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Vernacular and bioclimatic architecture and indoor thermal comfort implications in hot-humid climates: An overview

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ABSTRACT

Sustainable urban development, especially in disadvantaged regions, has increasingly gained a major strategic priority. New settlements and urban regeneration programs have to achieve an improvement of social life quality, promote economic growth and increase environmental protection practices and proper use of local resources. In this framework, building environment development must exploit natural resources with responsible approach by using local materials and traditional techniques. In this end, indoor comfort and energy consumption have to match the territories needs. Low energy and passive heating/cooling techniques should be considered as a valid option in many building projects.

The paper reviews some models evaluating thermohygrometric comfort in natural ventilated buildings, based on adaptive approaches. A focus is given on Mozambican building traditions, and, finally it proposes a case study where, by the recovery of Mozambican old traditions, a new healthcare facility is designed to be energy autonomous also including large use of natural ventilation.

1. Introduction

Today, many worldwide disadvantaged territories are enacting National measures delivering new goods and services for people and it appear clear that contrary to what has always happened in developed countries it is a new opportunity for skilled people for applying sustainable and bioclimatic principles in order to favourite proper global growth.

In this line, several international experiences have highlighted the key-role of the traditional materials and techniques based on the vernacular architecture [1–5]. Indeed, it was worldwide demonstrated that the exploitation of traditional design and construction practices is capable to better guarantee indoor comfort conditions with respect to a modern building [6,7] thanks to environmental, social and cultural people background [8–11].

So that, this paper aims to discuss more recent implications between vernacular/bioclimatic principles and indoor thermal comfort models and approaches applied in hot and hot-humid climates. Finally, this research proposes a case study, located in Mozambique, where results of the reviewed adaptive models are compared.

More in detail, in Section 2, an overview of on vernacular and bioclimatic architecture is showed by analysing some representative scientific studies; in Section 3 the review is focused on existing thermal comfort models on hot-humid climates for Naturally Ventilated Buildings (NVB); Section 4 describes the Mozambique context, while Section 5 concerns the case study application. Finally, in the Section 6 results of application of the previous thermal comfort models are reported and commented.

2. A brief overview on vernacular architecture, bioclimatic principles and energy saving

As affirmed by Labaki and Kowaltowski [12] application of bioclimatic strategies depend on accurate climate definitions and it concerns: orientation of building in, prevailing wind assessment, wall thickness, materials and colour definition, shading conditions, roof construction, natural ventilation window and so on. Furthermore, authors consider evaporative cooling and solar heating systems as a part of bioclimatic design, since passive air-conditioning does not have energy consumption.

As affirmed by Labaki and Kowaltowski [12] In this line Chandel et al. [13], reviewed the above mentioned aspects by focusing on building energy performances and their implications on indoor thermal comfort, also highlighting the great potential to match modern and

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vernacular principles in building design as the best-way to achieve energy saving.

Also, Singh et al. [14] studied 42 old vernacular houses located in North-East India, identifying several energy characteristics coming from people modifications on building and able to better maintain indoor comfort conditions. Also in this case, authors confirm that the application of traditional techniques and vernacular concepts improves both thermal comfort quality and energy saving.

Furthermore, it must be cited the study performed by Manzano-Agugliaro et al. [15]. The authors have studied the energy strategies, based on bioclimatic architecture, able to improve indoor thermal comfort and to achieve at the same time good building energy performance. More in detail, by using bioclimatic Givoni diagram [16] authors have defined climate conditions and relative associable energy strategies (i.e. passive actions where possible) and they affirmed that the same strategies and principles could be worldwide applied by assuming a similar climate conditions. Furthermore, authors have analysed, country-by-country, 34 scientific studies of vernacular and bioclimatic architecture strategies, by highlighting the energy saving results achieved by these approaches that can be worldwide applied under similar climatic conditions.

Moreover, Rupp and Ghisi [17] have highlighted the role of the chosen method assessing thermal comfort for the determination of energy saving potentiality in commercial buildings located in hot-humid climates. Authors have proposed a case study located in Brazil and have dynamically simulated the building. In order to identify the proper thermal comfort, they have applied three different models: ASHRAE55 for determining acceptable thermal conditions both in occupied spaces and in Naturally ventilated buildings and Givoni diagram for hot-humid climate. Finally, authors found that the use of air-conditioning system is strongly dependent on air temperature and absolute humidity, and affirmed that ASHRAE 55 approach for occupied spaces is not applicable on commercial buildings located in hot-humid climates.

Moreover, Kwok and Rajkovich [18] have highlighted the great potential of traditional strategies application for building energy conservation that also allows to tend toward low-carbon economy.

