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# Thermal comfort evaluation in cruise terminals

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ABSTRACT

The variations of building typologies contribute to the difficulty of performing a correct analysis of the comfort conditions in buildings that do not fit the more common geometries and occupation patterns. The main objective of the article is to evaluate the comfort conditions of cruise terminal buildings, an example of this type of problem. A twofold strategy, comprising in-situ measurements and user surveys was implemented. A total of 20 independent field measurements of thermal comfort parameters underwent in 2 facilities located in Portugal. The in-situ measurements supported the comfort assessment by the PMV analytical index and by the ASHRAE 55 and EN15251 adaptive approaches. The responses to 572 questionnaires to judge sensations and preferences of the passengers were obtained. Other aspects were also inquired, such as the time spent in the facilities and the health status. The comparison of the comfort assessment with the results of the survey showed that the adaptive models provided a broader acceptance of the measured environmental conditions, in line with the broader acceptance demonstrated by the users. The significant restriction of the PMV model application in this building typology was emphasized. The contrast of sensations by passengers of different national origin, with tropical originals feeling neutral at higher operative temperatures than temperate climate originals, was detected as an influencing factor. Waiting time was another relevant factor found, as the time spent inside the buildings pointed to a greater demand by passengers.

## 1. Introduction

Environmental sustainability and green energy sources are an ever more increasing concern in nowadays society. Policies to tackle the issues on energy consumption and carbon footprint in pivot domains, like the building sector, are a present reality in the European Union. By 2014, in the EU-28, the share of the building sector in final energy consumption was of approximately 40%. The CO2 emissions by this sector contributed with 36% of the total [1,2]. The Energy Performance of Buildings Directive (EPBD) 2002/91/EC [3], and its recast [4], express the continuous orientation towards the preservation and reasonable use of energy in buildings [5]. Additionally, the increasing consideration on occupant performance, health and overall comfort, has to be addressed [6]. Building standards must pursue a weighted approach on the energy consumption and thermal comfort of users, since good indoor climate and environmental sustainability are strongly dependent on this symbiosis. The definition of what constitutes a comfortable environment depends on the thermal perception of the occupants. It is therefore a complex subject that can be influenced by past thermal history, non-thermal factors and thermal expectations [7]. The variations of building typologies contribute to the difficulty of performing a correct analysis of the comfort conditions in buildings that do not fit the more common geometries and occupation patterns. Cruise terminal buildings are a good example of this problem. Their geometry will frequently correspond to a large volume space and the occupancy patterns are very different from well-studied office spaces [8,9], schools [10,11] or commercial facilities [12]. Moreover, the effect of the air-conditioning system and the temperature/wind distribution are crucial for the indoor thermal comfort [13]. The expectations of the users, however, should be investigated in order to adequately design this specific type of buildings. The mobility of the passengers and the side effects of the environment inside the ship also play an important role [14,15]. The research presented by Zheng et al. [16] proved the importance of ventilation and HVAC on the reduction of infectious disease propagation in cruise ships. These conclusions can be extended to cruise terminals, putting a focus on the necessity to achieve comfort

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conditions without compromising the health of the users.

Standardized methodologies for the evaluation of indoor thermal comfort include the PMV-PPD model described in ISO 7730 [17] and ASHRAE 55 [18], first developed by Fanger [19,20]. Environmental factors (air temperature, humidity, air velocity and mean radiant temperature) and individual factors (activity and clothing insulation) make the basis on the heat balance of the human body in this model. The thermal comfort can also be analyzed with adaptive models [21,22], which, according to EN 15251 [23] and ASHRAE 55 [18], are valid for buildings without mechanical cooling systems where there is easy access to operable windows and occupants may freely adapt their clothing to the indoor and/or outdoor thermal conditions.

The perception of the thermal environment by the occupants, however, can diverge from the results defined by the standardized methodologies. This is likely to occur when the buildings do not fit the scope of the standards. Several thermal comfort studies brought this subject to light by conducting occupant surveys. Results in mechanically ventilated, mixed-mode and free running buildings, show that surveyed subjects find comfort in a wider spectrum of conditions, leading to wider acceptable operative temperatures [24,25]. This was found for different types of climates according to Kottek et al. [26], except for type E − polar climates - environments and free running buildings were the predominant typology. A field work in several Portuguese cities, targeting office spaces, dwellings, elderly and educational buildings, found discrepancies with the standardized acceptability limits. It proved that the occupants can feel comfortable in a much broader range of temperatures, depending on local climate and building characteristics [27]. Physics and physiology alone do not express the thermal sensation of users accurately, even with little behavioral adaptation incorporated (clothing and air velocity adjustments). Several subjective factors (behavioral, physiological and psychological), influenced by climate, nature of buildings, thermal expectation, time spent indoors, social and cultural context, among others, take place in the thermal comfort of users in a given environment [28].

