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

Arianna Brambilla[a], Graziano Salvalai[a,*], Chiara Tonelli[b], Marco Imperadori[a]

[a] Politecnico di Milan, Department of Architecture, Built Environment and Construction Engineering (ABC), via G. Ponzio 31, 20133 Milan, Italy
[b] University of Rome TRE, Department of Architecture, Largo Giovan Battista Marzi, 10 00154 Rome, Italy

The relationship between indoor comfort and climatic context is essential to assure a superior liveable environ-ment 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 sin-gle-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 ex-pectation with an energy saving estimation of about 1.7% for each half degree Celsius reduction.

Keywords: Energy efficiency, Thermal comfort, Active house vision, Solar decathlon, Sustainability, Efficient design

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.

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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.

* Corresponding author.
Email addresses: arianna.brambilla@polimi.it (A. Brambilla); graziano.salvalai@polimi.it (G. Salvalai); chiara.tonelli@unirome3.it (C. Tonelli); marco.imperadori@polimi.it (M. Imperadori)

Based on these three major points, different energy standards and certifications have been modified to include the new requirements toward NZEB target [7,8]. 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 [18] 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:

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

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:

$$T_{op} = \frac{H_r \cdot T_r + H_c \cdot T_{air}}{H_r + H_c} \quad (2)$$

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].

2.2. Climate characterization

The four locations used for the assessments are representative of different weather conditions across the Europe: Paris, as reference for the continental climate, Milan, Rome and Palermo, represents three different sub-climatic zone of the Mediterranean region. The comparison between the results underlines the resilience of the design to climatic assumptions, it is helpful to understand the robustness of the prototype chosen as case study to external stress and it highlights the reliability of the certification method in Mediterranean region. The weather file used for the simulations are the typical meteorological years (TMY) [32].

Referring to the Koppen- Geiger classification method [33] it is possible to classify and characterize the three climates. Paris presents a marine west-coast climate, with mild summers and winters (Cfp climate). During the warm season, temperatures can reach 25 °C and average low temperatures around 14 °C; averagely, 1840 h of sunshine are available per year. Milan is classified as mild humid sub-tropical climate without dry season (Cfa climate). Summers are hot and humid with mild precipitations from mild-latitude cyclones. Average monthly temperatures can vary of 22 °C, indicating a big variance between seasons, during summer the average is 27.6 °C and the average low 16.3 °C. On average, there are e1900 hours of sunshine on 4383 possible, signing that 56.7% of daylight hours in a year are cloudy, haze or with low sun intensity. Both Rome and Palermo are in the zone of hot Mediterranean subtropical climate (Csa climate). They are characterized by hot and dry summers, with high daily temperatures and warm nights. Fig. 1 shows the different monthly temperatures for the four locations. The high variability related to Milan is clearly visible in peaks temperatures, which can reach the same magnitude of Palermo. This introduces a great uncertainty in the design phase for this location, since that a building should be able to face a wider range of external conditions with consistent variations.

Table 1
Description of the evaluation method defined by Active House for different thermal comfort category [19].

Comfort set point	
Minimum operative temperature	1: $T_{op} > 21.0$ °C
Applied when $T_{rm} < 12$ °C, evaluated through hourly Top, requirements should be met for at least 95%	2: $T_{op} > 20.0$ °C
	3: $T_{op} > 19.0$ °C
	4: $T_{op} > 18.0$ °C
Maximum operative temperature	With cooling system
Applied when $T_{rm} > 12$ °C, evaluated through hourly T_{op}, requirements should be met for at least 95%	1: $T_{op} < 25.0$ °C
	2: $T_{op} < 26.0$ °C
$A = O{,}33{*}T_{rm}$	
	3: $T_{op} < 27.0$ °C
	4: $T_{op} < 28.0$ °C
	Without cooling system
	1: $T_{op} < A+20.8$ °C
	2: $T_{op} < A+21.8$ °C
	3: $T_{op} < A+22.8$ °C
	4: $T_{op} < A+22.8$ °C

3. Case-study description

The prototype used as reference building for the analysis is RhOME [34,35], a single family apartment designed and built for the international competition Solar Decathlon Europe 2014 [36]. The goal of the Solar Decathlon is to design a small building autonomous from the energy point of view according to the Zero Energy Building definition [37]. The prototypes should be designed to meet specific requirements and to face specific criticisms, according to the external and socio-cultural context decided by the teams and often these houses become real examples of innovation [38,39]. RhOME building (namely "a home for Rome") was an apartment of a multi-storey social housing, aiming at being a future model for cities densification. The main purpose of the concept is "more synergy, less energy", highlighting the will to create an efficient system between the envelope, the technical installation and the users (Fig. 2).

