ISSN: 0975-833X

Available online at http://www.journalcra.com

International Journal of Current Research
Vol. 14, Issue, 06, pp.21754-21765, June, 2022
DOI: https://doi.org/10.24941/ijcr.43585.06.2022

INTERNATIONAL JOURNAL OF CURRENT RESEARCH

REVIEW ARTICLE

REVIEW OF OVERALL BUILDING COMFORT IN A TROPICAL CLIMATE

[1]Clément AHOUANNOU, [2,*]Didier B. APOVO, [3]Sibiath O. G. OSSENI and [4]Pierre C. GBADO

[1]Full Professor, Laboratory of Energetics and Applied Mechanics (LEMA), Polytechnic School of Abomey-Calavi, University of Abomey-Calavi. 01 BP 2009 Cotonou / Benin.
[2]PhD student, Laboratory of Energetics and Applied Mechanics (LEMA), Polytechnic School of Abomey-Calavi, University of Abomey-Calavi, Benin,
[3]PhD,Laboratory of Sciences, Engineering and Mathematics. National School of Energy and Process Engineering; National University of Sciences, Technologies, Engineering and Mathematics of Abomey, Benin
[4]PhD, Laboratory of Energetics and Applied Mechanics (LEMA), Polytechnic School of Abomey-Calavi, University of Abomey-Calavi, Benin

ARTICLE INFO

Article History:
Received 14th March, 2022
Received in revised form
19th April, 2022
Accepted 25th May, 2022
Published online 30th June, 2022

Key words:

Climate, Comfort,
Energy Efficiency,
Environment.

Corresponding Author:
Didier B. APOVO

ABSTRACT

The well-being of building occupants depends primarily on their health, comfort and the safety conditions in which they can carry out their activities. The search for comfort by building occupants means that the building sector remains a major source of energy consumption and pollutant emissions worldwide. Countries in tropical regions, such as Benin, have a relatively warm climate, which requires appropriate technologies and comfort prediction models to provide the desired level of comfort for building users. It is commonly accepted that good comfort conditions require the coexistence of four main components: hygrothermal, acoustic, visual and olfactory. The simultaneous study of these four components proves to be complex due to the poor knowledge of the relationship between measurements and the subjective evaluation of physical and chemical parameters or the lack of consensus on certain indicators. This paper focuses on a literature review on the overall comfort of building occupants in the tropical climate. A synthesis of the different models and characteristics of comfort components was presented as well as approaches to global comfort indicators.

Citation: ***Clément AHOUANNOU, Didier B. APOVO, Sibiath O. G. OSSENI and Pierre C. GBADO.*** **2022.** "Review of overall building comfort in a tropical climate*". International Journal of Current Research*, 14, (06), 21754-21765.

INTRODUCTION

In a concept of sustainable development, the building sector remains a major source of energy consumption and pollutant emissions on a global scale (Lou, 2012; Daouadji, 2017). In general, the factors that influence energy consumption in buildings can be related to the characteristics of the building, the climatic region, the behaviour of the occupants and the conditions of the indoor environment (Zhang & Bluyssen, 2021). Reducing the energy consumption of a building and improving the quality of the indoor environment are two major challenges facing building professionals worldwide (Valdiserri, et al., 2015; Kim, et al., 2017; Yılmaz & Yılmaz, 2020). This dual requirement is even more pronounced in tropical regions with high temperatures, where about 40% of the world's population currently lives and probably more than 60% by 2050. (Renaudeau, et al., 2005; Brittany, 2014). This demonstrates the importance of these regions in terms of population and the need to meet comfort requirements. The energy and environmental challenges in the building sector are therefore huge and very complex. There is a great deal of research on comfort in housing, but very little of it has focused on housing in tropical regions, where design methods are too often modelled on those of temperate regions. Most studies on the comfort of tropical housing have focused on hygrothermal comfort, without taking into account aspects such as acoustics, visual and olfactory comfort, although we know that human well-being is particularly sensitive to many other factors (Kimnenh, 2020). The performance of buildings can be assessed in terms of indoor air quality, thermal comfort, lighting quality and acoustic quality (Lai & Man, 2017). Uncomfortable climatic environments lead to or provoke more or less severe reactions in the human organism, which can reduce human performance and efficiency (Fouillet, 2007).

Improved indoor air quality and comfort also have a significant impact on health-related expenditure, quality of life and generally on people's productivity (Lucon, et al., 2014). Indeed, comfort is part of the definition of well-being. It is expressed by several physical, psychological, physiological, cultural, and personal parameters that more or less influence its different components defined according to Moser (2009) by existential, material, aesthetic, social, conformity and sensory comfort (light, sound, sight, air, ...). Comfort is related to feelings, perception, mood and situation. It therefore depends on the physiological capacities and psychological appreciation of each individual (Grosdemouge, 2020). The notion of comfort is therefore difficult to define; it is the subject of much research in many disciplines. It is probably understandable that there are only a few comfort situations capable of satisfying all individuals whose physical and psychological characteristics may be very different. This situation makes it difficult to control the comfort parameters of the occupants simultaneously. Generally, comfort in a building is influenced by its external climatic environment and appreciated with a view to rationalising energy consumption. Therefore, taking into account the local climate is important.

The climate characterisation is based on annual and monthly statistical measurements of local atmospheric data, i.e. temperature, air pressure, precipitation, sunshine, humidity, wind speed. According to Köppen's classification (Kottek, et al., 2006)The climate can be tropical (wet or dry), temperate, continental or polar. The tropical climate is marked by high annual precipitation (higher than the annual evaporation) and above all by monthly average temperatures exceeding 18°C.
This article presents a state of the art that is part of a process of better appreciation of the notion of comfort in buildings in a tropical climate, with a view to making objective recommendations for predicting the level of occupant satisfaction. The study focused on overall comfort (hygrothermal, visual, acoustic and olfactory) in buildings in tropical climates. The objective is to assess the comfort indicators for each of the components of overall comfort and the different indices of overall comfort found in the literature.

METHODOLOGY

The methodology used to carry out this literature review was to review studies proposing topics related to energy performance and overall comfort in buildings in tropical climates. Several databases were used to search for articles, books, conference proceedings and theses. These include ScienceDirect, ResearchGate, Scopus, PdfDrive, Google Scholar, etc. Several keywords were exploited in different orders and combinations, such as: building, tropical climate, global comfort, hygrothermal comfort, visual, acoustic, olfactory, energy performance, air quality, indoor/outdoor environment, bioclimatic, passive building, daylighting, to name a few. Depending on the relevance of the results obtained, several other documents were consulted on the basis of bibliographic references found in some of the publications initially studied. A synthesis of these works made it possible to identify the environmental requirements linked to each component of overall comfort, the criteria for evaluating comfort and the quality of indoor environments, and then the approaches to overall comfort indices. These recovered results were then commented on.

