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Ergonomics of Built Environment i.e. How Environmental Design Can Improve Human Performance and Well-Being in a Framework of Sustainability

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Abstract

Ambient conditions in buildings are called to assure a delicate balance between environmental pressure and a so variable human response, the first expressed by the level and the combination of different environmental stimuli from physical factors, the second elicited by a wide range of individual capacities activated by people to cope and to elaborate those stimuli. Ergonomic /Human Factors approach is crucial in design of a physical space intended as an environmental support for users performance and comfort, since it provides theoretical principles, data and methods for understanding the interactions among humans and other elements of whatever system, and for identifying how conditions are able to make that system really fitting its users' needs and expectancies. Starting from an overview about effects on occupants of buildings physical factors, the paper summarizes principles of ergonomic design of built environment, for tending to sustainable and really supportive living environments for people.

Keywords: Environmental Design; Air Humidity and Air Velocity; Visual; Intensity; Complexity; Mystery; Novelty

Introduction

During our lives we spend the most part of time acting into and around designed environments. Environmental factors may work as positive stimuli for humans, or as stressors, given that the human body is regulated by adaptive physiological and psychological processes that allow us to be solicited by a range of ambient conditions. Nevertheless, when stimuli go over human reaction resources, stress occurs, well-being and performance decrease and in extreme situations, they could even lead to death.

Conditions inside the buildings are described by a range of physical factors impacting on humans. Air, warmth or cold, lighting, daylight and views, sound and acoustic setting, layout and building details, are all important elements in designing healthy life spaces and productive work places. There is broad evidence-based literature about the effects of environmental conditions on a wide range of human performance in different contexts. Particularly in productive buildings, the associations of occupant's health, comfort and performance, to indoor environmental quality have been fully demonstrated, and ill-health and absenteeism costs reported as relevant in decreasing productivity of private and public organizations [1,2].

Occupants comfort is one of the main goals of building design. It commonly expresses a state or a situation in which one is relaxed and does not have any unpleasant feelings caused by external factors. It affects, and is conditioned by, how human activities are performed, since comfort level may foster or hamper people performing their tasks, due to the effects of human physiological and psychological perceptions and reactions to the environmental conditions, in the different situations that may occur.

But a combination of sex, age, experience, education, fitness and health, inherent abilities and social values makes every person unique. Thus predicting comfort is a complex task, since it is a not-standardized and non steady human state, affected by personal and individual condition, in which rapid variations may occur, due to unpredictable physiological and psychological reactions to environmental factors [3,4].

Ambient conditions in buildings are called to assure a delicate balance between environmental pressure and a so variable human response, the first expressed by the level and the combination of different environmental stimuli from physical factors, the second elicited by a wide range of individual capacities to cope and to elaborate those stimuli.

Ergonomic /Human Factors approach is crucial for tending to this balance in design of a physical space intended as environmental support for users performance and comfort, since it provides theoretical principles, data and methods for understanding the interactions among humans and other elements of whatever system, and identify how conditions are able to make that system really fitting its users' needs and expectancies. Going beyond stereotyped human and contextual models, usually depicted by fixed code of conduct and mandatory standards, environmental design based on ergonomics principles, improves the traditional approach usually applied to design of built environment [5].

Understanding Effects of Buildings Physical Factors on Occupants

In buildings, a physical factor affects occupants in physiological, psychological and behavioral terms. Thermal environment affects humans both in terms of thermal sensation, as effect of thermoregulation, both as perception of thermal comfort, depending on the desired psychological state. Air and surfaces temperatures, relative air humidity and air velocity, together with insulation of clothing and metabolic rate, shape human-environment thermal interaction and are the basic variables of thermal comfort [6]. From a strictly physiological perspective it could be said that a person is in a thermal comfort state when his body is in thermal neutrality, that is when the heat generated by its metabolism is dissipated, and thus when the thermal equilibrium with surrounding is established. Nevertheless thermal balance is not necessarily the preferred condition as, usually, in winter and in summer, people declare to be satisfied with temperatures warmer or cooler than neutral [7].