Thanks to its performances monitored during the competition weeks and its accurate design it won the 2014 edition, becoming a symbol of a perfect integration between architecture, engineering and sustainability. The main characteristics of the building have been reported in the Table 2. (Fig. 3).

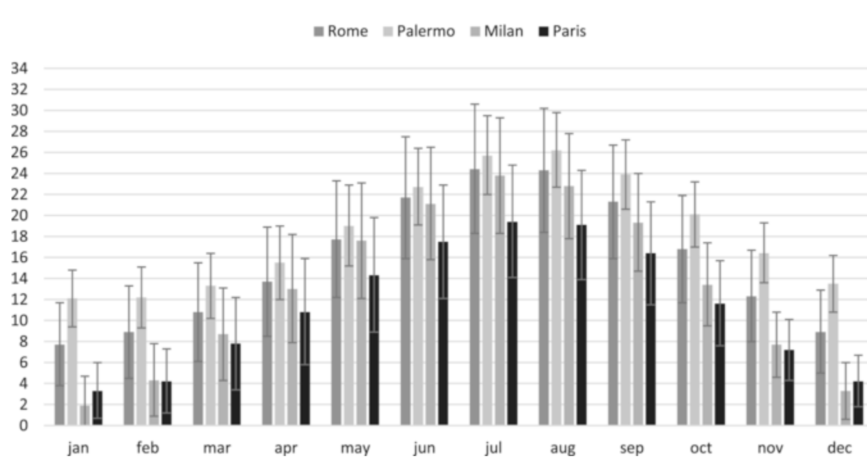

Fig. 1. Mean temperature level for different climate locations.

Fig. 2. Right side: the main façade of RhOME with the big loggia. Left side: the south façade with the PV systems and the solar thermal collectors.

Table 2
Boundary conditions and control set-points of the building.

Location	Rome (Paris)
Gross surface	79 m^2
Gross volume	366 m^3
Heated surface	62 m^2
Heated volume	244 m^3
Envelope's surface	350 m^2
U value walls	0.14 W/m^2K
Thermal capacitance	5704 kJ/K
Occupants	According to UNI EN ISO 7730:2007 (2 persons sedentary activity)
Lighting	Included in appliances
Appliances	5 W/m^2
Heating system	Set point temperature 20 °C, relative humidity 60%
Cooling system	Set point temperature 26 °C, relative humidity 60%
Ventilation system	Relative humidity 50%, heat recovery 25 °C, air flow 1.5 ach

The reference case has been chosen due to the sustainable concept, the proven efficient performance, the data available about energy consumption and provided comfort collected by a smart energy monitoring system. RhOME building has been certified as Active House [40] for the Solar Decathlon venue (Paris) making possible a consistent comparison between the continental climate (of the certification – Paris) and the Mediterranean one (of the optimization – Rome), assessing the sensitivity of the AH ranking method to warmer climatic contexts.

3.1. Energy need

The RhOME building is designed with an energy efficient envelope: the structure is made by a total modular wood prefabricated components, which include structure, insulation, technological layers and finishing. The modules incorporate an external insulation layer, which assure a high thermal resistance minimizing the losses through the enclosure during wintertime. Inertial components are instead necessary to smooth high summer thermal peaks of Mediterranean climate; for this reason, a massive layer of free sand has been added as wall layer [41]. This layer is placed in the internal part of the walls, next to the indoor space, in order to store heat during the day and to release it during night due to the cross natural ventilation [42]. Its contribution is maximized in middle seasons, where natural ventilation and heat recovery system are enough to maintain comfortable temperatures. The windows position is studied to maximize the winter direct solar radiation as natural heater and, at the same time, protecting the indoor spaces from overheating during summer. The big transparent surfaces area are protected by loggias, which shade the glazed part of the envelope and create a buffer zone between indoor and outdoor (Fig. 4).

