from all four countries had smart lighting control systems in their living areas.

Even though a small number of respondents have smart lighting control systems, they are currently considering sustainable lighting solutions that would improve lighting quality and use both environmentally friendly and cost-effective lighting. As discussed, residential lighting is mainly dependent on electricity and our results support this as well. Also, the role of artificial lighting is more pronounced during winter because of the seasonal changes in day length and sunshine duration [72]. Respondents from Turkey (46.4%) and the U.K. (36.0%) used between 4 and 6 h of artificial lighting in their homes on a winter day, while this number of hours of artificial lighting usage increased to between 7 and 9 h in the winter in Poland and Sweden. Average day length and sunshine duration recorded between November 2020 and January 2021 in Poland and in Sweden were the lowest among all countries, so residential lighting in Poland and Sweden relied mainly on electricity, in contrast to Turkey and the U.K in which the average day length is 9.7 h and 8.4 h respectively. Most of the respondents from all four countries used environmentally friendly and cost-effective LEDs, but a significant number still use incandescent, fluorescent, and halogen lamps in their living areas which may be caused by the relatively high prices of LED lamps. Because LEDs, which are highly recommended to alleviate sustainability concerns, are still more expensive than other sources (halogen and fluorescent lamps). In a detailed analysis of household income levels, a very low correlation ($r = 0.220$, $p = 0.014$) was found with mainly used artificial lighting type only in Poland among other countries. So, as the monthly household income levels of the participants living in Poland increases from "below the national average" to "above the national average", they prefer to use LEDs. As LED prices continue to fall [73], participants from Poland who earn above the national average (57.6%) may prefer using LEDs since they can easily afford them. However, further correlations concerning financial status and artificial lighting-type preferences could not be detected for other countries. 47.2% of living areas in Poland had LEDs, followed by halogen and fluorescent lamps, and most had ceiling-localized lighting. Living areas in Turkey were also mostly lit with LEDs, although incandescent and fluorescent lamps were still in use. The most preferred artificial lighting system in Turkey was general ceiling lighting. Besides LEDs (34.4%), incandescent and fluorescent lamps were used in Sweden and most of the living areas were lit by ceiling-localized or general ceiling lighting. In the U.K. LEDs were preferred by 25.6% of our respondents. Moreover, incandescent lamps had a significant usage share (18.4%) and most of the living areas had general ceiling lighting. The use of LEDs in living areas is important in terms of sustainability, but the presence of other lamp types and the lack of smart systems can be insufficient for creating an overall understanding of sustainability.

The lack of overall understanding of sustainability can also be seen in the light-related adjustments that participants have made in their living areas (i.e. applied lighting adjustments) and light-related changes they intend to make to secure better lighting conditions (i.e. desired lighting adjustments). Answering open-ended questions was optional, so out of 500 respondents, 184 comments were received on light-related adjustments they have made in their living areas and 203 comments were received on light-related changes they plan to make to have better lighting conditions (See Fig. 10). NVivo 12 qualitative software was used to analyze the open-ended survey questions. After initial evaluations and data reduction, 3 main themes were identified from the participants' comments for two open-ended questions (See Table 1).

As shown by the theme extraction concerning light-related adjustments in participants' living areas, 46.20% made lighting alterations with sustainability in mind (See Table 1), with replacing artificial light lamps with energy efficient ones the most commonly considered adjustment (19.02%). This was followed by making arrangements to take advantage of more daylight in their living areas (15.22%). Overall, only 11.96% of respondents made adjustments related to smart lighting control systems. Although some solutions like using LEDs and/or making arrangements for taking advantage of more daylight in living areas suit sustainability, the motivation behind these choices could be economic. The other adjustment made was relocating (9.78%) and augmenting the characteristics (19.02%) of artificial light in the living area, as there is a correlation between satisfaction with artificial light and basic artificial light characteristics such as brightness level, uniformity, and color rendering index (See Fig. 8). The reason why participants want to relocate and augment the characteristics of their artificial lighting can be the relationship between luminaire mounting height and the illuminance uniformity [74]. Another key consideration extracted from the question was adding more artificial lighting in the living area to have better lighting conditions, which was mentioned in the comments of 25% of the respondents. We can understand that participants add extra artificial lighting to increase the uniformity of artificial lighting in their living areas.