The type C climatic regions – moist subtropical mid-latitude climates –, according to the Köppen-Geiger climate classification [26], are the ones with the wider thermal comfort range of temperatures observed during experimental studies [24]. Thus, the premise of low energy use has the most potential in them. For these reasons, it is important that studies from similar climatic zones, and preferably with a high cultural background overlap, should be the ones focused on a preliminary analysis. Considering that the field study presented in this study was conducted in this region, other examples from literature were therefore focused in similar climates.

Several proposals for the adaptation of standardized models can often be found in literature. A study for both winter and summer conditions was conducted in different university buildings of Bari, southern Italy [29]. It included thermal comfort surveys, with a total of 1849 polled subjects. A trend to overestimate the neutral temperatures by the PMV index was found.

Measurements in naturally ventilated university and high school classrooms in Turin, Italy, were conducted during morning and afternoon lessons. They showed an extension from the (−0.5; +0.5) to a (−0.5; +1.1) PMV vote acceptable intervals for category B buildings, emphasizing the acceptability of less homogeneous thermal environments. The slightly warm voted environments aligned with a prevailing no change choice by the users answers [30]. The same sort of conclusions were manifested in a more recent study [31].

Measurements in Portuguese free-running educational buildings were conducted during occupation periods, applying 1 min logging intervals of physical parameters and simultaneous questionnaires to occupants. 487 questionnaires were filled in this field work. It was concluded that acceptable environments align with the comfort ranges of adaptive models, while most of the monitored spaces failed to perform when classified by the PMV-PPD model [32]. Overall, the model predicted a lower mean thermal sensation than the one found in the surveys responses. Even so, the preference for slightly warmer environments was found since the mean thermal sensation (MTS = 1) goes along with a neutral mean thermal preference. Measured local thermal discomfort due to warm or cool floor met the category C requirements, while discomfort by radiant asymmetry fulfilled category A conditions, according to ISO 7730 [33]. Other studies on thermal comfort in educational buildings in Portugal align with the pointed conclusions [34,35].

A thermal evaluation in free running office buildings took place in Lyon, France, during August and September 2004 and March and June 2005 [36]. The data was collected in alternate visits during morning and afternoon for entire workweeks. The measuring device circulated among every workers desk for a 10 min measurement period, while the worker questionnaire filling underwent. The overestimation of the warm sensation in the warm season and the cool sensation in the cooling season by ISO 7730 [33] was pointed, underlining the inadequacy of this standard in the simulation of the thermal environment. The sample answers got better comfort acceptability with ASHRAE 55 than with EN 15251, since the upper limits of the latter are slightly more conservative.

In 2011, a study in northern Italy cities, during summer and winter seasons, was conducted with 575 independent thermal comfort surveys taking place amongst nine open plan offices. A low correlation between the mean thermal sensation of the workers and the PMV of the logged data was found [37]. It was emphasized that the lack of possibilities for the thermal environmental modification by the occupants and the low air speeds, which lead to dissatisfaction due to vertical air temperature gradient, were the probable causes.

During summer and winter months of 2012 and 2013 in airport terminals of London and Manchester, United Kingdom, a thermal comfort fieldwork was carried out, with simultaneous measurements and surveys to passengers and workers in the buildings [35]. The neutral preferred temperatures of the passengers were found to be lower than the measured indoor temperatures. This has implications in energy savings, by avoiding overheating in the winter.

Other authors also applied the PMV-PPD model to evaluate transport facilities. Katavoutas et al. [38] performed extensive measurements that allowed for an evaluation of the thermal comfort conditions on subway waiting platforms. The importance of design characteristics of the stations has been demonstrated as they lead to different interactions with the outdoor conditions.

The need for further study in different types of buildings is supported by the continuous improvement of standardized thermal comfort models. Several studies come up with their own adaptive comfort equations [39–41], besides the ones based in meta studies [21,22]. The systematic comparison between the standardized models and the results from occupant surveys proved to be a solid strategy for a supported extension of the application scope of those models.

The objective of this work is to evaluate the comfort conditions of cruise terminal buildings. To do so, an extensive measurement campaign was performed and the collected data was analyzed in the frame of standardized thermal comfort models. An extensive survey to the comfort conditions acceptability of the users was performed. It is intended to:

- Evaluate the thermal comfort of two cruise terminal buildings using the PMV-PPD model and the adaptive models;
- Compare that evaluation with the results of the user surveys;
- Conclude on the applicability of the standardized models and detect possible causes for deviation between the models and the perception of the users.