From the energy supply point of view, RhOME building is designed in order to produce the small amount of energy needed in a very smart and effective way: thermal energy for the floor-panels and sanitary hot water is produced by a thermodynamic system, included in the loggia balustrade and connected to a heat pump. The electrical energy is provided by flexible monocrystalline photovoltaic panels, installed on the south-oriented roof. These two devices generate a virtuous symbiosis within the loggia itself: the PV becomes a precious heat source for the parapet, more efficient at high temperatures, while this latter con-

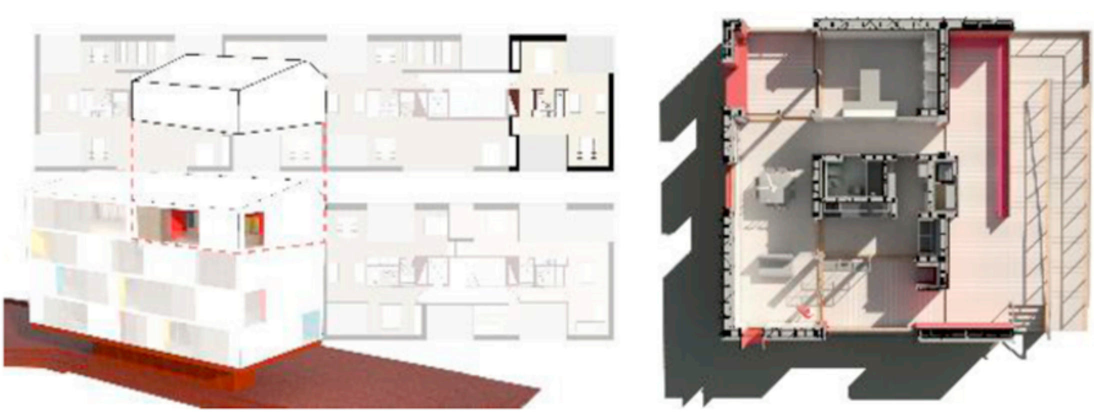

Fig. 3. Right side: the prototype RhOME is an apartment of a multi-storey social housing. Left side: the floor plan of RhOME prototype.

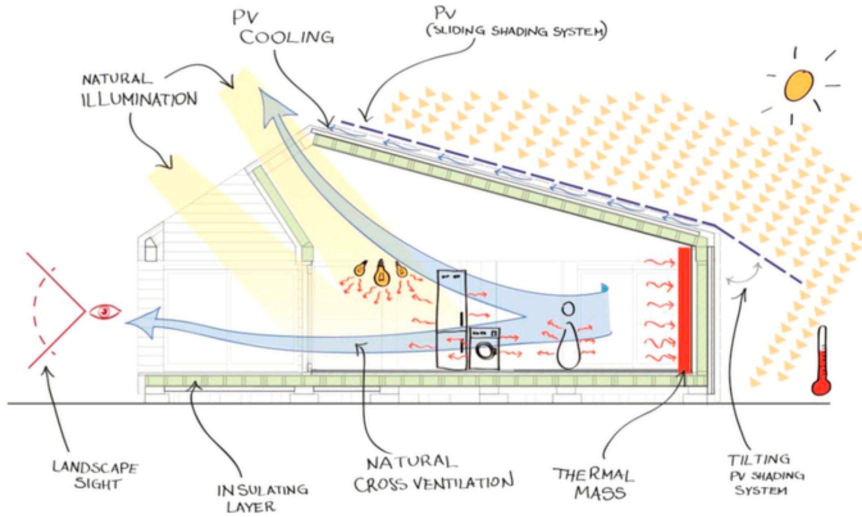

Fig. 4. The bioclimatic strategies of the building.

tributes to cool down PV cells when in function, maximizing their production efficiency (Fig. 5).

The HVAC system integrates different solutions in a perfect synergy able to manage a self-sufficient energy balance. The hearth of the system is the heat pump with three units: an internal device, an external one and a water tank. This latter recalls the hot water produced by the thermodynamic balustrade and feeds the radiant panels for indoor heating and cooling. Mechanical ventilation takes care of the quality of the air and it is connected to a heat recover device, able to free cool during summer nights the heath released by the inertial mass, thanks to a by-pass.

The total energy consumption measured during the two contest weeks was very low: only 3.48 kWh per square meter. As reported in Table 3 and Fig. 6, the biggest contribute is given by cooling, which accounts for more than half of the energy demanded by the prototype; appliances are the second biggest issue. The results confirm that very efficient buildings minimizing thermal exchanges with the outdoor are becoming internal loads dominated.