The survey results showed that there is no clear preference in choosing an artificial lighting solution, but participants mostly choose their artificial lighting solution intuitively regardless of the country (31.0%), as can be evidenced from the respondents' answers to the question about artificial lighting selection method. Moreover, they intuitively add extra artificial lighting in their living areas without getting a professional help, which can increase energy demand and thus affect sustainability. Participants also brought artificial lighting brightness and uniformity to desired levels through relocating and augmenting their characteristics. Although the national lighting policies were not very well known among the participants of this study (Poland: 80.0%, Turkey: 80.0%, Sweden: 89.6%, the U.K.: 75.2%), the use of LEDs in Poland (47.2%) is higher than in the other countries, which can be achieved through applying regulations on switching to LEDs (Commission Regulation 2015/1428). However, more attention and solid actions are needed for all countries investigated in this study. The inability of light-related policies and standards to reach their target audience (end-users) may be caused by the complexity of policies and standards. Reaching and informing the majority of end-users may be challenging, but the reward will be valuable; if everyone is conscious about sustainable lighting and applies solutions accordingly, a significant reduction in energy demand and diminished carbon footprint will be obtained. Therefore, raising the participatory awareness and information about sustainable lighting solutions in residential areas are key to achieving this holistic goal.

Participants in this study expressed plans to make various changes to their lighting conditions in order to improve their living areas (See Table 1). For example, 22.16% of participants planned to add more artificial lighting sources in their living areas while 16.26% planned to make permanent changes in the allocation of artificial lighting, such as changing the localized ceiling lighting to general ceiling lighting. 40.89% of participants indicated that they planned to use more sustainable solutions in their living areas for better lighting conditions. Among other sustainability-related changes, the most common plan from participants was to add windows or increase window size, at 13.30%. Indeed, most light-related changes that participants planned to make related to their windows and better daylight conditions. Participants' written responses included "Well, I will put more windows I guess.", and "Would have a larger rear window to allow more light in." Most of the participants want more daylight in their living areas. Many other studies have highlighted the benefits and importance of daylight for health and well-being [1,18,21,75] and the presence of daylight can, for example, reduce Seasonal Affective Disorder symptoms (SAD, also known as winter depression) [18,76]. Thus, the amount of daylight in living areas can be one of the most influential factors in health and well-being. However, key consideration is how to establish a wise balance between daylight coming from outside, and the light emitting from electric systems in the living area which requires a professional perspective.

In brief, all the survey questions about residential lighting conditions provide impactful insight relating to sustainability, national lighting

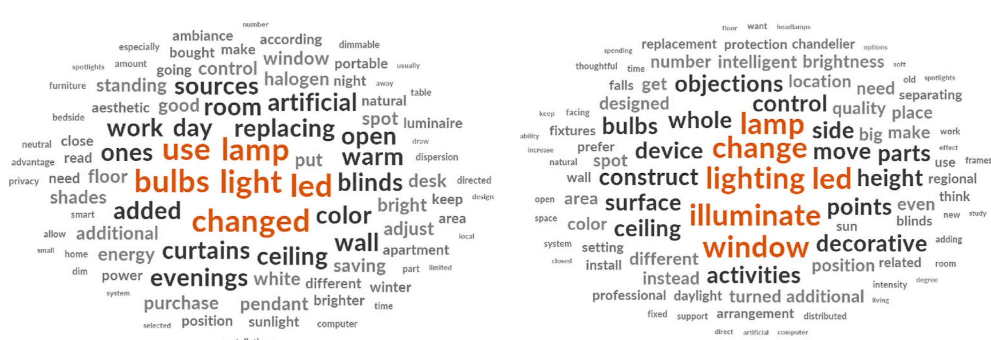

Fig. 10. The word clouds for applied lighting adjustments (on left) and desired lighting adjustments (on right).

Table 1
Identified themes from the open-ended questions.

