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# Comfort analysis applied to the international standard “Active House”: The case of RhOME, the winning prototype of Solar Decathlon 2014

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## ABSTRACT

The relationship between indoor comfort and climatic context is essential to assure a superior liveable environment for occupants. The international approach called Active House (AH) proposes a ranking system to evaluate the provided indoor comfort, which is the same through the whole Europe, without acknowledging the variety of social-cultural contexts of each country. This paper aims to understand whether the AH methodology can be proposed both for continental and Mediterranean climates, evaluating the indoor comfort performances of a single-family home in four different climatic conditions, representative of different climate severities. The RhOME for denCity building, the winning prototype of the international competition Solar Decathlon 2014, has been used as experimental case study. From the results a variation of the AH comfort thresholds is proposed to fulfil the cultural and social environment of warm regions, considering the acclimatization process which arise the boundary of comfort acceptability. The proposed new comfort threshold still provide high thermal comfort expectation with an energy saving estimation of about 1.7% for each half degree Celsius reduction.

## 1. Introduction

Buildings use a huge amount of energy during their operation. According to Eurostat [1], buildings account for 38.1% of energy consumption in the European Union, more than any other sector, including transport (33.3%) and industry (25.9%). The residential buildings account for 24.8% of the total. The vast majority of the energy used in buildings is due to heating and cooling systems (85%). Moreover, the construction sector in Europe accounts for more than 40% of the total carbon emissions [1,2]. With the actual tendency, the prevision for the near future is critical: in the retail sector, for example, the electricity requested has doubled in the period between 1980 and 2000, and it is expected to increase up to 50% by 2050 [3]. Considering the South-European situation, up to 37% of the building stock was built before 1960 and about 49% in between 1961 and 1990 [4]. So that, more than 80% of the constructions were built before energy and carbon emissions limitations, with corresponding high-energy consumption. European Union tried to enhance buildings performance and limiting their energy use through the Energy Performance of Buildings Directive (EPBD) and the related recast Directive, aiming at the drastic reduction of buildings greenhouse gas emissions of 80% by 2050, through a step-by-step definition of minimum requirements that will lead to the Nearly Zero Energy Buildings (NZEB) limits [5]. The main introductions of the norms on this issue are:

- harmonization of the energy calculation methods based on the overall energy performance,
- introduction of a mandatory energy certification for buildings, which not only has to detail the energy efficiency level of the dwelling but also include recommendations for cost-effective improvements in the overall efficiency,
- Introduction of a new set of progressive minimum requirements that must be established by each Member State.

Based on these three major points, different energy standards and certifications have been modified to include the new requirements

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*Abbreviations:* AH, Active House; $CO_2$, Carbon dioxide; EPBD, Energy Performance of Building Directive; GHG, Greenhouse Gas; GWP, Global Warming Potential; HVAC, Heating, Ventilation, Air Conditioning system; NZEB, Nearly Zero Energy Building; $PM_{10}$, Particulated Pollution; $T_{op}$, Operative Temperature; $T_{rm}$, Running Mean Temperature; TMY, Typical Meteorological Year; Cfa, Temperate climate without dry season and with hot summer; Cfb, Temperate climate without dry season and with warm summer; Csa, Temperate climate with dry season and hot summer; CMV, Controlled Mechanical Ventilation; VOC, Volatile Organic Compounds

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toward NZEB target [6–8]. Improving buildings energy performance and reducing their environmental impacts can be achieved by a simple two steps approach: reducing the energy demand and exporting energy optimally [9,10].

Reduce the energy consumption of building is achievable using simple measures such as thermal insulation material for the building envelope [11] and designing properly the building in terms of orientation and ratio between opaque and transparent surfaces [12]. It is clear that energy efficiency alone is not enough, but to minimize buildings environmental impacts it is important a performance optimization on the whole life cycle, including LCA in efficiency standards [13]. On the other hand, it is also necessary to consider that buildings must provide a comfortable indoor environment to users [14,15]. Energy efficiency, environmental impacts and thermal comfort usually influence each other in an opposite way but should all encompassed in sustainability visions [16,17]. On this purpose, new generation standards are trying to get updated and consider all these parameters: not only including quantitative factors but, at the same time, enlarging the vision to qualitative aspects related to the social, psychological and cultural environment. From measurement tools, they are becoming design tools, helpful during the design stage to take decisions and assessing a general performances analysis in early design stage. The Active House standard is one of these. The Active House Standard is a vision of buildings that create healthier and more comfortable lives for their occupants without affecting negatively on the environment [19]. The vision represents the next generation of sustainable buildings that take in count energy, comfort and environmental impacts. A building labelled as Active House represent a combination of these three areas:

- it is strongly energy efficient with a positive final balance, producing more than what it consumes,
- it minimizes the impacts on environment and use of resources, encouraging natural and recycled or recyclable materials,
- it assures optimal indoor conditions in terms of comfort, well-being and health.