3.2. Environmental analysis

To minimize the environmental influences, the case study uses as much as possible recycled or renewable materials. The selection made is based on the reduction of energy consumption on life cycle assessment, from the production to the disposal [43]. Wood represents the main material, it is employed for structure, finishing and insulation and it comes from only certified sources. However the most interesting feature is the massive layer: it is free sand or it comes from resulting materials from the excavation site or also waste from demolition process, highlighting the possibility of taking resources available on the site (or from the construction process) for responding to specific buildings requirements in a sustainable way. The Fig. 7 shows the technological

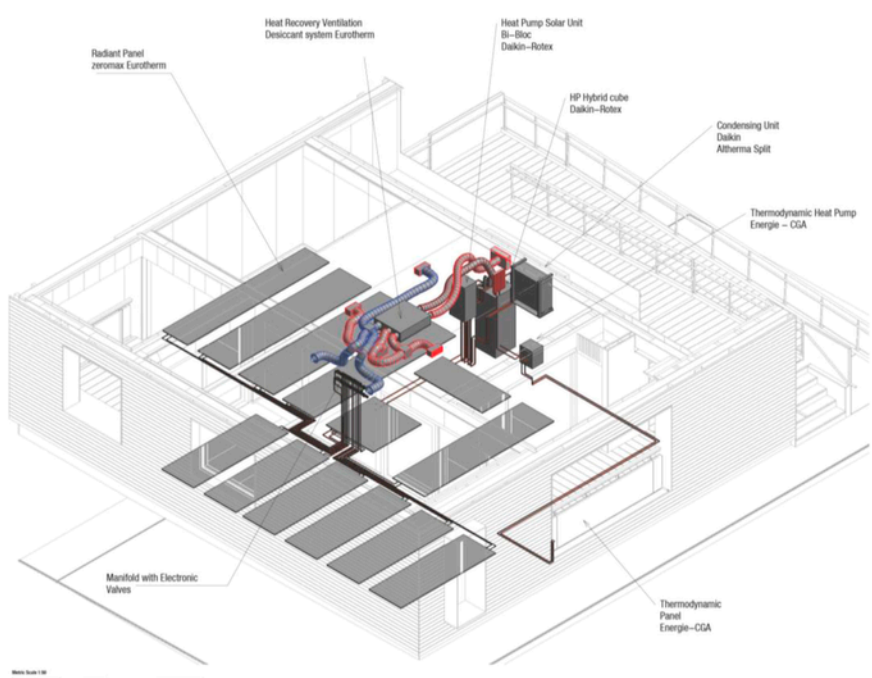

Fig. 5. The HVAC system.

Table 3
Energy consumptions monitored during the contest's week.

	Energy consumption in the contest week [kW h/m^2]	Percentage on the total consumption [%]
Cooling	1.93	55.5
Appliances	0.93	26.6
Monitoring	0.29	8.41
Domestic hot water	0.26	7.43
Lighting	0.06	1.85
Ventilation	0.01	0.21
Total	3.48	–

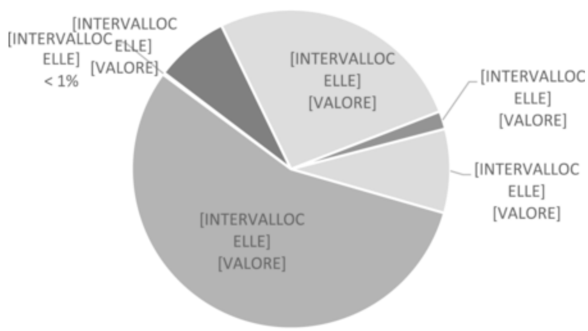

Fig. 6. Share of the total energy consumption monitored for different uses.

detail of the building envelope. LCA facilitates the decision-making during the design process, orienting the building towards environmental neutrality [44].

3.3. *Comfort analysis*

The RhOME building is designed to maximize the benefit of natural resources for enhancing the occupants' wellbeing inside the spaces. Big openings to south and north improve the cross ventilation, preventing overheating during summer and assuring thermal comfort in middle seasons. Moreover, the implementation of buffering zones is aligned to cultural and social habits of the South of Italy, introducing the psychological side of comfort to the building system. Natural light enters from the windows facing north, exploiting the cold light without direct radiation, which is not only the principal cause of overheating, but also for the glare discomfort due to the direct sun light (Fig. 8).

Comfort means also healthy spaces [43]: for this reason, the quality of the air is a priority for home's design. RhOME system uses an active reduction of PM10 and it prevents the backlog of CO_2 and VOC inside with a very low energy consumption, using the possibility to use directly the water from the heat pump for air dehumidification, thanks to the absence in the main unit of the compressor.

4. Results and discussion

The Active House standard classifies the thermal comfort performances on the basis of daily operative room temperature, which should follow into the class boundaries for at least 95% of the occupied hours (Table 1). The methodology and the threshold vary according to the cooling method used: if the space is mechanical cooled than the static approach should be used, otherwise the adaptive one. The main difference of these approaches relies on the adaptive opportunity of human beings to acclimatize [45–49]. The prototype used in this study has a hybrid energy efficient system: it relies mainly on passive strategies (free cooling) and uses the cooling system (active cooling) only if strictly necessary. The results also point out that the use of different comfort models has a significant influence on the comfort rating.

