Current approaches regarding the assessment of quality of the buildings from the perspective of the user’s perception

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Abstract. The article focuses on the satisfaction of the users/beneficiaries and on the quality level of the construction industry. Monitoring user satisfaction brings benefits in the construction industry by improving communication between the parties, engaging in mutual agreements, evaluating progress and monitoring the results and changes made. Users have certain claims about how they want to be treated, moreover, the physical product obtained must fit within their internal value system.

1. Introduction
The quality level of the built space represents the extent to which the building can respond by its characteristics to the demands of the users, the specific requirements of the destination and the social order.

Construction companies are engaged in increasingly tough competitions, which require greater attention in the relations with the beneficiaries and the satisfaction of the users. User satisfaction studies provide valuable information to entrepreneurs, who need to understand the needs of users and come to their foreplay. Also, users have expectations regarding the behavior of the service providers, behavior that can positively influence the level of satisfaction when the quality of services exceeds the level of expectations.

The system in which the constructions are integrated, respectively the adjacent external environment, the related socio-economic, urban and temporal environment, together with the interior system defined for the occupants, can be monitored throughout the life of the building and can generate specific actions to respond to the demands made by users.

2. User satisfaction and building quality

2.1. User satisfaction
The satisfaction of a customer is found in the relationship between the perceived quality and the failure to respond to his expectations from the product in question. Customers compare the performance of a product with a standard of performance. Satisfaction occurs when the perceived performance exceeds the standard (in a positive way), while dissatisfaction occurs when the performance falls below the standard (in a negative way).

In the constructions field, the measure of user satisfaction is defined later, when the product is already purchased.
User satisfaction is one of the key elements in the Total Quality Management - TQM building. Analyzing and understanding user requirements is essential in ensuring user satisfaction.

For a fair assessment of user satisfaction, all the actors involved in this process must be identified. Potential clients who may have requirements and expectations that may affect the quality of a construction may be: contractors and their partners, project managers, design team members, contractors and subcontractors, service providers, product and service users and the society in general. User satisfaction as the last element in this decision-making chain is affected by the individual goals and interests of the members of this group.

Determining the quality of a building is a complex task. In general, defining quality can have two approaches: compliance with requirements and user satisfaction. Compliance with the requirements is an approach that follows how well the building responds to the project specifications. The limitations of this approach are that the users cannot know how well the product or services respond to the project conformations.

Addressing user satisfaction defines quality as the extent to which a product or service meets or exceeds user expectations. The advantage of this approach is that it determines what is important to the user, rather than setting standards based on managerial decisions that may be inaccurate. The weakness of this approach lies in the difficulty of monitoring users' expectations and the differences given by the short or long term evaluation.

2.2. The relationship between user satisfaction and quality at the design level
User expectations play an important role in evaluating the performance of the contractor. The satisfaction of the users in the construction industry is related to the degree of response to the formulated demands, and the quality of the project is perceived as meeting these requirements.

There is a distinction between the quality of a product and the quality of a process. The quality of a product refers to the quality of the materials, equipment and technology integrated in the building, while the quality of the process refers to the achievement of quality through the way the project is organized in the three stages: design, construction, use and maintenance [1].

At the design level, the user evaluates the performance of the contractor in relation to three comparisons, with an impact on the degree of satisfaction (figure 1).

![Figure 1. Interrelationships between customer satisfaction and quality at project level](image)

2.3. User perception and quality assessment through the satisfaction level –PMV-PPD
Predicted Mean Vote PMV was developed on the principle of thermal balance and experimental data collected in a room with controlled environment, and refers to the performance index of the comfort perceived by the users of a building, on a seven-point scale, from -3 (cold) to +3 (warm), where 0 corresponds to thermal neutrality (ideal value). To find out the satisfaction rate of the users of a building,
we use an equation that implies the percentage of dissatisfaction (Predicted Percentage Dissatisfied) $PPD$. This relationship is based on studies in which the interviewed subjects are in a room where the indoor environment conditions are precisely controlled, ignoring the location and adaptation to the thermal environment, maintaining a constant temperature throughout the year. These indicators take into account not only the values of the microclimatic parameters but also the nature of the activity and the type of clothing.

