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# The use of adaptive thermal comfort models to evaluate the summer performance of a Mediterranean earth building

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ABSTRACT

In Europe and worldwide several legislations are adopting comfort models that include the variability of occupants behaviour based on the external climate conditions. The latest adaptive comfort methods consider outdoor temperature not only as a steady variable but also as the representation of occupants past thermal history.

The paper presented deals with a summer environmental monitoring carried out in a Sardinian earth building. These traditional houses are very often without AC systems and the control of summer conditions is based mainly on natural ventilation. By the use of adaptive comfort model, the different thermal performance between the upper and lower floor of the two storey building are investigated. Different models have been implemented, some included in current technical standards, some other still experimental.

The results show the capability of the case-study to provide comfort conditions, but only in the lower floor. The upper floor that traditionally was used as a depository and now hosts the bedrooms shows overheating problems. The change of use, in this case, is the main cause of the bad performance, as highlighted by the microclimatic survey.

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## 1. Introduction

The determination of the comfort perceived in indoor spaces provides the predicted response of users to the thermal environment, but it serves also as an efficient tool to evaluate building and HVAC systems efficiency.

Currently, according to European and American standards for the analysis of thermal comfort [1,2], a methodology founded on the Fanger's model [3] is prescribed for any typology of air-conditioned building, whereas a methodology based on a model of adaptive comfort [4,5] is prescribed for buildings that use natural ventilation in summer conditions. According to the first model, the global PMV and PPD indexes and the local discomfort ones are calculated through the analysis of environmental parameters (air temperature, relative air humidity, mean radiating temperature and air velocity) and personal factors (metabolism, clothing insulation). The adaptive comfort models, on the other hand, takes into account also the occupants' ability to adapt to varying conditions on a physiological, psychological and behavioural level. The degree of adaptability depends on the external conditions. However these differ in the two most adopted methods. The former [4] is based on the mean monthly outdoor temperature ($T_{a,\,\mathrm{out}}$), the latter [5] introduces the concept of *past thermal history* which finds its expression in the *running mean outdoor temperature*, $T_{\mathrm{rmn}}$ [6].

Initially elaborated by Auliciems [7], the adaptive comfort method was developed with the aid of two important experimental studies: ASHRAE's RP *884 Project* on which Brager et al. worked [4,8,9] and the European *Scats Project*, coordinated by Oxford Brooks University with a consortium of academic and industrial researchers from the UK, among whom Nicol et al. [5,6,10]. The RP 884 research studied, using both Fanger's and the adaptive method, 160 office buildings across four continents with climate conditions that ranged from the Mediterranean to the continental. The buildings studied were divided into two groups: HVAC buildings (air conditions buildings) and NV (Naturally Ventilated buildings). The analysis was carried out both in winter and summer conditions.

The Scats Project instead focused on 26 buildings in Europe, located in England, France, Greece and Portugal. In this case the variable used to calculate external conditions was the $T_{\mathrm{rmn}}$, afterwards inserted also in the current European standard [1].

The increase of energy consumptions and fossil fuel prices are the driving force for the development of buildings with low energy

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### Symbols

| | |
|---|---|
| $A_r$ | effective radiation area of human body [m$^2$] |
| $A_d$ | DuBois surface area [m$^2$] |
| $f_{\mathrm{cl}}$ | ratio of body surface while clothed to surface while nude |
| $h_c$ | convective heat transfer coefficient between the human body and the environment [W/m$^2$ K] |
| $h_r$ | radiative heat transfer coefficient between the human body and the environment [W/m$^2$ K] |
| $I_{\mathrm{cl}}$ | thermal resistance of clothing [m$^2$ K/W] |
| met | metabolic rate [met] |
| $M$ | metabolic rate [W/m$^2$] |
| PMV | predicted mean vote according to ISO 7730 standard |
| PPD | percentage of dissatisfied according to ISO 7730 standard |
| RH | relative humidity |
| SET | standard effective temperature [°C] |
| $T_{24,n}$ | mean daily outdoor temperature n days before measurement [°C] |
| $T_a$ | indoor air temperature [°C] |
| $T_{a,\mathrm{out}}$ | mean monthly outdoor air temperature [°C] |
| $T_{\mathrm{cl}}$ | clothing surface temperature [°C] |
| $T_{\mathrm{comf}}$ | comfort temperature, i.e. a temperature by which a defined percentage of occupant is in neutral thermal state [°C] |
| $T_{e,\mathrm{ref}}$ | running mean outdoor temperature calculated according to [11,12] [°C] |
| $T_g$ | temperature measured by the globe thermometer, according to ISO 7726 standard [°C] |
| $T_l$ | lower limit of comfort band [°C] |
| $T_{\mathrm{op}}$ | operative temperature, i.e. the temperature of a fictitious uniform environment, in which an occupant exchanges by radiation and convection the same amount of heat exchanged in the real environment [°C] |
| $\bar{T}_r$ | mean radiant temperature, i.e. the temperature of a fictitious uniform environment, in which the occupant exchanges by radiation the same amount of heat exchanged in the real environment [°C] |
| $T_{\mathrm{rmn}}$ | running mean outdoor temperature [°C] |
| $T_u$ | upper limit of comfort band [°C] |
| $v_{\mathrm{ar}}$ | air velocity |
| $x$ | specific humidity [g/kg] |
| $W$ | external work [W/m$^2$] |
| $\varepsilon=$ | average emissivity of clothing or body surface (value = 0.95) |