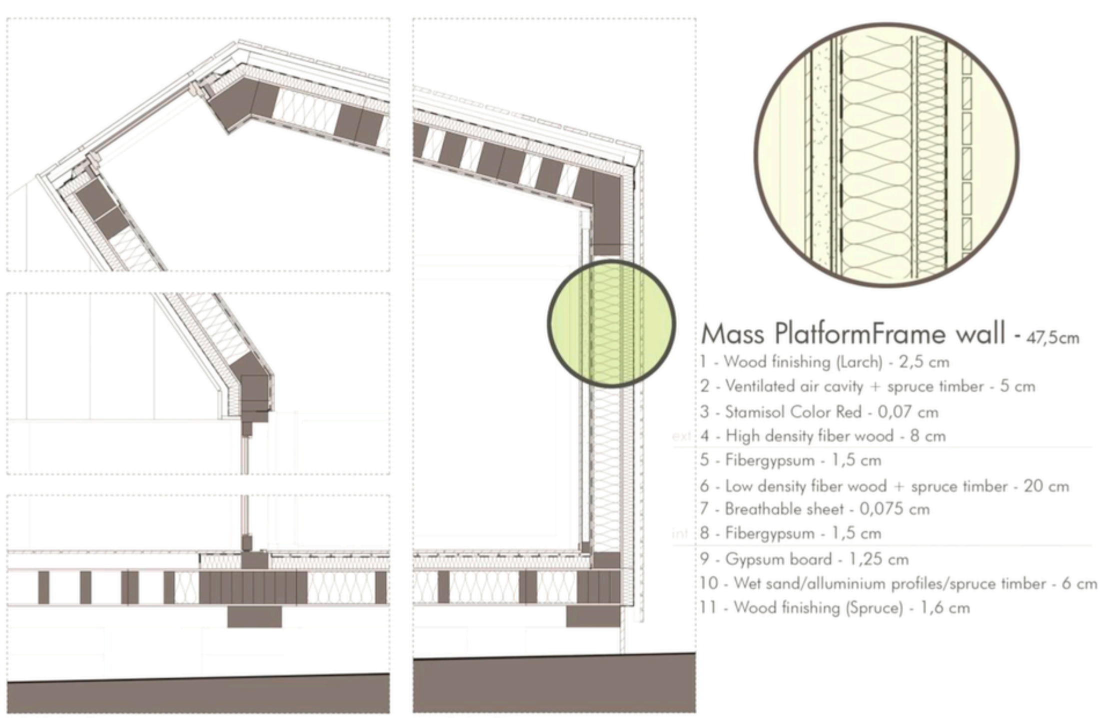

Fig. 7. The envelope technology: natural material derived from wood and wet sand contained in recycled aluminium pipes, acting as thermal mass. The material description from point 1–11 are from inside to outside of the wall.

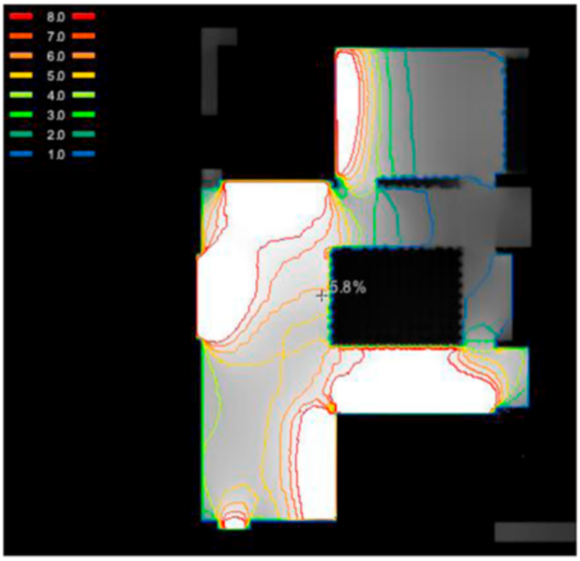

Fig. 8. Daylight factor analysis.

The system is calibrated according to the adaptive algorithm, and the active cooling intervenes when it is impossible to stay in the comfort band defined by the EN 15251:2007 only by free cooling. However, this complexity cannot be described with the classification tool. For the purpose of this analysis, the static approach has been used to evaluate the results despite its restrictiveness.

The first analysis conducted is the comparison between the prototype's performances in different climates in this way a complete fan of option is created to assess the robustness of the design to climates.