2.3.1 Global indicator $PMV$. The state of thermal comfort supposes that the temperature of the human body remains constant, near the value of 37 ºC. This is done in case of maintaining a balance of the quantities of heat transferred between the human body and the microclimate of the building. The mathematical relation that an ideal thermal balance should respect is as follows:

$$Q_{\text{internal}} + Q_{\text{received}} = Q_{\text{ceded}}$$

where: $Q_{\text{internal}}$ – the amount of heat produced by the human body in an arbitrary period of time $\tau$;

$Q_{\text{received}}$ – the amount of heat received by the human body over time $\tau$;

$Q_{\text{ceded}}$ – the amount of heat lost from the human body during the time $\tau$.

In real conditions, the equality in relation (1) cannot be respected, so that:

$$\Delta Q = Q_{\text{internal}} + Q_{\text{received}} - Q_{\text{ceded}} \neq 0$$

where $\Delta Q$ has the meaning of a thermal residue, the value of which must be as close as 0 to meet the conditions of thermal comfort.

There are several ways to determine the PMV indicator.

A first possibility consists in the use of the relation (3), results from the thermal balance equation of the organism, in which both the internal microclimatic characteristics (objective factors) and the metabolic rate, the energy consumption required for performing a mechanical work and the thermal resistance of the clothing are involved (according to SR ISO 7730/2006) [3].

$$PMV = \left(0.303 \cdot e^{-0.036 \cdot M} + 0.28\right) \cdot \Delta Q$$

where: $M$ - energy metabolism (the amount of heat produced by metabolism, depending on the type of activity carried out, expressed as the average unit thermal flux in W/ m$^2$);

$\Delta Q$ - thermal residue, depending on the temperature of the indoor air and the interior surfaces, the speed of circulation and the humidity of the indoor air, the average temperature of the interior surfaces, but also on the energy metabolism and the thermal resistance of the clothing.

A second way of determining the PMV index is in the annexes of the mentioned standard, the PMV index values are shown for different values of the operative temperature, the air speed and the type of work done and clothing.

The third way to assess the PMV indicator is through direct measurements on a sufficiently large number of subjects, using a special device (integrator capture).

2.3.2 Global indicator $PPD$. When the thermal residue $\Delta Q$ is zero, so the body discharges the amount of heat it produces (and that it eventually receives), according to the relation (1.3) the $PMV = 0$ indicator, so that the thermal sensation of the subjects should be fully comfortable.

Experiments on a large number of people have shown that it is practically impossible to create an environment where absolutely everyone declares themselves in a state of thermal comfort. Even when $\Delta Q = 0$ (so also $PMV = 0$), on average 5% of the subjects feel slightly uncomfortable.

Under these conditions, a new parameter was defined, noted with $PPD$ (Predicted Percentage Dissatisfied) which represents the average percentage of people who declare a state of thermal discomfort in relation to a given environment.

The $PPD$ indicator can be evaluated according to the $PMV$ values based on the relationship:

$$PPD = 100 - 95 \cdot e^{\left(0.0335 \cdot PMV + 0.2179 \cdot PMV^{-1}\right)}$$

(4)
A second way of appreciating the $PPD$ indicator, also based on the $PMV$ parameter, is using the graph in figure 2.

According to the regulations in use, the buildings must be constructed in such a way that the thermal environment in the spaces occupied by people corresponds to the comfort requirements demanded by the activity to be carried out under the conditions of an appropriate clothing. The $PMV$ indicator should be within range $-0.5...+0.5$, and the $PPD$ index should be less than $10\%$ (figure 2).

The ASHRAE 55-2010 standard uses the $PMV$ model for the regulation of indoor environment conditions, with the requirement that at least $80\%$ of the occupants be satisfied.

2.4. Adaptive comfort

The concept of adaptive comfort emphasizes that the occupants of the buildings do not passively receive the thermal environment suggested by the heat/cold diagrams, but interact with the building actively. The model is particularly applicable to naturally ventilated buildings and hybrid buildings, where the outside climate influences the indoor comfort during different seasons of the year. The questionnaires show that the occupants of the naturally ventilated buildings accept and prefer the higher temperature variations, which are in close relation with the outside temperature, to the detriment of a sealed environment, controlled by the air conditioning systems. The occupants can control the equipment mechanically or non-mechanically, in search of personal comfort, which leads to energy savings. Basically, there are three categories of thermal adaptation, namely behavioral, physiological and psychological. The actions of the residents are related to social, cultural and technical factors [4].

