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A Dynamic Daylight Assessment Model for Measuring Visual Comfort in Egyptian Houses

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Abstract

In present times, daylight metrics have evolved to include dynamic metrics. However, Egyptian codes continue to rely solely on the static metric of illuminance to evaluate daylight within a space, although recent research has shown that illuminance alone falls short of describing daylight quality within a space. This study investigates daylight factors and metrics in various assessment models, it develops a comprehensive assessment model that can measure visual comfort in Egyptian residential buildings. An analytical-qualitative approach was employed to identify both physical and non-physical quality factors of dynamic daylight. This approach involved examining daylight quality models, international and national codes, and green building rating systems. Also, the use of environmental assessments to measure daylight factors was studied to ensure that the assessment model was applicable. Findings show that visual comfort can be measured in Egyptian residential buildings in several factors using a combination of metrics, technical environmental assessments, and observer-based environmental assessments.

Keywords: *Dynamic Daylight, Visual Comfort Assessment, Daylight Metrics, Residential Buildings, Egypt*

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1. Introduction

The concept of visual comfort is constantly evolving, making it difficult to provide a universal definition. However, visual comfort can be achieved by considering a combination of factors that enhance well-being and comfort. These factors include the quantity of light in the building, the quality and accessibility of views from within the building, and the overall quality of the surrounding space. This definition clarifies that the most commonly used and accepted metrics by lighting professionals, these metrics primarily revolve around ensuring adequate daylight by focusing on the quantity of daylight throughout the year, which is influenced by the building's location and orientation. Additionally, it focuses on the distribution of light as perceived by the eye, whether the space will be excessively bright or have high contrast. Other concepts are also taken into consideration by academics, such as user preferences for space lighting and the impact of daylight on subjective experience (Thuillier, 2021). These metrics are grouped into two categories: daylight quality and subjective experience, both of which are complementary and used to assess the quality of the surrounding space. daylight quality measurements are objective and focused on space, while subjective experience contains subjective measurements to assess space quality from the users' point of view. (AMORIM, et al., 2021) Achieving visual comfort in space is therefore accomplished by providing several standards, including appropriate daylight quality for the space through various physical factors and ensuring user experience within spaces is satisfactory through the provision of non-physical daylight factors.

- ***Physical Factors for Daylight Quality***

Physical factors refer to the measurable elements that affect daylight and are based on the physical quantities that describe the amount and distribution of light in space. The physical factors for lighting quality are studied by evaluating some factors that characterize the relationship between human needs and the light environment. According to (Carlucci, et al., 2015), daylight quality, as a broad concept, encompasses several factors that affect the visual comfort of users within the space. Based on the (U.S. EPA Green Lights Program, 1995), some of the most influential main daylight factors affecting daylight quality include:

1. Daylight Level: Also known as illuminance, it is the light intensity measured at a certain level in a specific location. Using simple mathematical calculations and light measurements, you can predict the lighting of a specific area.
2. Luminance: It is the light that we actually see. Luminance can be measured as the light emitted from the light source or the light reflected from the surface of an object. If luminance is not controlled, it can lead to glare levels that can either hinder or prevent the execution of the required task, taking into account surface illumination and surface reflection.
3. Glare: It can be described as direct or reflected glare, which can then lead to discomfort or hindered vision.
4. Light Color: The quality of light color is detected by classifying the color temperature.
5. Daylight Distribution and Uniformity.

- ***Non-Physical Factors for Daylight Quality***

While non-physical daylight factors refer to the sensory elements that are experienced by users, which do not rely on physical quantities. Non-physical factors are studied in a complementary manner with physical factors to create a comprehensive concept based on both measured quantities and user opinions. This is achieved through evaluating various factors that characterize the relationship between human needs and the light environment, from the perspective of users' subjective experience.

- ***Dynamic Daylight***

Dynamic daylight refers to the variations or changes that occur in natural lighting. This can include changes in the timing of lighting on a daily, monthly, or yearly basis, changes in illuminance, light color, directionality, and contrast between shadow and light, which can be due to the obstacles used in the space. Thus, a change in one of these elements or a combination of several of these elements can create dynamic daylight in space. These variations can be evaluated by assessing the atmosphere of the surrounding environment. (Gandy, 2017) defined the atmosphere as a direct form of perception, identified through subjective experience. Architects use this concept to illustrate that spaces are directly designed and built for users to use and experience. Atmospheres can be created through a combination of sensory elements such as lighting, sound, scent, and furnishings.