- **Study of building comfort in a tropical climate**
- **Hygrothermal comfort**
- **Definition of hygrothermal comfort**

The concept of hygrothermal comfort is characterised by the state of satisfaction in the thermo-hygroscopic conditions of the environment. This satisfaction is expressed by the impossibility for the subject to specify whether he or she prefers a "colder" or "warmer" environment (Fanger, 1970). According to De Dear, its aim is to (2004) to provide a healthy indoor climate that ensures well-being and does not affect the productivity of users. Of course, people are different biologically and physically, and if individuals are subjected to the same thermal conditions in the same room, it is not normally possible to satisfy them all at the same time (Dribat, 2015; Grosdemouge, 2020). However, it is possible to create an optimal climate in a room, i.e. conditions in which the maximum percentage of individuals are in a state of thermal comfort. The thermal environment of the individual is characterised by four physical quantities (air temperature, radiation temperature, relative humidity and air speed). These variables react with the activity (metabolism) and clothing of the human body to establish its thermal state, and together constitute the six basic parameters of thermal exchange between humans and their environment (Jannot & Djiako, 1994; Dhalluin, 2012). Man is a homeotherm and his temperature is not directly dependent on the outside temperature, but is governed by different thermoregulatory mechanisms, either behavioural or physiological. The heat produced by the metabolism can be compensated or added to the exchanges by convection, conduction with surfaces, evaporation (sweating or breathing) and/or radiation. A simple model of the body's enthalpy balance allows the thermal load to be calculated as a function of environmental and individual variables.

$$S = M - W - R - (C + C_{res}) - (E_{res} + E_{dif,p} + E_{sud}) \quad \text{(Eq.1)}$$

With,

S : thermal load (W.m^{-2});
Mmetabolic energy production (W.m^{-2});
Wexternal mechanical work supplied by the body (W.m^{-2});
R Thermal radiation from the body (W.m^{-2});
C Thermal convection of the body (W.m^{-2});
C_{res} Respiratory convection (W.m^{-2});
E_{res}Heatlossthroughrespiratoryevaporation (W.m^{-2});
$E_{dif,p}$ Evaporative heat loss by moisture diffusion through the skin (W.m^{-2});
E_{sud} Heat loss through sweating and evaporation of sweat (W.m^{-2}) .

If this is zero (), the individual is in thermal equilibrium. If this equilibrium is reached with few physiological reactions, the body is in thermo-neutrality: comfort is then possible. One of the problems of comfort in the tropics is that it is necessary to use the characteristics of the climate to achieve thermal comfort conditions. Tropical areas are often characterised by high daytime outdoor temperatures, which impact on the internal comfort of buildings and can lead to intensive use of air conditioning systems. Like temperature, humidity also influences the internal comfort of a building, particularly in humid tropical environments.

Table 1. Overview of thermal comfortdefinitionmodels/Benefit and limitations

Approaches	**Authors**	**Advantage**	**Deficiencies**
Static (rational)	Fanger (1970)	• simple and based on the use of heat balance equations of the human body	• static model assumptions ; • lack of correlation with external conditions ; • limitation in terms of climate zones ; • Not applicable to various types of ventilation (especially natural ventilation) due to the presence of transient weather conditions (Van Hoff, 2008).
	Gagge et al. (1971)	• allows the calculation of physiological variables under transient conditions for low and moderate levels of activity in cool and very hot environments • updating the VMS	• equivalent characteristic of certain fictitious environments, with fixed factors taken into consideration as derived from empirical models. • consideration of the physiological functioning of the occupants (human body) in only two nodes (body centre and skin)
	Zhang et al. (2010a; 2010b; 2010c)	• allows hygrothermal comfort to be addressed also in transient and/or non-uniform environments. • predicts the local sensations of the different parts of the body and the global sensation	• not valid for several experimental conditions
Adaptive	Humphreys & Nicols (1998)	• use of very simple empirical models • consideration of the occupant	• not taking into account all the physical parameters determining the microclimate inside the buildings. • problem of generalisation.
	Dear et al, (1998)	• Index developed for outdoor studies from the Gagge indoor model • takes into account all climatic factors influencing thermal comfort	• steady-state calculation • initially developed for an open environment, especially for the radiation absorbed by the human body.
	Olissan (2016)	• Adaptation of the Fanger model to the climatic conditions of the coastal region of Benin	• Not suitable for all buildings in the same climate context (Kiki, et al., 2020).

Table 2. Hygrothermal comfort indices

Indexes - Reference	Type Index (Unit)	Principle / Model	Climate - application environment	Benefits	Boundaries
PMV (Fanger, 1970; ASHRAE, 2001)	Thermal sensation vote (No dimension)	Heat balance equation for the human body	All climates - Indoor environment	• one of the most widely used indoor indices • takes into account climatic factors influencing thermal comfort	• steady-state calculation that reaches its limits for taking into account rapid changes in the outdoors • Total evaporation of perspiration is assumed • Overestimation of the thermal perception of individuals
PT (Perceived Temperature) - (Gagge, et al., 1971)	Equivalent temperature (°C)	Heat balance equation for the human body - Klima-Michel model	All climates - Outdoor environment	• clothing varies according to the season (summer / winter) • improved calculation of latent heat flux: humidity sensitivity better taken into account • external radiation added to the model	• Not applicable in the context of indoor occupant comfort; • Steady-state calculation ; • model developed with recorded weather data for German cities; • little tested in tropical climates in studies.
SET* (Standard Effective Temperature) - ((Gagge, et al., 1971; Gagge, et al., 1986)	Equivalent temperature (°C)	Heat balance equation for the human body - two-node model	Temperate to warm climate - Indoor and outdoor environment	• takes into account all climatic factors influencing thermal comfort	• index more suitable for assessing thermal comfort indoors than outdoors • limited to two nodes
OUT_SET* - (Pickup & De Dear, 2000)	Equivalent temperature (°C)	Heat balance equation for the human body	Temperate to warm climate - Outdoor environment	• developed for outdoor studies from the Gagge indoor model • takes into account all climatic factors influencing thermal comfort	• steady-state calculation • initially developed for an open environment, especially for the radiation absorbed by the human body

Continue …

PET (Physiological Equivalent Temperature) -	Equivalent temperature (°C)	MEMI (Munich Energy balance Model for Individuals) - Two node model	All types of climate - indoor and outdoor environment	• flexible and practical assessment with a thermal scale that can be adapted to the climate • index validated in numerous studies for different climates, different seasons and for even complex urban forms	• steady-state calculation • model defined for indoor conditions with light activity and a constant value for clothing and metabolic activity
UTCI (Universal Thermal Climate Index) (Jendritzky, et al., 2012; Fiala, et al., 2012)	Equivalent temperature (°C)	Fiala's multi-node human Physiology and thermal Comfort model (FPC) coupled with a clothing model	All climates - Outdoor environment	• the most comprehensive index, including the latest physiological models and the effect of clothing • dynamic model • Universal index: Applicable in all types of climate, all seasons and for all types of outdoor exposure	• A recent and still untested index for tropical climates • value of clothing deducted as a function of outdoor air temperature and based on observations in Europe • Thermal sensation scale representative of an individual living in Europe
ET (Effective Temperature) - (Houghton & Yaglou, 1923)	Equivalent temperature (°C)	Multiple regression analysis on laboratory measurements	All types of climate - Indoor and outdoor environment	• The thermal perception scale of the index can be adapted to the climate (field surveys with measurements of climate variables and questionnaires)	• laboratory measurements • does not take into account personal variables or the average radiant temperature measurement which has a great influence on thermal comfort
WBGT (Wet Bulb Globe Temperature Index) - (ASHRAE, 2001; ISO 7243, 2017)	Equivalent temperature (°C)	Empirical model	Warm climate - Indoor and outdoor environment	• More dynamic index than humidex and heat index • takes into account sunshine and wind speed • recognised in ISO standards and widely used in the field of work and health impact	• requires an assessment of activity level, clothing and other personal factors for proper interpretation. • requires specific measuring equipment. Errors can occur if measuring instruments are not standardised and if calibration is not well done.