Comparative ASHRAE studies for HVAC (Heating, Ventilation and Air Conditioning) and NV (Naturally Ventilated) buildings in the same climate (Singapore) show that acceptability in the two thermal environments has similar values ($78\%$ and $76\%$) in very different indoor environment conditions. Thermal thresholds in naturally ventilated buildings are larger than those in mechanically ventilated buildings and are accounted for by expectations, physical and behavioral adaptation [5], and to some extent by stronger air movements in naturally ventilated buildings. (on average $0.22\, \text{m/s}$ compared to $0.11\, \text{m/s}$ in mechanically ventilated buildings) (figure 3).
Figure 3. Similar rates of acceptability for different indoor environments - HVAC and NV (Singapore buildings) [5].

The models of adaptive thermal comfort are implemented by the European standard EN 15251 and ISO 7730 in the case of hybrid buildings, and ASHRAE 55 in the case of naturally ventilated buildings.

2.5. Drivers of diversity in human thermal perception
Extensive research on human thermal perception by multiple disciplines has led to extensive knowledge about the general and specific aspects of this topic. Interest in this area has increased in recent years and has led to new approaches in thermal perception modeling.

Global and local challenges related to thermal perception
Climate change in recent years has led to an increase in average temperatures during summer, but also a high frequency of heat waves, precipitation levels and an increase in sea level due to the melting of glaciers. These climate changes affect the energy consumption necessary to obtain the comfort conditions inside the buildings. An increase in the need for cooling in the summer is forecast and a decrease in the need for heating in the winter.

Climate change can be associated with health and productivity - heat waves and cold winds are associated with thermal discomfort, decreased physical performance and increased mortality.

Thermal comfort
Thermal comfort is defined by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) as “the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation” [6].

Physiological drivers of diversity in thermal perception
From the physiological point of view, a great weight in the thermal perception has the distribution of the internal temperature of the body and the state of acclimatization of the skin. Recent research also discusses other physiological factors that may influence an individual's thermal perception, such as physical condition. This can be determined by demographic factors, by their own factors, such as sex and age, and a number of physiological variables, such as body composition and fitness, which may change over time or conform to the situation. Let's review them:
Age
From a physiological point of view, the thermoregulatory capacities change substantially from childhood to old age. These physiological changes include, for example, lower body temperature in both older men and women, as well as structural skin changes and metabolic changes. As the age increases, the thermoregulatory capacities of the human body decrease, especially if the level of fitness is reduced.

Sex
The physiological reasons for the thermoregulatory differences between men and women are manifold. For example, women have a higher surface-to-volume ratio (which allows for greater heat loss through the skin), different body composition (higher fat mass and lower muscle mass) and lower metabolic rate (less active), metabolic free mass in women and thus with up to 20% less heat production [7-8].

Body composition and fitness
Body composition is an important parameter in the thermoregulation of the human body. A thick layer of subcutaneous fat increases insulation and reduces heat exchange through the skin, which helps maintain body core temperature in a cold environment. In contrast, heat loss could theoretically be affected at higher temperatures when the subcutaneous fat layer is thicker. Several previous physiological researches report higher body temperatures in obese people compared to ascetic people when exposed to heat and physical exercise [9–10].

Metabolic rate
Of all physiological parameters, metabolic rate is the only one incorporated in the PMV model as input parameter. The metabolic equivalent of task (MET) is one of the standard values in the PMV model (next to clothing insulation, air temperature, radiant temperature, air speed and humidity). MET is a commonly used physiological concept considered a simple procedure for expressing the energy cost of physical activities as a multiple of the basic metabolic rate [11]. Importantly, absolute metabolic rate is not only determined by activity, but also by other physiological parameters and environmental conditions, such as body composition, diet, adaptation state and temperature.

Physiological adaptation to the thermal environment
The extraordinary ability of the human species to adapt to a wide range of outdoor temperatures is well known. For example, indigenous people who are living in extreme climatic conditions have adapted over thousands of generations. However, the human body, even without any specific genetic predisposition, can adapt to a wide range of thermal conditions, both acute and long-term. The fluctuations of the temperature of the natural environment are counteracted by natural physiological adjustments for the vast majority of the population (the succession of seasons, the day-night cycle, etc.).

Habituation of different climatic zones
Regarding the habit of the different climatic zones and its effect on the thermal perception, two review documents have been identified. If we consider the fact that repeated exposure to a thermal challenge has as a consequence the physiological adaptation, it is obvious that the subjective perception of the thermal environment also changes. The ideal of thermal comfort differs from one climatic region to another, being adjusted to local conditions, but with quite small differences from the average.

Seasonal adaptation
In the climatic regions that have distinct temperature differences in the different seasons, a change of the thermal sensation and of the comfort temperatures throughout the year is perceived, with a variable mainly due to the clothing.