needs that implement, among the other strategies, also the use of natural ventilation in the summer season. In some European countries it led to national legislations which adopt the adaptive method. In Netherlands, for example, the Adaptive Temperature Limits, ATL [11] is already in force. This standard was developed for naturally ventilated buildings and offices and is based on the evaluation of the weighted running mean of the exterior temperature ($T_{e,\mathrm{ref}}$) [11,12], derived from $T_{\mathrm{rmn}}$.

The research hereby presented deals with the use of adaptive thermal comfort models to assess the capability of an earthen residential building to provide summer comfort conditions without the use of air conditioning. This particular constructive technique, common worldwide and particularly rooted in the Mediterranean climate region, is characterised by a high thermal inertia. It historically adapted itself to provide optimal comfort conditions during summer period, by the use of the only natural ventilation [13]. Thus it represents an interesting application for adaptive comfort models. Among the two most adopted standards, the one developed by Brager et al. (referred in the following as *standard method*) has been preferred because the conditions of applicability subsist. The absence of any mechanical air cooling system and the presence of only manual means to regulate the indoor climate conditions (opening and closing windows) exclude the one developed by Nicol et al.

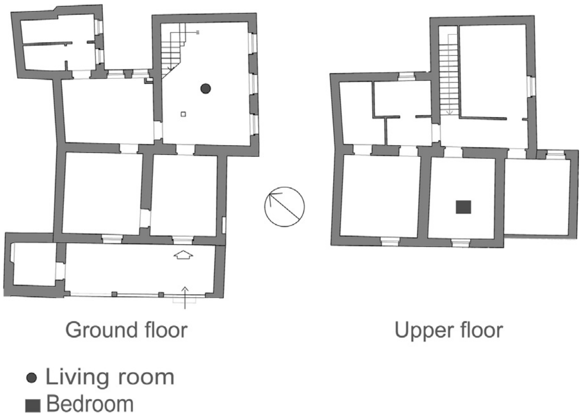

**Fig. 1.** Plans of the ground and upper floors.

The analysis is extended also to other experimental models. One is the already cited ATL [11] based on the concept of past thermal history. Its application let to appreciate the differences that can occur when using the daily mean outdoor air temperature instead of the monthly one, as prescribed by the standard model.

The third model adopted is introduced to evaluate the effects of humidity on comfort temperature limits, by the use of standard effective temperature (SET). Even if humidity is not taken into account by standard model, its effect, as shown in the following, is currently under discussion. The aim of this analysis is just to highlight how and how much the use of SET could affect the prediction of the comfort perceived.

The results show the performance of an earth building under Mediterranean summer conditions, testing its positive and negative features. The case study has recently been renovated and the former depository on the upper floor has been changed into bedrooms. By the use of adaptive comfort models the different behaviour of the upper and the lower floor is highlighted. As the results show, the change of use of the upper floor without suitable solutions to improve thermal performance is the cause of the lack of comfort for most of the monitoring time.

## 2. Methodology

In the summer of 2010 the environmental monitoring of an adobe brick building took place. The term adobe derives from the Arab *al-tub*, the raw earth sun-dried brick commonly known in Sardinia as *ladiri*—rooted in the island's building tradition. Sardinia boasts of the largest number of historical centres built of raw earth in Italy.

### 2.1. Case study

The case study is situated in the historical centre of the municipality of Serramanna in the Medio Campidano province and can be classified as a house with double courtyard. The two storey building, with a portico built in 1920, is what remains of a historical complex of rural houses and was renovated just after 2000 (Fig. 1). The renovation works were mainly addressed to reorganize the spaces distribution. In the past years the former depository

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