As thermal comfort is defined as a condition of mind, a combination of a large number of personal and psychological differences between people, have influence on their satisfaction about thermal environment [8]. Female occupants are particularly sensitive to environmental conditions, since they express more dissatisfaction than male in the same thermal environment, and their heat demand is higher [9]. Aged people have shown a smaller range of comfort indoor temperature than younger and less ability to heat adaptation, due not only to physiology and an age-related decline in health, but mainly to their fears and anxieties about extreme heat [10]. Conversely children prefer temperature lower than the standardized one [11]. Exposure time to hot or cold environment affects comfort. Occupants respond to thermal environment on the basis of their thermal experience, especially to the more recent one, that is different in different climates, so much so that people result better tolerant about indoor temperatures that are close to the outdoor temperature. Inhabitants from temperate climatic regions have a weak tolerance to the heat stress than people from tropical and dry countries [12]. Geographic background and costumes affect people behavioral adaptation, since populations living in different climates have different susceptibilities to environmental stimuli, and so different habits due to socio-economic reasons [13].

Cultural conventions influence the perception of thermal comfort. Many local cultures or institutions have rules of proper social behavior, usually manifested in formal dresses, being worn independently by their adequacy to climate. High formality of Japanese employees, for example, restricts their ability to adjust clothing on workplaces, whilst the lack of formal restrictions resulting from North American societies, encourages people to wear comfortable clothes on working [14]. Moreover indoor air quality is a combination of the CO_2 level, temperature and relative humidity, in which air movement speed plays an essential role, especially relating to perceived comfort at elevated temperatures and in hot and humid climate [15,16]. In moderate environments it has been showed that insufficient air movement and constant values of temperature and humidity can cause dissatisfaction, since occupants comfort is frequently associated to thermal factors fluctuation rather than static conditions [17].

Indoor features of a building have significant effects also on auditory environment since, being sound the effect of mechanical wave resulting from the vibration of a sound source; it propagates after having impacted on surfaces enclosing the space and within the space. The physical properties of walls, ceilings, pavements and furniture, and the shape of the room, with the number and distribution of the sources, define the movement of the sound waves, concur to outline characteristics of sound within the space, and so determine its acoustic quality.

Auditory stimulus arouses two types of human responses: the auditory sensation, that is the unelaborated elementary awareness of stimulation, and the auditory perception, involves sound stimulus recognition. On the basis of both responses, humans may discriminate between different sounds, and tag them as pleasant or unpleasant. Noise is a sound perceived as an unpleasant feeling, a stimulus irritating to hearing. Adverse noise effects may be induced by the physical characteristics of the auditory stimulus, or/and by subjective mental changes due to auditory perception. By a quantitative perspective, elevated exposures to high intensity noise affect human health, since the strong sound pressure gradually damages the auditory system. An habitual noise level higher than 85 dB, as the sound of clock alarm, cause a gradual hearing loss in a significant number of individuals, while the loss of auditory sensitivity occurs initially around a frequency of 4 kHz, with high pitched sounds, and gradually increases to both lower and higher frequencies, if exposure is continuous.

Moreover, the exposure to higher noise intensity, starting from 120-130 dB, as those emitted by a rock concert or a jackhammer, may cause dizziness, nausea, balance disorder, usually reversible after the end of the sound stimulus, but may lead to deafness if the high level of sound persists for a long time [18]. Psychological effects of noise on performance and comfort are considerably and not associated to the sound intensity. Aged people are less tolerant to building noise than younger, as well as workers from Southern Europe compared to those from Central and North Europe Region [19]. Sleep and rest may be affected by a prolonged annoyance, also considering that at night the noise tolerance is significantly lower than in the daytime. Ambient sound that refers to long-term background sound becomes normal to the listener and it is not noticed, while transient or sporadic sounds generally are more annoying and distracting [20].

As it has been summarized, there are four non-physical factors that affect noise perception and performance: the nature and the complexity of the task; the noise context and the people attitude toward the noise; noise perceived control and its predictability; personality and mood [21]. In general, people are more annoyed and distracted by sounds they consider unnecessary, than by sounds they view as inevitable. Unexpected sounds and noises generated by others tend to be more annoying than sounds that are predictable and under the individual's control. Distraction effect is high if the sound has high information content. Hearing meaningful sounds lessens cognitive performances, especially in open plans, where speech is considered the most annoying and distracting type of noise, independently from its loudness, since the human ear is most sensitive in the range of frequencies used in the human voice and a normal conversation may spread from 30 to 50 decibels [19]. Particularly, background noise by intelligible speech is perceived by employees as more disruptive than irrelevant or non sense speech [21].

On the other hand too much silence can be as stressful and distracting as excessive noise. It may provide a sense of isolation and disorientation, especially when people move in an unfamiliar space. Virtually, blocking out noise completely in a space, means blocking out opportunities for occupants to connect and collaborate, and to be self-conscious about the environment. So physical factors of built environment should be managed in order to provide acoustical conditions so that sounds are not so elevated as to be dangerous, annoying or intrusive, but do not became as low as to be undetectable [22].