Diurnal rhythm
The temperatures of the human body change during the day and night at a diurnal rate (24 hours), the basic temperature being minimum early in the morning (~ 05: 00 AM) and at the highest in the late afternoon/early evening [12].
Psychological drivers of diversity

Considering the definition of thermal comfort as "that condition of the mind that expresses satisfaction with the thermal environment" [13], we can expect psychological factors to play an important role in thermal perception. Of all the psychological aspects, personal control received the greatest attention in comfort research, followed by the effect of personality, self-efficacy and anticipated costs of an action.

Effects of personal control

Paciuk [14] pointed out that personal control can be one of three things: available control, exercised control, and perceived control. The effect of available but not exercised control can be considered a psychological aspect, as can perceived control. However, exercised control will change environmental conditions and will be discussed in the section on contextual drivers. Hence, only studies were included that allowed assessment of solely the psychological component of personal control, i.e. studies where environmental conditions were identical in the control and no control condition, or where the outcome variable was the neutral temperature calculated based on thermal sensation votes at different operative temperatures.

Contextual drivers of diversity

Besides physiological and psychological aspects of the human body, thermal perception indoors is very much determined by contextual factors of the built environment.

In real life situations, the environmental conditions that people often encounter differ, sometimes easily and gradually, such as increasing the heating point, but sometimes more extreme and sudden, for example when entering an air-conditioned building during a hot summer day. The destination of a room or a building area also determines the different temperature requirements.

Local effects and non-uniform environments

Local effects and uneven environments affect thermal sensation and comfort and are another source of diversity between people even when sharing the same space. From the contextual perspective of the building, this refers to the stratification of air temperature and radiant asymmetry: two aspects that are very determined by the type of air conditioning systems, the thermal insulation level of the building envelope and the level of air conditioning control.

Clothing adaptability

Clothing adaptation is a common and effective strategy used by the occupants of a building. Occupants can tolerate operating temperatures up to 29° C only by adjusting clothing [15]. Therefore, the ASHRAE 55 standard [5] applies to buildings with operable windows, without operation or limited operation of mechanical cooling and heating systems.

In addition, research has shown that the level of isolation of people's clothing is adapted to the external and internal conditions. The clothing of men versus women is different; the level of isolation of men's clothing is less variable than that of women. In addition, the latter show that clothing isolation levels also differ between age groups, with older age groups wearing garments with higher isolation levels.

In conclusion, there is a huge variety of potential drivers of diversity and much more research is required to understand better the underlying mechanism of diversity. This information is required in order to rule out irrelevant factors and in particular to reveal the important and significant drivers of diversity.

Knowing the true drivers of diversity will be helpful in preparation for global challenges because the indoor thermal conditions chosen by an individual do not only affect the energy use – in itself a driver of climate change – but also affect health, wellbeing, and productivity [16].

3. Perception of Transient Thermal Environments: pleasure and alliesthesa

The term "alliesthesa" is defined as the perception of external stimuli as pleasant or unpleasant, depending on the internal state of the human body [5]. The term is used to differentiate thermal pleasure from thermal neutrality or acceptability, or in other words, the perception of neutral thermal conditions
as "comfortable", but not "very comfortable". International comfort standards encourage exclusive reliance on HVAC usage by largely restricting thermal asymmetries and transients within indoor environments as potential sources of discomfort. The perception of thermal conditions as "very comfortable" comes from the area of asymmetrical and transient environments, encountered in naturally ventilated or hybrid buildings. Recent research indicates that dynamic thermal environments can potentially deliver higher levels of occupant satisfaction than static, homogenous indoor environments.

Schalter et al. (2010, p. 274) [17] concludes in his work: "... changes in skin temperature mediate the thermo-behavioral response to maintain the level of heat and regulate the temperature. These behaviors are preceded by changes in the thermal comfort index and sensations, contributing to the initiation of a coordinated behavioral effort." [17]. Schalter's emphasis on skin temperature for thermal pleasure can be found in the model proposed by Hardy et al (1971) and Hensel (1981) [18-19] - figure 4. They show that while neural stimuli for cold and heat sensations are primarily skin thermoreceptors, the perception of thermal comfort depends on a more complex suite of signals, including:

- reactions of the thermoreceptor (internal and dermal);
- the neural pathways for temperature regulation, generated in the anterior hypothalamus;
- the effector thematic regulator acts by itself - tremors and vasoconstriction in the cold environment and sweating and vasodilation in the hot environment.

