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Thermal comfort: Design and assessment for energy saving

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ABSTRACT

Thermal comfort is one of the most important aspects of the indoor environmental quality due to its effects on well-being, people's performance and building energy requirements. Its attainment is not an easy task requiring advanced design and operation of building and HVAC systems, taking into account all parameters involved. Even though thermal comfort fundamentals are consolidated topics for more than forty years, often designers seem to ignore or apply them in a wrong way. Design input values from standards are often considered as universal values rather than recommended values to be used under specific conditions. At operation level, only few variables are taken into account with unpredictable effects on the assessment of comfort indices. In this paper, the main criteria for the design and assessment of thermal comfort are discussed in order to help building and HVAC systems designers and operators to navigate the complex and varied world of standards in the field of thermal environment for improving indoor environmental quality and energy saving. The examples discussed in the paper will also be useful for the standardization, leading to harmonized documents more readable for all users.

1. Introduction

For many years acoustic comfort [1,2], thermal comfort [3–5], visual comfort [6,7] and indoor air quality [8,9] have been studied separately by physiologist, engineers, occupational health specialist, industrial hygiene experts and architects. The first studies about the physiological response of man with respect to the thermal environment were made by Claude Bernard [10] who dealt with the biological regulation in his famous work published in 1865 and entitled "Introduction à l'étude de la medicine éxpérimentale".

Only in recent years, application of the ergonomics principles stated the need to achieve a good IEQ (indoor environmental quality), as a result of thermal, visual, acoustic comfort and indoor air quality. The awareness increased that an adequate design of the indoor environment – where people work and live – requires a synergic approach to all facets involved [11–13] in full compliance with sustainability [13–18].

IEQ strictly affects the overall building energy performances – as expressed in the 2002/91/EC European Directive [19,20] – and it exhibits an antagonistic relationship with respect to the energy saving requirements. Reaching thermal comfort requires a good building design and conditioning of the space (heating, cooling, and ventilation). A good lighting requires either large transparent surfaces (natural light, windows) or artificial lighting, which both may result in too high indoor temperatures, too high heat losses/gains and electrical energy use. Assuring a good indoor air quality (IAQ) requires a good selection of low emitting building materials and a ventilation system (natural, mechanical or hybrid). Therefore, the simultaneous maximization of the overall comfort and the reduction of the building energy demand has become a must. From this perspective, using sources of renewable energy – as required by more and more pressing international laws [21–23] and programs like the European Horizon 2020 [24,25], several US plans [26–28] – can obviously contribute to achieve such a goal. It is even more important to change the way we design the buildings and systems by taking into account the binomial "IEQ – building energy use". As a consequence, project teams need to be multi-disciplinary and in an integrated design process be able to simulate energy performance of buildings and evaluate indoor environmental conditions.

Another not negligible matter is that a poor IEQ can promote increasing symptoms of SBS [29], acute respiratory illnesses

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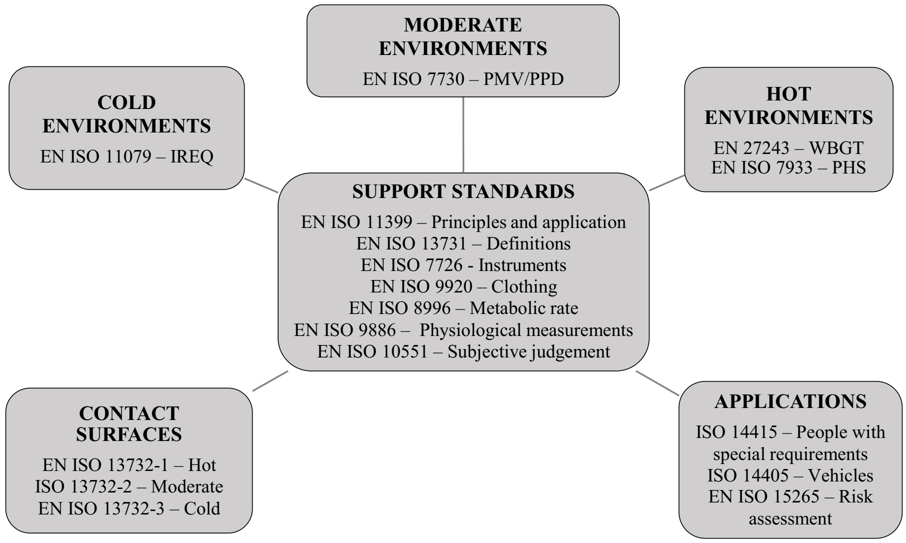