- ***Daylight Measurement***

For a while, daylight measurement in spaces used to rely on the basic static metric of illuminance to calculate the amount of light present. However, illuminance is no longer the sole metric that can describe daylight quality within a space, as it only measures the amount of light at a particular point in space and time. In recent years, there has been a significant advancement in the understanding of daylight as a dynamic light source, leading to the development of a new set of metrics that take into account the dynamic nature of daylight (Rockcastle, 2017). These dynamic metrics consider factors such as building location, window orientation, and occupancy patterns, making them more suitable for measuring as they are influenced by geographic variations, sky conditions, time of day, and spatial orientation.

- ***Daylight in Residential Buildings***

The presence of daylight is vital in residential settings as it plays a crucial functional role in enabling the comfortable and efficient completion of daily activities. It is essential to ensure visual comfort for users inside their houses to meet their needs effectively, as the absence of such comfort can pose risks to their health and well-being. Usually, the required lighting quantities for residential buildings and techniques for meeting them are determined by various national building codes or energy efficiency codes published by official authorities or local law regulations. These are typically in the form of recommendations to be followed during the building design process. However, adhering to these recommendations does not guarantee better daylight design quality or visual comfort for users, but often helps prevent poor decisions regarding daylight in spaces, as it is crucial for building design.

In Egyptian codes, the evaluation of daylight within a space relies solely on the static metric of illuminance, which is insufficient to describe the quality of daylight, which indicates the need for a more comprehensive assessment model that can measure visual comfort in Egyptian residential buildings. To address this issue, this study was conducted to investigate various daylight factors in different assessment models, to reach a comprehensive dynamic daylight assessment model that can significantly improve the evaluation of daylight quality within a space and enhance the visual comfort of occupants in Egyptian residential buildings.

2. Existing Daylight Assessment Models

According to (AMORIM, et al., 2021), before using daylight assessment models, daylight evaluation in architectural spaces relied heavily on a single metric, horizontal illuminance intensity. This was because measuring illuminance using a Luxmeter was accurate and affordable, explaining its long-term use. However, illuminance represents only one aspect of daylight, which fails to consider other important factors that contribute to overall daylight quality, such as glare, contrast, light color, and the user's perception of the surrounding environment. This is because users tend to perceive brightness instead of illuminance. Therefore, measurements solely based on illuminance cannot provide a comprehensive daylight evaluation in architectural spaces.

Daylight assessment in space has been a subject of interest for various institutes in the field of architecture and engineering. In this regard, several models have been developed, including Quality Assessment Models, and Green Building Rating systems, with some different methods mentioned in Codes and Laws. These models represent a significant contribution to daylight assessment in the field.

2.1. Daylight Quality Assessment Models

Daylight Quality Assessment Models have been used for assessing daylight quality, they are frameworks developed by various engineering organizations to evaluate lighting. They typically integrate both natural and artificial lighting components. These models in [Table 1] are based on their chronological order of appearance, ranging from oldest to newest.

Table 1. Factors in Daylight Quality Assessment Models

Model	Year	Physical Daylight Factors	Non- Physical Daylight Factors
IESNA (Rea, 1994)	1994	Luminance – Contrast – Illuminance – Glare – Light Color – View out – Spatial and Visual Clarity –System Flexibility	Visual Interest (Perception) - Psychological Orientation (User Experience)
IEA Task 21 (Ruck, et al., 2000)	2000	Illuminance – Distribution and uniformity– Glare – Directionality	--
European standard EN-12464 (CEN, 2011)	2011	Luminance Distribution – Illuminance – Directionality – Variability of Light – Light Color – Glare - Flicker	--
PERCIFAL (Ulf, et al., 2011)	2011	Illuminance – Distribution and uniformity – Shadows – Reflection – Glare – Light Color	Measuring All Factors through User Observation Only
IEA Task 61 (AMORIM, et al., 2021)	2022	Illuminance – Distribution and uniformity – Illuminance of Objects – Directionality – Glare – Light Color – View Out – Temporal Light Modulation	User Perception – Subjective Experience

Source: The Authors

Based on the analysis of previous models, the IEA Task 61 model stands out as the most comprehensive and reliable option. This model seamlessly blends physical factors, measured through technical means, with non-physical factors based on individual observation. Furthermore, It's the newest among daylight quality assessment models, incorporating the most advanced tools and techniques that have evolved from other models. By utilizing advanced devices, software, and user assessments, it can be relied upon as a starting point for daylight quality evaluation.