![Figure 4. Neural stimuli for thermal comfort [18-19].](image)

Heat balance models are widely acknowledged as inadequate in evaluating the effects of asymmetrical or transient environments on comfort. We don’t know why certain environments are pleasant sometimes, and distinctly unpleasant other times. The renewed interest in thermal alliesthesia seems timely given the recent advances in modeling and global uptake of adaptive comfort principles.

**Thermal pleasure and the built environment**

Thermal stressors are ranked according to their impact on homeostasis in order to prioritize behavioural responses. This led Cabanac (1992) [21] to suggest that such a system of negotiation requires a common currency to evaluate each instance of conflicting stimuli. The currency he proposed was pleasure. In his
interpretation priority is given to any behavioural response that maximises pleasure (or minimises displeasure) with minimal regulatory strain. Pleasure is deemed greatest immediately after a successful response, continually diminishing until a new equilibrium is reached, and at this point in time pleasure disappears altogether. Connotations of the word ‘pleasure’ are likely to vary between individuals and between pleasant and unpleasant [20]. The experience of pleasure in our thermal environment is a daily phenomenon that we share and appreciate, but, surprisingly, little is known about the casual process. If either the environment or the subject is static, there is no opportunity for the body to interpret the ‘usefulness’ of a stimulus for thermoregulation. Thermal pleasure can therefore only be experienced in transient states [21].

For this reason, we are tempted to say that in order to feel pleasure, we must first experience the state of dissatisfaction. It’s not entirely true. People are constantly exposed to environments that disturb the thermal balance when they are traveling (between buildings, in traffic to the workplace, etc.). Pleasure is rarer than dissatisfaction simply because any stimulus experienced in excess can become unpleasant.

If we look further afield, a similar discourse is taking place in product development and user experience evaluation where pleasure has emerged as the design goal. Coelho & Dahlman (2000) [22] suggest that concepts of comfort and pleasure overlap, but pleasure holds dimensions that are not included in comfort. In this sense it is not a cause-and-effect relationship; comfort is an aspect of pleasure.

In conclusion, the inherent difficulties of pleasure are recognized and this is a field of research that needs to be further developed. An alliesthesial model of pleasure may help to explain occupant acceptance of dynamic indoor environments. Pleasure depended on the nature of the physiological change caused by transitions, and only lasted for short periods immediately after.

4. Conclusions
The satisfaction of the end users of a building, regardless of the architectural program, is an increasingly prominent factor in the decision-making at the level of designers and contractors.

The purpose of this paper is not to suggest the abandonment of the conventional concept of comfort, but to explore how dynamic indoor environments have a beneficial influence on its occupants, as opposed to the static and uniform ones.

Until the introduction of the concept of alliesthesia by Cabanac in 1971, it was decided to control the temperature of the interior environment of buildings artificially, so that it would be maintained at a preset value, theoretically optimal. With the exploration of the principles of adaptive comfort and alliesthesia, there were developed ways of taking over the concept of dynamic environment by illustrating new methodologies for putting the previous idea into practice, in opposition to the static approach of thermal comfort. The antithesis of the two systems led to the rethinking of the design of buildings, furthering the concepts of natural or hybrid ventilation solutions.

In this new approach, sunlight is an important factor in the variability of indoor temperature, which can become similar to that of the outdoor environment, highlighting an increased level of comfort for the occupants of the building. The latter are assigned an active role in avoiding the extremes of the interior natural lighting, in this case imposing the intelligent control of the illumination, avoiding furthermore the feeling of discomfort. In the areas that cannot fully benefit from the contribution of natural light, one can resort to the use of biodynamic lights, whose intensity varies during the day.

The active role of the occupants of the building can also be extended to ensure thermal comfort, by facilitating access to the ventilation, heat and humidity control devices. Thus, the thermal neutrality and the dissatisfaction associated with it will be avoided. The concept of alliesthesia investigates the thermal pleasure resulting from the transient thermal environments, where they can experience sudden temperature changes, with a beneficial effect in the short term, an effect that ceases with the return to thermal neutrality. The same change in ambient temperature can be both pleasant and unpleasant, depending on several subjective factors specified in chapter 2.5.

Due to the increased attention in the pre-design stage towards the needs of the users it is possible to avoid errors in the design process, which can result in long-term dissatisfaction or costly rectification.
solutions. Thus, the existing buildings can be monitored, together with the occupants interviewing, resulting in the appropriate completion of the project, in relation to meeting the new comfort requirements generated by the principles of the active and dynamic indoor environment.

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