Also the light and the lighting inside the buildings, impact humans in many ways: visually, since it affects visual comfort and visual task performance; non visually, since it evokes mental states and concurs to the formation of the emotional impression of the space, and moreover it produces biological long term effects on human health. Visibility is the first step for an adequate quality level of luminous environment, since the most obvious effect of light on humans is in enabling vision. Performance of visual tasks is firstly affected by quantitative parameters, since a minimum level of illuminance is necessary for a clear vision without tiredness. But an excessively abundant illumination can be perceived as uncomfortable. Lower illuminance level are preferred for office VDT and paper-based horizontal tasks, while higher level are associated to visually demanding task as reading and writing [23]. Increasing level of illumination in the environment and on the working area improves visual performance, but a visually comfortable luminous environment depends also on other lighting-related factors, as the distribution of the light sources in the space, light colour characteristics and the limitation of glare [24]. Recommended average illuminations are generally fixed according to the room typology and activity, and light levels ratios between the task area and its surroundings are given [25]. Level of lighting uniformity depends on the occupant's tasks and required performance. Glare is an unwanted luminous energy invading the eyes, due to excessive bright light in the visual field for the presence of windows, luminaries or reflecting materials that can cause eye tiredness, and consequent errors and injuries. Glass surfaces and glossy finishing of walls, flooring and furniture may also cause similar effects for the uncomfortable veiling reflections on objects [24]. Non visual effects light are numerous. Variations of light parameters and colors can affect mood and trigger emotions. When people can control their lighting levels and colour temperature their mood is better and comfort increases [26]. Higher illuminance levels induce greater arousal [27], and then lead to lauder conversation and more communication [28]. Light intensity plays a role also in alertness regulation. Bright light may improve wakefulness or, the opposite, dim light may decrease it [29].

Daylight and views are relevant factors of visual performance and comfort. The balanced spectrum of colors and wavelengths of natural light, varying over the day with latitude and seasons, help control not only vision, but a wide range of non visual functions, including nervous and endocrine systems activation and circadian rhythms balancing [30]. Even if from a subjective perspective, people mood reacts to daylight factors: lower levels of daylight in a room spread a sense of gloomy, whereas higher levels of sun light improve a state of forcefulness [31].

Visual task requires less effort if color of artificial lights is close to that of daylight. Moreover using full-spectrum bright lights has been shown to have positively effects on health and wellbeing in environment where direct daylight missing [32].

It is generally accepted that having a view is central for having a pleasant visual environment, particularly when the outside opening focuses on natural surroundings. Having a grater view complexity reduce the sensitivity of observer to discomfort glare [28,33].

Emotional impact of a space is a function of brightness contrast and light colour rendering, so that specific luminous patterns may have a consistent and definable effect on an occupants subjective impression of indoor environment, in terms of: spaciousness/confinement, visual clarity or haziness; relaxation or activation; private or public. Spatial wideness and perceptual clarity of a room are evoked by uniform bright light from ceiling and higher horizontal luminance in a central location, better if light is cold colored. Conversely non-uniform environmental lighting, high-brightness on wall and low brightness in area of occupancy reinforce the impression of spatial privacy, preferably using warm colors. Relaxation is cued by non uniformity of wall lighting and lower light levels; especially warm colors, whereas higher levels of bright light improve arousal. Moreover lighting affects behaviors, so it can be used for aiding orientation in the space. People move in the direction of the bright light, so brightness of paths and walls may focus attention and support way finding. Vertical spatial borders are emphasized by illuminated wall surfaces; floor illumination accentuates objects and pedestrian surfaces. By using different levels of illuminance, different part of a room can be placed in a visual hierarchy [25].

We all experience that comfort and performance need spatial dimensions adequate to our ability and task, as accessibility issue confirms [34]. But interiors affect humans, also in terms of accessibility, not only by a dimensional point of view. Building layout and details concur to the integration of thermal, visual and auditory environments, providing ambient conditions that affect occupant's perceptions, influencing mood, thoughts, behavior and health [1]. Shapes, colors, textures, proportions, relations and sequence of spaces, may exert a range of different psychological impacts on humans that produce positive or adverse effects, depending on the nature of tasks. The perception of red in achievement contexts, for example, is hypothesized to impair performance because it evokes a motivational tendency to avoid failure that, ironically, undermines performance [35].