	Open-ended Q1		Open-ended Q2	
Identified themes	Indicate the light-related adjustments (both artificial light and daylight) that *you have done and still effectively using* in this living area		Indicate the light-related changes (both artificial light and daylight) that *you would do in this living area if you could design it from the beginning*	
Subthemes	N (%)	Sample quotes for Q1	N (%)	Sample quotes for Q2
Adding artificial lighting	46 (25%)	- Added extra floor lamps in corners of room. - Added a desk lamp for working and a standing lamp that adds warmth and is aesthetically pleasing.	45 (22.16%)	- Increasing the number of lighting points, e.g. an additional free-standing lamp. - Add additional ceiling lighting/change from localized to general lighting.
Altering artificial lighting	53 (28.80%)		75 (36.95%)	
***Subtheme:* Relocating artificial lighting**	18 (9.78%)	- Located the lighting away from my vision so that they do not disturb my eyes. - I like reading in the bed. So I rearrange light system and bring the portable light near my bed.	33 (16.26%)	- Moving the ceiling lamp centrally above the table. - Multiple points of light instead of a ceiling lamp in one place.
***Subtheme:* Augmenting the characteristics of artificial lighting**	35 (19.02%)	- Switched some bright white LED bulbs for a much warmer white LED bulb.	42 (20.69%)	- Artificial lighting could be distributed more homogeneously and attention could be paid to blind spots in the kitchen and study room. - Replacing the chandelier with lamps that provide more light throughout the room in a neutral white color.
Sustainability	85 (46.20%)		83 (40.89%)	
***Subtheme:* Lamp change**	35 (19.02%)	- Changed all bulbs to LEDs. - Replacing light bulbs with energy-saving ones.	19 (9.36%)	- Change the spot lights with more energy efficient alternatives. - I would use all LED bulbs.
***Subtheme:* Smart controls**	22 (11.96%)	- Changing color and intensity via smart controls.	25 (12.32%)	- I wish the light level and color could be changed. - I would add a degree of control, like a dimmer, to be able to adjust the brightness based on my preference at each time.
***Subtheme:* Using daylighting more**	28 (15.22%)	- Taking advantage of natural light by putting my desk in front of my window. - I keep my curtain open to take advantage of the daylight.	12 (5.91%)	- I would arrange the room to face south, not west. Since the work surface is not illuminated enough and my shadow falls on the table, I would place indirect lighting on the wall of the desk instead of a pendant general lighting. - When it comes to lighting the room with daylight, I would change the location of the block, I would definitely move to another one, which currently prevents access to daylight.
***Subtheme:* Adding window or increasing size of window**	–	–	27 (13.30%)	- Well, I will put more windows, I guess. - Would have a larger rear window to allow more light in.

policies, light-related adjustments made by participants, and lighting-related changes they plan to make in future to have better lighting conditions. Through the thematic analysis of a total of 387 comments, 3 main themes emerged (See Table 1), highlighting the importance of studying residential lighting through quantitative and qualitative survey responses. This study therefore provides a comprehensive understanding of residential lighting through these differing analytical methods.

4. Conclusions

This study gathered subjective assessments and identified the needs and problematic issues regarding lighting in residential areas by conducting an international survey in Poland, Turkey, Sweden and the U.K. The study's findings revealed similarities and differences of residential lighting conditions in different countries. Besides highlighting the potential factors influencing high-quality day and artificial residential lighting living areas for all, this study also showed important outcomes about policies and standards. Since most standards and policies provide detailed technical instructions on how to test detailed building designs with regards to the stated criteria [77], they are less applicable for end-users who have not received sufficient education or training on lighting. Additionally, available technologies and user demands are constantly changing. It is not always so easy and applicable to adapt each and every standard and/or policy to changing conditions [14].