Generally, these models measure daylight quality without addressing dynamic daylight. Variations in light were only briefly mentioned in EN-12464 and superficially in IEA Task 61 as a modern alternative to fixed metrics but lacking detailed specifications.

2.2. Daylight in Codes and Laws

There are numerous energy codes worldwide, each tailored to the specific needs and regulations of the country. These codes typically address lighting as a significant factor affecting energy consumption, with some specifically addressing daylight. Recently, there has been the emergence of a unified code for daylight in Europe. This code aims to standardize practices and regulations regarding daylight across European countries, ensuring more efficient and sustainable daylight solutions.

2.2.1. International Codes

Many international codes focus on lighting as a key factor affecting energy consumption, with some specifically addressing daylight. Additionally, there are many standards and guidance books concerning lighting in general, its energy impact, and its effect on various building types. This can categorize codes addressing daylight into three distinct groups: Daylight, Energy, and Building codes.

A. Daylight Codes

They are codes that have emerged either at the international level or within various organizations, listed chronologically in [Table 2] from the newest to the oldest.

Table 2. Factors in International Daylight Codes

Code	Year	Physical Daylight Factors	Non- Physical Daylight Factors
European Standard EN 17037 (CEN, 2018)	2018	Illuminance and Distribution (in DF or LUX) – View Out – Sunlight Exposure – Glare (in DGP)	--
ISO 10916:2014 (ISO, 2014)	2014	Illuminance (in DF)	--
CIBSE The SLL Code for Lighting (Fitzpatrick, et al., 2012)	2012	Illuminance (in DF) - Glare	--

Source: The Authors

B. Energy Codes

They are the international energy codes that have focused on studying daylight within their energy conservation assessments. Two codes were studied to understand how international energy codes deal with daylight, the first is The International Energy Conservation Code (IECC, 2021), and the second is ANSI /ASHRAE /IES Standard 90.2-2018 (ANSI/ASHRAE/IES, 2018). Interestingly, neither of these codes mentions physical or non-physical daylight factors directly. Rather, they offer guidance about designing proper daylight within a space, such as providing permanent control through sensors or controllers.

C. Residential Buildings Codes

They focus on studying residential buildings while considering their mentioning of factors affecting daylight within spaces. Specifically, The California Residential Code (ICC, 2022) was examined, which is considered the leading international source for building codes, standard regulations, and safety solutions. While this code does not directly address daylight factors or metrics, it does cover various aspects affecting the presence of daylight within a building, Such as aperture glass-to-floor ratio.

2.2.2. National Codes and Laws

The Egyptian laws contain several codes and regulations that directly address daylight or deal with aspects that indirectly influence daylight. The following codes were examined:

First: The Egyptian Energy Efficiency Code for Residential Buildings (Egyptian Code Committee, 2008) which addresses both natural and artificial lighting in terms of standard values, ratios, and aspects influencing light inside a space. It mentions:

- The recommended illuminance levels in various residential spaces are based on their use, measured in lux.
- Requirements for daylight in interior and exterior design elements, such as maximum allowable obstruction angle θ, The window-to-wall ratio (WWR), glass visible light transmittance coefficient (VLT), and Projection Factor (PF).
- The dimensions and colors of the space should be naturally lit.
- Determining the percentage of glass shading based on the shading method.

Second: Law No. 119 of 2008 for the regulation and guidance of construction works (Ministry of Housing, 2009), which addresses some of the aspects that affect daylight within residential spaces, mentioning:

- Specifications for the area and clear height of residential spaces.
- Criteria for daylight in terms of the opening number, length, and area.
- Maximum building heights compared to road dimensions.
- Specifications for projection, especially for balconies.

Third: The Egyptian Code for Design of Residential Buildings and Housing Complexes (Egyptian Code Committee, 2009), which addresses daylight in terms of levels, mentioning:

- The variables affecting lighting levels within architectural spaces.

- Providing lighting requirements through a table of required illumination levels in lux according to activity, and how determining measurement points, clarifying window exposure conditions.

Regarding codes and laws in general, the researchers in the paper (Tregenza & Mardaljevic, 2018) agreed that the current state of lighting codes and standards is inadequate, particularly concerning the inconsistency between daylight assessments and codes in general. As a result, they recommend a thorough examination of the nature of codes, their various classifications, and the prerequisites for predicting daylight, starting with defining what a good code should entail.