Each hour of the reference year has been classified according to the Active House specifications, the percentage of hours that fall into the different classes is reported in Figs. 9 and 10. It is possible to notice that, in general, the building is resilient to the climatic change, assuring an overall thermal performance acceptable for Active House classification method in all the four locations.

However, the close correlation between the outdoor context and the indoor comfort is detected by the percentages distribution. Palermo is the warmer climate and its hot spells are reflected into a higher risk of overheating, visible on the graph from the significant percentage of hours in lower active house classes (Fig. 10). On the opposite, site Paris is representative of a continental climate, characterized by cold winter and cool summer, thus it is easier to keep lower indoor temperature

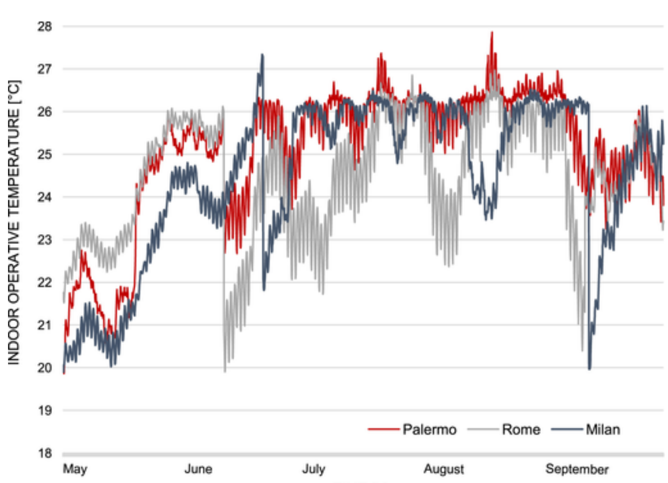

Fig. 9. Hourly operative temperature for a reference year in the Mediterranean locations.

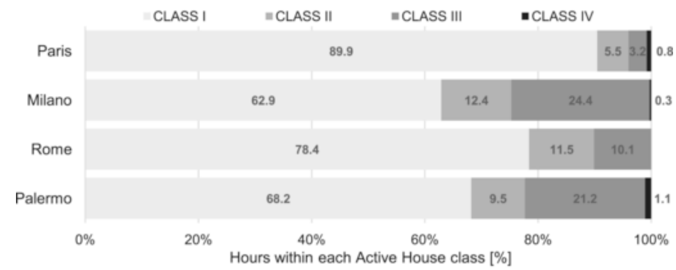

Fig. 10. Percentage of hours in a year within each Active House comfort class.

and achieve better results. The comfort's level achieved in Rome is a mean value, reflecting the milder climate respect the two extremes locations. An interesting outcome is the exception of Milan: results and performance of this reference city are similar to the ones achieved for Palermo. The high summer temperatures variability shown by the analysis on the climate of Milan (Fig. 1) results to be the cause of the high percentage of hours outside the first Active house classes. Moreover, natural ventilation and night cooling are very difficult to be used as free cooling strategies in this area, due to the geographical conformation of the landscape around the city and the high humidity rate. This phenomenon is easily visible in Fig. 8, where the temperatures in Milano are not decreasing sensibly during the night time as in Rome. However, RhOME's reactivity to the climatic conditions allows the prototype to keep the indoor conditions enough comfortable, according to the classification system used.

RhOME building has been designed as model of efficiency for warm climates and it has been optimized on Rome context, hence a deeper study on this climate has been done. The set point temperature of the active cooling has been iteratively changed to achieve the first AH comfort class, meaning that 95% of the cooling hours have a Top within the boundaries defined for this class. The analysis helps to understand the variations induced on the energy consumption by the progressive reduction of the cooling set point aimed at a comfort level's increment. Using a standard set point temperature of 26 °C, RhOME can be classified as an Active House with a score of 3. The Fig. 11, shows the correlation between the set point temperature and the percentage of hours within each Active House class.

To increase of 1 class the final ranking of RhOME, it is necessary to decrease the set point temperature of half degree; but to achieve the best class possible the reduction needed is three time bigger: from 26 °C to 24.5 °C. These values could seem negligible on the AH energy performance indicators, which change from score 1 to score 1.6; this low variation on energy side is due to the highly efficient supply system. However, in absolute terms, a lower set point temperature implies higher cooling needs and higher energy consumption. Considering the adaptive comfort model, a strong correlation between comfort and cli-