Fig. 1. Map of the main ISO and CEN standards in the field of the Ergonomics of The Thermal Environment.

[29,30], allergies and asthma, sick leaves and a significant reduction of the people's performance [30]. As a consequence, the costs related to a poor IEQ could be even greater than those related to a good building design and HVAC system and far higher costs than energy [31].

Unfortunately IEQ is often used in marketing with slogans like "Buy our product and reach the living comfort", where the performance is not documented. It is understandable that a common user or occupant lack information and expertise on what is a good indoor environment. It is however not acceptable that some designers use the word comfort in contexts where this is not justified, probably aiming to win a client with interesting or intriguing solutions.

Designing the indoor environmental quality is not an easy task. To follow technical standards (see Fig. 1) and building codes or blindly trust results obtained with a commercial software, generally is not enough to achieve a design compliant with the environmental quality. Designing IEQ means thinking case by case, project by project in order to find the best solution under the specific context every time. There are general rules to be respected, but a designer should always remember that a project of comfort is a project that ultimately puts people and their needs in the center. It must be approached from both ergonomic and technical points of view. Assessments and commissioning should be treated in a similar way. Concerning specific skills and general rules to be followed, it is noteworthy to mention that often a strict compliance with the rules does not guarantee comfort for all occupants/users. It could happen that a perfect project from the regulatory point of view can create problems for some people. This is due to the fact that our methods and standards are not perfect, and that people are very different in their requirements to the environment. This paper will show that the standards are sometimes unclear because in some situations it is not easy to understand the application of certain criteria. As a consequence, this may result in different or inconsistent interpretations.

To help building, HVAC systems designers and operators to navigate the complex and varied world of standards in the field of thermal environment, this paper will show ways to design and assess thermal comfort. At design level, it will be shown that input values suggested in standards can be used only under specific conditions to obtain the required IEQ levels. At operational level a great importance will be devoted to the variables to be taken into account for the calculation of comfort indices. Examples here discussed will be useful also for the Standardization, leading to harmonized documents more readable for all users. All issues of the discussion will be seen from the perspective and practice of a European designer. The general principles discussed here are however valid all over the world.

2. Thermal comfort

According to the definition by ASHRAE [32,33], thermal comfort is the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation. This condition can also be assessed by means of objective investigations looking at the human body as a thermodynamic system exchanging heat with the surrounding physical environment [34,35].

2.1. Overall thermal comfort

The thermal comfort conditions of the human body as a whole can be evaluated by means of the PMV index [36] which integrates the influence of the thermal comfort factors (air temperature, air velocity, mean radiant temperature, humidity, clothing and activity) into a value on a 7-points scale [33] (see Table 1). The PMV-index is an objective method based on an analysis of the heat balance equation for the human body together with the influence of the physical environment and expressed as a subjective sensation. Although PMV index is expressed on a thermal sensation scale, it defines thermal comfort conditions rather than the thermal sensation. Therefore it can be used as an index for the thermal environment assessment from the perspective of building and HVAC system performances.

PMV has been formulated on the basis of experimental studies with people exposed to different thermal conditions during tests in controlled climatic room [5,36] and it can be used under the

Table 1
7-points ASHRAE thermal sensation scale [33].

+3	Hot
+2	Warm
+1	Slightly warm
0	Neutral
−1	Slightly cool
−2	Cool
−3	Cold