The same can be said about the current situation in Egyptian codes and laws, where they address daylight and its influencing aspects, but only in terms of quantity without addressing daylight quality or its impact on users. Furthermore, they solely rely on illuminance in lux, without considering other metrics such as Daylight Factor (DF) or dynamic metrics. This is due to their outdated versions compared to international codes and rating systems. In addition, they have a greater focus on the influencing aspects of lighting, rather than the factors involved. As a result, they are considered more as design guidelines rather than measurement tools. Similarly to international codes, they are not entirely satisfactory as they only scratch the surface of lighting considerations.

2.3. Daylight in Green Buildings Rating Systems

Green building rating systems aim to mitigate the impact of buildings on the natural environment through sustainable design. Several well-known assessment systems were selected for study in the research, including the Egyptian system and three of the most widely used systems internationally in European and American countries.

2.3.1. International Rating Systems

They are the rating systems used in Europe and America, listed chronologically in [Table 3] from the newest to the oldest.

Table 3. Daylight Factors in International Rating Systems

Rating System	Year	Physical Daylight Factors	Non- Physical Daylight Factors	Dynamic Metrics
LEED v4.1 (USGBC, 2021)	2021	Illuminance (in LUX)	--	Spatial Daylight Autonomy (sDA) Annual Sunlight Exposure (ASE)
BREEAM (BRE, 2020)	2020	Illuminance (in LUX) - Temporal Light Modulation – Sunlight Exposure - View Out – Glare (in DGP)	--	--
WELL, (Delos Living LLC, 2016)	2016	Illuminance (in LUX) – Glare – Reflection - Light Color	--	Spatial Daylight Autonomy (sDA) Annual Sunlight Exposure (ASE)

Source: The Authors

2.3.2. Egyptian Rating System

In the Green Pyramid Rating System (GPRS), it is required to have consistent daylight for 75% of the floor area of the space, with illumination levels exceeding 250 lux for 75% of the space area per hour. Additionally, a glare control system such as curtains, baffles, or diffusers must be provided. Lighting control systems should also be in place to allow users to adjust the lighting as needed, covering 75% of the space area. (HBNRC, 2017).

Based on previous studies, it appears that BREEAM utilizes assessment criteria influenced by the quality-focused European Daylight Code EN 17037, using four main criteria. However, like the European Code, BREEAM does not use dynamic metrics for evaluation, which are instead used in other international rating systems like LEED and WELL. This indicates a recent trend towards using dynamic metrics for daylight evaluation because of their ability to capture the unique and variable aspects of buildings better than static metrics.

While American codes tend to prioritize energy, the IES organization has a separate handbook for the Low-Rise Residential Energy Design Code named IES lm-83-12 which depends on the code (ANSI/ASHRAE/IES, 2018). This handbook is used as a foundation for LEED and WELL rating systems for implementing dynamic daylight metrics. outlines the procedures for utilizing two types of dynamic daylight metrics: Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE). However, rating systems hold greater significance as they award points when reaching the required values with these metrics.

2.4. **Daylight Quality Factors and Metrics**

Based on the analysis of assessment models, codes, laws, and rating systems, it is possible to identify factors for evaluating the quality of daylight. These factors can be categorized into three groups: physical factors of daylight quality, non-physical factors in user assessments, and factors of dynamic daylight. There are 20 sub-factors in total for daylight, and each of them can impact the quality of daylight in a given space, therefore affecting users' visual comfort. These sub-factors have been organized according to each main factor, as shown in [Table 4]. The table also illustrates which assessment models, codes, and rating systems measure each sub-factor. This information helps to identify the frequency of certain factors or if they are absent from these models.

Table 4. Daylight Sub-Factors Daylight Quality and its relationship with assessment models

	Quality Assessment Models					Codes								Rating Systems			
Factors	**IESNA**	**IEA Task 21**	**EN-12464**	**PERCIFAL**	**IEA Task 61**	**Egyptian Energy Efficiency Code**	**Egyptian Code for Design of Residential**	**EN 17037**	**Energy Efficient Design of Low–Rise Residential Buildings**	**IECC**	**CIBSE**	**California Building Code**	**ISO 10916:2014**	**LEED v4.1**	**GPRS**	**BREEAM**	**WELL**
Daylight Level																	
Illuminance	√	√	√	√	√	√	√	√	√		√		√	√	√	√	√
Illumination of Objects					√						√						
Distribution and Uniformity																	
Uniformity		√															
Distribution		√		√	√												
Directionality		√	√		√												
Glare																	
Glare	√	√	√	√	√			√			√						√
Flicker			√													√	
Temporal Light Modulation					√												
Reflection				√				√									√
Luminance																	
Luminance	√																√
Shadows				√													
Light Color																	
Light Color			√	√	√												√
Other																	
View Out					√			√								√	
Contrast	√																
Spatial and Visual Clarity	√																
Daylight Variations																	
Variability of Light			√						√								
sDA														√			√
Sunlight Exposure & ASE								√	√					√			√
Subjective Experience																	
Visual Interest	√				√												
Psychological Orientation	√				√												

Source: The Authors

The most important Factors that can be used to assess daylight quality were identified from both physical and non-physical factors, comprehensively after reviewing models for assessing daylight quality.