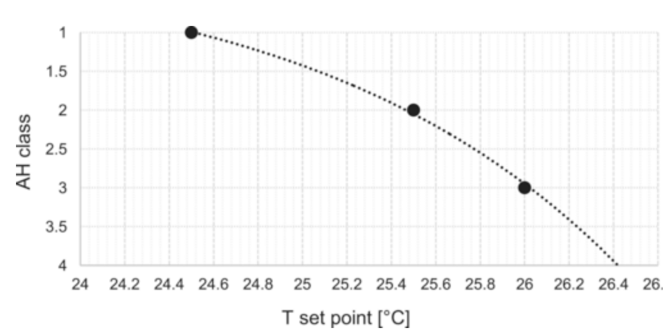

Fig. 11. Correlation between the cooling set point temperature and the related Active House class achieved in the thermal comfort category. The Active House standard describe the level of ambition into four levels where 1 is the highest level and 4 is the lowest.

mate can be deduced. In Mediterranean area, in fact, the thermal neutrality is higher than in the Northern Europe, due to the acclimatization of the population to the external temperature, that often reach peaks of more than 30 °C. History and tradition of a population, in conjunctions with contextual factors, in fact, modify consistently thermal expectations and perceptions, increasing the threshold of acceptability of indoor temperatures in warmer areas and decreasing it in colder regions [50,51]. The AH thresholds for the first two comfort classes are really restrictive and almost unusual for warm climate, since that these are translated into operative indoor temperatures lower than 25 °C (or 26 °C for the second class). A new ranking threshold has been introduced to acknowledge for the acclimatization opportunity, the Italian standards and the results highlighted in the previous analysis (Table 4).

The thresholds' variation is relatively small, just one degree for the first class and half for the second one, but they may influence the results in a consistent way. From Figs. 12 and 13 it is possible to see the effects of the new temperature limit introduced in Table 4.

Table 4
Proposal for the new classification system for the evaluation of thermal comfort in warm climates. The A* is equal to 0.33*Trm.

Proposed comfort set-point	
Maximum operative	With cooling system
Temperature (T_{op})	1: T_{op} < 26.0 °C
Applied when T_{rm} > 12 °C, evaluated through hourly T_{op}, requirements should be met for at least 95%	2: T_{op} < 26.5 °C
	3: T_{op} < 27.0 °C
	4: T_{op} < 28.0 °C
	Without cooling system
	1: T_{op} < A* + 21.8 °C
	2: T_{op} < A* + 22.0 °C
	3: T_{op} < A* + 22.8 °C
	4: T_{op} < A* + 22.8 °C

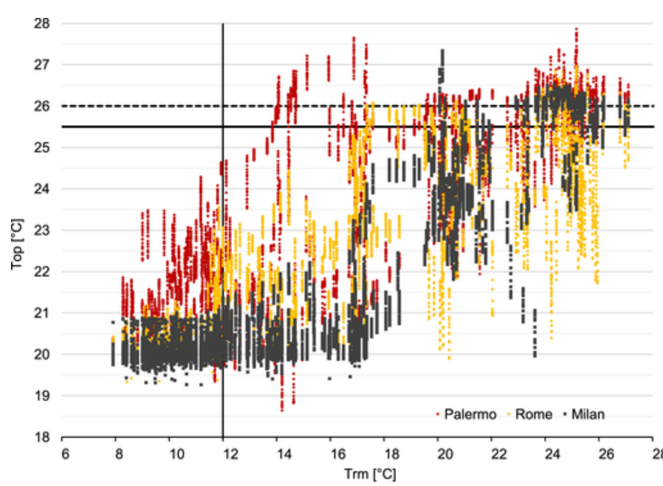

Fig. 12. Operative temperatures expressed as function of the outdoor running mean temperature. The vertical line defines the cooling season in AH method (Trm > 12.0 °C), the horizontal thick line is the limit for the first class of thermal comfort (Top < 25.5 °C), the dashed horizontal line is the proposition for the threshold of the first class (top < 26 °C).

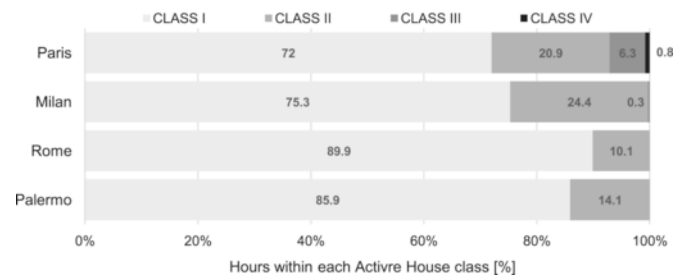

Fig. 13. Percentage of hours in a year within each Active House comfort class.