Since our study included self-assessments from residential users, our results can be used as reliable recommendations for residential lighting conditions in early planning stages including policymaking, architectural and lighting design. In order to create effective policy and standards, decision-makers should understand how light-related decisions are made by end-users in residential areas. As Altomonte et. al. [21] stated, "ensuring ongoing dialogue between researchers and standard-setting bodies who influence building design and operations, feedback loops through both building and occupant evaluations, a commitment to interdisciplinary collaboration, and building research that can be communicated to funding bodies, policy makers, and researchers" (p. 9) are the steps for achieving a holistic lighting goal. Our study highlighted the importance of lighting quality in residential buildings, which has increased especially when accounting for restrictions associated with the COVID-19 pandemic. Overall, we pointed out the possible study areas using participants' self-assessments that new research on residential lighting is urgently needed. Finally, the findings presented briefly below can be used to build future transdisciplinary collaborations:

- Owing to differences caused by culture, geography, annual day length pattern, and sunshine duration across the four countries investigated in this study, significant correlations could not be detected in terms of day and artificial lighting assessments from this study's participants. We expected some correlations between day and artificial lighting assessments and living areas' geographical orientations, however correlations could not be detected since our participants' had diverse geographical orientations and residential area characteristics that prevented finding a relationship. As a consequence, these results reveal that regardless of cultural, geographical, annual day length pattern and sunshine duration differences, there is an universal urge to improve residential lighting, which may have arisen as a result of COVID-19 pandemic and/or complicacy of "decide-announce-defend model".

- Regardless of country, lighting sufficiency was found as the most important factor in determining day and artificial lighting satisfaction. In addition, satisfaction with daylighting quality depends on daylighting uniformity, number of sunlight hours, view-out and ratio of windows to floor area of the living area. Whereas satisfaction with artificial lighting quality depends on artificial lighting uniformity, artificial lighting brightness, and artificial lighting's color rendering index. Other factors should be examined in more detail, such as user control over the overall lighting [78], thermal comfort [45], glare, reflections and contrast [79] and this study's findings on effecting lighting satisfaction.
- Most of the respondents from all four countries used environmentally friendly and cost-effective LEDs, but a significant number of participants still use incandescent, fluorescent, and halogen lamps in their living areas. Decreases in household costs from the enhanced life-cycle of lamps can also be a dominant reason in selecting LEDs rather than just considering sustainability [80,81]. Dependency on daylighting can be preferred over environmentally friendly lamps because of their longer pay-back time.
- Participants mostly replaced artificial light lamps in their living areas with energy efficient ones. Besides, they augmented the characteristics of their lamps (brightness level, uniformity, and color rendering index of artificial light in the living area). Participants made some arrangements for taking advantage of more daylighting in their living areas such as changing the locations of their furniture.
- Participants were planning to add more artificial lighting sources in their living areas and wanted to make permanent changes in the allocation of artificial lighting, such as changing the ceiling localized lighting to general ceiling lighting. Also, if they could redesign their living areas, participants would add windows or increase window size.

Our study identified occupants' priorities regarding residential lighting, which fills the gap regarding all aspects about day and artificial lighting. As a conclusion, the findings of the study showed the potential factors that can be used to effectively change the day and artificial lighting in residential areas, leading to a sustainable and better lighting environment.

Authorship contribution statement

R.A.: Conceptualization, Methodology, Formal analysis, Investigation, Writing - Original Draft, Visualization, Supervision.

J.K.K.: Conceptualization, Resources, Investigation, Writing - Review & Editing.

S.Y.: Formal analysis, Investigation, Writing - Review & Editing, Visualization.

P.P.: Conceptualization, Methodology, Investigation, Writing - Review & Editing.

B.U.: Conceptualization, Methodology, Investigation, Writing - Review & Editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Summative table for the results related with window and view-out in percentages