For each element of the main physical and non-physical factors directly related to visual comfort, several sub-factors were selected based on the following:

- The latest daylight quality assessment model, which is IEA Task 61.
- European daylight code EN 17037, as the first specialized code for daylight quality unified in Europe.
- Illuminance requirements specified in the Egyptian Energy Efficiency Code.
- LEED and WELL rating systems, aligning with Egyptian codes to achieve consistent measurements with both static and dynamic metrics.

This leads to criteria of daylight quality factors that are suitable for use in residential buildings in Egypt, as shown in [Figure 1].

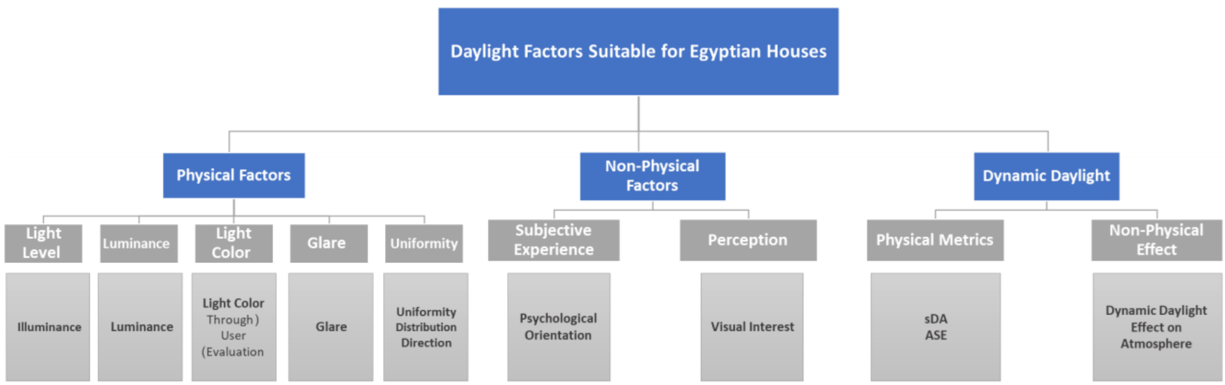

Figure 1: Criteria of Daylight Factors Suitable for Egyptian Houses

Source: The Authors

2.5. Environmental Assessment to Measure Daylight Factors

According to (AMORIM, et al., 2021), the previous factors of daylight can be measured through assessments based on environmental quality evaluation, known as environmental assessments. Environmental assessments are objective measurements of place characteristics, testing how a population perceives a location. They measure the physical and spatial characteristics of the environment or the social climate. Environmental assessments focus on the place and aim to measure physical characteristics. They use a variety of tools, questionnaires, or personal observation with rating models (Gifford, 2012).

The quality of environmental features such as daylight can be assessed in two methods: technical environmental assessment (TEAs) and observer-based environmental assessment (OBEAs) (Gifford, 2007). Technical environmental assessment is referred to as "place-oriented" and "objective" because it includes tools and metrics to produce readings of environmental quality in one or more places. Observer-based environmental assessment is typically called "person-oriented" and "subjective" because it relies on self-reporting tools through which people express their perceptions, observations, and impressions. It uses human perception to determine environmental quality (Johansson, et al., 2013).

2.5.1. Technical Environmental Assessment

To assess the physical factors of daylight quality, Technical Environmental Assessment (TEAs) is utilized. TEAs employ mechanical monitoring equipment or other physical means to produce readings of environmental quality (Gifford, 2007). This is done to achieve an objective assessment using physical measurement tools and methods, which can be either through devices or simulations.