Intensity, complexity , mystery and novelty of building indoor features, such as loud noise, brilliant light, bright colors particularly at the red end of the spectrum, influence levels of stimulation. Human beings are enhanced by moderate levels of stimulation, especially if contrast and random changes for the senses to react to are provided [36]. A lack of environmental stimuli leads to boredom and overstimulation causes distraction and cognitive overload, especially in people with mental illness. Migraine and Parkinson's, patients have a great sensitivity to verticality and wavy patterns. Walking across geometric patterns affect balance, leading to the illusion to perceive an undulating surface, as it was resulted by a study on vomiting effects of a carpet with ticking stripe pattern of kid's, in a treatment lobby of a children's hospital. Curved walls are preferred solutions for supporting people with autism, since it has been proven that moving in linear corridors increase their anxiety [37].

Building coherence, defined as the level of comprehensibility of building elements and forms affect the effectiveness of people tasks. Purposive actions require legible interiors, where users are able to simply deduce about the identity, meaning and locations of objects inside the buildings, enhanced by regularity of geometric shapes, distinctive building markers, and multiple repetitive features. Building plan may foster people behaviors. Affordances express how we understand interior space according to our understanding of functions that they provide us. Circular shaped settings, for example, invite occupants to reciprocal interaction since they are perceived as informal, while rectangular, even if formal and less active and participative, are resulted more effective in increasing levels of attention and concentration (Canter, 1970, 1983) [38,39]. The extent to which the spaces are distant or interconnected, influences social regulation capability of spaces. Privacy is affected by spatial hierarchy within buildings, since size and location stimulate the sense of intimacy of environments. Interiors may have restorative effects on occupants, providing elements that draw our attention effortlessly [40]. Interesting visual scene, particularly natural views have a positive effects, since there is strong evidence that landscape surrounding buildings can mitigate occupant stress, and in healing environment, decrease patient's recovery days [41].

Changing the Point of View Thanks to Ergonomic Approach

One of the distinguishing features of the HFE discipline and profession is the understanding of how human–system interactions should be designed, since HFE has positioned itself as a unique, design-oriented discipline. Design is concerned with the ability to implement knowledge about human-systems interactions, as previously identified, described, assessed and modeled, and use this knowledge to develop systems according to people needs. It is based on the assumption that humans interact with systems, in the environment, aiming at a fundamental scope: to perform specific tasks, required to accomplish life activities. A complex outcome needs to be addressed: identify how systems are needed to be realized, for supporting humans performing their activities, in the best possible conditions, i.e. with effectiveness, efficiency of task, and people wellbeing.

The link of human, system, environment and task is the core elements of ergonomic design approach. For optimizing this link, the specific context in which it is performed needs to be observed considering, by a systemic point of view, different aspects of the environment (physical, social, informational, etc.), from micro-level (e.g. humans using tools or performing single tasks) to meso-level (e.g. humans as part of processes or organizations) to macro level (e.g. humans as part of networks of organizations, regions, countries, or the world).

Human is the focus of the design approach. Focusing the actual activities of the real people involved in the specific task, and observing how they really are, rather then they might be, different aspects of the humans need to be considered, including physical, psychological and social features. These factors not only consist of individual differences, including gender, age, body measures and health, race and national origin, but also concern perception of environments, human processing and cognitive functioning, relating to comprehension and reasoning, attention and motivation. The scope is the understanding ability and limitations of people, tasks they have to perform, and environment where they are performed, for designing effective systems that fit human specific needs.

Managing Users Diversity and Tasks Variability

Ergonomic approach goes beyond the consideration of stereotyped human models, usually depicted by fixed code of conduct and mandatory standards. Human variability and diversity are emphasized and not standardized, since the range of people's capability and behaviors are very different. Human variability and diversity refers to the multiplicity of human characteristics, including not only the variety of personal attributes such as age, gender, body size, physical capacity, and limitations, but also cognitive attributes such as intellectual abilities, attitudes, motivation, lifestyle, education level, or culture of origin. Particularly, inter-individual human variations cover all the changes that individuals undergo during the life; intra-individual human variations concern the differences among individuals, in relation to the great geographic and ethnic social groups and the variations between genders [42].

Understanding the Task

To analyze the extent to which a system supports or fails to support the execution and evaluation phases of human activity, a model of action may be traced. In this model each phase of the action are linked by goals, which define the purpose of the activity. A goal is translated into intention, which is in turn translated into a sequence of actions, which are finally executed. Feedbacks on the effects of the action are perceived by the human sensory systems, those perceptions are then interpreted, and interpretations evaluated and related to the goal [43].