Homod et al. [19] studied the effect on energy saving through integrating control both on mechanically and naturally ventilated buildings. Authors have analysed under tropical climate conditions, the factors affecting indoor air temperature paying particular attention to indoor comfort level. Results demonstrated that the indoor thermal comfort is increased by natural ventilation system, while energy consumption decrease about of 31.6% with respect to a typical mechanically ventilated one. In this regard, Etheridge et al. [20] highlighted that airflow rates constantly vary with the weather conditions, while Gratia et al. [21] analysed the natural ventilation implication on cooling and heating loads by comparing different orientations, prevailing wind directions and window surfaces. Authors affirmed that free-cooling strategies could reduce cooling needs of about 30%.

In this way, the exploitation of natural ventilation strategies appears a good way to reduce energy consumption and to improve indoor thermal comfort in hot and hot-humid climates.

However it must be noted that to analyse comfort in this kind of ambient is more difficult than in controlled ones, and the proper adaptive model analysis is required. For this reason in the following section, several adaptive approaches are reviewed by focusing on their application in hot-humid climates.

3. Thermal comfort models for Naturally Ventilated Buildings (NVB) under hot-humid climates

Generally, occupants having a certain access to room indoor parameters control have lower discomfort than those who have less access [22–26]. On the other hand, in developed countries, global indoor comfort maintenance is more and more entrusting to the smart control building devices able to manage thermohygrometrical [27,28], visual [29,30] and indoor air quality conditions [31,32] and to tend toward nZEB targets [33,34].

However, where climate requires heating loads dissipation, building design is worldwide addressing to minimize energy consumption by using passive technologies such as natural ventilation. Hence, it appear fundamental to understand the comfort implications of these strategies and under specific climate condition in order to apply the proper thermal comfort model.

In the following sections, several thermal comfort model are reported with specific focus on natural ventilated buildings (NVB) located in hot and hot-humid climates. However, authors think that the reviewed thermal comfort models could be applied also in other areas in order to promote passive energy strategies.

3.1. Other extensions of the PMV approach

As defined by Höppe [35], in defining thermal comfort, there are three principal approaches: psychological, thermophysiological and based on the human body heat balance. More in detail, since 1997 the ASHRAE [36] defined the psychological approach as the "condition of mind when people have to express satisfaction with the surrounding environment". However, it must be considered that the most difficult issue to address is the "subjective judgment" about thermal environment and in this end, the well-known approach established by Fanger [37] more than 40 years ago has solved that.

Indeed, the thermal sensations could be different among people even in the same confined space and the PMV-PPD model is able to classify conditioned and moderate thermal environments according to the occupant' subjective sensation.

Nevertheless, the PMV purpose is to predict thermal vote in a conditioned ambient, an extension of it, called PMVe [38], can be applied in unconditioned areas, especially in hot-humid climates. It must be noted that, this model could have a great potential application also in the Mediterranean area where, due to hotter and hotter summers occurrence year-by-year [39].

So, the corrected PMVe model can predict occupants' thermal sensation by using an appropriate expectancy factor (e), ranging from 0.5 to 1, depending on the climate context and building air-conditioned percentage occurrence, because, people with low expectation are more likely to accept a wormer ambient [40]. In these climates, according to [38], the neutral PMVe upper and lower limits, of the neutral condition, have been set to ± 0.7, while the metabolic rates must be reduced by 6.7% for every scale unit of PMV as shown in Eq. (1):

$$MET_{(e)} = MET\left(1 - \frac{6.7 \cdot PMV}{100}\right) \tag{1}$$

PMVe-PPDe model has been applied and validated in NVB by other authors [41,42]. I.e. Olanipekun [43] found a discrepancy as regard the applicability of the PMVe-PPDe model in NVB. Indeed, author compared the obtained results from measurement (according to ASHRAE 55 [44] and ISO 7730 [45] Standards) and from PMVe-PPDe calculation. Therefore, the obtained PPDe results showed only a slight overestimation of about 8.9% of the percentage of dissatisfied under neutrality conditions.

Furthermore, as affirmed by Yao et al. [46], an empirical factor λ can help to better assess the adaptive process affecting the thermal comfort sensation. Indeed, the adaptive approach is based on the adaption of people comfort according to the environmental condition change [47]. In this line, authors proposed another extension of the PMV index called *a*PMV (Eq. (2)), by using a "black box theory", applied and validated by several authors during the time [48,49].

$$aPMV = \frac{PMV}{1 + \lambda \cdot PMV} \tag{2}$$

On the other hand, as demonstrated by Kalmár and Kalmár [50], a