2.5.2. Observer-Based Environmental Assessment

Observer-Based Environmental Assessment (OBEA) is a useful approach to complement Technical Environmental Assessment (TEAs), forming a comprehensive assessment for Post-Occupancy Evaluation (POE). OBEA enriches understanding of the quality of the environment, the behavior of users, and their opinions. (AMORIM, et al.,

2021) It utilizes human perceptual abilities to judge the quality (or other attributes) of space. OBEA is a measure of environmental quality "as experienced" by users. (Gifford, 2007)

OBEA can capture information that cannot be measured through TEAs. When and how users are surveyed depends on the monitoring objectives. The process involves choosing the appropriate survey method (such as questionnaires or interviews) and selecting the survey tool, which is the final step. (AMORIM, et al., 2021)

The subjective experience of daylight on humans consists of three effects: visual, physiological, and psychological effects. These effects can be evaluated by OBEAs using different techniques. According to (Laike 2020), these techniques include:

- Physical technique: This involves measuring the visual impact of daylight using the Perceived Indoor Lighting Quality (PILQ) for Lighting Experience assessment, which provides several meaningful words with explanations, and then requests users to assess the space.
- Psychological technique: This method utilizes the Semantic Differential Environmental Description (SED) assessment, which presents several meaningful words with explanations and requests for assessment from users through various means such as questionnaires, interviews, focus groups, or systematic observations.
- Physiological technique: This involves laboratory measurements and analyses of users within the space under analysis to determine functions such as melatonin and cortisol levels.

For optimal observation-based assessment (OBEA), a combination of two or more techniques is used. Therefore, to evaluate the lighting's impact on the overall subjective experience, two techniques can be utilized:

The first is the physical technique for measuring the visual interest of daylight on users through perception through the Perceived Indoor Lighting Quality (PILQ). The second is the psychological technique for measuring the Psychological Orientation of users through the Basic Emotional Process Scale (BEPs) (Gentile, et al., 2018) .

Moreover, The non-physical effects of dynamic daylight can also be assessed by measuring the impact of dynamic daylight on the atmosphere of the surrounding environment, it can be assessed using five fundamental dimensions, based on (Vogles, 2008) , (wang, et al., 2014) , and (Sawyer & Chamilothori, 2019). All attributes belonging to a specific dimension are assessed under one title. There are 13 attributes in total, and a questionnaire made of a 5-point Likert scale can be used to evaluate each point under each dimension.

Therefore, three main forms can be used to assess non-physical daylight factors and dynamic daylight effect on the environment atmosphere, as shown in [Table 5].

Table 5. Attributes of the Forms Used in Assessing Non-Physical Daylight Factors

Form	Score Range	Dimension	Dynamic Metrics
PILQ	1 - 7	PCQ*	=AVG(Soft + shaded + no flicker + (8-unpleasant) + evenly distributed + (8-sharp)) /6
		PSQ*	=AVG (brilliant + light + (8-darb) + (8-weak)) /4
		PAQ*	=AVG (monotonous + unnatural +(8-Colored) + Cool) /4
		PDQ*	=AVG (concentrated + focused) /2
BEPs	1 - 4	Activation	=AVG (rested + (5-drowsy) + awake) /3
		Orientation	=AVG (interested + (5-Quiescent) + engaged) /3
		Evaluation	=AVG (Friendly + (5-sad) + anxious) / 3
		Control	=AVG (independent + (5-indecisive) + (5-weak)) /3
		Emotional Status	=AVG (Activation + Orientation + Evaluation + Control) /4
Dynamic Daylight Effect on Atmosphere	1 - 5	Coziness	= Cozy + Safe
		Liveliness	= Liveliness + Stimulating + Inspiring
		Enjoyment	= Pleasant + Interesting + Calming
		Attachment	= Spacious + Private
		Ambience	= Ambience + Attractive + Complex

* PCQ: perceived comfort quality; PSQ: perceived strength quality; PAQ: perceived appearance quality; PDQ: perceived distribution quality.

Source: The Authors

3. Results and Discussions

The factor of daylight level or **illuminance**, a part of the daylight quantity factors, is measured in almost all models. This is due to various reasons, including ease of measurement using lux meters compared to other factors, cost-effectiveness, or its ability to represent instantaneous daylight quantity values in a space. However, only the Egyptian codes rely solely on illuminance measurements. Additionally**, uniformity** is not measured in codes but only in assessment models, with a greater focus on assessing daylight distribution in spaces or directionality. As for **glare** assessment, glare is the most widespread factor among assessment models, assessed in 8 models analyzed. Temporal light modulation, however, is only measured in IEA Task 61 as the latest development, replacing flicker. **Luminance** is the least measured factor in various models, with sub-factors rarely mentioned, except in the IESNA model, an older daylight assessment model, and WELL rating system. Regarding **light color**, it is not mentioned as a measurable factor in codes but is referenced in assessment models and also in the WELL rating system.