Table 3. Analysis of the visual comfort models presented

Models	Indexes	Benefits	Deficiencies
Quality of light	Illumination (Em) (Dhalluin, 2012)	The advantage of this approach is that it is simple and immediate, since all that is needed is a light meter to measure the amount of light.	-The measurement is local and depends on the orientation of the illuminated surface. -Does not take into account changes over time. -Type of light source not considered
	Daylight Factor (DF) (Walsh, 1951)	Only natural light is considered, which is very good for a sustainable building.	-Does not take glare into account -Does not take into account absolute values of illuminance, as it is expressed in %.
	Daylight autonomy (DA) (Reinhart & Walkenhorst, 2001)	It conceives visual performance through a single value expressed as a percentage. DA takes into account the actual weather conditions of the site.	Don't give importance to daylight illuminance values that are below and above the recommended threshold.
Light distribution	Uniformity of light (Uo) (Narboni, 2006; Carlucci, et al., 2015)	A zonal and short-term index assessing the uniformity of light.	Rather recommended for artificial lighting or roof lights.
Glare	Daylight glare (DGI) (Guth, 1963)	Consider several light sources.	Considers uniform light sources, excludes direct sunlight.
	Unified Glare Ratio (UGR) (ICE17, 1995)	Recognised as suitable for use in accordance with the conditions laid down in standard EN 12464-1	The UGR only deals well with very small sources of glare at very low solid angles.
	Probability of glare (DGP) (Wieldnold & Christffersen, 2006)	A function of the illuminance in the vertical plane as well as the luminance of the glare source, its solid angle and its position index. Shows a strong correlation with user responses.	-Valid in the DGP range between 0.2 and 0.8, and for vertical illuminance (Ev) greater than 380 lx. -Very complicated calculation

Table 4.Comparative analysis of acoustic comfort indices

Indicators	Benefits	Deficiencies
	Adopted by several authors to determine the sound pressure level, it is taken as an indicator of acoustic comfort.	Requires arrangement in case of multiple sources.
	Calculates the noise level between a transmitting and a receiving room	Depends on the actual and reference reverberation time
(Alfano, et al., 2010)	A simple basic indicator for assessing acoustic comfort in schools.	Clears short-lived amplitude peaks observed during the period under consideration.
(Sabine, 1901; EN ISO 3382-2, 2008)	The oldest and often most important characteristic quantity in room acoustics. It is used to evaluate the absorbency of a room.	The reverberation time is determined in bands of one octave, which varies from zone to zone.

Table 5. Analysis of the olfactory comfort indices presented

Models	Benefits	Deficiencies
Single marker indices (Dhalluin, 2012)	Enables the concentration of pollutants in the air and their intensity to be determined.	As their name suggests, they study a single pollutant. They identify only one pollutant at a time.
Olf and Decipol indices (Fanger, 1988; NF EN 15251, 2007)	Allows the analysis of the olfactory discomfort linked to the presence of humans. This model proposed by Fanger makes it possible to regulate the rate of air renewal according to the pollution and the activity in the room.	Does not allow for a dynamic regime study, as the emission rates of each source are set constant.
The Jokl model (Jokl, 2000)	Enables the perception intensity of CO_2 and TVOCs to be determined. It is also possible to estimate which of the components : CO_2 or TVOC plays the dominant role in air contamination.	Deals only with the case of CO_2 and TVOC

Thermal and hygroscopic comfort approaches: There are two families of hygrothermal comfort assessment approaches, each with its potentialities and limitations. These are the static approach and the adaptive approach (Benharkat & Rouag-Saffidine, 2015; Allab, 2017). The static approach is also called the rational approach or heat balance. It studies thermal comfort in an analytical way. It is not restricted to buildings. In buildings, the most commonly used static thermal comfort models are Fanger's PMV (predicted mean vote) and Gagge's SET (standard effective temperature). The Fanger model was used as the basis for the international standard ISO 7730 (1994) which deals with comfort conditions in moderate thermal environments, and the Gagge model for the American ASHRAE Standard 55, which also specifies thermal comfort conditions in buildings. The adaptive approach recognises the existence of a dynamic equilibrium between people and their thermal environment, so that changes in the environment can be compensated for, for example in clothing or through physical activity. The adaptive approach was first articulated by Nicol and Humphreys (2002). Nasir et al, (2012) found that people in tropical environments were able to cope with warmer, more humid outdoor conditions and less air movement than those living in temperate climates. Table 1 summarises the different approaches to hygrothermal comfort identified.

Hygrothermal comfort indices: Hygrothermal comfort indices are indicators for decision making. They are linked to thermal comfort approaches. They are measurable or calculable as a result of hygrothermal comfort assessment models by different authors. Several indicators have been identified in the literature. Table 2 presents the most relevant ones with their specific parameters

Visual comfort

Definition of visual comfort: The most important human sense is that of vision, as 80-90% of our data input is based on what we can see (Hegger, et al., 2008). Visual comfort refers to the lighting conditions to ensure optimal clarity inside a building. Lighting is an extremely important factor in the health and safety of building occupants as poor lighting leads to excessive eye strain. The factors responsible for good lighting are good light distribution and propagation, building orientation, absence of glare and sharp shadows. Optimal visual comfort for work areas is guaranteed when the luminance at the workplace (ambient luminance) is adapted to the respective visual task (direct luminance). This can be achieved, in principle, with daylight, artificial light or a combination of both. However, daylight (natural light) creates more comfortable conditions, as it includes all colours of the spectrum. There are several parameters that determine visual comfort. These include: luminance distribution, light intensity, daylight factor, level of dependence on daylight, glare, colour of the light source and its rendering.

Models and visual comfort features: Most visual comfort recommendation documents are based on average illuminance (E_m), given by the following correlation:

$$E_m = \frac{d\phi}{dA} \qquad \text{(Eq.2)}$$

Light flux falling uniformly on a surface (in lumen), Area of the surface covered by the luminous flux (in m²).

Dhalluin used this index in his study which investigated the ventilation strategy to improve indoor environmental quality and occupant comfort in a classroom. Visual comfort is associated not only with the amount of light in a space, but also with its distribution. The illuminance uniformity (Uo) of a given plane is defined as the ratio, at a given time, between the minimum value of illuminance on the plane () and the average illuminance () on this plane . It is also possible to use the ratio between the minimum and maximum value () of the illuminance on the given plane, but this must be specified. Their formulae are respectively :

$$\mathrm{U_{o,moy.}} = \frac{\mathrm{E_{min}}}{\mathrm{E_{moy.}}} \qquad \text{(Eq.3)}$$

$$\mathrm{U_{o,max}} = \frac{\mathrm{E_{min}}}{\mathrm{E_{max}}} \qquad \text{(Eq.4)}$$

In 1895, Trotter first introduced the daylight factor (DF) and defined it as the ratio of the natural illuminance at a point on a given plane to the illuminance on a horizontal plane due to an unobstructed hemisphere of that sky . Direct sunlight is excluded for indoor and outdoor illuminance values . The expression for the daylight factor is given by :

$$\mathrm{DF} = \frac{\mathrm{E_{p,obs}}}{\mathrm{E_{p,unobs}}} \qquad \text{(Eq. 5)}$$