	Poland	Turkey	Sweden	U.K.	Overall (All four countries)
Number of windows					
1	**30.4%**	25.6%	16.0%	28.8%	25.2%
2	27.2%	**36.8%**	**32.0%**	**33.6%**	**32.4%**
3	16.0%	9.6%	17.6%	20.0%	15.8%
4	20.0%	7.2%	15.2%	7.2%	12.4%
5	2.4%	5.6%	12.0%	2.4%	5.6%
6 or more	4.0%	15.2%	7.2%	8.0%	8.6%
Window location					
Only Sidelighting on one wall	**64.0%**	**63.2%**	**56.8%**	**44.0%**	**57.0%**
Only Sidelighting on two walls	24.0%	21.6%	25.6%	24.0%	23.8%
Only Sidelighting on more than two walls	7.2%	14.4%	6.4%	11.2%	9.8%
Only Rooflighting	1.6%	0%	1.6%	8.8%	3.0%
Rooflighting and sidelighting on one wall	0.8%	0%	4.0%	4.0%	2.2%
Rooflighting and sidelighting on two walls	1.6%	0%	3.2%	4.0%	2.2%
Rooflighting and sidelighting on more than two walls	0.8%	0.8%	2.4%	1.6%	1.4%
Other	0%	0%	0%	2.4%	0.6%
Ratio of Windows					
Less than 10%	7.2%	14.4%	8.0%	12%	10.4%
10%–20%	32.0%	**31.2%**	32.8%	27.2%	30.8%
20%–40%	**40.8%**	**31.2%**	**38.4%**	**31.2%**	**35.4%**
40%–60%	8.8%	12.8%	11.2%	18.4%	12.8%
More than 60%	4.0%	0.8%	4.0%	2.4%	2.8%
Hard to decide	7.2%	9.6%	5.6%	8.8%	7.8%
View-out through windows					
No obstructions on skylight at all	28.8%	31.2%	30.4%	26.4%	29.2%
Some obstructions, but mostly skylight is seen through the windows	**40.0%**	**34.4%**	**43.2%**	**44.0%**	**40.4%**
Buildings and objects (trees, etc.) obstruct view-out on skylight heavily	31.2%	30.4%	25.6%	25.6%	28.2%
Cannot see skylight at all through my windows	0%	4.0%	0.8%	4.0%	2.2%

Appendix B. Correlation table for the results related with daylighting (the level of significance* was defined as for $p < 0.01$)

		ratio of windows	view-out	daylight sufficiency	daylight uniformity	daylight satisfaction	sunlight number of hours
ratio of windows	Correlation Coefficient	1000	−0,029	-.117*	-.097*	-.136*	.115*
	Sig. (2-tailed)		0,522	0009	0,030	0002	0,010
	N	500	500	500	500	500	500
view-out	Correlation Coefficient	−0,029	1000	.261*	.271*	.316*	-.111*
	Sig. (2-tailed)	0,522		0,000	0000	0,000	0013
	N	500	500	500	500	500	500
daylight sufficiency	Correlation Coefficient	-.117*	.261*	1000	.422*	.548*	-.188*
	Sig. (2-tailed)	0,009	0000		0,000	0000	0,000
	N	500	500	500	500	500	500
daylight uniformity	Correlation Coefficient	-.097*	.271*	.422*	1000	.473*	-.220*
	Sig. (2-tailed)	0,030	0000	0,000		0,000	0000
	N	500	500	500	500	500	500
daylight satisfaction	Correlation Coefficient	-.136*	.316*	.548*	.473*	1000	-.280*
	Sig. (2-tailed)	0,002	0000	0,000	0000		0,000
	N	500	500	500	500	500	500
sunlight number of hours	Correlation Coefficient	.115*	-.111*	-.188*	-.220*	-.280*	1000
	Sig. (2-tailed)	0,010	0013	0,000	0000	0,000	
	N	500	500	500	500	500	500

Appendix C. Correlation table for the results related with artificial lighting (the level of significance* was defined as for $p < 0.01$)

		artificial light sufficiency	artificial light uniformity	artificial light brightness	Color rendering index	artificial light satisfaction
artificial light sufficiency	Correlation Coefficient	1000	.309*	.300*	.280*	.463*
	Sig. (2-tailed)		0,000	0000	0,000	0000
	N	500	500	500	500	500
artificial light uniformity	Correlation Coefficient	.309*	1000	.292*	.269*	.366*
	Sig. (2-tailed)	0,000		0,000	0000	0,000
	N	500	500	500	500	500
artificial light brightness	Correlation Coefficient	.300*	.292*	1000	.137*	.124*
	Sig. (2-tailed)	0,000	0000		0,002	0006
	N	500	500	500	500	500
Color rendering index	Correlation Coefficient	.280*	.269*	.137*	1000	.279*
	Sig. (2-tailed)	0,000	0000	0,002		0,000
	N	500	500	500	500	500
artificial light satisfaction	Correlation Coefficient	.463*	.366*	.124*	.279*	1000
	Sig. (2-tailed)	0,000	0000	0,006	0000	
	N	500	500	500	500	500

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