With the new assessment, the only climate, which present hours below the second class is Paris. The cause is the free cooling in middle seasons and the certification made on active cooling assumption. Beside this criticism, the results show a resilient behaviour of the prototype to high temperatures, classifying the 100% (89.9% in Class 1% and 10.1% in Class 2) of the operative cooling hours as at least an Active house of the second class. It is easy to understand that a slight variation into the classification system is translated into big differences on the results. From the energy point of view considering the climate of Rome, changing the control set-point from 25.0 °C to 26 °C allow to save 3.4% of cooling energy with benefit on GHG emissions.

5. Conclusions

The aims of the presented work consist on applying the Active House principles to an energy efficient building model in order to understand the resilience of the AH vision in warm climate. The reference building adopted is the building prototype RhOME, the winning project of Solar Decathlon 2014. The results of the Mediterranean adaptation assessment indicate that an optimized building is capable to keep indoor comfort in different climatic contexts, showing the robustness of an integrate design that includes passive and active heating/cooling strategies. On the other hand, thanks to the assessment, the threshold for comfort definition in Active House revealed difficulties to describe the social, cultural and traditional context, which induce a process of acclimatization (adaptive opportunity to increased indoor temperatures). For this reason, a modification to the ranking threshold has been proposed to acknowledge for different climate contexts. The new scale slightly differs from the original: the first class is associated to one-degree higher threshold, the second with a half degree and the others are kept equal to the original version. This relatively small change has a big influence on the results, since that it is translated into indoor operative temperatures at least equal to the usual set point temperature applied for building in Mediterranean building, which is 26 °C. The previous classification imposed for the first and the second AH class a temperatures level below 25 °C, which are not reliable in warm climates for both energy and comfort issue. The acclimatization process allows hotter comfort temperature and the external climate makes it energy expensive to cool the indoor environment up to 25 °C or less. The results show that with the modified threshold there is an increment up to 40% of the hours eligible for the first AH class, allowing the case study to achieve at least the second class in all the climates. Assessing the results with the proposed threshold the indoor comfort proposed results more than acceptable (Indoor temperatures lower than 26.5C for more than 95% of the total occupied hours). The changes are made on the ranking system without affecting the building operation, which is modelled with a cooling set point temperature of 26 °C, reflecting the standard practice in Mediterranean area. The new thresholds affect positively the AH classification system for warm climate on both the indoor comfort and energy label. In fact, the new thresholds encompasses the possibility to use the system to better balance the design in hot climate. In this case, the cooling power requested for keeping the operative temperature below a certain point could be drastically increased. For this reason, a 1.0 degree Celsius change for the first category (0.5 degree Celsius for the second) would allow the project to be classified as AH class 1, considering the acceptable indoor condition. The case study presented has been optimized using the active house approach, giving a concrete feedback on the additional energy needed for achieving the AH class 2. Considering 1 degree Celsius lower set point, the cooling energy consumption can be reduced of about 3.4%. It is clear that the new threshold better reflects the warm-climate context while enhancing the energy efficiency. Moreover, it does not have any critical drawback as it implies a broader range of acceptability of the first two classes without increasing the acceptability level, represented by the fourth class that is not modified.

The main findings can be summarized as follows:

- Is important to have an adaptable classification method, which could account for different climatic contexts. Considering the degree of innovation and efforts requested to the construction sector for moving towards a more sustainable future, it is important to have easy tools capable to optimize the design phase and not considering general strategies, applying the same solutions to different climatic conditions. Design tools, created to support decision making from the early design process, needs to be feasible and effective for the context; in this case, for example, a relative strictness in the summer operative temperatures is not reliable. An internal temperature below 25 °C can be perceived as overcooling if applied in hot regions and lead to excessive cooling loads. Flexibility of the evaluation method should be guaranteed to acknowledge the European variety of socio-cultural contexts.
- It is difficult to describe with standard evaluation methods the new generation of low-energy buildings. In this case the hybrid active/passive systems led to an underestimation of the building performances, due to the impossibility to include all the plant system technologies into one definition. This is also a warning about the impossibility to create a certification tool that measures just few values in a very restrictive way.
- The modified comfort set point (Table 4) makes the tool more useful and applicable through the whole range of climates that characterise Europe. In this way, it could be easier to enhance buildings efficiency, encouraging the use of a design compass, able to guide towards sustainability.

Future development of the research will aim to understand better the resilience to increasing temperature of high efficient buildings, designed following the Active House vision. This will be an important step considering the climate change and the global warming that we are facing, which is estimated to increase the temperature globally of 2 °C for 2100 [51]; buildings are requested to resist, during their operational life, to hotter environment characterized by more frequent hot spells and their resilience will be a pivot issue.

Uncited reference

[6].

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