With The horizontal illuminance at a point P due to the presence of a room that obstructs the view of the sky, The horizontal illuminance at the same point P if the view of the sky is not obstructed by the room. Daylight autonomy (DA) was first proposed in 1989 by the Swiss Electricians' Association. It is defined as the percentage of occupied hours in the year, during which a minimum illuminance threshold is reached by daylight alone. It is expressed in the following form:

$$\mathrm{DA} = \frac{\sum_i (\mathrm{wf_i} \times \mathrm{t_i})}{\sum_i \mathrm{t_i}} \in [0, 1] \qquad \text{(Eq. 6)}$$

$$\mathrm{w_{f_i}} = \begin{cases} 1 \text{ si } \mathrm{E_{jour}} \geq \mathrm{E_{limit}} \\ 0 \text{ si } \mathrm{E_{jour}} < \mathrm{E_{limit}} \end{cases} \qquad \text{(Eq. 7)}$$

With weighting factor based on the values of and which are, respectively, the horizontal illuminance at a given point due to daylight alone and the illuminance limit value. Note that the glare index is one of the factors that aim to give an assessment of the level of visual comfort. The glare measure uses luminance rather than illuminance and takes into account the location, size and brightness of individual glare sources. Glare occurs when light sources in the field of view cause visual irritation or eye strain. Increasing the size or brightness of the source can lead to a loss of contrast in the retinal image, resulting in disability glare . Thus, Guth developed the DGI, which is expressed as follows.

$$\mathrm{DGI} = \left(\frac{0{,}5}{\mathrm{L_v}^{0{,}44}} \sum_s \frac{\mathrm{Ls} \times \mathrm{Qs}}{\mathrm{Ps}}\right) \mathrm{N}^{-0{,}0914} \qquad \text{(Eq.8),}$$

with :

$$\mathrm{Qs} = 20{,}4\ \mathrm{ws} + 1{,}5\ 2\ \mathrm{ws}^{0{,}2} - 0{,}075 \qquad \text{(Eq.9)}$$

Total number of sources

Luminance of the source S in the field of view. Solid angle at which the source is viewed S. Guth position factor for the direction of the source S; the latter factor expresses the fact that the glare caused by a source depends on its position in the field of view; it is given by an analytical function. Average luminance of the visual field. Using data collected over a period of 10 months, in a specially designed test cell. The daylight glare index (DGI) was evaluated by The daylight glare index (DGI) was evaluated by means of a number of different interpretations of the background luminance (Lb). The evaluation of the models led to a better understanding of the effect of the adaptation function and a modified DGI is explored in the light of these results. The Unified Glare Rating (UGR), which is the CIE model for predicting discomfort glare caused by artificial lighting, was also evaluated to identify differences between the two approaches and to test the potential for developing a general UGR ($\mathrm{UGR_{exp}}$) that would include both lighting environments . The expression of the UGR is as follows:

$$\mathrm{UGR} = 8\log_{10} \frac{0{,}25}{\mathrm{L_b}} \sum_{i=i}^{n} \frac{\mathrm{L_s^2} \omega_s}{\mathrm{P^2}} \qquad \text{(Eq.10)}$$

$$\mathrm{UGR_{exp}} = 8\log \mathrm{L_a} + 8\log \sum \frac{\mathrm{L_s}}{\mathrm{L_b}} \frac{\omega}{\mathrm{p^2}} \qquad \text{(Eq.11),}$$

with Average luminance over the hemisphere of vision, Average luminance on the inner surface of the chamber. Evaluations were carried out by Wieldnold & Christffersen to evaluate existing glare models and provide a reliable database for the development of a new glare prediction model. They developed a new index, the daylight glare probability (DGP). The DGP is a function of the illuminance in the vertical plane as well as the luminance of the glare source, its solid angle and its position index. The DGP showed a very strong correlation (squared correlation factor of 0.94) with the user's response to perceived glare. Its expression is as follows:

(Eq. 6)

$$\mathrm{DGP} = 5{,}87 \times 10^{-5} \mathrm{E_v} + 9{,}18 \times 10^{-2} \log\left(1 + \sum_i \frac{\mathrm{L_{s,i}^2} \omega_{s,i}}{\mathrm{E_v^{1{,}87}} \mathrm{P_i^2}}\right) + 16 \qquad \text{(Eq.12),}$$

with the illuminance in the vertical plane of the view [Lux],
the luminance of the source [$\mathrm{cd/m^2}$],

Solid angle of the source,
P: Guthposition factor.

The following table 3 presents the visual comfort models and indexes, their advantages and limitations.

Acoustic comfort

Definition of acoustic comfort: A sound is characterised by a frequency, also called "pitch" and expressed in Hz, which distinguishes low-pitched sounds from high-pitched sounds; a sound level (Lp) or "amplitude", also called sound pressure level, expressed in dB, and a duration (continuous, intermittent or impulse sounds). Acoustic comfort inside a building is achieved when the indoor environment is not subject to the following parameters: external noise, noise from neighbouring dwellings, equipment noise and echo or reverberation effects.

Models and acoustic comfort characteristics: The sound pressure level or sound level is defined as the logarithm of the pressure or intensity of the sound wave. For the definition of the acoustic decibel, the reference level is the audibility threshold at 1000 Hz, for which the acoustic intensity is $I_0 = 10^{-12}\ \mathrm{W/m^2}$ (intensity corresponding to a pressure variation $p_0 = 2.\ 10^{-5}$ Pa). The sound level in decibels is therefore :

$$\mathrm{L} = 10 \log\left(\frac{\mathrm{I}}{\mathrm{I_0}}\right) = 20 \log\left(\frac{\mathrm{p}}{\mathrm{p_o}}\right) \qquad \text{(Eq.13)}$$

A sound wave arriving at a wall is partly reflected, partly absorbed and partly transmitted. Sound insulation consists of reducing the fraction of sound waves transmitted through the walls of a room. Acoustic correction (or absorption) corresponds to the reduction of the reflected part inside a room and the increase of the absorbed part of the acoustic waves generated in a room. Hereafter, we will speak of standardised insulation ($D_{n,T}$), which corresponds to the gross insulation (D), i.e. the difference in noise level between a transmitting room and a receiving room, corrected according to the real reverberation time (T) measured in the receiving room and a reference reverberation time (To) such that :

$$D_{nT} = D + 10\log\left(\frac{T}{T_0}\right),\ [dB] \qquad \text{(Eq.14)}$$

With

The internal acoustics of a room are characterised by the way in which sound waves propagate in it and in particular by its reverberation time. This is the time (in seconds) needed for the existing sound level in a room to decrease by 60 dB, or for the intensity of the sound to decrease. The reverberation time is determined in octave bands for frequencies from 125 Hz to 4 000 Hz and is calculated according to Sabine's formula formula, as follows:

Where

$$T_r = 4 \times V \times \frac{\ln 10^6}{C \times A} = 0{,}163 \times \frac{V}{A}\ \text{Where}\ A = \sum_i S_i a_i \qquad \text{(Eq.15)}$$

With

Absorbing surface of a room in [m^2]
Sound absorption coefficient of a surface depending on the covering material and the underlying layers.
Wall area in [m^2]
Speed of sound in [m/s]
Volume of the room in [m^3]

The equivalent sound pressure level L_{Aeq} and the reverberation time T_r have been used as basic simple indicators for assessing acoustic comfort in schools. The equivalent sound pressure level, which is an index that takes into account the temporal variation of the noise level, is used to assess the exposure of an individual to noise. The equivalent continuous level Leq,t (in dB) of a steady or fluctuating noise is equivalent, from an energy point of view, to a continuous, permanent noise that would have been observed at the same measurement point and during the same period. Its expression is as follows:

$$L_{eq} = 10 \cdot \log\left[\frac{1}{T}\int_0^T 10^{0,1.L(t)}dt\right] \qquad \text{(Eq.16)}$$

With t: the measurement time in seconds, T: the exposure time. It is often expressed in dB(A) and symbolised by LAeq,t. This level is very regularly used as an indicator of annoyance. In practice, there is a good correlation between this value and the hearing discomfort experienced by an individual exposed to noise. However, the LAeq,t indicator erases the short duration amplitude peaks observed during the period under consideration. Table 4 shows the advantages and limitations of the different indicators described above.