Based on this model, task analysis methods; allow observing the task user have to perform, on the place where the task is carried out. The usual process of a Hierarchical Task Analysis is to identify and classify the goals of the activity, and identify (in advance or by direct observation) each operation is necessary human do to achieve each goal. The information needed to perform a task analysis are focused on the user, and are relative to the operating mode, the postures and movements that he/she makes, and in general to the use of the system necessary to achieve the goals, in the environment where they are achieved.

Link analysis and layout analysis are used to examine the spatial relationships between the operations or task steps that the user carries out. It can be applied to identify the spaces or functions, most frequently accessed by an operative in a task so that they can be grouped together in the most prominent and readily accessible part of the workstation or the building plan. For this reason, link analysis is most often used in the design of new plant and equipment but it can also be a useful technique in understanding inefficient procedures (which are prone to non-compliance), and in improving the design of workstations and control interfaces.

Designing Usability

Indoor environment supportiveness may be expressed by building usability. According to the definition from the international standard on usability as '….usability expresses the effectiveness, efficiency and satisfaction with which a specified set of users can achieve a specified set of tasks in a particular environment [44], building usability is concerned with a building's ability to support the user organization's economic and professional objectives . The usability of the built environment focuses on user perceptions of the ease and efficiency with which they can use the building, considered as a facility. Usability cannot be evaluated only analyzing the building, but looking at the context of its use, depending on users' values in culture, context, time, and situation. Even though a partial vision of building usability, dealing with aspects of accessibility management in buildings (i.e. constructional aspects of access to buildings, to circulation within buildings, to egress from buildings in the normal course of events and evacuation in the event of an emergency), some practical application of usability on specific buildings and activities show a more comprehensive consideration of the concept, where usability requirements and their related markers have been formulated, in terms of way finding and paths efficiency, aesthetic and affective elements, comfort and well being, flexibility and safety aspects [45]. The ability of the building to enable adaptation, for example, is crucial for thermal comfort, since occupants need to remain comfortable in variable conditions, and do so through behavior. In addition to donning or removing clothing, adaptive opportunities of the buildings include all interior features allowing actions which people might take to improve their thermal perception, i.e. personal control on mechanical conditioning (thermostats, fans, heaters, coolers), operating windows and solar shades, buildings layout that allow occupants to move within a space, or between spaces with different temperature, to find more comfortable conditions, rooms and workstations allowing posture adjustments and changes of activity [1].

Ergonomics for Buildings Sustainability

Being ergonomic approach aimed to optimize human interactions with systems, in order to make activities more efficient, safe, comfortable and satisfying, architectural design and building construction and management can be enhanced by the consideration of human factors perspective, because it gives the cultural and practical references to envisage how technical solutions and details constituting the building, can be effective, efficient and satisfying as fitting, primary, the whole of needs derived from people's life and work activities they perform, "in or for" it. On the other hand to be sustainable a building has to offer an high performance, not only in environmental terms, as energy efficient but also as all lifecycle durable and effective, and occupant safe, secure and productive. All these aspects can be addressed by human factors approach [46,47].

Conclusion

The construction sector is gaining a growing attention in sustainable development policies, since it has been shown that energy consumption and CO_2 emissions related to the construction and use of buildings they are comparable and sometimes exceed those produced by the sectors of transport and industry. The concept of sustainable building is usually characterized by an approach centered on natural resources saving, and construction practices developed over the time, have been primarily aimed at limiting energy waste for designing buildings so-called "green", and for reducing their environmental impact, neglecting other aspects. This situation is creating paradoxical results, since we often see new buildings, designed for energy and environmental efficiency maximization that show a number of critical issues related to both the low efficiency of the established activities, both the insecurity and discomfort of the occupants.

Indeed, the inescapable goal of sustainable development needs to be pursued by considering, also in relation to built environment, all aspects of sustainability: environmental, social and economic. Ergonomics may play a crucial role in design of sustainable built environment, since it may be applied in architectural design process, from planning and executive stage, to management and use. By an environmental perspective, ergonomics and human factors approach, for example, may improve occupants observation, considering human diversities and subjective dimension of comfort, in order to understand how their needs and behavior influence the energy used in buildings and, moreover, how buildings energy systems may be designed and selected to be easy to use and maintain. By a social perspective ergonomics promotes users participation in design. Moreover accessibility and inclusivity demands are strongly addressed by the human factors–ergonomics perspective as it focuses on cognitive, sensory, or physical abilities and impairments of all building users, setting the problem of the human variability consideration within the building design process. Ergonomic design of built environment may be significant also by an economic point of view, since it may contribute to improve not only natural resources savings, but also organizations global effectiveness and productivity, through a design of physical spaces increasing occupant's performance and well-being.

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