Other physical factors for evaluating daylight quality, not falling under the five main daylight quality factors, have been mentioned in one assessment model (IESNA) and in only one code, the European Code EN 17037, indicating a recent focus on providing daylight in spaces. **Views out** are addressed in the latest quality models (IEA Task 61), the European Code En 17037, and BREEAM rating system, a recent factor introduced with the European code and thus emphasized in the BREEAM rating system, appearing in the latest assessment model among the models analyzed. **Contrast** and **spatial clarity**, however, have only been mentioned once in the oldest lighting measurement model, IESNA.

When it comes to assessing the **subjective experience** of non-physical daylight factors, visual interest, and psychological orientation are measured, these factors only appeared in daylight assessment models, and prominently in the latest IEA Task 61. This model outlines the measurement details used and emphasizes the necessity of user evaluations to complete the assessment of daylight in indoor spaces. Regarding assessing **dynamic daylight**, the European Code EN 17037 highlights the importance of sunlight exposure but lacks specific measurement methods. However, methods for measuring daylight diversity and sun penetration appeared in a handbook from one institution involved in drafting the American Energy Design Code (ANSI/ASHRAE/IES, 2018) but not in the code itself. Nevertheless, evaluating daylight diversity and sun penetration emerged as modern metrics in rating systems like LEED and WELL. This indicates that codes have not fully shifted towards evaluating dynamic daylight as part of the factors affecting daylight quality in spaces and thus user visual comfort.

Analysis of these sub-factors also reveals that **quality assessment models** are more comprehensive, encompassing a greater number of sub-factors compared to codes, which mainly focus on illuminance. Additionally, assessment models are the only ones to address user evaluations, which are absent in codes or rating systems. Comparing models, it's evident that both IESNA and IEA Task 61 are extensively exposed to various daylight factors, with IEA Task 61 being the most comprehensive, incorporating both the five main factors of physical daylight quality and non-physical factors. It also represents the latest evolution among daylight quality assessment models, building upon previous models' frameworks.

In general, **Codes** mostly focus on the required specifications for designing spaces with adequate lighting, but they do not concern themselves with measuring the lighting inside the space except to provide appropriate illumination levels in each code. This is because they are building design codes or energy design codes, so there is no specific code dedicated to designing daylight in buildings except for the SLL code - which is not an international code and is non-mandatory. The European Code EN 17037 is the only code dedicated to designing daylight in buildings and is standardized across all European countries. This code has shown an interest in various factors of daylight quality different from other codes, as it evaluates daylight through four points covering the provision of daylight, measuring illuminance inside the space, reducing glare inside spaces, the importance of providing views out for users inside the space as a factor of daylight quality, and the importance of appropriate sun exposure. Therefore, the European code is unique as a comprehensive code that deals with daylight quality uniformly for all European countries.

While in America, no similar codes have emerged, and all focus on energy or factors affecting lighting, similar to Egyptian codes. Therefore, the situation in Egyptian codes and laws is unsatisfactory as they deal with daylight and its influencing aspects more importantly than focusing on measurements, especially beyond illumination quantity alone. They did not mention any modern or dynamic metrics, so they can be considered more design guidelines than measurement tools. This also applies to American energy or building codes, where daylight is superficially addressed similarly to Egyptian codes but with different standards required for designing spaces that comply with each code area, with a greater focus on artificial lighting design.

As for **rating systems**, four systems were discussed, three international and one national, with most of these systems mentioning sub-factors. The WELL system, which focuses on people's health and well-being, showed the most attention to dynamic daylight by mentioning dynamic metrics such as sDA and ASE as evaluation measures for spaces. However, despite covering more factors than other systems, the WELL system is the most complex in its assessments. On the other hand, the BREEAM system uses assessment standards influenced by the four points used in the European code, which focus on quality, but like the European code, it does not use dynamic metrics for evaluation. The Egyptian GPRS system only addressed the importance of aligning lighting intensity in spaces with required rates in national codes, making it the least rating system interested in daylight. From this, it was found that dynamic metrics are being used in American systems, indicating that recent interest is shifting towards dynamic metrics for daylight assessment because they more strongly reflect the individual differences in buildings beyond regular measurements.

From the analyses, and after clarifying the relationship of factors with models, codes, and rating systems, it can be said that the measurement model IEA Task 61, the required lighting levels for illuminance in Egyptian codes, the factors present in the European code EN 17037, and the American rating systems such as LEED and WELL – as the systems exposed to dynamic daylight - are the primary models relied upon primarily to derive sub-assessment factors under the main physical, non-physical, and dynamic factors for achieving visual comfort. As illustrated in [Table 6].