Olfactory comfort

Definition of Olfactory Comfort: Olfactory comfort ensures effective ventilation, controlling sources of unpleasant odours. The speed of air circulation is also a factor that affects the sensation of comfort, and in particular it acts on the regulation of heat flows between the body and the ambient environment. It is therefore clear that olfactory comfort depends on air quality, air speed and the rate of air renewal.

Models and characteristics of olfactory comfort: There are two types of approaches to assess indoor air quality: the "health" approach based on the analysis of the exposure of occupants to a pollutant or a mixture of pollutants and the "olfactory" approach based on the assessment of the level of odours experienced by occupants. Different indices characterise the exposure of occupants and are expressed in $mg.m^{-3}$. We note the average exposure ., is given by the following relationship:

$$E_{moy} = \frac{1}{(t_1 - t_2)} . \int_{t_1}^{t_2} C(t)dt \qquad \text{(Eq.17)}$$

With the concentration of the pollutant at a time t. Air quality is mainly determined by people's sensations to different odours. Odour perception depends, on the one hand, on objective factors: concentration and toxicity of air pollutants (bio-effluents), level of activity, outdoor air flow, and on the other hand, on psychological factors of a subjective nature . The relationship between the perceived odour intensity and its concentration is in accordance with a power function whose expression is the following.

$$S = kC^{\beta} \qquad \text{(Eq.18)}$$

With Intensity of odorant, Concentration of odorant, exponent of a psychophysical function and : characteristic constant of a material. We also have the degree of odour pollution in a given room by the following relationship:

$$C_i = C_p + \frac{10\,G}{q_a} \qquad \text{(Eq.19)}$$

With Outdoor air flow rate, in l/s, indoor air quality (in Decipol), outdoor air quality (in Decipol), G: concentration of indoor air contaminants. These indices are referred to as single-marker indices. To overcome the problem of identifying odorous chemical species and interpreting their concentrations, Fanger introduced the unit " "to quantify the intensity of a source of odour pollution and the unit "l" to express the perception of the odour by the users of the building. The Olf unit indicates the air pollution produced by an average adult working in the tertiary sector, sedentary, in thermal equilibrium and with a typical hygiene equivalent to 0.7 baths per day. However, Fanger is not limited to the analysis of odour nuisance related to human presence, and assumes that any odour source can be quantified against this reference. The unit Decipol is the air pollution perceived in a space with a pollutant source of 1 Olf, ventilated by a flow of fresh unpolluted air of 10 litre/s, assuming steady state conditions and homogeneous mixing. One (01) Decipol therefore corresponds to 0.1. With reference to Fanger's work on thermal comfort, the Decipol is the analogue of the PMV for olfactory comfort. Using a panel of 168 judges in the presence of bio-effluents from 1000 subjects, he correlated this sensation (in L/s Olf) and the number of dissatisfied people PD (in %), according to the following relationship

$$PD = 395 \times \exp(-3{,}25) \times S^{-0{,}25}\ \text{si}\ S \le 31{,}3\ \text{décipol} \qquad \text{(Eq.20)}$$

$$PD = 100\% \qquad \text{si}\ S > 31{,}3\ \text{décipol} \qquad \text{(Eq.21)}$$

This correlation can also be expressed from the ventilation rate in a polluted room of 1 Olf. The model proposed by Fanger makes it possible to regulate the rate of air renewal according to the pollution and the activity in the dwelling, with the aim of reducing losses due to air renewal. It is thus possible to predict the ventilation volume flow rate necessary to maintain a given pollution inside a room by the following correlation:

$$\dot{Q} = 10 \cdot \frac{G}{s_i - s_0} \cdot \frac{1}{\varepsilon_v} \qquad \text{(Eq.22)}$$

With

ventilation volume flow rate [L/s].
G: intensity of the pollution source [olf].
perceived or desired air quality [decipol].
perceived outdoor air quality [decipol].
ventilation efficiency [Cste].

The Fanger model has been presented in many books, but has been rejected for inclusion in the European standard on indoor environmental quality. Fanger's theory has some limitations that have been analysed by . It should be noted that the Olf-Décipol method does not allow for a study in a dynamic regime, since the emission rates of each source are defined as constant (whereas the odorous emission of building materials fades with time).

Moreover, it considers a linear relationship between the odour load of the environment and the perception of the odour, which is contrary to Stevens' law. Finally, this method assumes the independence of perception with respect to the different odours, which seems unlikely. Two new units have been proposed by to evaluate air quality, considering that all human sensory perception mechanisms are governed by the same laws. Jokl therefore took the logarithmic relationship defining the sound pressure level and adapted it to the perception of odours in intensity. The criteria used are carbon dioxide, whose production is proportional to human metabolism, and volatile organic compounds, which are emitted by many building sources. Their wide ranges in concentration allow this logarithmic approach. According to Jokl, it is assumed for both 'adapted' and 'non-adapted' people that optimal odour levels are obtained when the PD is less than 20% (10% for asthmatics) and that levels are permissible above 30% (20% for asthmatics) for the non-adapted. The equations governing odour levels are formulated as follows:

$$L_{odor(CO_2)} = 90.\log\frac{C_{CO_2}[ppm]}{485}\,[dCd] \qquad \text{(Eq.23)}$$

$$\text{ou} \quad L_{odor(CO_2)} = 90.\log\frac{C_{CO_2}[\mu g.m^{-3}]}{875} \qquad \text{(Eq.24)}$$

$$L_{odor(TVOC)} = 50.\log\frac{C_{TVOC}[\mu g.m^{-3}]}{50}\,[dCd] \qquad \text{(Eq.25)}$$

The odour intensity scale of these new decicarbdiox and decitvoc units therefore covers the same range as the acoustic scale in dB and the optimal odour value of 30 dB (odor) corresponds to the ISO Noise Rating Acceptable Value NR 30. It is also possible to estimate which component, CO_2 or TVOC (Total Volatile Organic Compounds), plays the most important role in air contamination. The following table presents the advantages and shortcomings of the olfactory comfort models previously discussed.

Summary of the components of overall comfort

Influences of the different components of overall comfort: The determination of a single model of overall comfort that would represent the grouped physical manifestations of the five different types of comfort, as well as the measurement of a weighted value of it, remains a major problem for researchers. Indeed, the overall comfort of a house is an important criterion for assessing the expectations of its occupants. Determining the overall comfort of a room means determining the factors that lead to a perception of pleasantness, or neutrality of the influencing factors. Some of these factors are often subjective to people and difficult to quantify and measure. Most of the approaches currently used aim to select a limited number of the most representative factors. For example, the concentration of CO_2 in the air for olfactory quality and the air temperature for thermal comfort, ... (Gallissot, 2012). Thermal comfort is often confronted with visual comfort, including assumed relationships between thermal and light perception, as well as the relationship between colour temperatures of lighting lamps. Several authors consider hygrothermal comfort to be the main component of overall comfort in the tropics, due to the high temperature levels in this area (Joffroy, et al., 2017). Indeed, when sunlight strikes an opaque surface, such as a building wall, some of it is reflected and the rest is absorbed and transmitted through the wall material. The darker the surface in question, the greater the proportion absorbed. After several reflections, almost all of the initial radiation is absorbed and re-emitted as heat. In an open room, this heat can be dissipated by natural ventilation, thus controlling the indoor temperature. If the room in question is located in a noisy environment, for example near a traffic route or exposed to odours, the discomfort caused can seriously disrupt the activities carried out in the room.