The validation system has been developed as general tool based on a simple ranking system [20,21]. Buildings performances are divided into categories and each of them has its own requirements to fulfil evaluated on a 4 points scale: from 1 (best) to 4 (worst but still in the Active House definition).

The classes' boundaries are defined within an upper limit given by the best possible solution, and a lower one, given by the cost-optimality design.

The Active House Specifications represent the document that summarizes all the threshold levels requested to a building for being validate as an Active House case. It has been developed involving an open-sources process: feedbacks from the research centre partners of the Alliance, the no-profit organization that works on the holistic approach and tries to promote it within the construction sector, were given to set up the performances goals. However, at the beginning, only the Northern European countries were part of it. For this reason, it is important to investigate whether or not the Active House Specifications are valid and robust for other European climates or if they need to be modified and calibrated on the different issues given by the warmer climate's criticisms [22]. In this paper, the Specifications are used to evaluate the performances of a very efficient buildings in different climatic conditions, aiming at a better understanding of the influences of the given threshold on the final AH classification. A comparison between the different climates allows to define the criticisms of the tool and, at the same time, proposing a refined calibration on the AH ranking system in order to include the local regional differences.

## 2. Methodology of work

The paper investigates the influences of the context on the effectiveness of the AH standard in evaluating a building's performance. The analysis is carried out on a real building prototype as case-study. RhOME for denCity is the winning model home of Solar Decathlon 2014 and it is an outstanding example of efficient building, it minimizes the energy consumption while maximizing the indoor comfort. RhOME, optimize for the Mediterranean context, represents a promising case to understand the efficacy and reliability of AH in representing the real performance of a building in warm regions.

This paper analyses the thermal comfort levels, evaluated according to AH principles, in four different climates. The adaptability and suitability of efficiency standards to different climatic zone is a theme known in literature due to the close interactions of climatic context and energy performances [23–26], for this reasons it is important to assess also the climate resilience of AH vision.

The paper, among the whole AH definition [27], analyse the effect of different heating/cooling threshold on two categories: energy demand (energy efficiency), and thermal comfort (indoor air quality). The analysis has been applied to a residential single-family house building with outstanding energy performances in order to assure the fulfilment of this AH category and summer indoor comfort is evaluated to classify the case study accordingly to the standard. The Active house validation has been conducted for four different climates: three representatives of the sub-climatic conditions present in warm European regions (Palermo, Rome, Milan) and one representative of a Continental regions (Paris). The reference cities used to characterize the climates are and Paris. At the end, the definition of thermal comfort is adapted to the Mediterranean context and a new ranking threshold for comfort evaluation in warm climate is proposed accordingly to the results.

### 2.1. Active House assessments

The study focuses on thermal comfort during hot season evaluated according to the Active House Specification. The AH calculation relies on the static comfort approach [28] for winter and summer time when buildings are mechanically cooled, while on the adaptive comfort approach [29] for summer in case of natural ventilated building. The threshold between summer and winter condition is set by the running mean temperature ($T_{rm}$) equal to 12 °C. This parameter is the weighted mean of the external temperatures of the previous days [30], expressed as:

$$T_{rm} = \frac{(T_d + 0.8T_{d-1} + 0.4T_{d-2} + 0.2T_{d-3})}{2.4} \tag{1}$$

where:

$T_{rm}$ is the running mean temperature

$T_d$ is the temperature of the day considered

The parameter used to assess thermal comfort is the Operative Temperature (Top), which is a mix of air temperature and the mean temperature of the surfaces delimiting the room [27]. The Top is a temperature closer to the real human perception and the values has been derived from the following formula:

$$T_{op} = \frac{H_r \cdot T_r + H_c \cdot T_{air}}{H_r + H_c} \tag{2}$$

where:

$T_{op}$ is the operative temperature

$H_r$ is the human heat transfer coefficient for radiation

$H_c$ is the human heat transfer coefficient for convection

$T_r$ is the mean radiant temperature of the surfaces

$T_{air}$ is the air temperature.

The Eqs. (1) and (2) are used to classify the building's performance in Active House classes through Table 1. An hourly calculation is necessary accordingly to evaluate the hourly indoor Top. The tool used to assess the performances analysis is the dynamic simulation software Trnsys v.17 [31].

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