Table 6. Visual Comfort Assessment Model in Residential Buildings in Egypt

	Factors	Metric	TEAs	OBEAs
Physical Factors	**Daylight Level**			
	Illuminance	Mean Illuminance in LUX	Luxmeter or Simulation	--
	Uniformity			
	Uniformity	Uniformity Ratio	Luxmeter or Simulation	--
	Distribution	--	--	Analyzing LUX Heatmaps Plans for LUX Distribution
	Directionality	--	--	Analyzing Heatmaps in Plans and vertical HDR Pictures
	Glare			
	Glare	DGP	HDR Pictures then Analysis or Simulation	Analyzing HDR pictures for Glare in space
	Luminance			
	Luminance	--	--	Analyzing Luminance Questions in Questionnaire Forms
	Light Color			
	Light Color	--	--	Analyzing Light Color Effect Questions in Questionnaire Forms
Dynamic Daylight	**Physical Metrics**			
	Daylight Variability	sDA	Simulation	Analyzing sDA Heatmaps Plans for sDA Distribution
	Sunlight Exposure	ASE	Simulation	Analyzing ASE Heatmaps Plans for ASE Distribution
	Non-Physical Effect			
	Effect on Atmosphere	--	--	Atmosphere Questionnaire Form
Non-Physical Factors	**Perception**			
	Visual Interest	--	--	PILQ Form in real space or using VR
	Subjective Experience			
	Psychological Orientation	--	--	BEPs Form in real space or using VR

Source: The Authors

4. Conclusion

The study examined the effectiveness of the existing Egyptian building codes for assessing daylight in a space. It found that the approach is insufficient for describing daylight quality and suggests the need for a more comprehensive assessment model to evaluate visual comfort in Egyptian residential buildings, by investigating various daylight factors in different assessment models, aiming to develop a comprehensive dynamic daylight assessment model. This can be clarified in the following:

- The situation in Egyptian codes and laws is unsatisfactory as they deal more with daylight and its influencing aspects than focusing on measurements. The mentioned measurements are only illuminance quantity and do not comprehensively address daylight quality. They have not mentioned any modern or dynamic metrics, so they are more design guidelines than a means of measurement.
- Egyptian code editions are outdated compared to international codes, which are more up-to-date and regularly updated with developments. Information in international codes regarding daylight assessment is either outdated or non-binding. Although Egyptian law is binding in terms of design elements affecting daylight, but it does not address daylight assessment.

- Quality assessment models are the most comprehensive as they contain a larger number of factors, unlike codes and laws, which have limited exposure to elements and generally focus more on illuminance quantity. Assessment models are the only ones that have been exposed to user assessment measurements, not addressed in codes or rating systems.
- Recent trends in green rating systems are shifting towards dynamic metrics for daylight assessment because they provide a stronger representation of buildings' individuality and differences compared to traditional metrics. They also provide certified ratings sought by modern building designs. Both local and international systems were studied.

This assessment model can significantly improve daylight evaluation of quality and enhance occupants' visual comfort. Visual comfort encompasses both physical and subjective experience factors. It is essential to provide dynamic daylight in a way that creates a natural environment for individuals, ensuring comprehensive visual comfort for users. However, it is important to ensure that the physical daylight quality values inside the space are within acceptable limits of design standards and suitable for activities. This also can be clarified in the following:

- Sub-assessment factors of daylight quality were derived from analyzing quality assessment models, codes, laws, and rating systems, which can be classified according to physical factors for daylight quality, non-physical factors for user assessment, and dynamic daylight factors. There are 20 factors for daylight, each of which affects the daylight quality inside the space and consequently the visual comfort of users.
- Daylight factors are measured through assessments based on environmental quality evaluation, called Environmental Assessment. Evaluating environmental characteristics such as daylight can be done in two ways: technical environmental assessment and observer-based environmental assessment. Both approaches are integrated to provide a complete evaluation for the post-occupancy stage.
- Physical measurements of Dynamic Daylight metrics are challenging due to their complex nature, making simulations the most suitable option to measure these metrics.

The research concluded with a guiding assessment model for assessing visual comfort with its comprehensive concept in residential buildings in Egypt. It clarified the relationship between the sub-factors measured with the metrics, along with explaining the appropriate measurement method for each factor and the values that each of these factors should achieve.

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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