To protect oneself, it is then tempting to close the room with glazing. The amount of light is slightly reduced, but the noise and odour can be controlled, and the glazing acts as a barrier to the infrared radiation inside the room. The heat that has been absorbed into the room can no longer escape, which is what we call the greenhouse effect. The room therefore heats up and the interior temperature can become incompatible or even unbearable with the activities carried out. It can be concluded that hygrothermal, visual, acoustic and olfactory comfort are closely linked due to the different physical phenomena that govern them and whose transfer or propagation matrix is the building material. Thus, the different types of comfort and the actions to curb their effects have a more or less preponderant influence on each other, from the point of view of the desired comfort results. The search for overall comfort is therefore particularly complex. In addition to this, the occupants' feelings are also highly subjective, depending on the existential context, i.e. age, clothing, activity, time of day, gender, etc. What is certain is that it is enough for one of the comfort parameters to be unsatisfied for the overall feeling of an environment to change negatively, which explains the difficulty in defining overall comfort. These links call into question the independence of "mono-sensory" comforts, and confirm the appropriateness of all research work in this area. It is therefore useful nowadays to look for a single global model for the comfort of a room, but it will be necessary to find a good compromise between the different factors linking the comfort parameters in order to improve the overall feeling in a room.

Overall comfort models: The links between the types of comfort presented above provide the basis for a convergence of comfort factors leading to a comfortable indoor building environment. In this study, we see that the optimisation of the different comfort factors is not enough to achieve the global comfort; it is necessary to integrate the different indices of the "mono-sensorial" comforts in a numerical model, thanks to a logic of interaction of the factors. Little work has been done to define a methodology for measuring overall comfort, i.e. multi-sensory comfort within a building. Authors such as Rohles et al. conducted a study to develop a global comfort index for the indoor environment. Their result has the advantage of determining comfort in a global, but totally subjective way since no environmental parameters (physical quantities) are involved (eq.26), and where the coefficients and were determined on the basis of experiments in real conditions (111 engineering students and 89 office workers).

$$\mathrm{Confort}_{\mathrm{global}} = \mathrm{a} \cdot \mathrm{Confort}_{\mathrm{hygrothermique}} + \mathrm{b} \cdot \mathrm{Confort}_{\mathrm{visuel}} + \mathrm{c} \cdot \mathrm{Confort}_{\mathrm{olfactif}} + \mathrm{d} \cdot \mathrm{Confort}_{\mathrm{acoustique}} \qquad \text{(eq.26)}$$

with, $\mathrm{a} = 21.9\%$, $\mathrm{b} = 24.0\%$, $\mathrm{c} = 24.0\%$ and $\mathrm{d} = 30.1\%$

This correlation has a major limitation recognised by the authors, because if one variable is judged totally unacceptable and the others are satisfactory, then the weighting mechanism will judge the environment as satisfactory. This is not the case in reality. Bruant reports this limitation by stating that this approach assumes an additivity of discomforts. He thus suggests a non-linear weighting method in order to take into account values that have a significant difference with the final score. This non-linear weighting approach is notably taken up in work related to sensory perception. According to NF EN 15251 the indoor environment can be assessed in a detailed or global way; in either case, the assessment will depend on the level of indoor quality for which the building and its heating, ventilation and air conditioning systems have been designed.
Chiang and Lai propose an index combining five categories of indoor environment: acoustic comfort, hygrothermal comfort, visual comfort, indoor air quality and electromagnetic environment. Each of these categories is based on one or more indicators and a score out of 100, in increments of 20, is associated with each. A high value indicates good environmental quality. In the case where a category is assessed by several indicators, if one of them is less than 60 then the lowest value is used for the whole category. If all indicators in a category are above 60, then the average of the indicators is used. Chiang and Lai then propose a model in which an aggregate index is obtained according to the following expression:

$$I_{CL} = 0{,}203 \cdot S_{acoustique} + 1{,}164 \cdot S_{visuel} + 0{,}208 \cdot S_{hygrothermique} + 0{,}29 \cdot S_{QAI} + 0{,}135 \cdot S_{EM}$$

(eq.27)

Where: the score for the acoustic comfort category; The score for the visual comfort category; The score for the hygrothermal comfort category; IAQ category score; The score for the electromagnetic environment category. Abadie, et al, have developed the TAIL index. This index is developed within the framework of the European Union-funded project ALDREN (Alliance for Deep Renovation in buildings), one of whose main tasks is to determine whether energy renovations affect the comfort and health of occupants. This index is intended to be used before and after renovation actions. They propose to rate four categories of comfort with a colour code ranging from green (good quality) to red (poor quality), referenced by the four letters of the acronym :

- T for Thermal comfort,
- A for "Acoustic comfort",
- I for "Indoor air quality",
- L for "Luminous comfort" or visual comfort.

An overall score out of 4 is also indicated in Roman numerals and aggregates the four categories. The lower the number, the better the indoor environmental quality. This approach is in line with EN 16798-1 (2019) which deals with indoor environmental parameters for thermal comfort, indoor air quality, lighting and acoustics. It should be noted that this project focuses on the tertiary sector. As a synthesis of all these models, it is possible to evaluate the occupants' perception of comfort, integrating their hygrothermal, acoustic, visual and olfactory requirements, based on a global indicator. It is clear that it is not a question of optimising each of the components in isolation in order to think of the overall optimum, but rather of taking into account the interferences and interrelations between the different components with physical, physiological and psychological influences. It should be noted that the approach of Rohles et al. (1989)s approach, which assumes an additivity of discomfort, is therefore limited. The approach of Chiang and Lai (2002) s approach incorporated a score defining the electromagnetic environment, which was seen as irrelevant in the assessment of overall comfort (Picard, et al., 2020). The approach of Abadie, et al, (2019) focused on the tertiary sector by integrating the four main categories of global comfort. Our study is interested in defining, in a tropical climate context, a global comfort indicator for building occupants, in particular school classrooms, that best integrates the data specific to this climatic environment and that takes into account the limitations of previous work.

Conclusion

This document presents a bibliographical study defining the different factors that influence the well-being of building occupants: hygrothermal comfort, visual comfort, acoustic comfort and olfactory comfort. To this end, the comfort parameters for each of the components of overall comfort and the comfort indicators studied in the literature were reviewed. In the remainder of this study, we will focus on the search for a better appropriation of the global comfort indicators and the definition of an indicator based on the specificity of the tropical climate. Its interest will be to have a numerical model to facilitate the prediction of global comfort in tertiary premises, and which would aggregate the building design parameters. An experimental validation of the model found will confirm the acceptability of the prediction indicator of global comfort. The objective is to significantly reduce the energy consumption of buildings in the service sector, in this case classrooms.

Nomenclature

ASHRAE : American Society of Heating, Refrigerating and Air-Conditioning Engineers
DA : Daylight Autonomy
DF : Daylight Factor
DGI : Daylight Glare
DGP : Daylight Glare Probability

ET : Effective Temperature
PET : Physiological Equivalent Temperature
PMV : Predicted Mean Vote
PT : Perceived Temperature
SET : Standard Effective Temperature
UGR : Unified Glare Rating
UTCI : Universal Thermal Climate Index
WBGT : Wet Bulb Globe Temperature Index

REFERENCES

1. Abadie, M., Wargocki, P., Rode, C. & Zhang, J., 2019. *Proposed Metrics for IAQ in Low-Energy Residential Buildings.* ASHRAE Journal ed. s.l.:American Society of Heating, Refrigerating and Air-Conditioning Engineers.
2. Alfano, A., L, B. & A, B., 2010. *Indoor environment and energy efficiency in schools.* Part I Principles. REHVA Guidebook n°13; ed. s.l.:s.n.
3. Allab, Y., 2017. *Experimental evaluation of the performance of ventilation systems in buildings: ventilation efficiency and thermal comfort,* Paris: École Nationale Supérieure d'Arts et Métiers.
4. ASHRAE, 2001. *ASHRAE Handbook Fundamentals.* ASHRAE ed. Atlanta: Handbook Fundamentals, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.
5. Benharkat, S. & Rouag-Saffidine, D., 2015. Adaptive approach to thermal comfort in university teaching spaces in Constantine (Algeria). *Nature & Technology /A- Basic Sciences and Engineering,* Issue 14, pp. 19-28.
6. Berghout, B., 2012. *Effect of the implementation of a collective building on the indoor hygrothermal comfort, case of Biskra, Algeria,* Montreal: École de technologie supérieur de l'université de Québec.
7. Brittany, S., 2014. *Expanding populations, emerging economies, threatened biodiversity: The tropics will never be the same.* [Online] Available at: https: //fr.mongabay.com /2014/09/ populations- en-expansion-economies-emergentes-biodiversite- menacee-les-tropiques-ne-seront-plus-jamais-ce-quils-etaient/[Accessed 25 November 2020].
8. Bruant, M., 1998. *Development and parameterization of fuzzy multi-criteria controllers of environmental comfort,* Lyon: INSA.
9. Calcucci, 2015. *A review of indices for assessing visual comfort with a view to their use in optimization processes to support building integrated design.* s.l.:s.n.
10. Carlucci, S., Causone, F., De Rosa, F. & Pagliano, L., 2015. A review of indices for assessing visual comfort with a view to their use in optimization processes to support building integrated design. *Renewable and Sustainable Energy Reviews,* 47(1), pp. 1016-1033.
11. Chiang, C. & Lai, C., 2002. A study on the comprehensive indicator of indoor environment assessment for occupants' health in Taiwan. *Build. Environ.* 37(4): 387-392.
12. CIE17, 1995. *Discomfort glare in interior lighting.* Vienna (Austria): Commission Internationale de l'Eclairage.
13. Daouadji, Y., 2017. *Evaluation of a passive cooling system in hot and arid areas by applying a Canadian well and solar chimney coupling.* Biskra: Université Mohamed Khider.
14. De Dear, R.-J. & Brager, G.-S., 1998. Thermal adaptation in the built environment: a literature review. *Energy and building,* 27(1), pp. 83-96.
15. Dear, R., 2004. Thermal comfort in practice. *Indoor Air,* 14(1), pp. 32-39.
16. Dhalluin, A., 2012. *Study of ventilation strategies to improve indoor environmental quality and occupant comfort in schools,* La Rochelle: University of La Rochelle.
17. Dribat, M. T., 2015. *Experimental study of the effect of PCMs on the improvement of thermal comfort in habitats.* Department of Renewable Energy, Kasdi Merbah University Ouargla: s.n.
18. EN 16798-1, 2019. *Indoor Environmental Input Parameters for Design and Assessment of Energy Performance of Buildings Addressing Indoor Air Quality,Thermal Environment, Lighting and Acoustics.* s.l.:s.n.
19. EN ISO 3382-2, 2008. *Acoustics - Measurement of room acoustic parameters - Part 2: Reverberation time in ordinary rooms.* s.l.:s.n.
20. Fanger, P., 1988. Introduction of the olf and the decipol units to quantify air pollution perceived by humans indoors and outdoors. *Energy and Buildings,* 12(1), pp. 1-6.
21. Fanger, P. O., 1970. *Thermal Comfort: analysis and applications in environmental engineering,* Copenhagen, Denmark, Danish Kr. 76, 50: DANISH TECHNICAL PRESS.
22. Fiala, D. et al., 2012. UTCI-Fiala multi-node model of human heat transfer and temperature regulation. *Int J Biometeorol,* 56(1), p. 429-441.
23. Fisekis & al, e., 2003. Prediction of discomfort glare from windows.
24. Fouillet, A., 2007. *Surmortality linked to heat waves: modelling spatio-temporal variations in general mortality as a function of climatic characteristics,* Paris-sud: Faculty of Medicine.
25. Gagge, A., Fobelets, A. & Berglund, L., 1986. *A standard predictive index of human response to the thermal environment.* 92 ed. United States: ASHRAE Trans.
26. Gagge, A. P., Nishi, Y. & Gonzalez, R., 1971. Standard effective temperature a single a single temperature index of temperature sensation and thermal discomfort. *Proceedings of the CIB commission,* W(45), pp. 229-250.
27. Gallissot, M., 2012. *Modelling the concept of comfort in the smart home: from multisensory to behaviour,* Grenoble: Grenoble Computer Science Laboratory, Doctoral School Mathematics, Information Science and Technology, Computer Science; University of Grenoble.
28. Grosdemouge, V., 2020. *Proposal of thermal comfort indicators and estimation of the average radiant temperature in a tropical urban environment. Contribution to the national evaluation method for EcoNeighbourhoods,* La Réunion: Laboratoire de Physique et Ingénierie Mathématique pour l'Energie, l'Environnement et le Bâtiment.
29. Guth, S. K., 1963. A method for the evaluation of discomfort glare. *Illuminating Engineering,* 58(5), pp. 351-364.
30. Halawa, E. & Hoof, J. V., 2012. The adaptive approach to thermal comfort: A critical overview.
31. Hegger, M., Fuchs, M., Stark, T. & Zeumer, M., 2008. *Energy manual: sustainable architecture.* 1st ed. Munich: Detail.
32. Höppe, P., 1999. The physiological equivalent temperature- a universal index for the biometeorological assessment of the thermal environment. *International Journal of Biometeorology,* 43(1), pp. 71-75.

33. Houghton, F. & Yaglou, C., 1923. Determining Equal Comfort Lines. *Journal of the American Society of Heating and Ventilating Engineers,* 29(1), pp. 165-176.
34. Humphreys, M. A. & Nicol, J. F., 1998. *Understanding the adaptive approach to thermal.* 104 ed. s.l.:ASHRAE transactions. American Society of Heating, Refrigeration and Air Conditioning Engineers.
35. Humphreys, M. A., Rijal, H. & Nicol, J., 2013. Updating the adaptive relation between climate and comfort indoors; new insights and an extended databaseq.
36. ISO 7243, 2017. *Ergonomics of thermal environments - Estimation of thermal stress based on the WBGT (wet and dark globe temperature) index,* s.l.: s.n.
37. ISO 7730, 1994. *Moderate thermal environments - Determination of the PMV and PPD indices and specification of the conditions for thermal comfort.* second edition ed. s.l.:s.n.
38. Jannot, Y. & Djiako, T., 1994. Energy saving and thermal comfort in tropical housing. *International Journal of Refrigeration,* 17(3), pp. 166-173.
39. Jendritzky, G., De Dear, R. & Havenith, G., 2012. UTCI-Why another thermal index? *International journal of biometeorology,* 56(1), pp. 421-428.
40. Joffroy, T., Misse, A., Celaire, R. & Rakotomalala, L., 2017. *BIOCLIMATIC ARCHITECTURE AND ENERGY EFFICIENCY OF BUILDINGS IN SENEGAL,* Senegal: Craterre.
41. Jokl, M., 2000. Evaluation of indoor air quality using the decibel concept based on carbon dioxide and TVOC" in Building and Environment.
42. Jones & Christoph, 2018. Effects of real-time simulation feedback on design for visual comfort.
43. Kiki, G. et al., 2020. Evaluation of thermal comfort in an office building in the humid tropical climate of Benin. *Building and Environment,* 185(1), pp. 1-10.
44. Kim, J. et al., 2017. Establishment of an optimal occupant behavior considering the energy consumption and indoor environmental quality by region. *Applied Energy,* Volume 204, pp. 1431-1443.
45. Kimnenh, T., 2020. *Analysis and modelling of building data for the evaluation of thermal behaviour.* s.l.:Liège University.
46. Kottek, M. et al., 2006. World Map of the Köppen-Geiger climate classification updated. *Meteorologische Zeitschrift,* 15(3), pp. 259-263.
47. Lai, J. H. K. & Man, C. S., 2017. Developing a performance evaluation scheme for engineering facilities in commercial buildings: state-of-the-art review.. *International Journal of Strategic Property Management,* 21(1), pp. 41-57.
48. Lou, C., 2012. *Towards a new methodology of building design based on their bioclimatic performance.* Institut National des Sciences Appliquées de Lyon: Ecole Doctorale Mécanique, Énergétique, Génie civil, Accoustique.
49. Lucon, O. et al., 2014. *Climate Change 2014: Mitigation of Climate Change.* Buildings, Chapter 9 of the Working Group III contribution to the 5th Assessment report ed. Cambridge: Cambridge University Press and New York.
50. Montenegro Iturra, E. E., 2011. *Impact de la configuration des bâtiments scolaires sur leur performance lumineuse, thermique et énergétique,* Quebec: Université Laval.
51. Moser, G., 2009. *Environmental psychology, the human-environment relationship.* 1st ed. Brussels: de Boeck.
52. Narboni, R., 2006. *Lumière et ambiances: concevoir des éclairages pour l'architecture et la ville: (analyses d'ambiances lumineuses moyens techniques problématiques de conception démarches environnementales exemples de réalisations.* Paris: Le Moniteur.
53. Nasir, R., Ahmad, S. & Ahmed, A., 2012. Psychological Adaptation of Outdoor Thermal Comfort in Shaded Green Spaces in Malaysia. Procedia. *Social and Behavioral Sciences,* 68(1), pp. 865-878.
54. NF EN 15251, 2007. *Indoor environmental criteria for the design and energy performance assessment of buildings covering indoor air quality, thermal, lighting and acoustics.* s.l.:s.n.
55. Nicol, J. & Humphreys, M., 2002. Adaptive thermal comfort and sustainable thermal standards for buildings. *Energy and buildings,* 34(1), p. 563-572.
56. Olissan, A., Kouchadé, C., André Philippe, A. K. N. & Hauglustaine, J.-M., 2016. Influence of glass fenestration on thermal comfort of buildings in tropical and humid climate: case of the coastal strip of Benin. *International Journal of Innovation Sciences and Research,* 5(6), pp. 766-777.
57. Parine, 1994. The use of odour in setting ventilation rates. Indoor Environment.
58. Picard, C.-F., Abadie, M. & Dhalluin, A., 2020. *Reliabiliser, Professionnaliser, Valoriser la Rénovation Energétique. Troisième volet : Valoriser le confort,* France: s.n.
59. Pickup, J. & De Dear, R., 2000. An outdoor thermal comfort index (OUT_SET*)-part I-the model and its assumptions. In: C. ICB-ICUC, ed. *ICB-ICUC Conference.* s.l.:ICB-ICUC Conference, pp. 279-283.
60. Reinhart, C. F. & Walkenhorst, O., 2001. Validation of dynamic RADIANCE-based daylight simulations for a test office with external blinds. *Energy and buildings,* 33(7), p. 683-697.
61. Renaudeau, D., Giorgi, M., Silou, F. & Weisbecker, J.-L., 2005. Influence of tropical climate and genetic type on zootechnical performance and feeding behaviour of growing pigs between 45 and 90 kg live weight. *Journées Recherche Porcine,* 37(1), pp. 259-266.
62. Rohles, F. H. J., Woods, J. E. J. & Morey, P. R., 1989. *Indoor environment acceptability: the development of a rating scale.* 95 ed. American Society of Heating, Refrigerating and Air-conditioning Engineers: ASHRAE transactions.
63. Roulet, C.-A., 2004. *Le confort intégré.* Lausanne, Journées de microtechnique LESO-PB, EPFL, 1015 Lausanne.
64. Sabine, W. C., 1901. Architectural Acoustics. Part. I. Reverberation. *J. Phys. Theor. Appl,,* 10(1), pp. 38-48.
65. Sarbu, I. & Bancea, O., 2009. Analysis of thermal and olfactory comfort in closed spaces. *WSEAS TRANSACTIONS on HEAT and MASS TRANSFER,* 4(3), pp. 56-64.
66. Tzikopoulos, A., Karatza, M. & J.A., P., 2005. Modeling energy efficiency of bioclimatic buildings. *Energy and Building,* Volume 37, pp. 529-544.
67. Valdiserri, P., Biserni, C., Tosi, G. & Garai, M., 2015. Retrofit strategies applied to a tertiary building assisted by Trnsys energy simulation tool. *Energy Procedia,* Volume 78, pp. 765-770.
68. Van Hoff, J., 2008. Forty years of Fanger's model of thermal comfort: comfort for all? *Indoor Air ,* Volume 18, p. 182-201.

69. Walsh, J. W. T., 1951. The early years of illuminating engineering in Great Britain. *Lighting Research and Technology,* 16(3 IEStrans), 49-60.
70. Wieldnold & Christffersen, 2006. *Evaluation methods and development of a new glare prediction model for daylight environments with the use of CCD cameras.* s.l.:s.n.
71. Yılmaz, Y. & Yılmaz, B. Ç., 2020. weighted multi-objective optimisation approach to improve based facade aperture sizes in terms of energy, thermal comfort and daylight usage. *Journal of Building Physics,* 44(5), pp. 435-460.
72. Zhang, D. & Bluyssen, P. M., 2021. Energy consumption, self-reported teachers' actions and children's perceived indoor environmental quality of nine primary school buildings in the Netherlands. *Energy & Buildings,* 235(110735), pp. 1-10.
73. Zhang, H., Arens, E., Huizenga, C. & Han, T., 2010a. Thermal sensation and comfort models for non-uniform and transient environments: Part I: Local sensation of individual body parts. *Building and Environment,* 45(2), p. 380-388.
74. Zhang, H., Arens, E., Huizenga, C. & Han, T., 2010b. Thermal sensation and comfort models for non-uniform and transient environments, part II: Local comfort of individual body parts. *Building and Environment ,* 45(2), p. 389-398.

****